2010 DOE Vehicle Technologies Program Review Presentation

Recovery Act—Transportation Electrification Education Partnership for Green Jobs and Sustainable Mobility

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ARRAVT038

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Overview

Timeline

- Start date: **2009/10/01**
- End date: **2012/09/30**
- Percent complete: 20%

Budget

- Total project funding
  - DOE share: $2.5M
  - Contractor share: $735,975
- Funding received in FY09: 0
- Funding for FY10: 320K

Barriers

- Lab renovation
- Purchase of lab equipment and development of technical content
- Leverage of consumer outreach effort

Partners

- AVL/A&D/NI in equipment
- GM/Ford/DTE in course development and teaching
- GM in short courses

Project Scope-Relevance

Objective:

To develop graduate, undergraduate and short courses and outreach activities in the field of Electrified Transportation

Graduates	Undergraduates	Professionals	Pre-College
Modular Courses available online (UMAA)	Multi-Campus Modular Courses (UMAA,UMD, Kettering) Strong Lab Experience	Web-Based Modular short Courses Face-to-face Short Courses (UMAA,UMD, Kettering)	Education Kits for electric automobile
Graduate students in all engineering disciplines M. Eng. Degree in Energy Systems and Automotive Engineering (UMAA), available through distance learning	B.S. with Energy concentration (UMAA)	Certificate Programs	K-12 student outreach, summer program
Training & Internship	B.S. with Green Mobility Specialty (Kettering)	Graduate degree through distance education	Science Teachers Outreach & Education
	B.S. with concentration in Electric Energy (UMD)		

Consumer Education

- Saturday morning seminars
- Web site development, consumer education nuggets

Overview of Project -Approach/Strategy

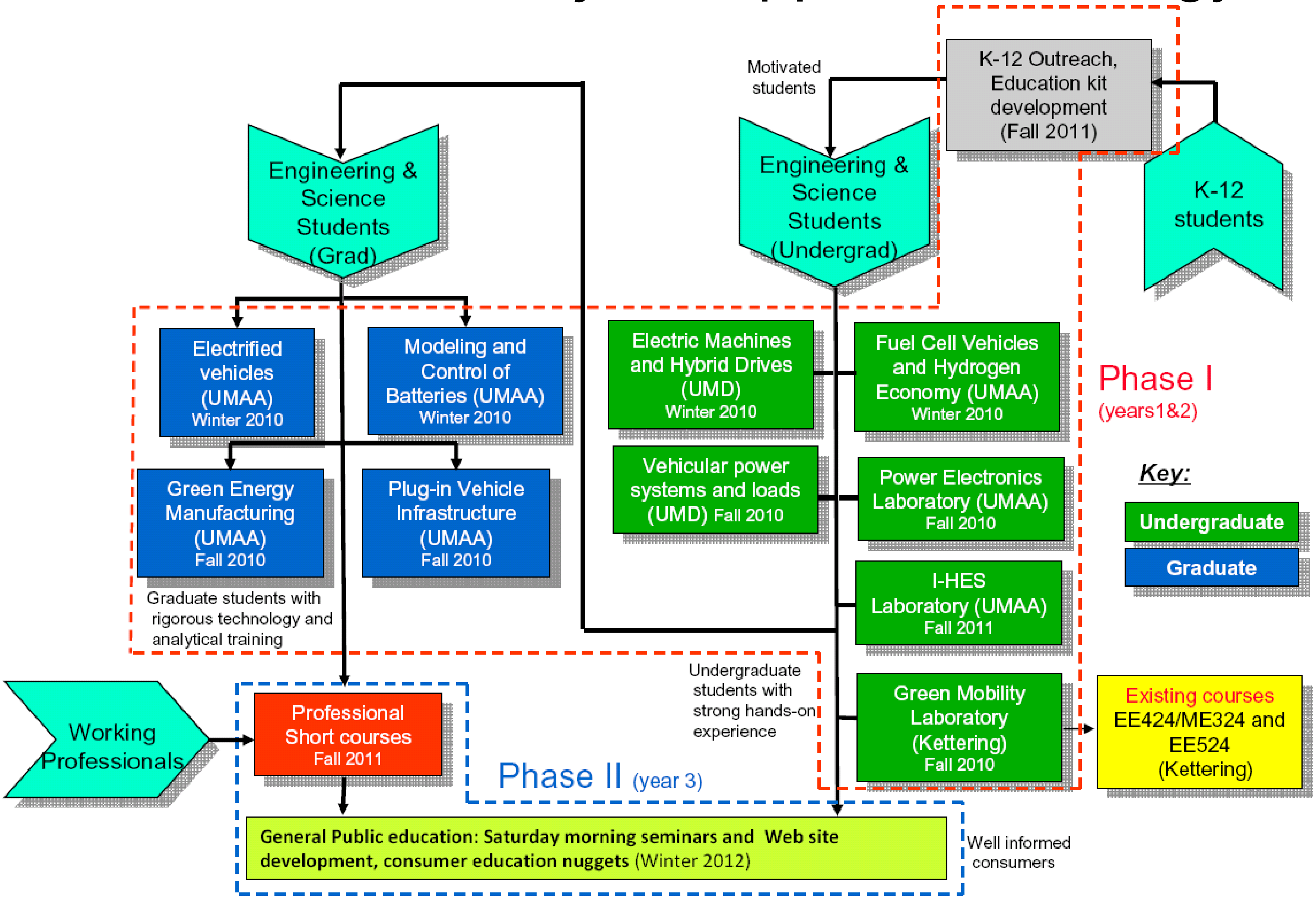


Figure 4 Flow chart and timing of the proposed educational activities

Project Timeline- Approach/Strategy

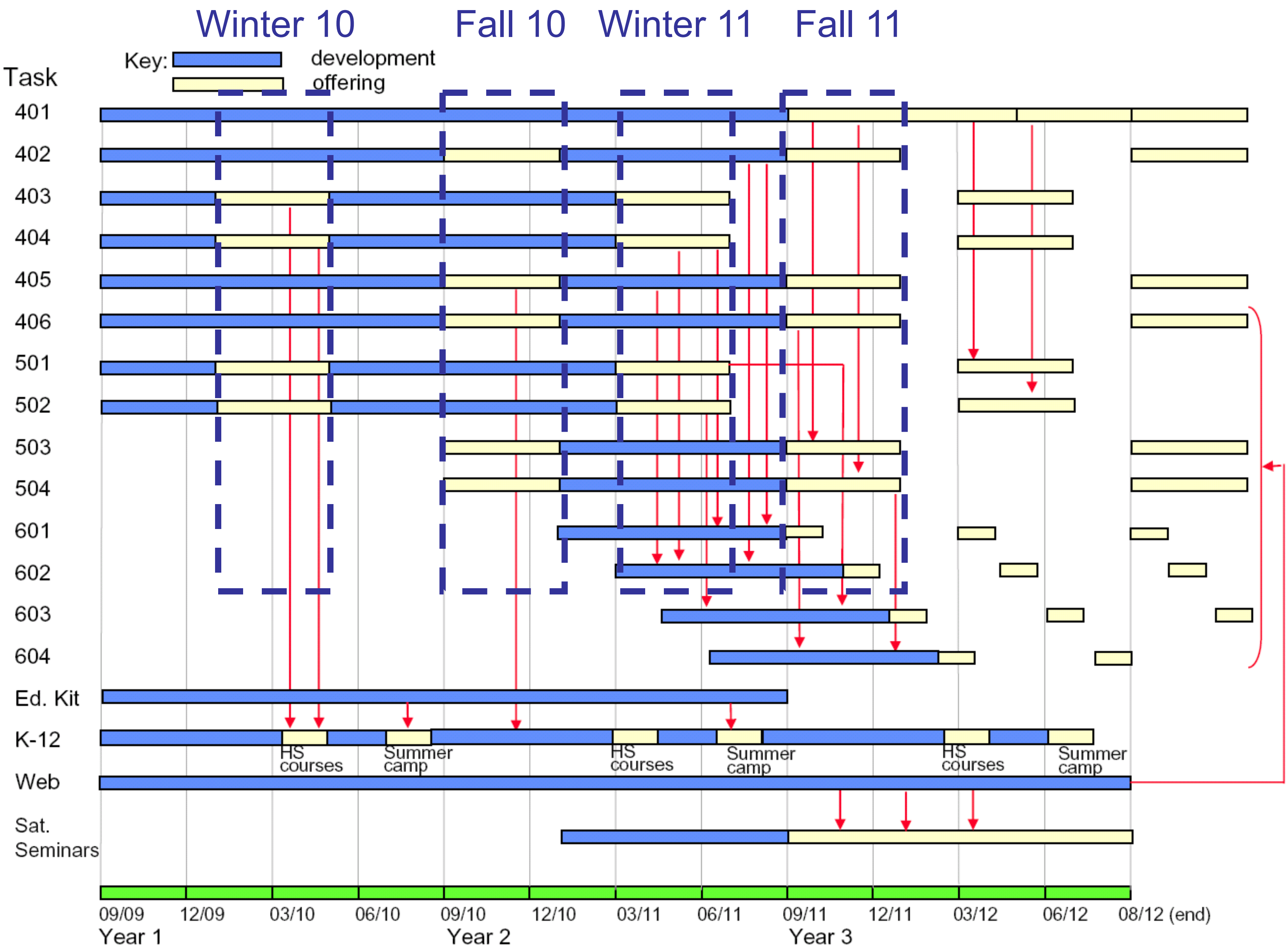


Figure 9 Proposed timeline

Tasks (years 1-2)-- Approach/Strategy

Task 1 – Development of 4 graduate courses

Campus	Course	Faculty	Title
UMAA	501	Peng & Filipi	Electrified Vehicles
UMAA	502	Stefanopoulou & Fathy	Modeling and Control of Batteries
UMAA	503	Hu	Green Energy Manufacturing
UMAA	504	Hiskens	Plug-in Vehicle Infrastructure

Task 2 – Development of 6 undergraduate courses and laboratories

Campus	Course	Faculty	Title
UMAA	401	Filipi & Peng	Integrated Hybrid Electric System (I-HES) Laboratory
UMAA	402	Hiskens	Automotive Power Electronics Laboratory
UMAA	403	Siegel & Stefanopoulou	Fuel Cell Vehicles and Hydrogen Infrastructure
UMD	404	Mi	Electric Machines and Hybrid Drives
UMD	405	Mi	Power Systems (vehicular power systems and loads)
Kettering	406	Gover, Thompson & Hoff	Green Mobility Laboratory

Task 3 – Development of K-12 outreach activities

Campus	Course	Faculty	Title
UMAA	"101"	Hiskens & others	K-12 Outreach
UMAA	"102"	Fathy	Development of an Education kit for Electric Automobiles

Tasks (year 3)-- Approach/Strategy

PHASE II (year 3)

Campus	Course	Faculty	Title
UMAA	"103"	Peng & Borbely	Saturday morning Seminars and Web site development
UMD	"601"	Mi	Power Electronics System Integration
	"602"	Gover	Electrified Vehicle Semiconductor Power Devices and Heat Transfer
UMAA	"603"	Stefanopoulou	Modeling and Control of Batteries
UMAA	"604"	Peng & Filipi	HEV and PHEV System Integration and design

Accomplishments and Progress

- W 10 Courses
- Summer Camp for high school students
- Automotive education kit
- Laboratory development

Winter 10 Courses

- 501 (Electrified vehicles, Peng&Filipi)
  - Distance learning to be offered in SP/SU
- 502 (Modeling and control of batteries, Stefanopoulou&Fathy)
  - Distance learning
- 403 (Fuel Cell Vehicles and Hydrogen Infrastructure, Siegel & Stefanopoulou)
  - Distance learning
- 404 (Electric Machines and Hybrid Drives, Mi)

With some minor changes: Course title, course level

501 Modeling, Analysis and Control of Hybrid Electric Vehicles

- Modeling, analysis and control of vehicles with electrified propulsion systems, including electric vehicles, hybrid vehicles, plug-in and fuel cell vehicles. Introduce the concepts and terminology, the state-of-the-art development, energy conversion and storage options, modeling, analysis, and simulation of key components, system integration and vehicle supervisory and servo-loop control systems.
- Enrollment: 33
- Distance learning in SP/SU: enrollment ~ 50

501 Course Outline

Lecture	Topic
1 (1/6)	Introduction, motivation
2 (1/11)	Introduction of electrified power-train concepts. Final project ideas
3 (1/13)	Energy for Transportation; environmental impact
4 (1/20)	MATLAB-SIMULINK review
5 (1/25)	APUs for hybrid electric vehicles – IC engine fundamentals, challenges and opportunities
6 (1/27)	APUs for HEVs – SI engine processes, performance and fuel efficiency
7 (2/1)	APUs for HEVs – CI engine processes, performance and fuel efficiency
8 (2/3)	APUs for HEVs – Novel combustion modes, synergy with hybrid systems
9 (2/8)	Integrated IC Engines systems: turbo-charging, aftertreatment and modeling
10 (2/10)	Power electronic devices and motors—introduction and modeling
11 (2/15)	Modeling of power split devices for hybrid vehicles
12 (2/17)	Integrated vehicle system model
13 (2/22)	Modeling and analysis of series electric hybrid powertrains
14 (2/24)	Driving schedules and impact on electrified vehicle design and control
15 (3/8)	**Midterm**
16 (3/10)	Case studies—simulations of three electrified vehicles
17 (3/15)	Vehicle control hierarchy and power management
18 (3/17)	Optimal design and control of a parallel hybrid vehicle
19 (3/22)	Plug-in hybrid vehicles—energy consumption, emissions and battery sizing optimization
20 (3/24)	Modeling and control issues of batteries
21 (3/29)	Modeling and control issues of batteries
22 (3/31)	Modeling and analysis of split hybrid power-trains
23 (4/5)	Modeling and analysis of split hybrid power-trains
24 (4/7)	Control of split hybrid vehicles
25 (4/12)	Emission issues— fundamentals, modeling and control
26 (4/14)	Major design issues and consideration of Hybrids
27 (4/21)	**Report/Final Project Presentation**

502 Vehicle Electrification (Part A): Battery Systems and Control

- Battery modeling, control and diagnostic methodologies associated with battery electric and battery hybrid electric vehicles. Emphasis is placed upon system-level modeling, model order reduction from micro-scale to macro-scale and surrogate models for load control, estimation, on-board identification and diagnostics for Lithium Ion batteries.
- Enrollment: 59 (with 5 distance learning students)

502 Course Outline

Chapter 1: Introduction

Battery Electric and Hybrid Vehicles (BEV and BEHV)
Voltage, Power, and the Electrical point of view
Chemistries and aging mechanisms

Chapter 2: Modeling and Simulation

Physics-based modeling: Concentration, Potential, Butler-Volmer, Aging
Numerical Approximation
Model Order Reduction

Chapter 3: Battery Controls

Control Minimal realization
State of Charge Estimation
Electric Circuit Equivalent
Control-Oriented Model Parameterization
State of Health Estimation

Chapter 4: Stack Management

Active Cell Balancing
Thermal Management

Chapter 5: Vehicle Power Level

Electric Architectures
DC/DC Converters
Fuel Consumption Minimization
Power management (PHEV)

403 Vehicle Electrification (Part B): Hydrogen and Fuel Cells

- Essential aspects of fuel cell vehicle technology, hydrogen fueling infrastructure, and potential benefits & barriers to the use of hydrogen as a vehicular fuel. Emphasis is placed upon system-level modeling and control issues of polymer electrolyte membrane fuel cells.
- Enrollment: 47 (with 4 distance learning students)

403 Course Outline

Chapter 1: Overview: Fuel Cell Vehicles (FCV) and Hydrogen as a vehicular fuel

- Benefits of a transition to FCV
  - (Reduced petroleum consumption, energy independence, lower CO_2 emissions…)
- Types of fuel cells and their Chemistries
- Barriers to the commercialization of FCV
  - (Infrastructure, H_2 production & storage, FC durability, DOE Performance and cost Targets)

Chapter 2: Modeling and Control of Polymer Electrolyte Membrane Fuel Cells

- Voltage regulation (Pressure boost & Voltage buck/boost)
- Air Flow Loop (sizing, pressure selection, stoichiometry, autonomy)
- Cooling Loop, Startup and Mal-distribution
- Hydrogen Loop (high pressure pure H2, Backpressure & Recirculation loop, Dead-ended)
- Water management
- Impedance diagnostics
- Degradation

Chapter 3: Fuel Cell Vehicle

- Basic architecture of a FCV ("a FCV is a HEV;" power electronics)
- Power electronics, Hybridization strategies
- Power Management, Battery and FC Sizing

Chapter 4: Hydrogen production technologies

- DOE Targets for cost and efficiency
- Technologies: Coal, natural gas (steam reforming), nuclear energy, electrolysis, wind and solar energy, biomass and photobiological processes

Chapter 5: Infrastructure for Hydrogen Distribution and Refueling

- Scenarios for the introduction of FCVs and their supporting infrastructure
- Distributed hydrogen production vs. production at central stations
- Maximum practicable number of vehicles that can be fueled by hydrogen by 2020
- Funding and policy actions needed to achieve that goal

Chapter 6: Hydrogen Storage I: Fundamentals

- DOE System-level targets, Types of storage: physical vs. chemical
- Chemical storage methods: conventional metal hydrides, complex hydrides, chemical hydrides, sorbents, Capacity, Thermodynamics, Kinetics

Chapter 7: Hydrogen Storage II: Engineering considerations

- Thermal conductivity, Effective media density
- Heat management during refill
- Control and interface with the FC powerplant

Chapter 8: Hydrogen Safety / Codes & Standards

Chapter 9: Life-cycle and Well-to-Wheels Analyses of FCV

- Introduction to the Argonne H2A Model, Petroleum consumption
- Greenhouse gas emissions (CO2 reduction), Energy efficiency/energy use
- Cost of ownership, Comparisons with: conventional ICE vehicles, HEV, PHEV, EV

404 Electric Machines and Hybrid Drives

- Course taught at UM Dearborn
- An introductory course on electric machines and drive systems. The topics covered in this course include DC machines, induction machines, permanent magnet synchronous machines, and switch reluctant motors and drives. Case studies in automotive applications such as electric and hybrid drivetrains are discussed.
- Enrollment: 45

404 Course Outline

- Characteristics of Vehicle Loads
- DC Motor Drives
- Permanent Magnet AC Drives
- Induction Motor Drives: Steady State and V/f Control
- Switched-Reluctance Drives
- Case Studies: EV, HEV, Plug-In Hybrid, Fuel Cell Vehicles
- Projects
- Exams

Summer Camp

- Hands-on examples
  - PHEV example from Dearborn
  - Motor and Battery lab
  - Solar car team
- Academic and industrial lecturers (Ford, GM, DTE)
- 11th and 12th graders (Huron and Pioneer, 20-30)
- August 11-13

Automotive Educational Kit

- First step is to gather information and purchase representative education kits already on the market, compare and learn from them.
- Short list of candidate undergraduate researchers identified. Final selection of 1-2 undergraduate researchers in progress
- NI NXT brick identified as foundation for robotic toy kit
- Conceptual design of coupled kits ongoing

Motivating Success Story

- The LEGO Robotic Toolkit…
- … An outgrowth of Piaget's/Papert's epistemology

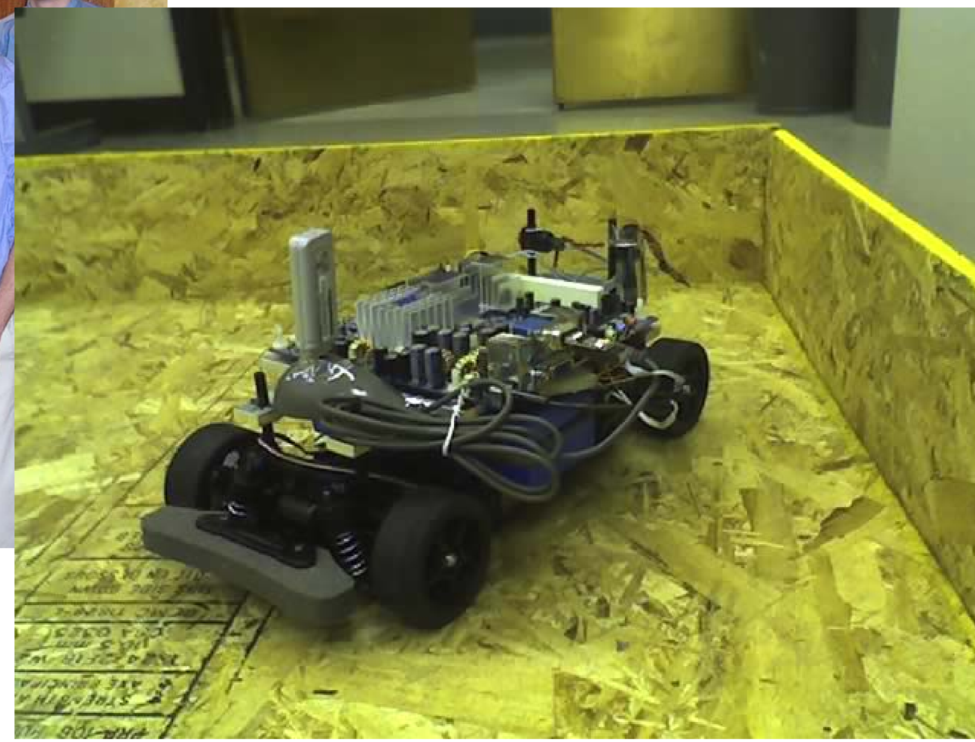
www.ni.com/academic/mindstorms

"I take from Jean Piaget a model of children as builders of their own intellectual structures. Children seem to be innately gifted learners, acquiring… knowledge by a process I call 'Piagetian Learning' or 'Learning without being taught'… If we really look at the 'child as a builder', we are on our way to [concluding that]…. All builders need materials to build with". ***Quote from Mindstorms: Children, Computers, and Powerful Ideas by S. Papert.***

Educational Kit Development Progress (3)

- Previous success stories…

Undergraduate Research Opportunity (UROP) Project on Development of a Driver-in-the-Loop Simulator for Analyzing Impact of Driver-to-Driver Variability on Vehicle Emission Variability



Graduate research project on development of a radio-controlled "toy car" that uses hardware-in-the-loop (HIL) simulation to accurately mimic the dynamics of a full vehicle (intended for indoor validation of inter-vehicle safety/communication systems)

- Develop a high-fidelity scaled toy car kit that mimics performance and energy consumption of electric vehicles, including PHEVs
  - Use toy car kit to introduce K-12 students to vehicle electrification
  - Also use kit for student competitions and summer camps
- Develop a high-fidelity “SimCity-like” videogame that allows K-12 students to explore design and control options for PHEVs
  - Build videogame around high-fidelity plug-in vehicle models
  - Use videogame as platform to introduce K-12 students to vehicle electrification concepts
- Introduce undergraduate engineering students to vehicle electrification by putting them in charge of developing above kits
- Integrate the kits to achieve combined simulation/hands-on experience

Laboratory Development

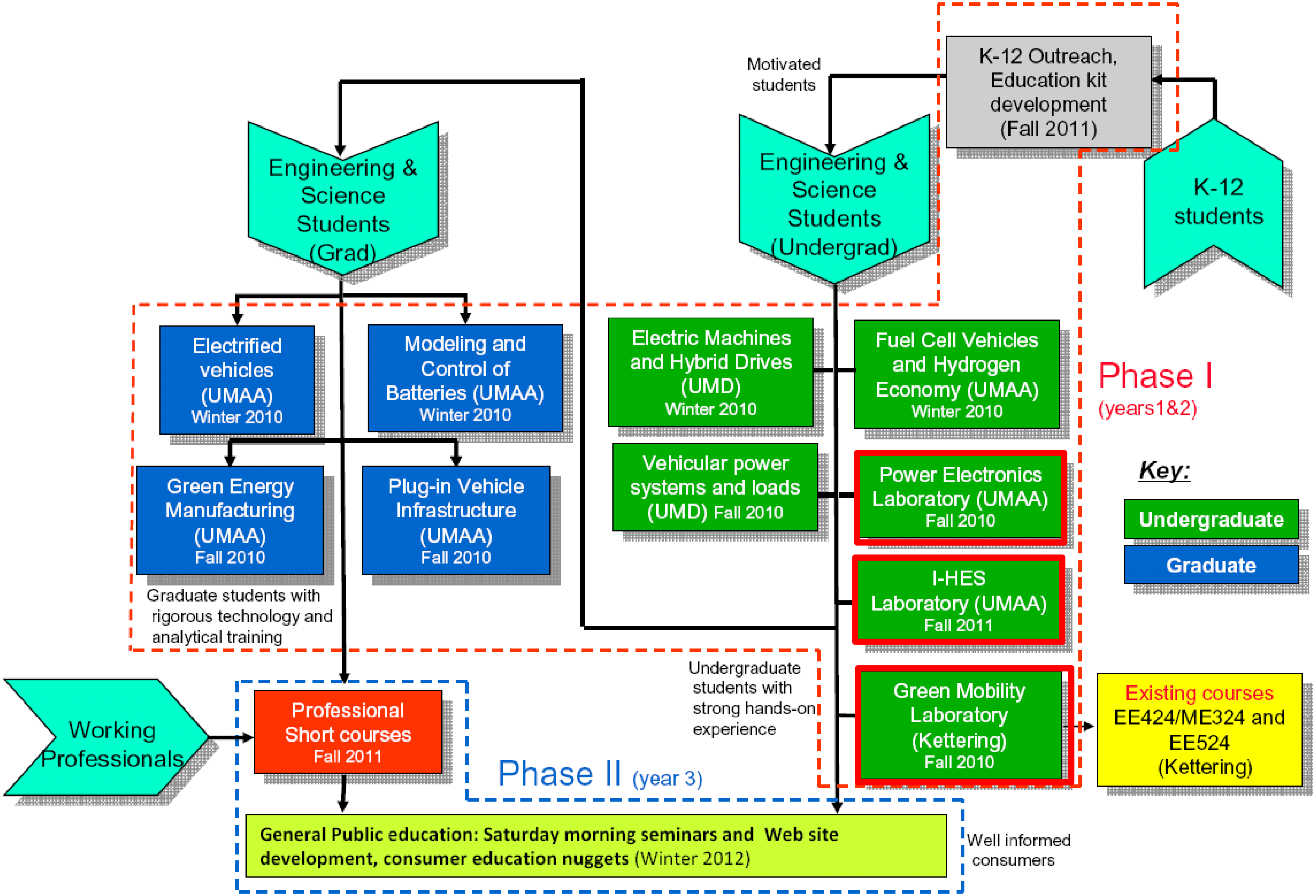
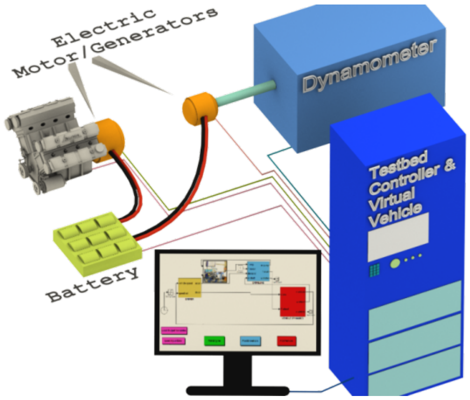
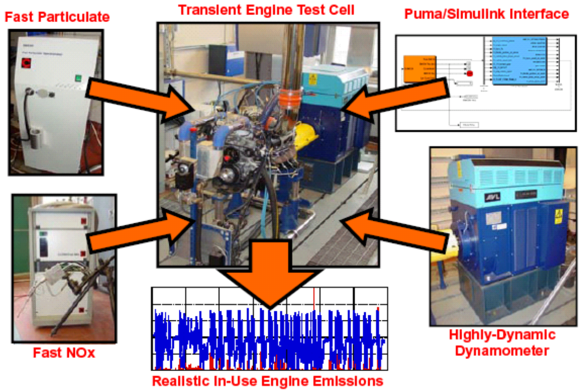


Figure 4 Flow chart and timing of the proposed educational activities

Laboratory Development

- Three Labs will be developed to support our undergraduate courses.
- Purchase/development will be done over the next 18 months.

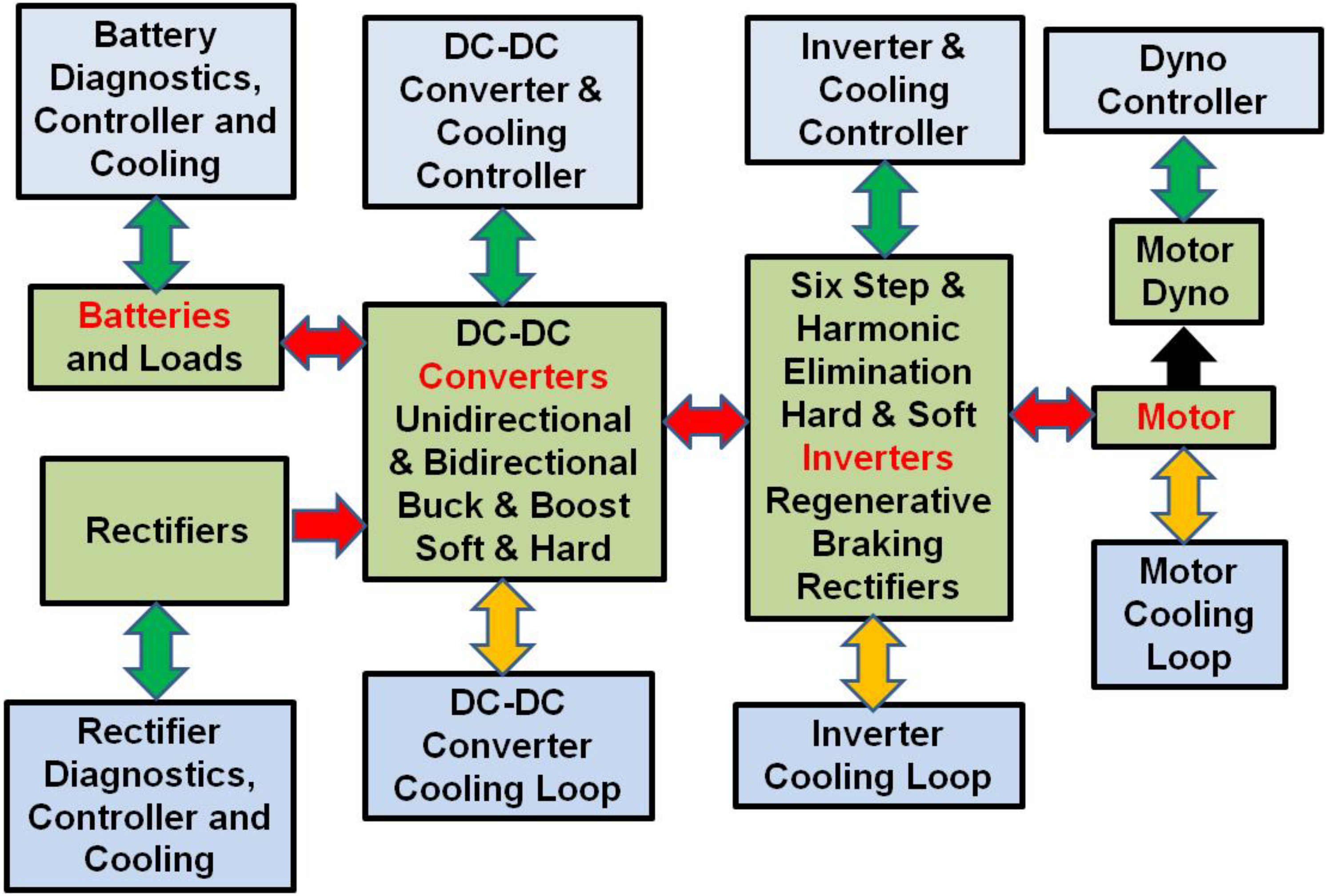




Kettering Lab Development

- Four experimental stations, 4 kW power at each station to study:
  - Batteries
  - DC-DC converters
  - Inverters
  - Motors
- One system-level station for vehicle level modeling.
- Courses utilizing DOE Lab:
  - Power Electronics for ME/EE
  - 2 Hybrid Vehicle System Courses
  - 2 DOE Sponsored Hybrid Vehicle Technology Courses (EE5XX/EE5YY)

Elements at Each Lab Station



Equipment Purchase for Lab 401 at AA

- Timeline and the type of facility requires purchasing a turn-key solution from a single vendor
- Three contenders:
  - A&D
  - AVL
  - National Instruments and Wineman Technology Inc.
- Strategy: obtain the best possible configuration that fits into our budgeted:
  - Vendors understood that they need to provide at least 25% discount to fulfill the cost-sharing obligation
  - The “showcase” value of the lab is clearly communicated (to the vendors and to the University)

Collaboration

- This project involves three partner schools: UM Ann Arbor, UM Dearborn and Kettering University.
- Industrial collaborators that have been involved in our course and lab development include
  - GM, Ford, DTE, AVL, A&D, A123.
  - They serve the roles of equipment providers, invited lecturers, course material provider, and support our K-12 outreach activities.

Proposed Future Work

- Develop and offer
  - 504 Plug-in Vehicle Infrastructure (Fall 10, UMAA)
  - 402 Automotive Power Electronics Laboratory (Fall 10, UMAA)
  - 405 Vehicular Power Systems and Loads (Fall 10, UMD)
  - 406 Green Mobility Laboratory and associated courses (Fall 10, Kettering)
  - 503 Green Energy Manufacturing (Winter 11, UMAA)
  - 401 Integrated Hybrid Electric System Laboratory (Fall 11 , UMAA)
  - 102 Development of an Education kit for Electric Automobiles (Fall 12)
  - 103 Saturday morning seminar series on Green Mobility and Web site development (Fall 12)

Expected Impacts

- In steady-state, the 10 credit courses are expected to impact 300-500 students annually.
- The short courses will impact 100-200 professional engineers annually.
- K-12 and other consumer education and outreach activities should impact > 1,000 annually.
- Final goal: job creation through training and education