Recovery Act – An Interdisciplinary Program for Education and Outreach in Transportation Electrification

Carl L. Anderson, P.I.
Jeffrey D. Naber, Co-P.I. & Presenter
Michigan Technological University

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Project ID #ARRAVT037
Overview

Timeline
• Start: Nov 2009
• Finish: Oct 2012
• Status: 85% Complete

Budget
Funding Total
• DOE: $2.978M
• Industry: $0.750M

Technical Targets
• Graduate and Undergraduate Interdisciplinary Engineering Instruction
• Targeted to on-campus and distance-learning
• Hands-on laboratories for all participants

Partners
• Project Lead
  - Michigan Technological University
• Industry
  - 3M
  - ABB
  - AVL
  - Argonne National Laboratory
  - Detroit Diesel
  - Halibrand
  - Eaton
  - EMP Engineered Machine Products
  - Engineering Society of Detroit
  - GM
  - Horiba
  - Kohler
  - MathWorks
  - Michigan Green Jobs
  - National Instruments
  - Pace
  - Phoenix International
  - Schweitzer Engineering Laboratories
  - Wineman Technologies
  - Woodward

Barriers and Risks
• Lack of established curriculum
• Lack of established books & reference materials
• Industry needs not clearly defined
Hybrid Electric Drive Vehicle Engineering

Primary objectives:

• Development of an **interdisciplinary curriculum** that can lead to a professional master’s degree with a focus on preparing students to work in industry and train those already in industry.

• **Undergraduate and graduate certificates** in Advanced Electric Vehicle Engineering; with the graduate certificate focused on distance learning for engineers working in industry and displaced engineers.

• Development of a **mobile laboratory** that includes subsystem learning stations, electrified vehicle software and hardware in the loop systems, a portable vehicle chassis dynamometer, and will utilize HEV’s provided by GM. **This laboratory serves as a key enhancement to the distance learning laboratories and to established university outreach activities.**
Curriculum Development and Outreach

Hybrid Electric Drive Vehicle Engineering

Program Goals:

1. Develop courses that lead to an Undergraduate Certificate
2. Develop courses that lead to a Graduate Certificate
3. Develop a Program of Study Leading to a Professional Masters with a certificate in Hybrid Electric Drive Vehicle Engineering (M.Eng.)
4. Design and Fabricate a Mobile Laboratory for Instruction and Outreach

*The Interdisciplinary Curriculum is Offered Both On-Campus and Through Distance Learning*
Objectives

Three-Year Objectives:

• Develop a master of engineering degree, and graduate and undergraduate certificate programs in Advanced Electric Drive Vehicles
• Target enrollment of 120 graduate students with an expected 50% split of on campus and distance students
• Address work force needs and competencies in emerging electric vehicle technologies for US based industries
• Promote and raise awareness for transportation sustainability through electric propulsion systems with outreach programs

Year 3 Objectives:

• Curriculum Development: Course content completed, continuous improvements based on results of evaluations
• Mobile Laboratory: Operational, learning stations integrated, and commissioned
• Collaborate with industry partners to identify work force needs and potential students
• Second round of course delivery along with course assessments
• Delivery of “Propulsion Systems for Electric Vehicles Laboratories” courses on campus MEEM/EE 4295 “Intro” and MEEM/EE 5296 “Advanced” via Mobile Laboratory
• Develop Outreach (Public Education) materials and deliver outreach activities
VT ARRA Program Relevance

Relevance to VT program goals:

• Create an education program to retrain the existing workforce and create the next generation of engineers to:
  ◦ Develop energy efficient and environmentally friendly technologies
  ◦ Develop EDV’s to reduce dependence on fossil fuels and increase energy security,
• Conduct outreach to K-12 to attract youth to engineering and science education
• Educate the public on the technologies and benefits of vehicle electrification

Relevance to the ARRA goals: This education is needed to support the creation of new jobs as well as save existing ones, spur economic activity, and invest in long-term economic growth:

This program is directly relevant to and will impact the VT ARRA program:

• Retrain displaced engineers
• Educate incumbent engineers in Vehicle Electrification Technologies, which will impact jobs in transportation related industries.
• Educate the next generation of engineers trained in innovative vehicle technologies
## Milestones

### FY10 & FY 11 Milestones

<table>
<thead>
<tr>
<th>Month/Year</th>
<th>FY10 &amp; FY 11 Milestones</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec-2009</td>
<td>Pilot Course taught to 96 distance students</td>
<td>Complete</td>
</tr>
<tr>
<td>Aug - 2010</td>
<td>Modifications Complete for on-campus “Propulsion Systems for Electric Drive Vehicles Laboratory” courses</td>
<td>Complete</td>
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<tr>
<td>Aug - 2010</td>
<td>Development and Modification Complete for 7 courses</td>
<td>Complete</td>
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<tr>
<td>Dec - 2010</td>
<td>First Round of Teaching Courses Complete</td>
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<tr>
<td>Dec - 2010</td>
<td>Mobile Lab 2\textsuperscript{nd} Stage Simulators</td>
<td>Complete</td>
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<tr>
<td>Dec - 2010</td>
<td>Senior Design Teams 1-4 Complete HEV Projects</td>
<td>Complete</td>
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<tr>
<td>May - 2011</td>
<td>Mobile Laboratory Complete/Commissioned</td>
<td>Complete</td>
</tr>
<tr>
<td>May - 2011</td>
<td>Development of Outreach Materials for 1st year</td>
<td>Complete</td>
</tr>
<tr>
<td>Aug -2011</td>
<td>All Course Development Complete</td>
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### FY12 Milestones

<table>
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<tr>
<th>Month/Year</th>
<th>FY12 Milestones</th>
<th>Status as of March</th>
</tr>
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<tbody>
<tr>
<td>Dec 2011</td>
<td>Senior Design Teams 5-6 Complete HEV Project</td>
<td>Complete</td>
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<tr>
<td>Dec 2011</td>
<td>Development and Modification Complete for 8\textsuperscript{th} and Final Course</td>
<td>Complete</td>
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<tr>
<td>Dec 2011</td>
<td>Second Round of Teaching Courses Complete</td>
<td>On Schedule</td>
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<tr>
<td>May 2012</td>
<td>Enterprise Teams Integrate Final Stage Simulators to Mobile Lab</td>
<td>On Schedule</td>
</tr>
<tr>
<td>Aug 2012</td>
<td>Proposed Outreach Components Developed</td>
<td>On Schedule</td>
</tr>
<tr>
<td>Aug 2012</td>
<td>Program Running in Sustainable Mode</td>
<td>On Schedule</td>
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</table>
Overall Project Approach

- Development of two key **Interdisciplinary Courses in Propulsion for HEV**: Create and implement these courses to provide students with background knowledge in propulsion systems.

- Development of two associated **Laboratories**: Create and provide learning opportunities through hands-on laboratory experiences.

- New Course Development: **New courses** in e-machines, electro-mechanical systems, energy conservation, vehicle dynamics, embedded systems, and battery management in electric vehicles.

- Enhancing Existing Courses: **Improving current courses** in electrical, chemical, materials, and mechanical engineering to provide cross access to respective departmental students.
Objective-Specific Approaches: Curriculum Development

• An **Interdisciplinary team** of faculty and staff in four engineering departments to develop and teach the courses.

• Courses are dual listed among four departments to attract a **diverse** student pool

• **Industry guided curriculum development:**
  • Partnered with Michigan Academy for Green Mobility Alliance (MAGMA), an organization lead by the automotive industry in partnership with the state and training providers
    ◦ MTU persons serve on the directors, advisory, curriculum and funding committees
    ◦ MTU certificate program was the first of the DOE sponsor programs that received full MAGMA approval for our certificate as assessed by industry experts
    ◦ MAMGA identifies students, both incumbent and displaced engineers to participate in the program. Funding for tuition covered through State/Federal Grants
  ◦ Preparing short courses with hands-on laboratories to be delivered on-sight via the mobile laboratory (HEV introduction, E-Machines, Batteries, Embedded software, …)
### Schedule of new course development, modifications to courses, delivery, and corresponding enrollments

<table>
<thead>
<tr>
<th>New Courses</th>
<th>Dept.</th>
<th>Number</th>
<th>Credits</th>
<th>Spring DL</th>
<th>Spring C</th>
<th>Summer DL</th>
<th>Summer C</th>
<th>Fall DL</th>
<th>Fall C</th>
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<tbody>
<tr>
<td>Intro. To Prop. Systems for HEV</td>
<td>EE/ME</td>
<td>4295</td>
<td>3</td>
<td>9</td>
<td>42</td>
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<td>Adv. Prop. Systems for HEV</td>
<td>EE/ME</td>
<td>5295</td>
<td>3</td>
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<td>6</td>
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<td>EE/ME</td>
<td>4296</td>
<td>1</td>
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<td>Adv. Prop. Systems for HEV Laboratory</td>
<td>EE/ME</td>
<td>5296</td>
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<td></td>
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<td></td>
<td>D</td>
<td>D</td>
<td>X</td>
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<td>Advanced Electric Machines</td>
<td>EE</td>
<td>5221</td>
<td>3</td>
<td>15</td>
<td>30</td>
<td></td>
<td></td>
<td>9</td>
<td>18</td>
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<td>Vehicle Battery Cells and Systems</td>
<td>MY/CM</td>
<td>5760</td>
<td>3</td>
<td></td>
<td></td>
<td>D</td>
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<td>Vehicle Dynamics</td>
<td>ME</td>
<td>4450/5450</td>
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<td></td>
<td></td>
<td></td>
<td>D</td>
<td>6</td>
<td>34</td>
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<td>Distributed Embedded Control Systems</td>
<td>EE/ME</td>
<td>4750/5750</td>
<td>3</td>
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<td>X</td>
<td>X</td>
<td>22</td>
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</table>

| Distance Learning Enrollment                      | 64    | 29    | 6      | 39     | 7 |
| Traditional Campus Enrollment                     | 22    | 92    | 51    | 74     | 113|

<table>
<thead>
<tr>
<th>Modified Courses</th>
<th>Dept.</th>
<th>Number</th>
<th>Credits</th>
<th>Spring DL</th>
<th>Spring C</th>
<th>Summer DL</th>
<th>Summer C</th>
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<td>Intro. to Motor Drives</td>
<td>EE</td>
<td>3221</td>
<td>4</td>
<td>X</td>
<td>65</td>
<td>M</td>
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<td>Power Electronics</td>
<td>EE</td>
<td>4227</td>
<td>3</td>
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<td>4228</td>
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<td>Power System Operations</td>
<td>EE</td>
<td>5230</td>
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<td>Power System Protection</td>
<td>EE</td>
<td>4223/5223</td>
<td>3</td>
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<td>M</td>
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<td>Power System Protection Lab</td>
<td>EE</td>
<td>4224/5224</td>
<td>1</td>
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<td>Distribution Engineering</td>
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<td>27</td>
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<td>Intro to IC Engines</td>
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<td>4220</td>
<td>3</td>
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<td></td>
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<td>87</td>
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<td>Internal Combustion Engines II</td>
<td>ME</td>
<td>5250</td>
<td>3</td>
<td>17</td>
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<td>35</td>
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</table>

| Distance Learning Enrollment                      | 27    | 15    | 38    | 40     | 196    |
| Traditional Campus Enrollment                     | 114   | 40    | 38    | 40     | 109    |

**KEY**
- **D**: Develop
- **T**: Teach
- **M**: Modify
- **DL**: Distance Learn
- **Status**
- **Dept.**
  - CM: Chem Eng.
  - MT: Mat Sci & Eng.
- **Level**
  - UG: Undergraduate
  - Tech: Technical
  - Grad: Graduate
  - ENT: Enterprise
### Schedule of existing course delivery, and corresponding enrollments

<table>
<thead>
<tr>
<th>Existing Courses</th>
<th>Dept.</th>
<th>Number</th>
<th>Credits</th>
<th>Distance Learning Enrollment</th>
<th>Traditional Campus Enrollment</th>
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<tbody>
<tr>
<td>Electric Energy Systems (EE/Non EE)</td>
<td>EE</td>
<td>3120</td>
<td>3</td>
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<td>368</td>
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<td>Power System Analysis 1</td>
<td>EE</td>
<td>4221</td>
<td>3</td>
<td>22</td>
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<td>Power System Analysis 2</td>
<td>EE</td>
<td>4222</td>
<td>3</td>
<td>28</td>
<td>102</td>
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<tr>
<td>Advanced Methods in Power Systems</td>
<td>EE</td>
<td>5200</td>
<td>3</td>
<td>13</td>
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<td>Classical Control Systems</td>
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<td>4261</td>
<td>3</td>
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<td>Thermodynamics/Fluid Mechanics (Non ME)</td>
<td>ENG</td>
<td>3200</td>
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<td>X</td>
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<td>Principles of Energy Conversion</td>
<td>ME</td>
<td>4200/5290</td>
<td>3</td>
<td>11</td>
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<td>Dynamic Systems and Controls</td>
<td>ME</td>
<td>4700</td>
<td>3</td>
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<td>Advanced Thermodynamics</td>
<td>ME</td>
<td>5200</td>
<td>3</td>
<td>11</td>
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<td>5670</td>
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<tr>
<td>Optimization</td>
<td>ME</td>
<td>5680</td>
<td>3</td>
<td>11</td>
<td>112</td>
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<tr>
<td>Dynamic Systems and Signal Analysis</td>
<td>ME</td>
<td>5700</td>
<td>4</td>
<td>11</td>
<td>112</td>
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<tr>
<td>Linear Systems</td>
<td>ME</td>
<td>5715</td>
<td>3</td>
<td>11</td>
<td>112</td>
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<tr>
<td>Fuel Cell Technologies</td>
<td>ME</td>
<td>4260/5220</td>
<td>3</td>
<td>11</td>
<td>112</td>
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<td>Senior Capstone Design (4 Projects, Avail DL)</td>
<td>EE/ME</td>
<td>4901/4911</td>
<td>2.2</td>
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<td>Fuel Cell Fundamentals</td>
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<td>11</td>
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<td>Fundamentals of Hydrogen as an Energy Carrier</td>
<td>CM/ENT</td>
<td>3977</td>
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<td>Hydrogen Measurements Laboratory</td>
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<td>Enterprise Courses</td>
<td>ENT</td>
<td>29XX</td>
<td>1</td>
<td>22</td>
<td>5</td>
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</table>

**Note:** The schedule includes the number of students enrolled in each course for Spring and Fall semesters, with corresponding enrollments in Distance Learning (DL) and Traditional (T) formats.
Objective-Specific Approaches: Mobile Laboratory

Mobile Laboratory Development:

- Courses
- Outreach
- Public Education
Objective-Specific Approaches: Mobile Laboratory

Classroom, Powertrain Testcells, & Multifunction Laboratory Benches

Hybrid Vehicles
- Saturn Vue MultiMode
- Configurable HEV
- Chevy Malibu BAS
- Chevy Volt EREV

Hands-On Outreach Activities

Portable Chassis Dyno
Objective-Specific Approaches: Mobile Laboratory

Vehicle Development Process
Model ⇒ Design ⇒ Develop ⇒ Test ⇒ Validation

Powertrain HIL (Batteries, E-Machines, Engines, Drivetrain, etc.)

Lecture & Configurable Outreach Space

On-Track with Configurable HEV’s

ECU HIL

Vehicle Simulation for Coursework and Outreach

On-Road with Production HEV’s
Objective-Specific Approaches: Outreach

The Mobile Laboratory is our key to outreach activities

Examples of Outreach to date:
• Mind Trekkers Tour
• Michigan Tech Summer Youth
• Michigan Tech Orientation Week
• K-12 visits to Local Schools
• Houghton Girl Scouts
• Keweenaw Cub Scouts
• Western UP Science Fair
• NSF RET and REU

Scheduled Outreach:
• Council of University Transportation Centers
• USA Science & Engineering Festival
• High School Enterprise in Partnership with GM
• Local fairs, parades, & K-12 visits
Objective-Specific Approaches: Outreach
Hybrid Vehicle Gaming Software

- Blue Marble Student Enterprise Group developing a HEV software game for education and outreach.

- Targeted K-12 students to virtually and interactively examine and experience vehicle hybridization and understand the operational characteristics while being a immersive fun game.

- To be Distributed on CD/Jump Drives at outreach events with the Mobile Lab and other events and via download from the web.

- Status:
  - Base environment (tracks, backgrounds) completed.
  - Vehicle physics models complete including hybrid and IC drivetrains.
  - Graphics models of several vehicles under development including conventional and hybrid vehicles (e.g., Ford Mustang, Chevy Volt...)

  Beta release set for April 2012
Objective-Specific Approaches: Course Delivery

A interdisciplinary team of thirteen experienced educators and researchers with different but complimentary technical expertise to:

• Established innovative, effective and engaging teaching and delivery methods for newly developed and current courses

• Work closely with OEMs and suppliers to ensure the program meets work force needs

• Distance Learning courses delivered with the same material and quality of instruction as traditional classroom based courses

• Deliver hands-on instruction with simulators and laboratories at the subsystem and vehicle level

• Target to concentrated locations (e.g, South East Michigan) by partnering with Michigan Academy Green Mobility Alliance
ME/EE 4295 Intro to Propulsion for HEV

- Introduction to HEV/EV history, hybrid architecture for series and parallel systems
- Model-based design in Simulink, IC engines, electric machines, electric drive systems, regeneration braking, power electronics, battery models as RC circuits. Students develop the Hybrid Vehicle Simulink model.
- Introduction of drive cycles and driver controls, effects of road conditions and energy efficiency over a specified drive cycle.
- The final HVM included torque blending between the IC Engine and E-Motor, Engine-stop, transmission gear selection based on ICE torque request and fuel usage in each available gear, regeneration during braking and over-all fuel economy for a given drive cycle. The IC Engine model contained the torque, fuel flow rate and engine speed from a current production engine. The E-Drive model is based on a production, PM motor with a student developed controller.

The HVM modeled in Simulink, this particular student included “extras” such as a Power Electronics module, a Friction Brake module with a complete front/rear brake bias algorithm for regeneration and determination of vehicle jerk for drive quality comparison.

The target velocity (drive cycle) and the vehicle velocity for a HEV with torque blending, a finite ratio transmission and a shift criteria to minimize fuel usage. The vehicle modeled is a large SUV.
Model Based: Analysis ➔ Assessment ➔ Design ➔ Control

Weeks 1-7
Vehicle Modeling ➔ Controls ➔ HEV Controls
Vehicle Dyn ➔ Drive Cycles ➔ Regulations

Weeks 8-14
Torque Split ➔ Optimization ➔ Final Project
Powertrain Architectures Case Studies

Impact of Vehicle Technologies on Reducing Fuel Consumption

- ACC Loss
- Drag
- RR
- Mass
- BSFC
- US/DS

Final Project
1. Model and validate a production HEV
2. Design a new HEV and compare existing HEV’s
3. Develop high order model for component and integrate into full vehicle model

Verification and Validation are key components. Must evaluate performance and fuel economy.
ME/EE 4296 & 5296 Intro & Advanced HEV Laboratory Courses

4296
• The HEV is analyzed as a series of energy conversion processes
• The vehicle is studied from a sub-system perspective
  ▪ Body / Chassis (aerodynamics / rolling resistance)
  ▪ Battery
  ▪ Engine
  ▪ Electric Machine

5296
• Focused on systems level integration
• Vehicle Development Process
• Final Project involves the optimization of the Configurable HEV through hardware and software changes

Preparing for Powertrain tests in the Mobile Lab
Setting up to log baseline data on the Configurable HEV
Coast down testing to understand rolling resistance and aerodynamic effects
Measuring mass of the Configurable HEV for model validation
Technical Accomplishments & Progress - FY12

Task 1
- Course content/material development complete for all courses
- Industry guided curriculum based on workforce needs
- Enrollment of students into newly developed graduate and undergraduate certificate programs and masters program, student recruitment continues; enrollment numbers increasing,

Task 2
- Mobile Lab operational for courses and outreach
- System integration and optimization at the vehicle level
- Mobile Lab learning stations and test cell assembly complete

Task 3
- Four Senior Design teams developed a Configurable Hybrid Electric Vehicle and integrated with laboratory courses taught using mobile lab.
- Additional Senior Design team developed HEV Outreach Learning Activity Station
- Enterprise teams developing Learning Station Software
- Graduate Students developing outreach activities

Task 4
- Second round of course delivery completed for all but one course
- Course and instructor evaluations completed
- Integrating continuous improvement into course modifications
Technical Accomplishments & Progress - Task 1
Curriculum Development

• Course content and materials developed for all 8 of the new courses
• Course content and materials developed for all of the 9 modified courses
  ▪ Improved courses with updated material EREV/BEV/battery technologies and provide interdisciplinary access to the respective departmental students
• Collaboration with MAGMA and industry to identify current and future workforce needs,
  ▪ Working with industry and state to identify and enroll distance learning students.
  ▪ Working with industry to provide short courses based on technical needs.
• Undergraduate and Graduate Certificates in place, along with a masters program, actively recruiting new students both on campus and distance learning
  ▪ Graduate certificate focused on distance learning for engineers working in industry and displaced engineers.
• Started a new HEV Undergraduate/Graduate Enterprise (40 students): 80mpg PHEV Cruze – Enables students further vehicle development education and experiences
Technical Accomplishments & Progress - Task 2
Mobile Laboratory Development

• Mobile Lab Team has completed configuration and assembly of learning stations. Mobile lab operational Summer 2011.
  ◦ Utilized for courses, short courses, and outreach
  ◦ Chevy Volt is an integral component for courses and outreach
  ◦ Several HEV themed outreach activities have been developed

• Four Senior Design Teams completed design and build of the prototype Configurable Hybrid Electric Vehicle (CHEV) for the Mobile Laboratory. The vehicle operates as an HEV with torque blending between the motor and engine, regenerative braking, and engine auto-stops. The CHEV is also used for outreach.

• Hybrid Enterprise Teams engaged to develop Interactive Electric Drive Vehicles Software for Education and Outreach activities. Teams have acquired an open-source vehicle gaming engine, and have begin incorporating various HEV solid and physics based vehicle models into the game.
The Mobile Laboratory is our key to established outreach activities, maximizing the educational experience with hands-on learning experiences for all levels of students (K-12, Undergrad & Graduate).

- Enhancement of NSF Research Experiences for Undergraduate Students (EEC-1062886): 3 year program for undergraduate research on Advanced Propulsion and Fuel Technology for Sustainable Transportation - **Started summer 2011**

- Enhancement of NSF Research Experiences for Teachers (EEC-10009617): 3 year program providing high school teachers research educational activities in Sustainable Transportation Technologies - **Started summer 2011**

- Undergraduate student teams involvement in Outreach Development:
  - Four Senior Design teams developed **Configurable Hybrid Electric Vehicle**.
  - A Senior Design team in partnership with GM completed design and construct an in-situ fuel consumption meter that will be used for the on-road and configurable HEVs in the course laboratories.
  - Additional Senior Design team to designed and built a **Hybrid Electric Bike** demonstration that can be used K-12 and community outreach. Senior Design team participated in a four city Mind Trekkers Tour sponsored by AT&T with their initial design concept.
  - BlueMarble Enterprise Team developing **Interactive Electric Drive Vehicles Software** for Education and Outreach activities. The program is specifically targeted at K–12 grade students, general public, community college, and non-degree seeking undergraduates to raise awareness for hybrid vehicles.
Research in Advanced Propulsion and Fuel Technology for Sustainable Transportation

Research opportunity for undergraduate students to participate in interdisciplinary research in advanced hybrid propulsion and renewable fuels in transportation.

Summer 2011 Program

- First year of three year program
- 9 REU students from 6 universities participated
- A series of professional development and ethics education seminars
- REU projects have contributed to the development of the mobile lab, HEV test bench, and several HEV teaching laboratories
- Program contributes to the development of a larger and diverse workforce in the areas of sustainable energy and transportation
Technical Accomplishments & Progress - Task 4
Course Delivery and Evaluation

• Course delivery to date: (Second round completed)
  ◦ 8 Newly developed courses
  ◦ 9 Modified courses
  ◦ 19 existing courses that are program electives delivered

• Enrollment:
  ◦ Enrollment numbers increasing for both on campus and distance learners.
  ◦ Majority of distance learners are employed or displaced engineers

• Distance Learning conducted with the same content and quality of materials as on campus courses.

• Courses taught by interdisciplinary team of faculty
  ◦ Mechanical, Electrical, Materials Science & Engineering, Chemical Engineering Departments, and Industry Experts
Course Delivery Fall 2011

New Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Offered</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE/ME 4295</td>
<td>11 DL</td>
<td>37 Campus</td>
</tr>
<tr>
<td>EE/ME 4296</td>
<td>15</td>
<td>Campus</td>
</tr>
<tr>
<td>EE 5221</td>
<td>9 DL</td>
<td>18 Campus</td>
</tr>
<tr>
<td>MY/CM 5760</td>
<td>19 DL</td>
<td>4 Campus</td>
</tr>
</tbody>
</table>

Intro Propulsion Systems for HEDV
Intro Propulsion Systems for EDV Laboratory
Advanced Electric Machines
Vehicle Batteries, Cells, and Systems

Modified Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Offered</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE 4227</td>
<td>29 DL</td>
<td>40 Campus</td>
</tr>
<tr>
<td>EE 4228</td>
<td>27</td>
<td>Campus</td>
</tr>
<tr>
<td>EE 5230</td>
<td>7</td>
<td>Campus</td>
</tr>
<tr>
<td>ME 5250</td>
<td>1</td>
<td>35 Campus</td>
</tr>
</tbody>
</table>

Power Electronics
Power Electronics Laboratory
Power Systems Operations
Internal Combustion Engines II

Existing Courses

- Thirteen existing courses; of those four were taught via distance learning in addition to on campus. (84 DL / 532 Campus)

Total Course Enrollment Fall 2011: 153 DL / 715 Campus
Course Delivery Spring 2012

New Courses
• ME/EE 5295 (1 DL / 32 Campus)  Advanced Propulsion Systems for HEV
• ME/EE 5296 (10 Campus)  Adv. Propulsion Systems for HEV Laboratory
• ME/EE 4750/5750 (37 Campus)  Distributed Embedded Control Systems
• ME 4450/5450 (6 DL / 34 Campus)  Vehicle Dynamics

Modified Courses
• EE 3221 (45 Campus)  Intro to Motor Drives
• EE 4225/5250 (27 DL / 31 Campus)  Distribution Engineering
• ME 4220 (8 DL / 40 Campus)  Intro to IC Engines

Existing Courses
• Five existing courses; of those two were taught via distance learning in addition to on campus. (40 DL / 320 Campus)

Total Course Enrollment Spring 2012: 82 DL / 549 Campus
Technical Accomplishments & Progress - Task 4
Course Delivery and Evaluation

• Traditional MTU survey of teacher effectiveness for each course taught every semester for both on campus and distance learning students

• Additional surveys were given –
  ° Survey distributed Fall 2010, Spring 2011, and Fall 2011
  ° 3 classifications of questions
    • Introduction and general questions (4 questions)
      - Students had prior knowledge of hybrid and electric vehicle systems, which improved over the duration of the course
    • Course-based questions (6 questions)
      - Students were highly supportive of classroom content, teaching methods, and laboratory experiences
    • Program-based questions (4 questions)
      - Significant numbers liked distance learning component
      - Students expressed interest in graduate certificate

• Results

<table>
<thead>
<tr>
<th></th>
<th>Fall 2010 (%)</th>
<th>Spring 2011 (%)</th>
<th>Fall 2011 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I took these courses because they were part of the (graduate or undergraduate) certificate in hybrid electric drive vehicle engineering.</td>
<td>21%</td>
<td>30%</td>
<td>62.5%</td>
</tr>
<tr>
<td>I took these courses because they were part of the Masters of Engineering with emphasis in hybrid electric drive vehicle engineering.</td>
<td>12.5%</td>
<td>9%</td>
<td>58%</td>
</tr>
<tr>
<td>After taking these courses, I am interested in the (graduate or undergraduate) certificate in hybrid electric drive vehicle engineering.</td>
<td>50%</td>
<td>70%</td>
<td>87%</td>
</tr>
<tr>
<td>After taking these courses, I am interested in the Masters of Engineering with emphasis in hybrid electric drive vehicle engineering.</td>
<td>29%</td>
<td>39%</td>
<td>61%</td>
</tr>
</tbody>
</table>
Team Collaborations

• Project Lead
  ◦ Michigan Technological University – *Education Provider, Program Developer*

• Industry
  - 3M – *graphic package for mobile laboratory*
  - ABB – *components for dynamometer drives*
  - AVL - *HEDV instrumentation, HIL components, controls expertise*
  - Argonne National Laboratory - *graduate student internships*
  - Detroit Diesel – *class 8 2006 Freightliner tractor*
  - Halibrand - *CHELM components, engineering support*
  - Eaton - *power management software and controls, battery technology expertise, transmission*
  - EMP Engineered Machine Products – *engineering support and coolant pumps*
  - Engineering Society of Detroit - *marketing, student recruitment, classrooms*
  - GM - *vehicles/vehicle components, student recruitment*
  - Horiba - *automotive test systems and expertise*
  - Kohler - *engines, engineering support*
  - MathWorks - *software and software expertise*
  - Michigan Green Jobs - *marketing, student recruitment*
  - National Instruments - *hardware for the data acquisition and control of the test cells*
  - PACE – *computers, monitors, and software, training*
  - Phoenix International - *electric motor, motor drives, engineering support*
  - Schweitzer Engineering Laboratories - *electric power systems and expertise*
  - Wineman Technologies - *software for the data acquisition and control*
  - Woodward - *energy controllers, controller software and controls expertise*
Future Work

Remainder of FY12

• Continue marketing HEV certificates and recruiting students at both undergraduate/graduate level (ongoing)
• Course Assessments and continuous improvements (ongoing)
• Enterprise teams integrate final stage simulators to Mobile laboratory and provide web versions (May, 2012)
• Final outreach during funding period complete (August, 2012)
• All course modifications including DL portions and courses and repeating outreach, senior design, and enterprise activities have been taught at least once. (August, 2012)
• Program running in a sustainable mode. (August, 2012)
Summary

- Interdisciplinary curriculum is in place with sustainable enrollments.
- Students across the College can integrate these courses into their degree programs at all levels.
- Mobile lab is operational and continues to be developed.
- Outreach content has been developed and continues to be developed.
- Outreach activities have started.
- Course assessment indicates student satisfaction is increasing with each semester.