GRADUATE AUTOMOTIVE TECHNOLOGY EDUCATION

GATE Center for Automotive Fuel Cell Systems at Virginia Tech

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Project ID #
TI011

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Outline

- Overview
- Objectives for FY 2010 – 2011
- Milestones
- Approach
- Accomplishments for 2010 – 2011
- Summary

- Additional Accomplishments for 2010 – 2011
- Response to May 2009 review comments
- Publications 2010 - 2011

Overview

Timeline

- Start – Oct 2005
- Finish – May 2011
  (No-cost ext Dec 2010)
- 100 % Complete

Budget

- Total project funding
  - DOE - $499,000
  - Contractor CS - $166,000
- Funding received in FY10
  - $131,000 (total, includes CS)
- Funding received in FY11
  - $33,000 (total, includes CS)

Barriers

- Barriers addressed
  - Insufficient supply of graduate engineers with proper background
  - Need new knowledge in critical technologies: durability, water transport
- Target
  - Provide industry with technical and human resources in interdisciplinary fuel cell and vehicle technologies

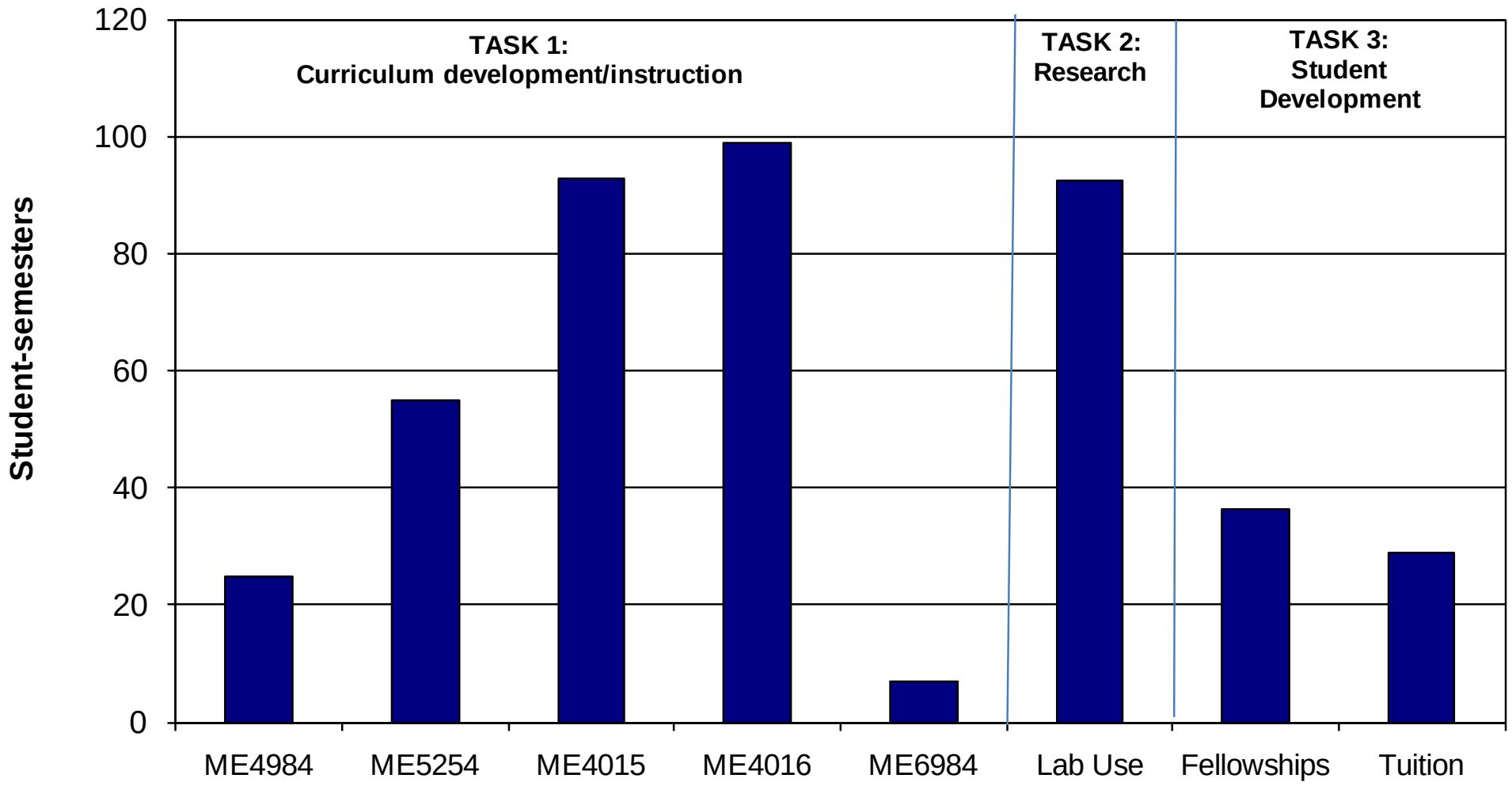
Partners

- Project Lead – Virginia Tech
- Industry Interactions –
  GM FCA, Fuel cell companies,
  Professional Development seminars,
  Conferences and Publications

Objectives for FY2010 – FY2011

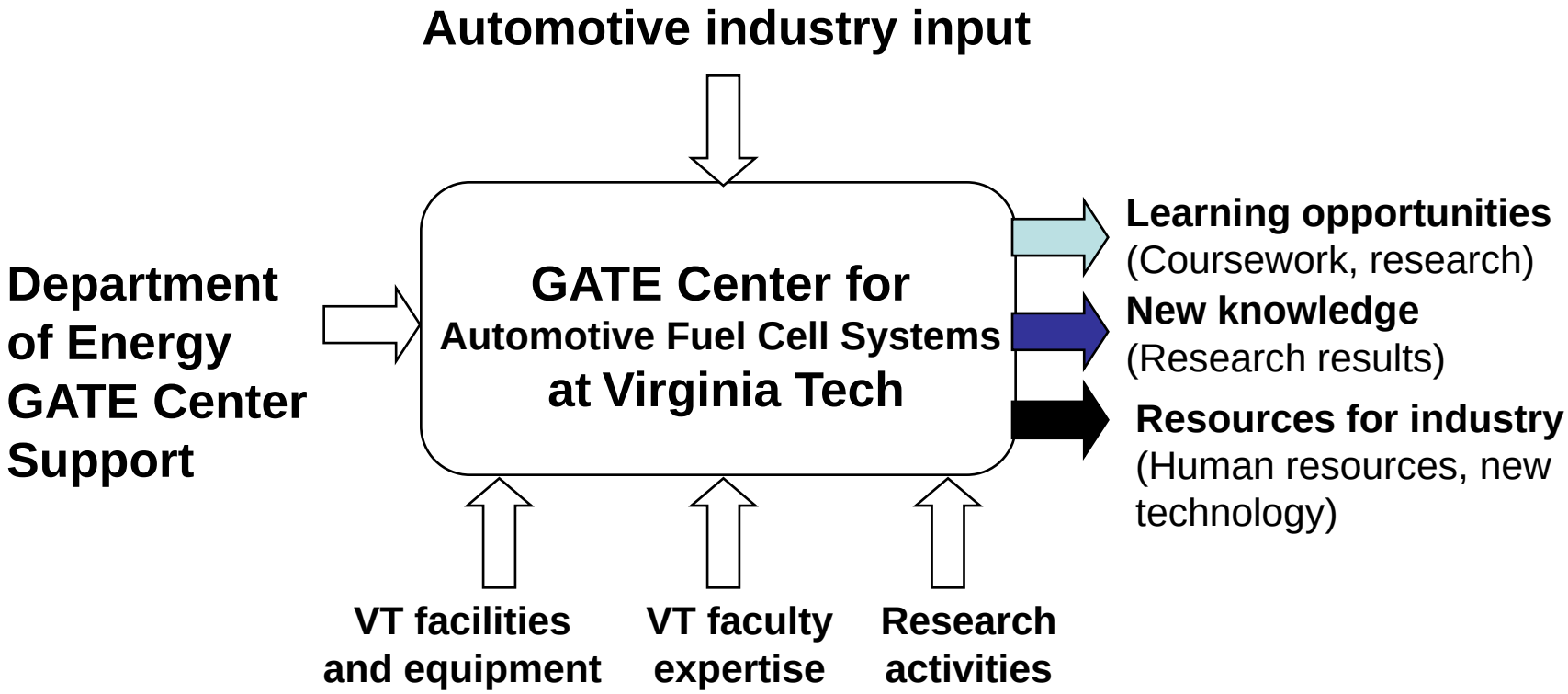
- Task 1 – Curriculum development
  - Develop new materials and enhance existing courses for a fuel cell and hydrogen systems curriculum
  - Specific new course development (Fall 2010)
    ME6984: Experimental and Analytical Techniques for PEMFC
- Task 2 - Engage students in research
  - Provide research opportunities for students that support the goals of the GATE Center
- Task 3 – Recruit students for GATE Fellowships
- Task 4 – Dissemination and scholarship
- Task 5 – Industry interaction

Milestones
Tasks 1-3: Curriculum, Research, Student Development



October 2005 - present

Concept for DoE/VT/Industry Interaction



Our primary objective and output is graduate degree engineers for industry with backgrounds in fuel cell and vehicle technologies research; the progress in this area is reported as numbers of students supported, graduated and hired. The individual research projects have potential to save energy, but it is difficult to make a quantifiable link between diverse projects and energy savings.

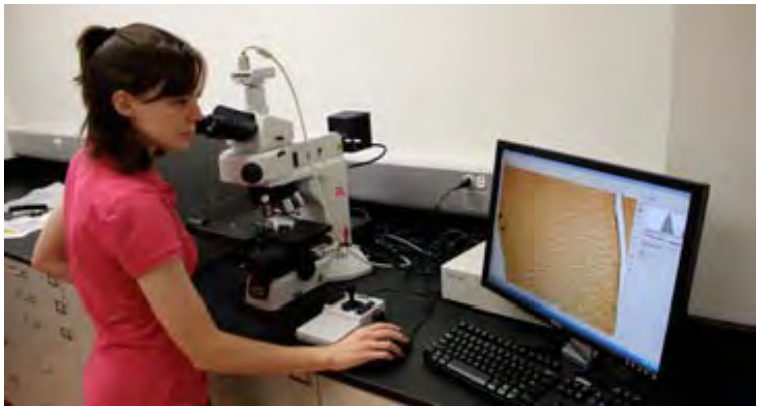
Approach: Collaborative Education and Research Across Disciplines and Academic Levels

- Research collaboration among academic departments
  - Mechanical Engineering – system modeling, nano-/meso-scale modeling, testing and materials characterization
  - Material Science and Engineering Department –material characterization related to fuel cell electrodes
  - Engineering Science and Mechanics Department – durability modeling and membrane characterization
- Research collaboration with undergraduate researchers
  - Jackie Chen: UG researcher in Spring 2011 (development of diffusion cell for crossover measurements)
- Educational collaboration across departments and academic levels for student projects and classes
  - Mechanical engineering, engineering science & mechanics, electrical engineering
  - Graduates, seniors, juniors

Task 1: New Course Development – Fall 2010

- ME6984: Experimental and Analytical Techniques for PEM Fuel Cells
- Experimental focus
  - Organized around series of characterization techniques
    - Polarization curves
    - Electrochemical impedance spectroscopy
    - Linear sweep voltammetry for crossover measurement
    - Cyclic voltammetry for catalyst area measurement
    - Nitrogen adsorption characterization of surface area and micropore volume
    - Diffusion media porosity, permeability, and capillary pressure
  - Hands-on laboratory time
- Course Content
  - Introduction; thermodynamics of fuel cells
  - Fuel cell electrochemistry
  - Electrochemical impedance spectroscopy
  - Polymer electrolyte membranes
  - Catalyst materials and porous electrodes
  - Gas diffusion media
- Continuing to teach ME 5452: Fuel Cell Systems in Spring 2011

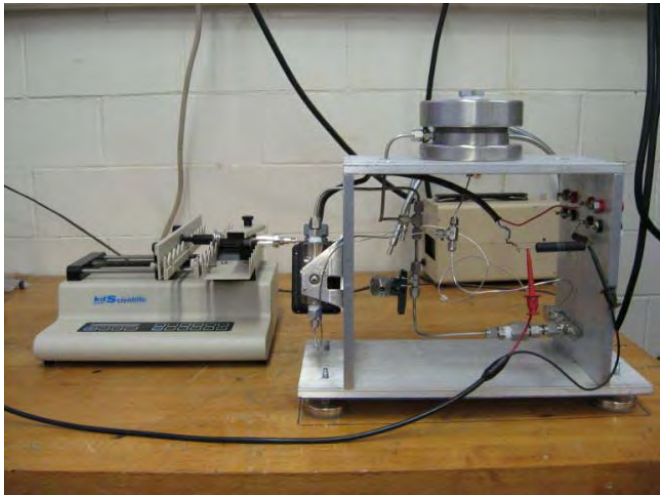
Task 2: Automotive Fuel Cell Research - Durability



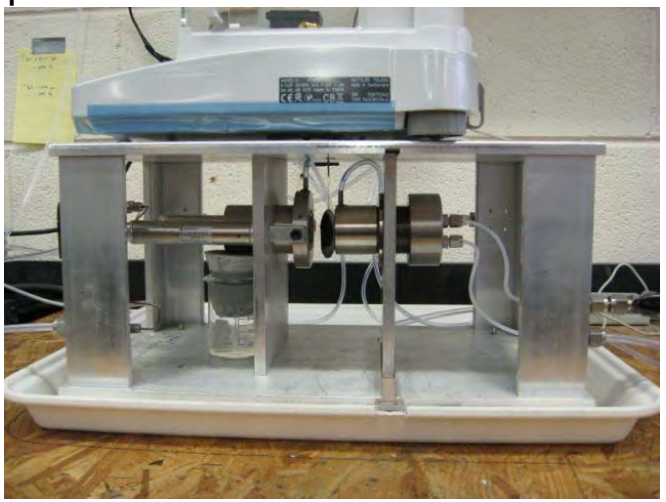
- Improvement of membrane durability requires an understanding of membrane mechanical properties and their relationship to membrane failure
- Research by students that have completed GATE center coursework, used GATE labs, or received GATE center funding (funding denoted by *) has addressed
  - Characterization of the linear and non-linear viscoelastic properties of PFSA membranes (Patankar)
  - Characterization of the linear and non-linear viscoelastic properties of PFCB membranes (Wright*)
  - Characterization of the fracture energy of PFSA membranes using a knife slit test (Li)
  - Characterization of the fracture energy of PFCB membranes using a knife slit test (Gordon*)
  - Simultaneous measurement of water uptake and strain in PFSA membranes (Finlay, Smith*)
  - Development of techniques for evaluation of the resistance of PFSA membranes to shorting (Fox*)
- Research has been conducted in conjunction with industrial sponsorship

Task 2: Automotive Fuel Cell Research - Water Transport

- Improvement of fuel cell performance, particularly at high current density, requires an understanding of liquid water transport in gas diffusion media
- Research by students that have completed GATE center coursework, used GATE labs, or received GATE center funding (denoted by *):
  - Development of characterization techniques for capillary pressure – saturation curves for materials of mixed wetability (Sole*, Van Dyke*)
  - Development of characterization techniques for relative permeability in gas diffusion media (Sole*)
  - Development of analytical models of the GDL that incorporate experimentally determined liquid transport characteristics (Sole*)
- Research has been conducted in conjunction with industrial sponsorship



Apparatus for measuring saturation pressure curves for PEMFC GDL's



Apparatus for measuring relative permeability of PEMFC GDL's

EPA labels now weight contributions from variety of cycles => tech changes for HEVs, FCEVs (Meyer*)

Cold FTP: 20 °F city cycle with heater operation
=> heater efficiency e.g. for EV; effect of engine warmup strategy on fuel econ.; battery performance impact

US06 Highway: up to 80 MPH, & higher accels
=> consideration in sizing component power output

SC03: 95 °F test of air conditioning use under simulated sunlight
=> must consider A/C compressor efficiency & strategy

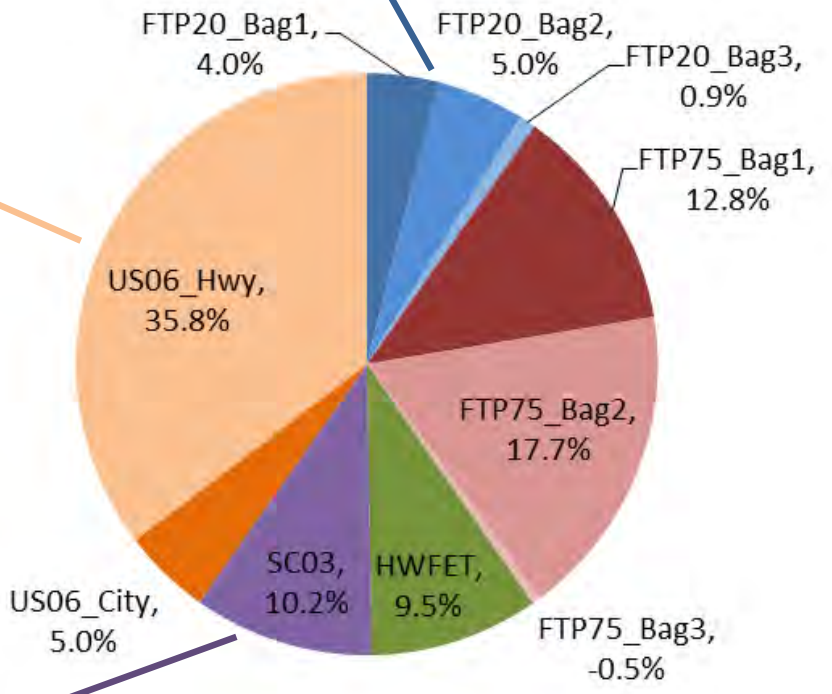
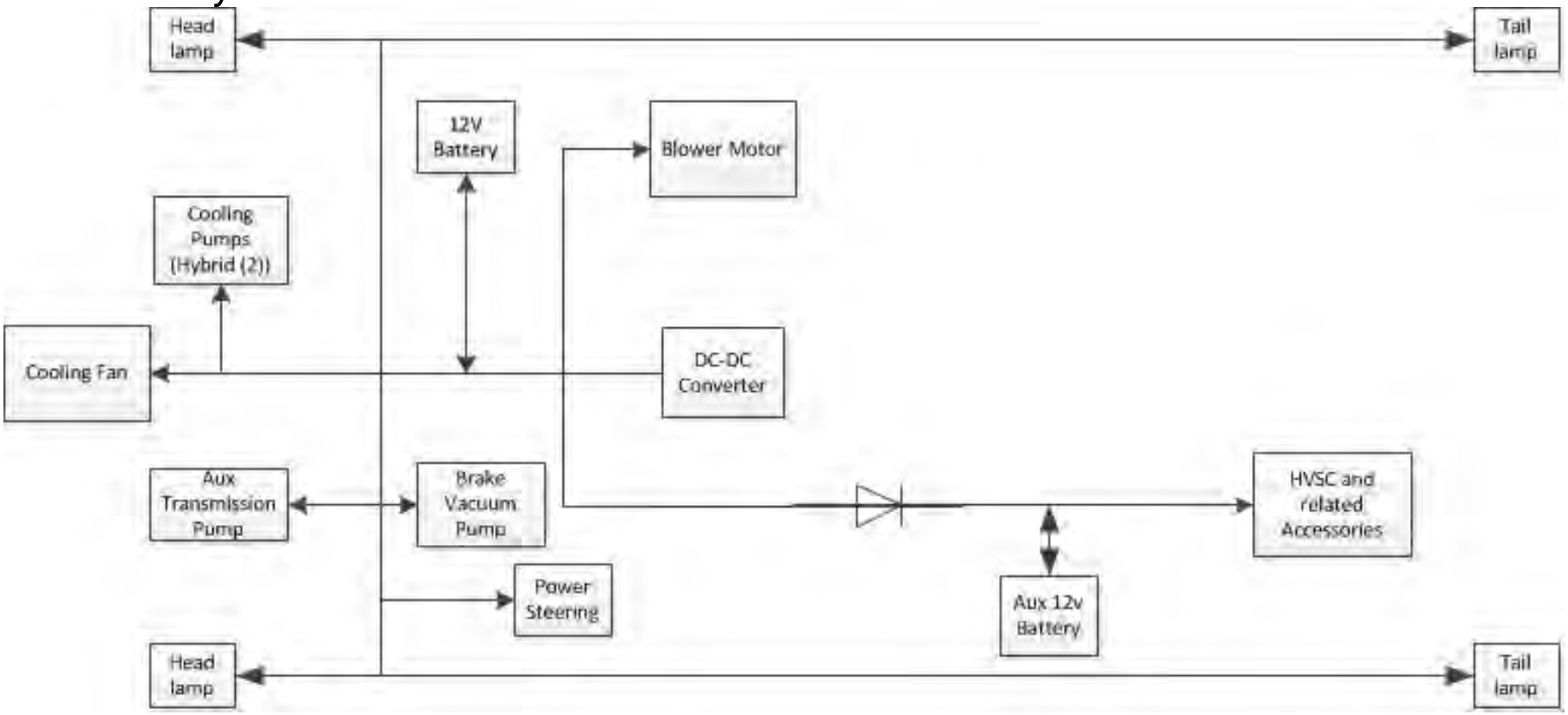


Chart: one form of the mathematical weighting of drive cycles on the city/highway combined fuel economy label

Assessment of Accessory Loads in a Plug-in Hybrid Electric Vehicle (Perkins*)

Objectives:

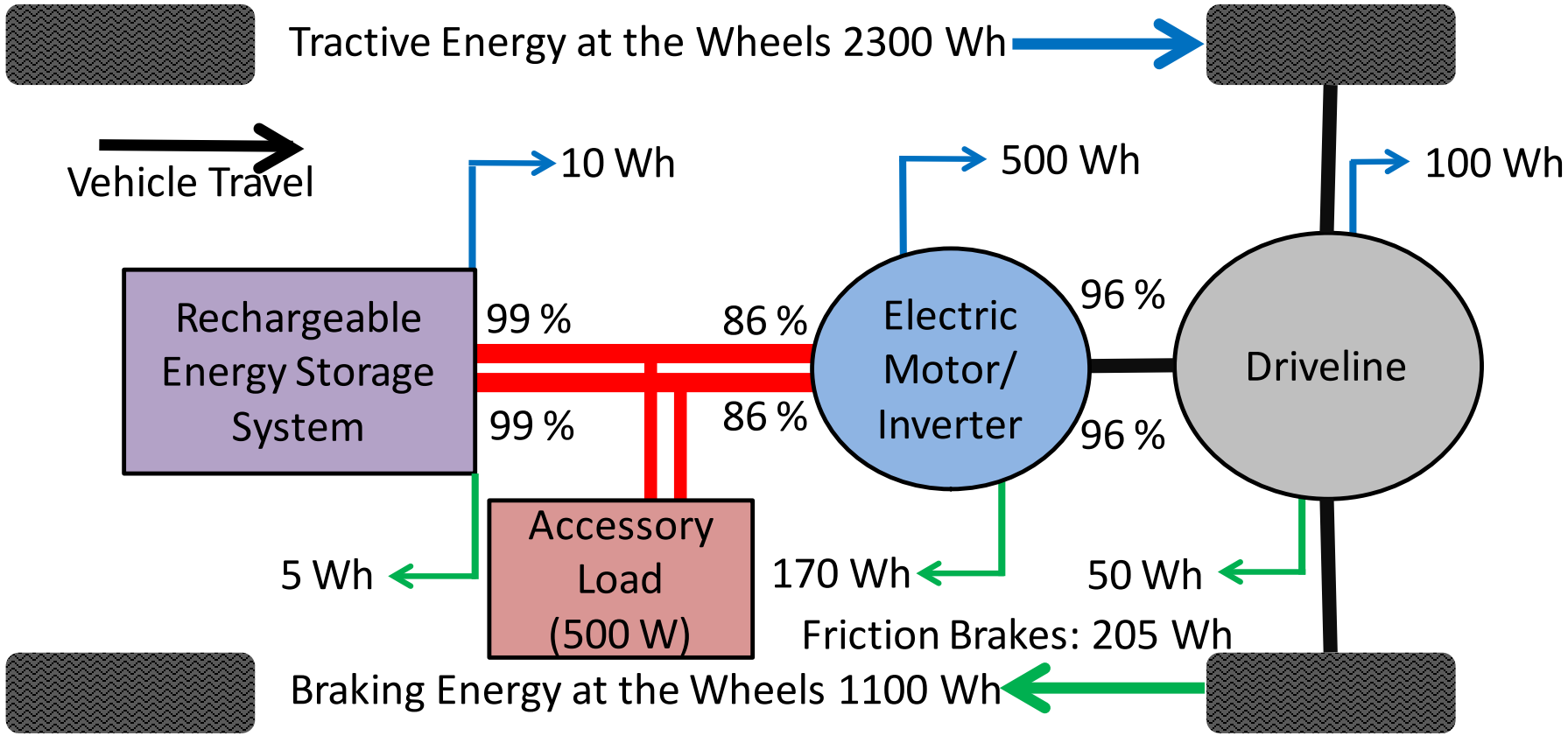
- Analysis of the impact of accessory loads on hybrid vehicle energy consumption
- Virginia Tech Range Extended Crossover (12 volt diagram shown below) as a test vehicle for measurement, analysis, and validation
- Identify key areas where improvements in energy consumption can be made by reduction of accessory loads



Design a Plug-in hybrid electric vehicle battery-only range by using energy weighted component average efficiencies and losses for propelling and braking to predict battery energy consumption (Gantt, Alley*).

Understand the direct impact and sensitivity of each parameter on the total battery range, losses, and energy required to complete a drive cycle as an aid to vehicle design, component selection, and sizing.

Losses and Efficiency for a FWD vehicle on a UDDS



Progress during reporting period (Jan. 2010 – Mar. 2011) for students that have received one or more semesters of GATE support

Continuing students

Charles Smith: continuing Ph.D. on "Quantum Thermodynamics: Application to Hydrogen Storage on a Carbon Nanotube and Theoretical Consideration of Non-Work Interactions," expected graduation August 2011.

Andrew Van Dyke: continuing M.S. on water management characteristics of gas diffusion media in PEMFC, expected graduation 2011.

Jessica Wright: continuing M.S. on viscoelastic characterization of novel PEM materials, expected graduation Summer 2011; continuing for Ph.D.

Ashley Gordon: continuing M.S. on fracture energy of novel PEM materials; expected graduation Fall 2011

Mark Meyer: continuing M.S. on "The influence on vehicle technology design decisions in seeking to improve fuel economy sticker values under new EPA 5-cycle testing", expected graduation Dec 2011.

Trey Perkins: continuing M.S. on "An Assessment of Accessory Loads in a Plug-in Hybrid Electric Vehicle", expected graduation May 2011.

Jesse Alley: continuing M.S. on "An Assessment of Accessory Loads in a Plug-in Hybrid Electric Vehicle", expected graduation May 2011.

Students recently hired in fuel cell and automotive fields 2010 – 2011

- Michael Diaz (MS): GM, HEV Controls, June 2010
- Ethan Filip (MS): Kollmorgen, Motor dev, Nov 2010
- Lynn Gantt (MS): GM, Energy Center, July 2011
- Patrick Walsh (MS): ANL Vehicle Systems, July 2011

Additional information for accomplishments on tasks are provided after the summary:

- Task 2: Automotive Fuel Cell Research - Modeling
- Task 4: Dissemination - Theses and Dissertations
- Task 5: Industry Interaction 2010-2011
- Publications for 2010 – 2011

Collaboration and Coordination with Other Institutions

- Summer interns at GM (industry) – Many, continuing
- Summer interns at ANL (Federal Lab) – 2
- Laboratory Graduate Research Appointment student at ANL for 2011 in Vehicle Systems
- Participating in EcoCAR Advanced Vehicle Technology Competitions (AVTC) (DOE VTP and GM)

  Many undergraduate students from AVTC enter our GATE graduate program and are then also active in our AVTC project at the graduate level

Proposed Future Work Planned for 2011

- Hybrid and Electric Vehicle Systems
  GATE proposal
- DOE objectives – Produce graduate degree engineers for industry with background in hybrid and electric vehicle technologies research
- Approach – Develop courses and research projects to benefit students and industry needs
- Collaborations – Industry projects, student hires, couple with AVTC vehicle projects, outreach

Summary: GATE Center for Automotive Fuel Cell Systems at Virginia Tech

- DOE objectives – Produce graduate degree engineers for industry with background in fuel cell and vehicle technologies research
- Approach – Develop courses and research projects to benefit students and industry needs
- Accomplishments – Courses, fellowships, projects, graduates, and publications
- Collaborations – Industry projects, student hires, summer interns, AVTC projects
- Plan for 2011 – Hybrid and Electric Vehicle Systems GATE proposal

Questions ?

Technical Back-UP Slides

Task 2: Automotive Fuel Cell Research - Modeling

- The synthesis, design, operation, and control of PEMFC, DMFC, and SOFC cells, stacks, and systems as well as fuel storage devices:
  - Development of detailed dynamic and quasi-stationary non-linear models
  - Multi-scale and multi-physics (e.g., lumped parameter, continuum, kinetic theory, and quantum thermodynamic) techniques at the nano-, meso-, and macro-scales
  - Effective techniques for analysis and large-scale optimization (e.g., multi-objective as well as decomposition strategies)
  - Development of uncertainty techniques applicable to already burdened dynamic synthesis/design and operational control optimizations and analyses
- Research by students that have completed GATE center coursework, used GATE labs, or received GATE center funding include the following:
  - Development and application of quantum thermodynamic techniques (as a replacement of and correction to the traditional approach of linear and non-linear molecular dynamics) to the storage of H_2 on carbon nanotubes
  - Integration of MIMO state space control into the dynamic optimal synthesis/design and operation/control of PEMFC systems
  - Dynamic PEMFC system synthesis/design and operation/control under uncertainty
    - Transformation from a deterministic to a probabilistic problem
    - Development and application of probabilistic techniques for large-scale optimizations

    - Demonstration of significance of load and cost uncertainties on meeting critical constraints (e.g., < 10 ppm of CO with a 95% confidence level under dynamic operation)
  - Study of the feasibility of replacing the best battery technology with fuel cells in micro-air vehicles
  - Design, construction and testing of micro-tubular H_2 and MeOH fuel cells and stacks
  - Development and application of 3D reconstruction techniques for porous SOFC and PEMFC electrodes using SEM and TEM images
  - Development and implementation of kinetic theory models to the mesoscopic 3D modeling of reacting mixture flows with and without phase change in porous SOFC and PEMFC electrodes
  - Development and implementation of 2D macroscopic durability models of SOFC electrodes
  - Development of modeling, optimization, and control strategies for SOFC APUs
- Research has been conducted in conjunction with both industrial and government agency sponsorship
- Dissemination
  - J. of Power Sources and ASME J. of Fuel Cell Science and Technology
  - 2 Ph.D. dissertations and 2 M.S. theses

Students who have not received fellowships but who have completed GATE Center classes or have conducted fuel cell research in GATE Center Facilities during the period Jan. 2010 – Mar. 2011

David Woolard: completed MS on “Performance Characterization and Modeling of a Passive DMFC Over a Range of Temperature and Humidity”, June 2010.

Ethan Filip: completed M.S. on “Evaluation and Application of Thermal Modeling for High Power Motor Improvements”, November 2010.

Lynn Gantt: completing M.S. on “PHEV Losses and EV Range”, July 2011

Patrick Walsh: completing M.S. on “PHEV Engine Emissions Control Strategy”, July 2011

Task 5: Industry Interaction 2010-2011

- Industry forums attended by GATE students and faculty
  - 2010 SAE Congress, Detroit, Michigan
  - 2010 EcoCAR Competition, Yuma, Arizona, and San Diego, California
  - 2010 ASME IMECE, Vancouver, British Columbia, Canada
  - 2010 Challenge Bibendum, Rio De Janerio, Brazil
  - 2010 SAE Powertrain, Fuels and Lubes, San Diego, California
  - 2011 EcoCAR Spring Workshop, EPA, Ann Arbor, Michigan
  - 2011 Challenge Bibendum, Berlin, Germany

- Interactions with industry
  - Luna Innovations, Inc.
    - Research on materials development for micro-tubular fuel cells for micro-air vehicles
  - Mr. Charles Strickler, Ecolectrix, LLC
    - Research collaboration
  - Dr. Ann Norris, Dow Corning Corporation
    - Discussion of possible collaborative research projects related to PEMFC's
- Professional Development
  - 2-day short course: "Techniques for the Modeling, Analysis, and Optimization of High-/Low- T Fuel Cells: From the Microscopic to the System Level"; Naples, Italy, Zaragoza, Spain