GATE Center of Excellence in

Innovative Drivetrains in Electric Automotive Technology Education (*IDEATE*)

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Project ID: TI 021

Overview

Timeline

- Start: 10/1/2011
- Finish: 9/30/2016
- 30% complete

Barriers

- Lack of advanced technology curricula
- Lack of trained engineers and scientists

Budget

- Project funding:
  - Government share: $954.2 K
  - Cost share: $253.4 K
- Government funding received in:
  - FY12: $303.3 K
  - FY13: $164.3 K

Partners

- University of Colorado Colorado Springs (project lead)
  - Specializing in *Battery Modeling and Control*
- University of Colorado Boulder and Utah State University
  - Specializing in *Vehicle Power Electronics*

Relevance/Objectives of *IDEATE*

- Establish a Graduate Certificate in Electric Drivetrain Technology
- Establish an MSEE option in Battery Controls and an MSEE emphasis area in Vehicle Power Electronics to educate a future workforce
- Develop courses and materials that support fundamental research, which will enable development of new technology in IDEATE topics
- Remove barriers to study by making IDEATE coursework nationally accessible via on-line means, and offering GATE Fellowships

Graduate Education in **Battery Controls**

UCCS University of Colorado **Colorado Springs**

Graduate Education in **Vehicle Power Electronics**

University of Colorado **Boulder**

Graduate courses supporting **PhD in EE** emphasis area in ***Battery Controls***

- Feedback Control
- Digital Control
- Multivariable Ctrl. Systems I, II, III

MSEE option in ***Battery Controls***

- Optimization
- System Identification
- Kalman Filtering
- Model Pred. Ctrl.

Graduate Certificate in ***Electric Drivetrain Technology***

- Modeling Battery Dynamics
- Battery Management & Ctrl.
- Power Electronics for Electric Drive Vehicles
- Adjustable Speed AC Drives

MSEE emphasis area in ***Vehicle Power Electronics***

- Intro. to Pwr. Elect.
- Res., Soft Switch
- Model/ctrl Pwr. Elect.
- Pwr. Elect Lab

Graduate courses supporting **PhD in EE** emphasis area ***Vehicle Pwr. Elect.***

- Analog IC Design
- Mix. Signal IC Des.
- Renewable Energy
- Ctrl. Sys. Analysis
- Embed. Sys. Des.
- Digital Control Sys.

Relevance of *IDEATE* Objectives

Addresses barrier 1: Lack of advanced technology curricula

- Creation of five new specialty courses:
  - Modeling, Simulation and Identification of Battery Dynamics
  - Battery Management and Control
  - Optimization Methods for Systems and Control
  - Power Electronics for Electric Drive Vehicles
  - Adjustable Speed AC Drives

Addresses barrier 2: Lack of trained engineers and scientists

- Graduate certificate in Electric Drivetrain Technology retrains engineers
- MSEE option/emphasis areas educate a future workforce
- Supports fundamental MSEE/PhD research in *IDEATE* topics to continuously advance knowledge in the field
- Removes barriers to study by making *IDEATE* coursework nationally accessible via on-line means, and through offering GATE Fellowships

Key *IDEATE* Milestones During FY12–13

Planned date	Category	Description	Status
12/2011	Milestone	Certificate program approved	Complete
03/2012	Milestone	Generate newsletter to prospective IAB members	Complete
03/2012	Milestone	Industry Advisory Board formed	Complete
03/2012	Milestone	Lab equipment received, installed	Complete
04/2012	Milestone	Make rubrics for evaluating GATE fellowship applicants	Complete
06/2012	Milestone	Applications for fellowships reviewed	Complete
08/2012	Milestone	First student cohort enters program	Complete
10/2012	Milestone	Generate newsletter to IAB	Delayed
11/2012	Milestone	Convene IAB, solicit direction	Delayed
12/2012	Milestone	Development of ECE5710 and ECEN5017 complete	Complete
12/2012	Milestone	First offering of ECE5710 and ECEN5017 complete	Complete
01/2013	Milestone	Curriculum development complete	Complete
01/2013	Milestone	Advertisement placed	Complete
04/2013	Milestone	Generate newsletter to IAB	Complete
05/2013	Milestone	Applications for fellowships reviewed	On schedule
05/2013	Milestone	MSEE option approved	Complete
05/2013	Milestone	Development of ECE5720, ECE5570, ECEN5737 complete	On Schedule
05/2013	Milestone	First offering of ECE5720, ECE5570, ECEN5737 complete	On schedule
05/2013	Milestone	First students complete certificate	On schedule
07/2013	Milestone	On-line lab for ECE5710 complete	On schedule
09/2013	Go/No go	All new courses developed	On schedule
09/2013	Go/No go	Minimum of 30 students apply for and enter IDEATE	At risk

Approach: Principal *IDEATE* Tasks, FY12–13

Administrative

- Officially establish university-recognized *MSEE degree option*
- Establish mechanisms for soliciting and reviewing applications for GATE Fellowships, and for disbursing funds to students
- Form industry advisory board for oversight and student placement
- Advertise availability of programs

Curricular

- Design curriculum for new courses; develop teaching materials
- Initiate first course offerings for the new courses
- Purchase/install equipment to gather cell-test data for battery courses

Future tasks

- Solicit feedback on curriculum from industry advisory board (IAB)
- Refresh courses based on IAB, experience; package for on-line delivery

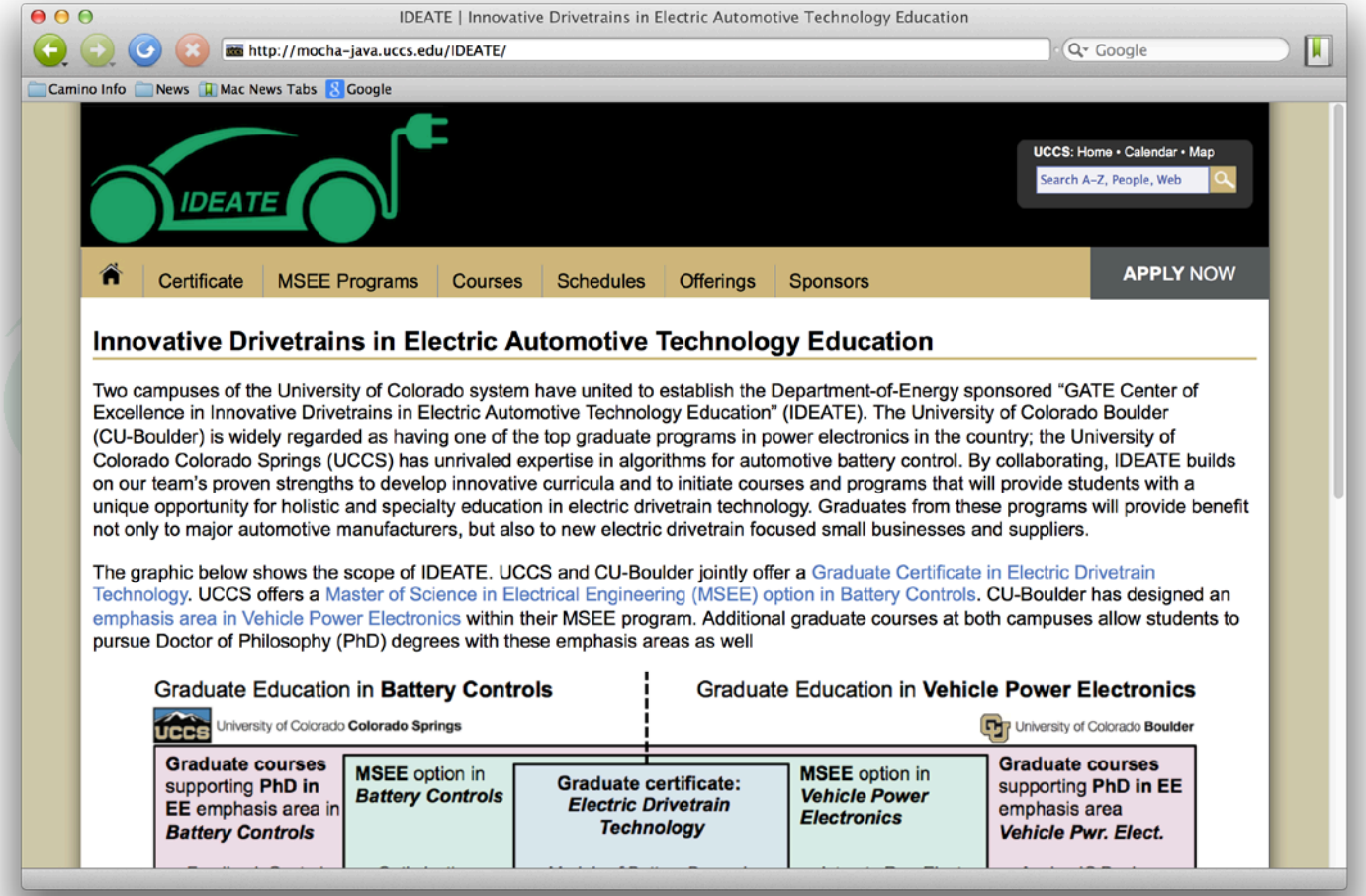
Technical Accomplishments

Administrative accomplishments since last annual merit review

- *MSEE option in Battery Controls* formally approved by university
- Application process for certificate and MSEE option defined
- Application process for GATE Fellowships defined
- Rubrics for evaluating GATE Fellowship applications developed
- Processes tested and validated by first cohort of students to enter the Graduate Certificate and MSEE option programs
- Industry Advisory Board formed

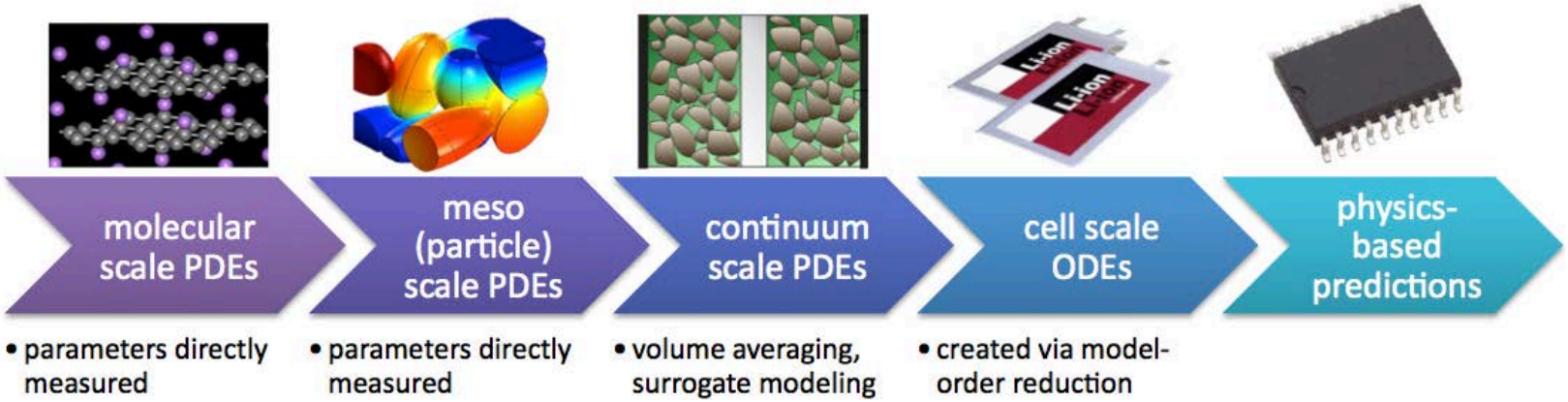
Technical Accomplishments: Advertising

- Web site: http://mocha-java.uccs.edu/IDEATE/
- Advertisement in *SAE Vehicle Electrification* (Feb. 2013)
- Through Industry Advisory Board (IAB)
- Booth at Colorado Sustainability Conference
- At SAE *HEV Academy*
- Flyers at other events



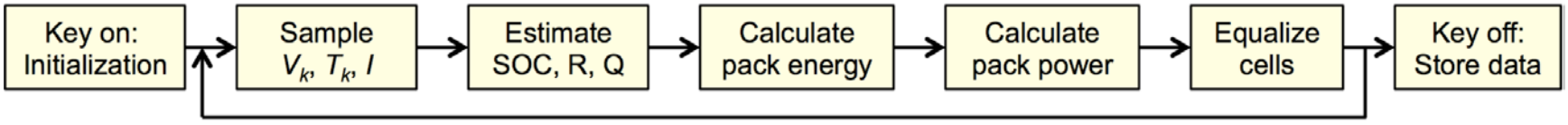
Technical Accomplishments: Curricular

- Developed curriculum and teaching materials for *ECE5710: Modeling, Simulation, and Identification of Battery Dynamics.* Offered Autumn 2012
  - Brief consideration of equivalent-circuit models and their limitations
  - Substantial attention given to deriving meso-scale homogeneous-phase physics-based models of internal cell dynamics
  - Volume-averaging techniques used to create continuum models via porous-electrode theory
  - Cutting edge methods for automatically converting continuum models to reduced-order controls models investigated in detail



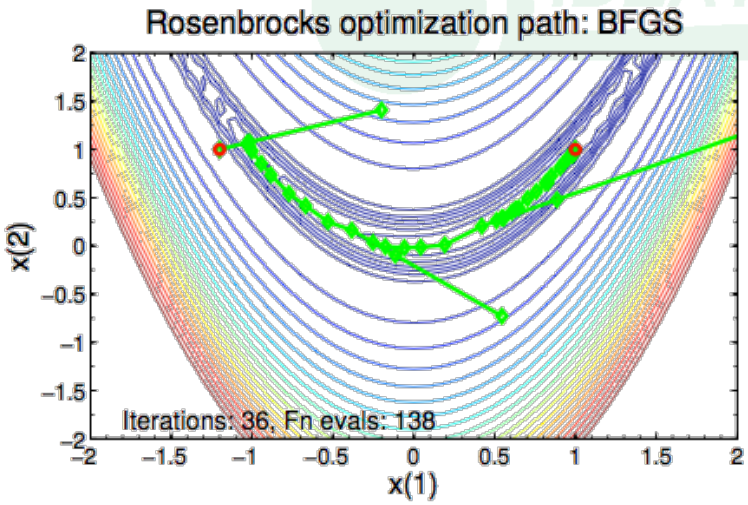
Technical Accomplishments: Curricular

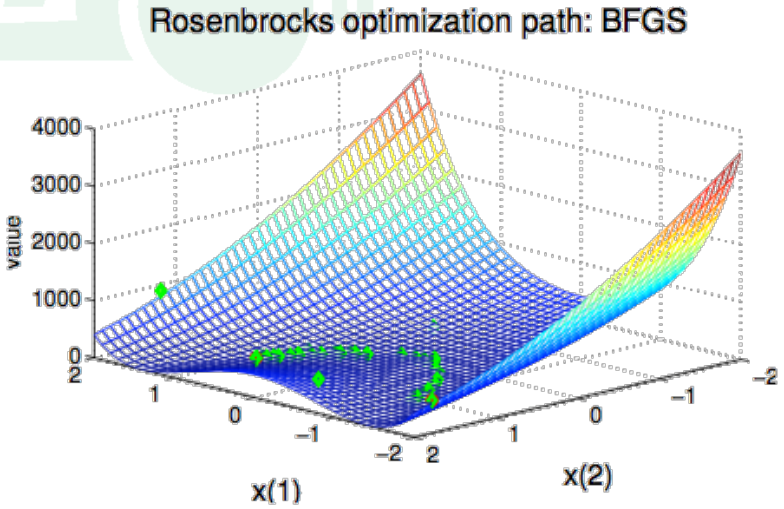
- Developed curriculum and teaching materials for *ECE5720: Battery Management and Control.* Offered Spring 2013
  - Overview of the major functions of a battery management system
  - In-depth consideration of several methods for battery state estimation
  - Some standard and improved methods for battery health estimation
  - Motivation and methodology for cell balancing
  - Voltage-based power limit estimation
  - Aging mechanisms and degradation models
  - Optimized controls for power estimation



Technical Accomplishments: Curricular

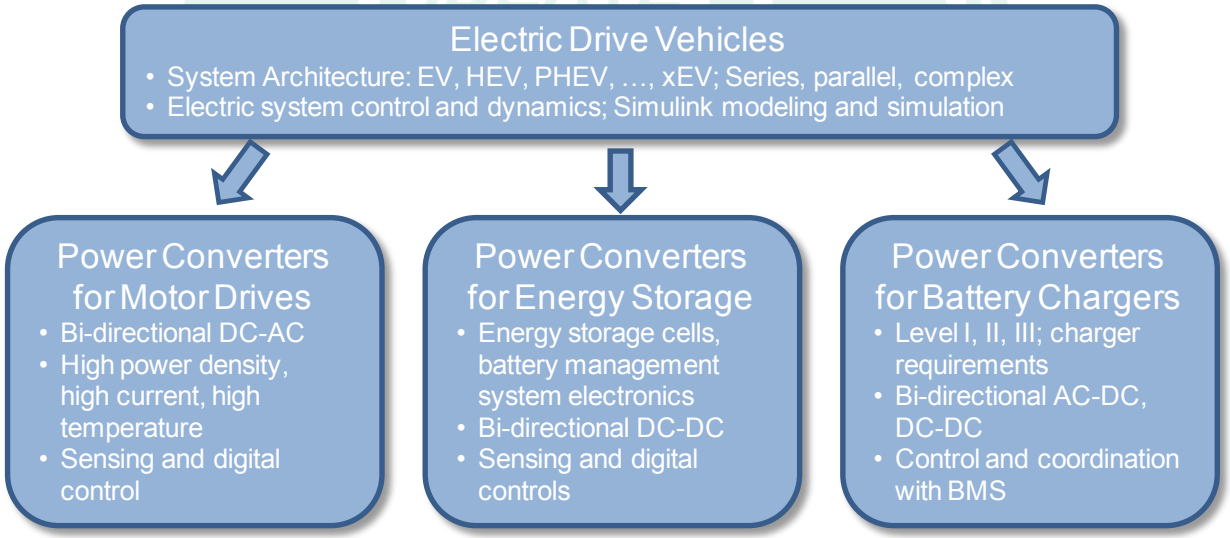
- Developed curriculum and teaching materials for *ECE5570: Optimization Methods for Systems and Control.* Offered Spring 2013
  - Introduction to optimization and linear systems review
  - Unconstrained and constrained parameter optimization
  - Dynamic systems optimization
  - Model Predictive Control (MPC) as an important application example
  - Linear Quadratic (LQ) optimal control as important application example





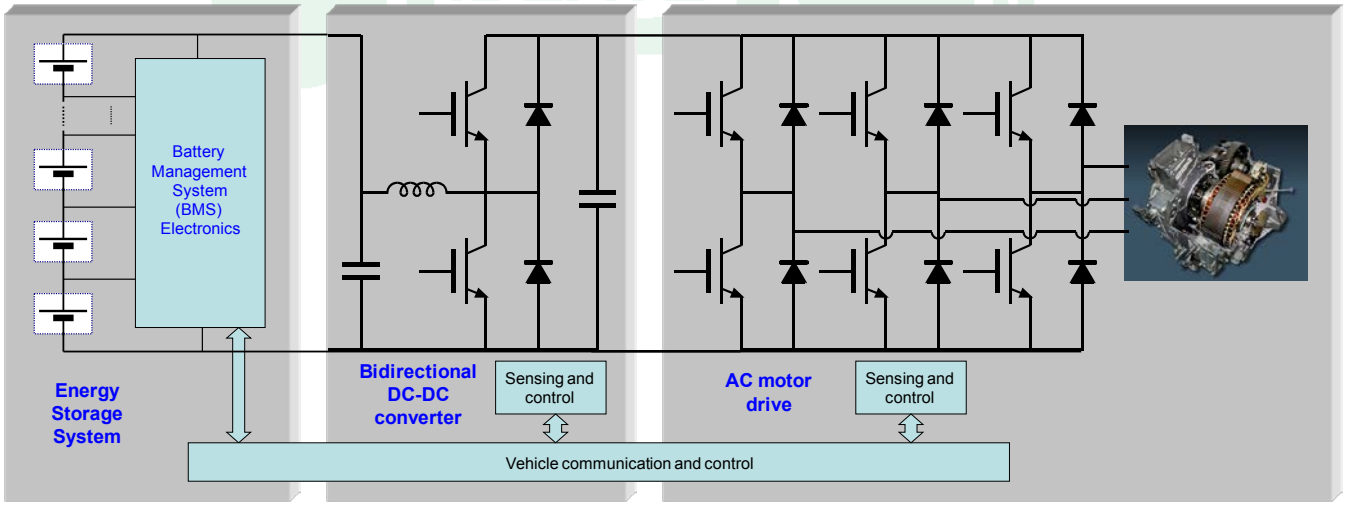
Technical Accomplishments: Curricular

- Developed curriculum and teaching materials for *ECEN5017: Power Electronics for Electric Drive Vehicles.* Offered Autumn 2012
  - Electric drive vehicle system architecture
  - Electric system control and dynamic modeling in Simulink®
  - Power converters for motor drives
  - Power converters for energy storage, battery management electronics
  - Power converters for battery chargers and utility interface



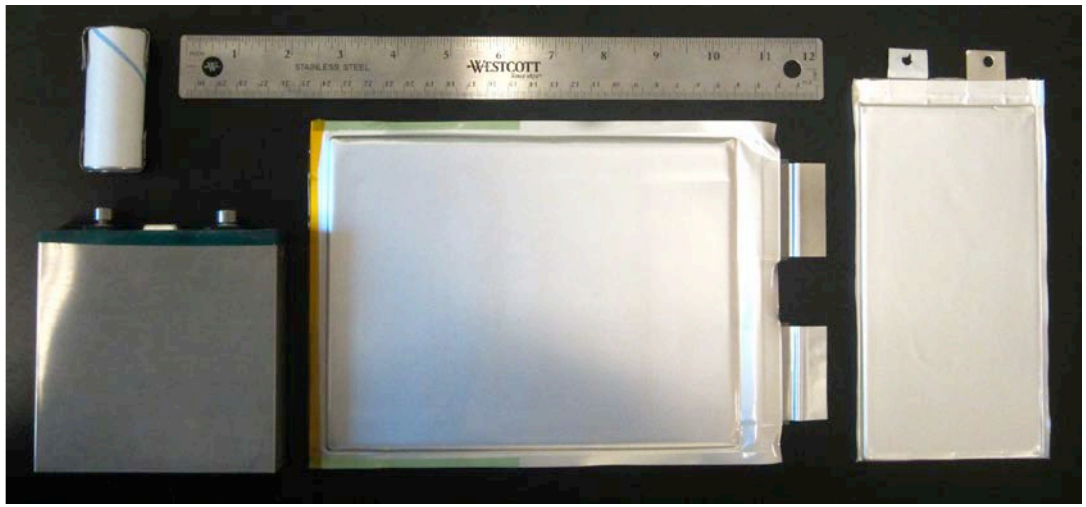
Technical Accomplishments: Curricular

- Updated existing course *ECEN 5737: Adjustable Speed AC Drives* curriculum and teaching materials to be direct companion to the *Power Electronics for Electric Drive Vehicles* course. Offered Spring 2013
  - Introduction to electric machines for electric vehicles
  - Principles for analysis of electric machines, reference frame theory
  - Operation and control of symmetrical induction machines
  - Operation and control of permanent-magnet synchronous machines



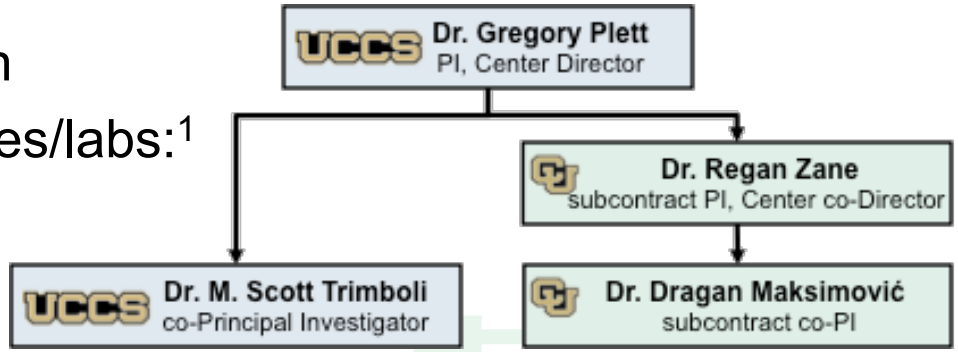
Technical Accomplishments: Curricular

- Environmental chamber and high-current sixteen-channel cell tester purchased, installed, commissioned
- Automotive- and consumer-grade cells purchased
- Now gathering data to be used in future course materials and class projects



IDEATE Collaborations and Coordination

- CU collaboration: org-chart shown



- Relationship with twelve companies/labs:[1]
  - Equipment manufacturer, vehicle companies, national laboratory, venture capital company, battery cell design/manufacturer, battery pack design companies, automotive semiconductor companies,
- This industry advisory board has expressed interest in:
  - Providing paid internship opportunities to *IDEATE* students who have completed at least one semester of coursework (27–46+ positions)
  - Hiring 10+ graduates from the program,
  - Providing guest lecturers as well as PhD qualified personnel to sit on thesis and dissertation committees.

[1] Arbin Instruments, Beyond Aviation, Chrysler, Ford Motor Company, General Motors, Infield Capital, LG Chem Power Inc., Linear Technology, LMS, NREL, Nilar, Texas Instruments

IDEATE Proposed Future Work

Plans for remainder of FY13

- Internal course assessment to capture list of curriculum, content, and teaching materials that need improvement
- Developing lab experiments/data collection for battery courses
- Convene virtual meeting of Industry Advisory Board, solicit input

Plans for FY14

- Refresh course curricula and content/teaching materials based on self assessment and input from Industry Advisory Board
- Begin to polish and package courses for enhanced on-line delivery, including related courses in controls and power-electronics curriculum
- Offer courses to next cohort of students
- Refine advertising strategy based on results of present efforts

Summary

- *IDEATE* addresses a technology workforce shortfall with programs emphasizing two key technologies necessary to propel U.S. automotive industry to the next level, the electrified drivetrain:
  - Battery Modeling and Controls
  - Vehicle Power Electronics
- New Graduate Certificate in *Electric Drivetrain Technology* and new MSEE options will retrain traditional automotive engineers and educate new entrants to the workforce
- All administrative procedures are defined; curriculum is designed; course materials have been developed
- First cohort of Graduate Certificate students will graduate May 2013; first MSEE-BC cohort will graduate December 2013

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Technical Backup Slides

Discussion of Delayed/At-Risk Milestones

Delayed milestones: Missed IAB newsletter, delayed IAB meeting

- Administration, curriculum and course-material development has been more intense than anticipated, delaying these milestones
- New target is to convene IAB meeting this summer, putting us back on schedule

At risk go-no go criteria: "Minimum of 30 students apply for and enter *IDEATE* programs in first two project years"

- Demand for Certificate courses has been strong: 8 students in ECE5720, 17 in ECE5710, 27 in ECEN5737, 64 in ECEN5017
- Demand for certificate and MSEE programs has been low: 3 students enrolled in Graduate Certificate; 3 in MSEE-BC option
- We anticipate that advertisements placed in FY13 and IAB word-of-mouth social networking will improve program enrollments

Sample certificate schedules

- Completing in one year

Fall semester		Spring semester	
ECE 5710: Model., Sim., Ident. Battery Dynamics	ECEN 5017: Pwr. Elect. for Electric Drive Vehicles	ECE 5720: Control of Battery Dynamics	ECEN 5737: Adjustable Speed AC Drives

- Completing in two years, option 1
- Completing in two years, option 2

Fall Y1	Spring Y1	Fall Y2	Spring Y2
ECE 5710: Model., Sim., Ident. Battery Dynamics	ECE 5720: Control of Battery Dynamics	ECEN 5017: Pwr. Elect. for Electric Drive Vehicles	ECEN 5737: Adjustable Speed AC Drives
ECEN 5017: Pwr. Elect. for Electric Drive Vehicles	ECEN 5737: Adjustable Speed AC Drives	ECE 5710: Model., Sim., Ident. Battery Dynamics	ECE 5720: Control of Battery Dynamics

Sample MSEE-BC schedule

Fall semester		Spring semester		Summer semester
ECE 5710: Model., Sim., Ident. Battery Dynamics	ECE 5550: Applied Kalman Filtering	ECE 5720: Control of Battery Dynamics	ECE 5560: System Identification	
ECE 5570: Optimization Methods for Systems, Ctrl	Course from elective list	ECE 5590: Model Predictive Control	Course from elective list	

Non-thesis track

Course from elective list	Course from elective list	MSEE project plus report

Thesis track

Determine thesis topic	Background work on thesis	MSEE thesis