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

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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

Barriers and Risks

- Lack of established curriculum
- Lack of established books & reference materials
- Industry needs not clearly defined

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

Introduction

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

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

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

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) a 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, …)

Objective-Specific Approaches: Curriculum Development

Schedule of new course development, modifications to courses, delivery, and corresponding enrollments

New Courses

Name	Dept.	Number	Credits	10 Spring DL	10 Spring C	10 Summer DL	10 Summer C	10 Fall DL	10 Fall C	11 Spring DL	11 Spring C	11 Summer DL	11 Summer C	11 Fall DL	11 Fall C	12 Spring DL	12 Spring C	12 Summer DL	12 Summer C	12 Fall DL	12 Fall C
Intro. To Prop. Systems for HEV	EE/ME	4295	3					9	42					11	37					T(DL)	T
Adv. Prop. Systems for HEV	EE/ME	5295	3	64						6	20					1	32				
Intro. To Prop. Systems for HEV Laboratory	EE/ME	4296	1	D			D	X	13					X	15			T(DL)			T
Adv. Prop. Systems for HEVLaboratory	EE/ME	5296	1	D			D	D		X	4					X	10	T(DL)			
Advanced Electric Machines	EE	5221	3				D	15	30					9	18						
Vehicle Battery Cells and Systems	MY/CM	5760	3	D			D	5	7					19	4					T(DL)	T
Vehicle Dynamics	ME	4450/5450	3											D		6	34				
Distributed Embedded Control Systems	EE/ME	4750/5750	3	X	22		M			X	27					X	37				
Distance Learning Enrollment				64				29		6				39		7					
Traditional Campus Enrollment					22				92		51				74		113				

Modified Courses

Name	Dept.	Number	Credits	10 Spring DL	10 Spring C	10 Summer DL	10 Summer C	10 Fall DL	10 Fall C	11 Spring DL	11 Spring C	11 Summer DL	11 Summer C	11 Fall DL	11 Fall C	12 Spring DL	12 Spring C	12 Summer DL	12 Summer C	12 Fall DL	12 Fall C
Intro. to Motor Drives	EE	3221	4	X	65		M			X	56		M			X	45				
Power Electronics	EE	4227	3					15	26				M	29	40					T(DL)	T
Power Electronics Lab	EE	4228	1					X	14					X	27						T
Power System Operations	EE	5230	3										M	X	7					T(DL)	T
Power System Protection	EE	4223/5223	3					M		29	26										
Power System Protection Lab	EE	4224/5224	1					M		X	16										
Distribution Engineering	EE	4225/5250	3	27	32					X	11			M		27	31				
Intro to IC Engines	ME	4220	3				M			9	87					8	40	T(DL)	X		
Internal Combustion Engines II	ME	5250	3		17								M	1	35					T(DL)	T
Distance Learning Enrollment				27				15		38				30		35					
Traditional Campus Enrollment					114				40		196				109		116				

KEY								
Status:	D = Develop		T = Teach		M = Modify		DL = Distance Learn.	
Depart:	EE = Elect. Eng.		ME = Mech. Eng		CM = Chem Eng.		MY = Mat.Sci & Eng.	
Level:	3XXX = UG	4XXX = UG Tech Elect			5XXX = Grad.		ENT = Enterprise	

Objective-Specific Approaches: Curriculum Development

Schedule of existing course delivery, and corresponding enrollments

Existing Courses				10		10		10		11		11		11		12		12		12	
				Spring		Summer		Fall		Spring		Summer		Fall		Spring		Summer		Fall	
Name	Dept.	Number	Credits	DL	C	DL	C	DL	C	DL	C	DL	C	DL	C	DL	C	DL	C	DL	C
Electric Energy Systems (EE/Non EE)	EE	3120	3	11	27	10	5	X	60	33	40	17	4	X	34	16	39			T(DL)	T
Power System Analysis 1	EE	4221	3					22	37					34	41					T(DL)	T
Power System Analysis 2	EE	4222	3	28	38					15	30					24	40				
Advanced Methods in Power Systems	EE	5200	3					13	9					18	14					T(DL)	T
Classical Control Systems	EE	4261	3					X	27					X	32					X	T
Thermodynamics/Fluid Mechanics (Non ME)	ENG	3200	4	X	112			X	77	X	106			X	76	X	117			X	T
Principles of Energy Conversion	ME	4200/5290	3	X	39			25	33					21	46					T(DL)	T
Dynamic Systems and Controls	ME	4700	(DL)/	2	108			X	126	X	103			X	109	X	119	T	X	X	T
Advanced Thermoddynamics	ME	5200	3					4	51			15	X	5	68					T(DL)	T
Experimental Design in Engineering	ME	5670	3					X	12					X	23			T	X	T	T
Optimization	ME	5680	3							7	22	15	X							T	T
Dynamic Systems and Signal Analysis	ME	5700	4					2	25			9	X	X	26					X	T
Linear Systems	ME	5715	3	X	24					4	16									T(DL)	T
Fuel Cell Technologies	ME	4260/5220	3					7	25					6	35						
Senior Capston Design (4 Projects, Avail DL)	EE/ME	4901/4911	2 & 2	X	20			X	20	X	5			X	5	X	5				
Fuel Cell Fundamentals	CM/ENT	3974	1					X	23					X	23					X	T
Fundamentals of Hydrogen as an Energy Carrie	CM/ENT	3977	1					X	15											X	T
Hydrogen Measurements Laboratory	CM/ENT	3978	1																		
Enterprise Courses	ENT	29XX-49XX	1																		
Distance Learning Enrollment				41		10		73		59		56		84		40					
Traditional Campus Enrollment					368		5		540		216		4		532		320				

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

Chevy Malibu BAS

Chevy Volt EREV

Configurable HEV

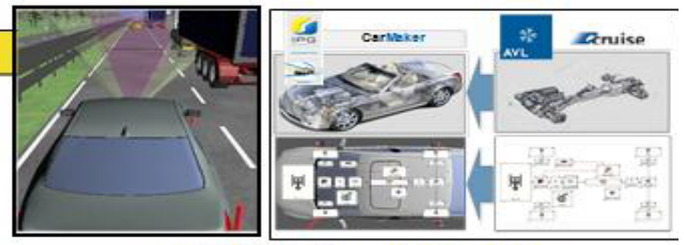
Hands-On Outreach Activities

Portable Chassis Dyno

Objective-Specific Approaches: Mobile Laboratory

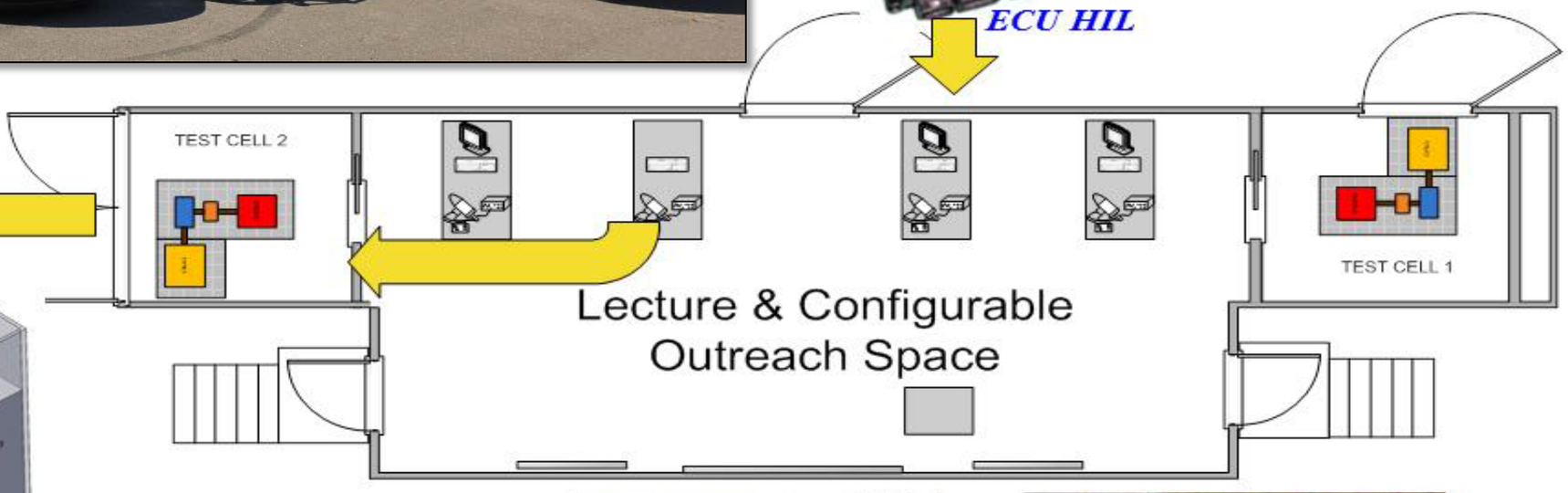
Vehicle Development Process

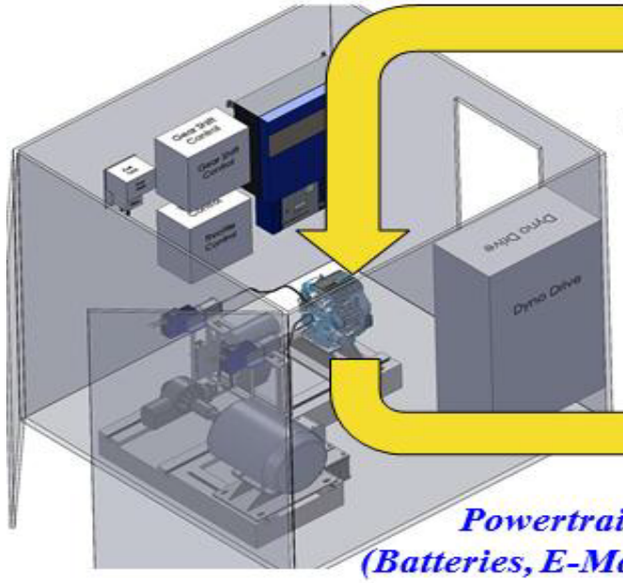
Model ⇒ Design ⇒ Develop ⇒Test ⇒ Validation



Vehicle Simulation for Coursework and Outreach

ECU HIL





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

On-Track with Configurable HEV's

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

Pre-college youth examining the effect of axle gear ratio on vehicle acceleration

Students examining electrical vehicle charging with an EREV

Scheduled Outreach:

- Council of University Transportation Centers
- **USA Science & Engineering Festival**
- High School Enterprise in Partnership with GM
- Local fairs, parades, & K-12 visits

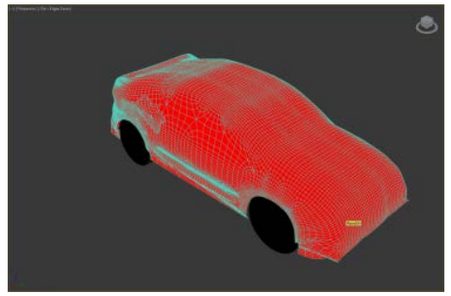
Pre-college youth "feeling" the effects of hybridization

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

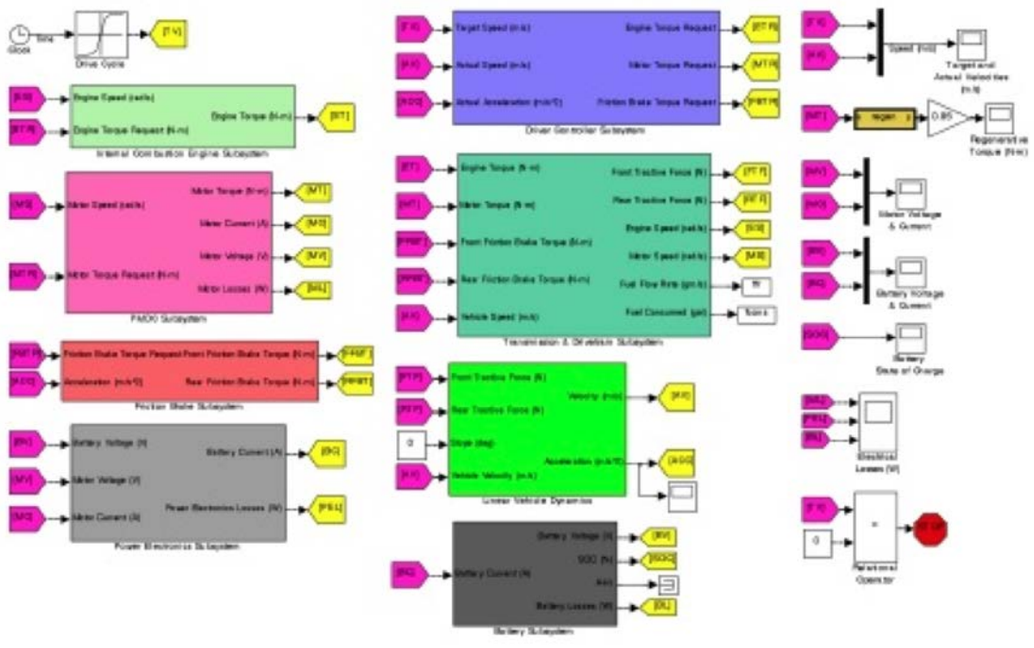
Objective-Specific Approaches: Course Delivery

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

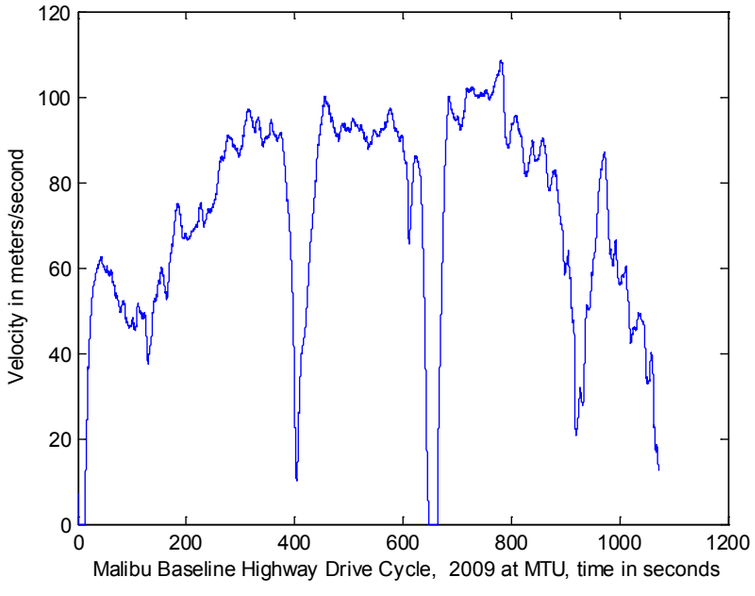
- Established innovative, effective and engaging teaching and delivery methods for newly developed and current courses
- Work closely with OEMs and suppliers to ensure the program meets work force needs
- Distance Learning courses delivered with the same material and quality of instruction as traditional 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.

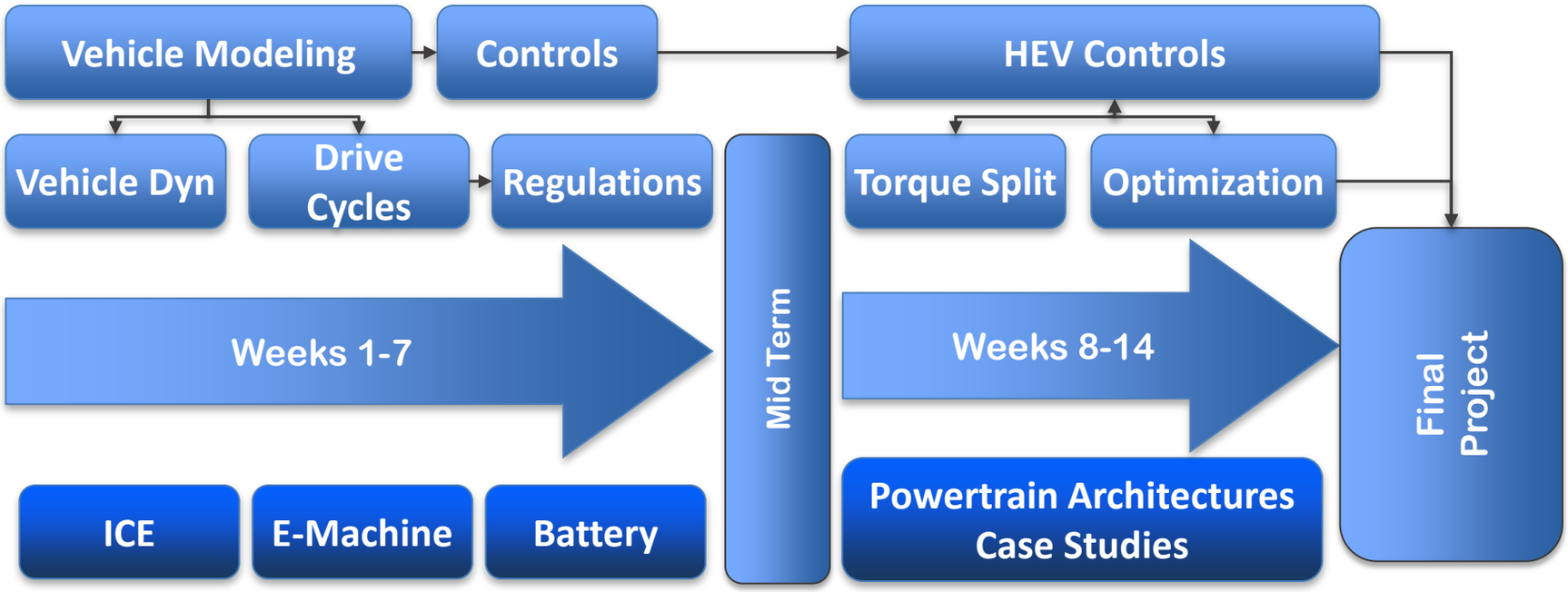


The HVM modeled in Simulink, this particular student included "extras" such as a Power Electronics module, a Friction Brake module with a complete front/rear brake bias algorithm for regeneration and determination of vehicle jerk for drive quality comparison.



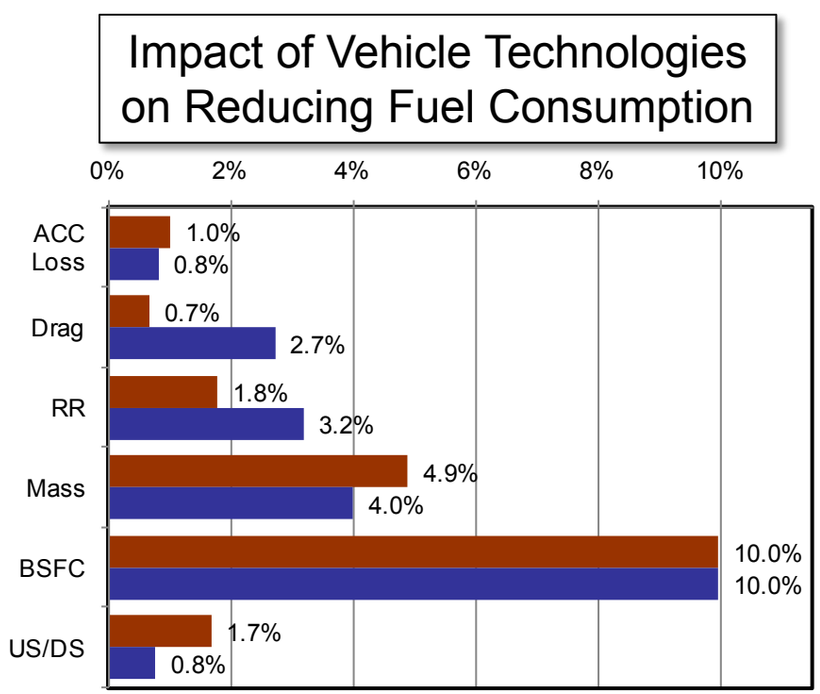
The target velocity (drive cycle) and the vehicle velocity for a HEV with torque blending, a finite ratio transmission and a shift criteria to minimize fuel usage. The vehicle modeled is a large SUV.

Model Based: Analysis ➡ Assessment ➡ Design ➡ Control



Group Taught
Faculty
Industry Experts

Active Learning Model



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.

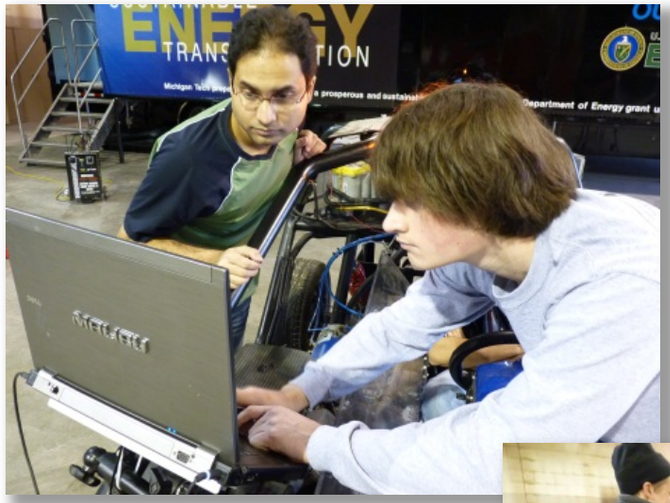
ME/EE 4296 & 5296 Intro & Advanced HEV Laboratory Courses

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

Coast down testing to understand rolling resistance and aerodynamic effects

Preparing for Powertrain tests in the Mobile Lab



Setting up to log baseline data on the Configurable HEV

Measuring mass of the Configurable HEV for model validation

5296

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

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,

3-Year Project Technical Tasks
1. Curriculum Development
2. Mobile Laboratory Development
3. Outreach Development & Execution
4. Course Delivery & Evaluation

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.

Technical Accomplishments & Progress - Task 3 Outreach (Public Education)

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

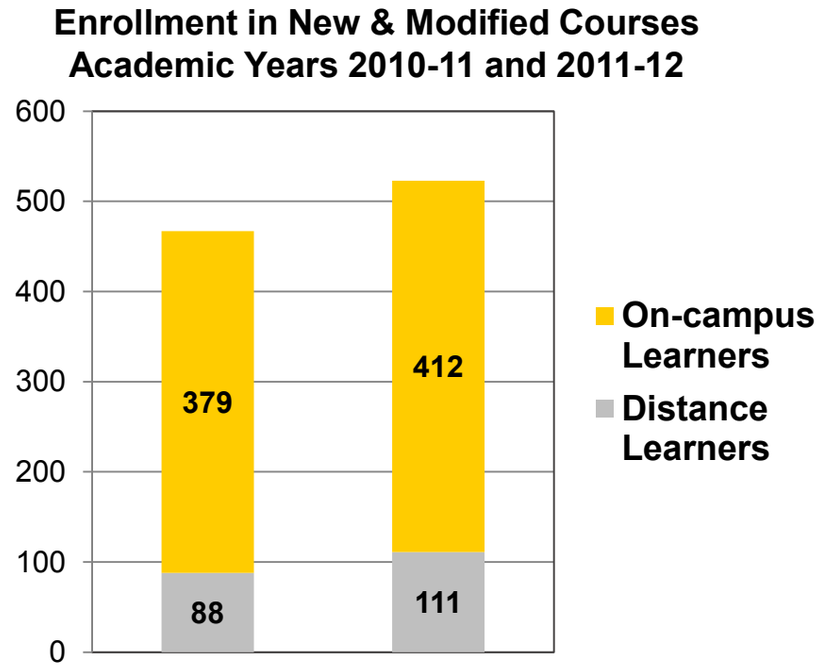
Technical Accomplishments & Progress - Task 4 Course Delivery and Evaluation

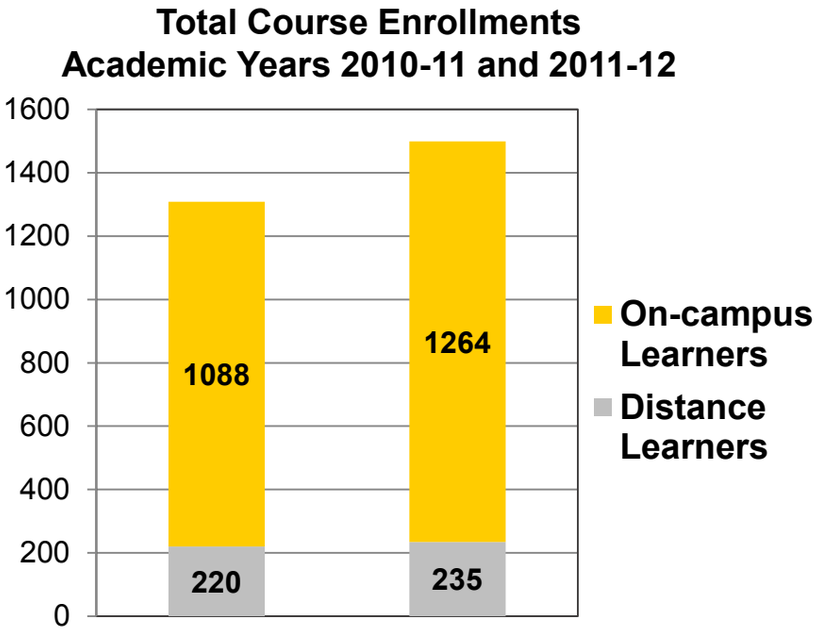
- Course delivery to date: (Second round completed)
  - 8 Newly developed courses
  - 9 Modified courses
  - 19 existing courses that are program electives delivered

- 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*





Technical Accomplishments & Progress - Task 4
Course Delivery and Evaluation

Course Delivery Fall 2011

New Courses

- EE/ME 4295 (11 DL / 37 Campus) Intro Propulsion Systems for HEDV
- EE/ME 4296 (15 Campus) Intro Propulsion Systems for EDV Laboratory
- EE 5221 (9 DL / 18 Campus) Advanced Electric Machines
- MY/CM 5760 (19 DL / 4 Campus) Vehicle Batteries, Cells, and Systems

Modified Courses

- EE 4227 (29 DL / 40 Campus) Power Electronics
- EE 4228 (27 Campus) Power Electronics Laboratory
- EE 5230 (7 Campus) Power Systems Operations
- ME 5250 (1 DL/35 Campus) 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

Technical Accomplishments & Progress - Task 4
Course Delivery and Evaluation

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

Comparison of course survey results.

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

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 - s*oftware 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 .