Final Report

Indiana Advanced Electric Vehicle Training and Education Consortium (I-AEVtec)

TE Education Grant DE-EE0002494

U.S. Department of Energy – NERL

Recovery Act – Transportation Electrification No. DE-FOA-0000028

Purdue University
Indiana University Purdue University
at Indianapolis (IUPUI)
Ivy Tech Community College

University of Notre Dame
Purdue University – Calumet
Indiana University - Northwest

PI: James M. Caruthers, Purdue University

Co-PIs: J. Eric Dietz, Purdue Univ.

Libby Pelter, Purdue Univ. – Calumet

Jie Chen, IUPUI

Glen D. Roberson, Jr., Ivy Tech

Paul McGinn, Notre Dame

Vinodgopal Kizhanipuram, Indiana Univ.-Northwest & North Carolina Central Univ.

Project Period: 10/1/2009 to 12/30/2012	Total Budget:	\$8,187,739
	Cost Share:	\$1,923,399
	DOE	\$6,264,341

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Table of Contents

Abstract	3
1. Introduction.....	3
2. I-AEVtec Partners in the DoE Grant.....	3
3. I-AEVtec Project Activities	4
3.1 Task 1: Develop Certificate and Degree Programs.....	5
3.1.1 Ivy Tech - Alternative Fuels Certificate.....	5
3.1.2 Ivy Tech - Electric and Hybrid Vehicle Certificate.....	5
3.1.3 IUPUI - Hybrid Electric Vehicle Technology Certificate	6
3.1.4 Purdue – MS in Chemical Engineering: Energy Storage	6
3.2 Task 2. Develop high-value educational and training products that address the full range of technologies needed to support electric drive vehicles.	7
3.3 Task 3. Deliver Educational Programs to a Diverse Group of Students	13
3.4 Task 4. Establish Electric Vehicle Hub	15
3.5 Task 5. Partner with the regional industries	15
3.6 Task 6. Develop a program appropriate for secondary school	16
3.7 Task 7. Initiate the Electric Vehicle Grand Prix Go-Kart Race	19
4. Jobs Created or Retained	20
Appendix	21
Course Work Content	21

Abstract

The Indiana Advanced Electric Vehicle Training and Education Consortium (I-AEVtec) is an educational partnership between six universities and colleges in Indiana focused on developing the education materials needed to support electric vehicle technology. The I-AEVtec has developed and delivered a number of degree and certificate programs that address various aspects of electric vehicle technology, including over 30 new or significantly modified courses to support these programs. These courses were shared on the SmartEnergyHub. The I-AEVtec program also had a significant outreach to the community with particular focus on K12 students. Finally, the evGrandPrix was established which is a university/college student electric go-kart race, where the students get hands-on experience in designing, building and racing electric vehicles. The evGrandPrix now includes student teams from across the US as well as from Europe and it is currently being held on Opening Day weekend for the Indy500 at the Indianapolis Motor Speedway.

1. Introduction

This report will summarize the activities of the Indiana Advanced Electric Vehicle Training and Education Consortium (I-AEVTec) that occurred over three year period from October 1, 2009 through December 30, 2012. The I-AEVtec program included five universities, 30-plus courses, hundreds of university/college students, and thousands of participants that were involved in both taking courses as well as participating in the various events that showcased electric vehicle technology. This report will first provide a summary of the various activities supported by the DoE grant. In a separate Appendix we will provide detailed information for each course including the syllabus, lecture material and homework.

This report is organized according to the various tasks that were identified in the original proposal to DoE and formally described in the project SOPO. After describing the work performed by the I-AEVtec team on the various grant tasks in Section 3, we will provide a table summarizing the number of jobs impacted by the DoE I-AEVtec grant.

2. I-AEVtec Partners in the DoE Grant

There were six institutional partners that worked together as part of the Indiana Advanced Electric Vehicle Training Education Consortium (I-AEVtec) grant from DoE. The role that each educational institution played is summarized below:

- ***Purdue University*** was the lead institution with educational, program management and reporting responsibilities. Purdue developed an MS Degree in Energy Storage Systems through the School of Chemical Engineering. Purdue also developed courses in batteries, electric motors/drives, hybrid engines, control systems, power electronics, electric grid technology and consumer perception/education. In addition to these technical/business

areas, Purdue was responsible for providing the cyber-infrastructure for the SmartEnergyHub, including professional web design services, creation of simulation modules and the capability for educational assessment. Purdue also (i) established relationships with K12 education organizations, (ii) coordinated relationships with the industrial and governmental organizations that employ the graduates of the I-AEVtec program and (iii) developed the Electric Vehicle Grand Prix.

- ***Ivy Tech- Lafayette*** was responsible for Associate Degree training programs that meet the practical needs of the electric vehicle industry. A unique feature of the Ivy Tech program is the hands-on nature of most of their courses, where a new hands-on Associate Degree program Electric and Hybrid Vehicle Certificate was developed. In addition, approximately 11,000 high school students per year either attend Ivy Tech or earn dual credit, during their junior/senior year as part of an accelerated academic program. I-AEVtec used this opportunity to engage these exceptional high school students to consider a career in electric vehicle technology.
- ***IUPUI*** developed Certificate programs in electric and hybrid vehicle technology as part of their current BS and MS degrees in Mechanical and Electrical Engineering. IUPUI special expertise in electrochemistry, power systems, hybrid vehicles and battery safety was deployed in their coursework.
- ***Notre Dame*** developed two courses in electric vehicle technology that are now offered as part of their BS and MS engineering degree programs, including content on fuel cells and the manufacture of fuel cells.
- ***Purdue-Calumet and North Carolina Central Univ.*** played a different role than the other I-AEVtec partners; specifically, they developed short modules that can be used in undergraduate chemistry or general science courses. This is an important contribution, because many educational/training organizations are not able to offer a comprehensive electric vehicle course program, where an introduction to this technology in other coursework is important.

3. I-AEVtec Project Activities

The primary project objective of I-AEVtec was to *develop the educational infrastructure needed to support the 21st century workforce that will develop, manufacture and maintain electric drive vehicles*. In order to meet this objective the six I-AEVtec partner education institutions have developed educational programs to meet this need. A description of the activities that were pursued during the DoE grant are described in the remainder of this section, where we have organized the report in line with the seven tasks that were the SOPO in the original project.

3.1 Task 1: Develop Certificate and Degree Programs

The objective in Task 1 was to integrate and deploy Indiana's educational institutions to develop programs for the education of the 21st century workforce needed to design and support advanced electric drive vehicles. This activity began by a discussion among the educational partners engaged in the various components of electric vehicle technology on what were the existing coursework/programs and what would be needed in the future. The I-AEVTec team then held several meetings with industry to discuss their needs with the emphases on the type/depth of knowledge needed by their employees. A number of degree and certificate programs were developed. A summary of each of these programs is given below;

3.1.1 Ivy Tech - Alternative Fuels Certificate

The 18 Credit Hours Alternative Fuels Certificate provides instruction and hands-on experience in the operation and maintenance of vehicles using alternative fuels. This certificate prepares students for the Automotive Service Excellence (ASE) Alternative Fuels, a national recognized certification. Courses Required:

AUTC 103	Principles of Alternative and Renewable Energies
AUTC 104	Liquid Propane Gas(LPG)
AUTC 106	Compressed Natural Gas I (CNG)
AUTC 107	Engine Principles and Vehicle Service
AUTC 152	Diesel Engine Theory
AUTC 211	Alternative Fuels Installation and Application

3.1.2 Ivy Tech - Electric and Hybrid Vehicle Certificate

The 21 credit hours Electric and Hybrid Vehicle Certificate program provides instruction and hands-on experiences in the operation and maintenance of EV and PHEV vehicles. Ivy Tech is currently working with industry and industry organizations to develop a nationally recognized certificate. Courses Required:

AUTC 103	Principles of Alternative Energies
AUTC 107	Engine Principles
AUTC 109	Engine Performance I
AUTC 113	Electricity and Electronics
AUTC 123	Electricity and Electronics II
AUTC 210	Hybrid Systems
AUTC 260	Advanced Hybrid and Electric Vehicle Technologies

3.1.3 IUPUI - Hybrid Electric Vehicle Technology Certificate

The Hybrid Electric Vehicle Technology Certificate program is for engineering students and will provide a core set of courses on HEV transportation, hybrid electric propulsion systems, energy storage devices and system, and powertrain integration. Also, the students are allowed to select two courses in related engineering disciplines. Students completing this certificate will be able to understand the foundations of the EV/HEV/PHEV and to use the knowledge combined with previous engineering training to serve the respective companies effectively.

The certificate requires 12 credit hours of graduate courses. There are courses in the primary and related areas. The certificate requires selection of at least two courses in the primary area and the rest in related area. The primary area courses consist of:

- ME 59700 Hybrid and Electric Transportation
- ECE 59500 Advanced Hybrid and Electric Vehicle Systems and Control
- ME 59700 Dynamics and Simulation of Hybrid-electric vehicles
- ME 59700 Energy Storage Devices and Systems
- ME 59700 Powertrain Integration
- ECE 61000 Energy Conversion (required for students in ECE)

The related courses include:

- ME 50400 Automotive Control
- ME 59700 Renewable Energy and Fuel Cells
- ECE 59500 Automotive Control (dual listed with ME 50400)
- ECE 59500 Introduction to Smart Grid Theory and Implementation
- ECE 58000 Optimization Methods for Systems and Control

3.1.4 Purdue – MS in Chemical Engineering: Energy Storage

An MS program in Chemical Engineering with a focus on Energy Storage was initiated as part of the DoE I-AEVtec grant, where the program was funded by a combination of support from the Indiana Economic Development Corp. and Naval Surface Warfare Center – Crane (NSWC-Crane). The program covered a range of fundamental engineering topics and specialized courses in various aspects of electrochemical storage of energy. The required courses are:

- CHE 540; Transport Phenomena
- CHE 597: Introduction to Energy Storage Systems
- CHE 597: Battery Laboratory
- MSE 597: Introduction to the Modeling of Rechargeable Batteries
- IE 546: Economic Decisions in Engineering
- ChE 597: Electrochemical Engineering
- MSE 597: Introduction to the Materials Science of Rechargeable Batteries
- IE 570: Manufacturing Process Engineering or IE 590 Power Systems & Smart Grid
- ChE 597: Research/Design Project I in Energy Storage Systems
- ChE 597: Research/Design Project I in Energy Storage Systems

3.2 Task 2. Develop high-value educational and training products that address the full range of technologies needed to support electric drive vehicles.

The development of educational material was the major activity of the I-AEVTec program where 38 courses were developed and/or enhanced. These courses include a wide variety of technical topics, ranging from the electrochemistry of batteries to electric power systems to motors to hybrid electric vehicles to electric vehicle maintenance and safety. The course offerings range from fundamental theory to hands-on application of engineering and technology principles. During the course of the grant courses suitable for BS/MS Engineering and Technology students were developed as well as coursework for Associate Degree programs for the technicians that maintain electric vehicles.

Brief descriptions of the various courses that were developed or enhanced as part of the I-AEVTec grant are given below. Detailed materials including course syllabus, lecture notes, handouts, etc. for each course are attached to this report.

Purdue University Coursework

1. Automotive Prime Movers (ME597) - The automotive industry is transforming itself to address concerns about dependence on imported petroleum, emissions of toxic pollutants, and climate change. New prime movers such as hybrid engines, fuel cell engines, and electric engines, are becoming viable alternatives to the conventional internal combustion engine (ICE). In the case of ICEs, alternative combustion systems which are more efficient relative to conventional engines are being developed. Historically, a significant number of Purdue engineering graduates have found employment in the automotive industry. In view of the rapid changes in the automotive industry, there is a compelling need to develop a new course which equips Purdue engineers with the skills and knowledge necessary to provide leadership in the industry.
2. Reenergizing Society through the Use of Battery Technology (IE 590) - This course will serve as an introductory course for students interested in learning the basic principles affecting the electric vehicle industry. The intended audience will be inter-disciplinary and the course will effectively appeal to students across the campus. After completing this course many students will be inspired to learn more about the EV industry and enroll in additional and more technical EV oriented classes.
3. Vehicles, Sustainable Energy Systems and Consumer Consideration (ECET 300)- The course is an introductory course in Electric Vehicle (EV) technology analysis and configuration. The course explores the integrated mechanical and electrical power and control systems in electric vehicles including the management of integrated power and control systems within a vehicle. The course material covers overall system configuration, power requirements, weight, structure, power system, control and energy storage media as well as efficiency optimization. Students perform detailed analysis of and develop approaches for power management and control systems integrated within the inherent engineering of electrically powered vehicles. The primary goal of this course is to provide students a rich and robust learning experience of frameworks, methodologies, and techniques in the area of electric vehicles, motors and battery functionality.

4. Design and Simulation of Rechargeable Batteries (MSE 500) At its very core, rechargeable battery technology improvement comprises the integration of: a) advances in the microstructural ionic transport in each electrode and b) innovation in the underlying material chemistries. This is a senior and graduate level class supported by a set of virtual tools and education demos where students can develop battery design, processing, and reliability criteria by starting from a solid theoretical and numerical basis. Theoretical and practical aspects of battery operation will be developed in this context, while placing an emphasis on the integration of electrochemical principles and materials science aspects for rechargeable battery technology.
5. Design and Analysis of Hybrid Electric Vehicle Drive Train (ME 597) - This 500 level graduate course addresses the fundamentals of design and analysis of Hybrid Electric Vehicles. - This course covers fundamental concepts and practical applications of the design and analysis of Hybrid Electric Vehicles. The course emphasis is placed on design, analysis and systems integration, based on the basic principles of HEV drivetrain and its relationships among the drivetrain subsystems. This course is multidisciplinary and will be team-taught. Electrical propulsion and electrical systems material is expected to comprise 20-25% of the total course material and will be taught by an ECET faculty member.
6. Introduction to Energy Storage Systems (ECE 610)- selected energy storage devices and connect with their electric power applications in electric vehicles. The course contains four major parts: batteries, fuel cells, supercapacitors, and power electronics for the electrical vehicles. The format of the course will consist of lectures, tutorials, demonstrations, site visits, computer simulations, assignments and discussion periods. This web-enabled course will be offered at least twice before the end of the project, where the initial offering is expected to be in the Fall semester of 2010. This course will be designed for both the West Lafayette campus as well as a component of off-site MS programs with Crane, Delphi and other technical organizations
7. Electric Vehicle Design and Fabrication (ECET/MET/CNIT 399) The course will explore the integrated mechanical and electrical power and control systems in electric vehicles. The primary goal of this course is to provide students a rich and robust practical learning experience in electric vehicle systems. The course will require students to develop a detailed design, time management and task responsibility plan, perform research on existing electric vehicle systems, develop a procurement plan for electric vehicle components, design and fabricate custom electric vehicle components, and execute the construction of an electric vehicle. Once completed, the electric vehicle will be extensively tested for safety, performance, and energy efficiency. Teams will perform comparative analysis of electrical vehicle parameters such as gear ratios, operational voltages, motor types and controller configurations, etc to evaluate the performance and energy efficiency of electric vehicles. Teams will also design and implement electronic tracking and performance instrumentation to monitor the performance of electric vehicles during everyday operation. Each team will be required to develop and present a final paper and presentation as part of the course deliverables. In addition, the teams will be

required to conduct design review presentations to share knowledge, gather feedback, and justify design decisions with the other teams and the instructors in the course.

8. Electromechanical Motion Devices (ECE 321) The general theory of electromechanical motion devices relating electric variables and electromagnetic forces. The basic concepts and operational behavior of dc, induction, brushless dc, and stepper motors used in control applications are presented.
9. Power Electronics (ECE 433) - Introduction to the fundamental operating principles of power conditioning circuits that are currently being used to effect power flow from ac to dc and vice versa. Emphasis is on the relationship between form and function of these circuits. Circuits discussed will include ac/dc line-commutated converters, dc/dc converters, dc/variable frequency converters, resonant converters, and ac/ac converters. Computer simulations will be used as a part of the course work.
10. Electrical Vehicle Systems 1 (ME 595) - This is a new course in Electric Vehicle (EV) system design as it pertains specifically to the electrical systems and subsystem located in an electric vehicle. This course will include both a lecture and hands-on laboratory component where the course participants will actually design and build component required to develop high performance, yet energy efficient electric vehicles.
11. EV - Electric and Hybrid Vehicle Systems (ME/ECE/ECET/ChE (Eng. 501) - Objective: To provide in-depth overview of subsystems and their characteristics of modern electric and hybrid vehicles.
12. Introduction to Electric Vehicle Technology (ECET/MET/CNIT 501) - The course is an introductory course in Electric Vehicle (EV) technology analysis and configuration. The course explores the integrated mechanical and electrical power and control systems in electric vehicles including the management of integrated power and control systems within a vehicle. The course material covers overall system configuration, power requirements, weight, structure, power system, control and energy storage media as well as efficiency optimization. Students perform detailed analysis of and develop approaches for power management and control systems integrated within the inherent engineering of electrically powered vehicles. The primary goal of this course is to provide students a rich and robust learning experience of frameworks, methodologies, and techniques in the area of electric vehicles, motors and battery functionality.
13. Electric Vehicle Systems Control (ME 597) - The goal of this course is development of a useful skill set for the automation of all control systems on an electric vehicle. Successful deployment of an electric vehicle requires more than a motor and batteries. The key performance component is the control system which is a combination of hardware and information technology. Due to the numerous areas in which electromotive power is used, such as trains, public transport and robotics, we will review the best practice techniques from these vehicle systems to apply control systems to our vehicles.

14. Electric Vehicle Event Infrastructure 1 (EPICS 301) - This is a hands-on course using state-of-the-art electric equipment in order to design and build an electric go-kart. This course will provide students with the entire design, assembly, build, and troubleshooting process as they create the electric go-karts used for the evGrandPrix. The students will gain an understanding of the electrical process and components as well proper chassis dynamics and balancing.
15. Major Event Planning (OLS 399) - The objective of this course is to gain an understanding on how you integrate project management tools into operating and running a major event. The project is the operations of the International evGrandPrix and the Purdue evGrandPrix.
16. Engineering Introduction to Electric and Hybrid Electric Vehicles (Eng 101) – The students in the class will gain an understanding of the types of electric and hybrid electric vehicles, operations, motors, controllers, and overall impact on society. The course will review hybrid operations, subsystems, potential fault areas and economics as a comparison with other forms of transportation.
17. Electric Vehicle Event Infrastructure 2/3 (EPICS 301) - Project course using project management tools and engineering design principles for the creation of educational materials to be used in community media and show displays. These materials were then used as demonstrations at a variety of major events including the Indiana State Fair.
18. Electric Vehicle Event Infrastructure 4 (EPICS 301) - Project course using management tools and engineering design principles for the creation of a high school electric vehicle go-Kart race, where the kart design is a step down from the university skill level used in the evGrandPrix. Course objectives include development of technical specifications, rules and safety analysis. Students will gain an understanding of risk management, process / budget controls, operations and event management.

Indiana University – Purdue University Indianapolis (IUPUI) Coursework

19. Automotive Control (ME 597) - Concepts of automotive control. Electro-mechanical systems that are controlled by electronic control modules via an appropriate algorithm (such as fuel injection timing control, emission control, transmission clutch control, anti-lock brake control, traction control, stability control, etc.). In-depth coverage on modeling and control of these automotive systems. MATLAB/SIMULINK modeling and simulation.
20. Dynamics and Simulation of Hybrid-electric vehicles (ME 59700) - The aim of this course is to teach students advanced multi-body dynamics and finite element computational techniques that can be used to predict the dynamic response of passenger cars with emphasis on hybrid electric vehicles. The vehicle geometry will be created using advanced solid modeling CAD software. The geometry will then be imported into high fidelity multi-body dynamics/finite element software to create computational models of the various vehicle components, including: chassis, tires, suspension system, steering system, drive-train, transmission system, electric drive (including motor and batteries),

gas engine, regenerative braking system and electric generator system. The computational models consist of rigid bodies and flexible bodies that are connected using various types of joints. Flexible bodies can be modeled using solid, shell or beam elements. Joints include **HEVTC Program** spherical, revolute, cylindrical and prismatic joints. In addition, the rigid/flexible bodies can come into frictional contact.

21. Renewable Energy and Fuel Cells (ME 597) - This course intends to provide engineers and students with a comprehensive yet practical guide to the characteristics, principles of operation, and power potential of the most dominant renewable energy systems, including solar energy, wind turbines, battery and fuel cells, biomass, geothermal energy and hydropower. The course focuses on the engineering and design of alternative energy systems. Students will learn details of renewable energy storage devices, with special emphasis on batteries and fuel cells, through hands-on project assignments.
22. Powertrain Integration (ME 597) - The holistic view of powertrain development that includes engine, transmission, and driveline is now well accepted. Current trends indicate an increasing range of engines and transmissions in the future with, consequently, a greater diversity of combinations. Coupled with the increasing introduction of hybrid vehicles, the scope for research, novel developments and new products is clear. This course discusses engines, transmissions, and drivelines in relation to their interfaces with chassis systems. This course also explores the concept to market evolution as well as powertrain and chassis integration.
23. Hybrid and Electric Transportation (ECE 597) - This course will cover fundamentals of hybrid electric and battery electric transportation systems with particular emphasis on automotive vehicles. It will cover basic powertrain configurations of Hybrid Electric Vehicle (HEV), Plug-in Hybrid Electric Vehicle (PHEV), and Battery Electric Vehicle (BEV). The principal elements of these powertrain will be discussed: Battery, Electric Motor, Engine, Transmission.
24. Introduction to Smart Grid Theory and Implementation (ECE 59500) - Electrical power system infrastructure and American national electricity policy; electrical transmission system operations; power system reliability; electricity market design and operation; Smart grid technologies – distributed generation, demand response, advanced meter infrastructure; Smart grid standards development – interconnection, interoperability and cyber security; Smart grid impact on power system reliability and electricity market
25. Energy Storage Devices & Systems (ECE 595) - Fundamental principles of battery science and engineering(battery reactions, charge and mass transport in batteries, battery safety, battery management, and materials development in the batteries, battery system designs and integrations), current state-of-the-art battery technology and the current technical challenges on the development of batteries, codes and standards for safe handling of batteries.
26. Hybrid Electric Propulsion Systems and Control (ECE 595000) - This course provides students with theoretical and design foundation to understand various aspects of operations and control of hybrid and electric vehicle (HEV) systems. The course covers

dynamics of internal combustion engine, electric motor and generator, energy storage devices and systems, batteries, and vehicle. Various design methods for HEV energy management systems and battery management modules are presented. Advanced control techniques for electric motor/generator, battery system, regenerative braking and other subsystems are discussed.

Notre Dame Coursework

27. Electrochemical Energy Conversion & Storage (400) - Fuel cells and batteries directly convert chemical energy to direct-current electrical energy via electrochemical reactions. Such electrochemical conversion and storage of energy is an attractive alternative energy option for transportation and stationary applications. This course offers a comprehensive look at the electrochemical nature of energy conversion and storage in fuel cells and batteries, the engineering requirements that must be fulfilled for their efficient operation and the technology of their construction.
28. Electric and Hybrid Vehicles (400) This course provides an introductory treatment of electric and hybrid electric vehicles. Fundamental relationships that govern the performance and behavior of ground vehicles are discussed in some detail so that students can actually use MATLAB to simulate a variety of driving cycles. IC engines such as Diesels (Turbo-Diesels), gas engines, rotary engine, Stirling engine etc. are summarized and their performance characteristics and efficiencies are covered. An introduction to electric and hybrid electric vehicles is provided in a next step and overall vehicle architectures are discussed. The most promising electric motors in EV and HEV drive trains are then introduced and the fundamental torque producing mechanisms in electric motors are derived from fundamental principles. Energy storage devices such as batteries, ultra-capacitors and flywheels are presented before the subject of particular HEV drive trains is revisited in more detail. Finally, energy optimal power application schemes are explored. Some of the concepts will be illustrated using lab equipment that is currently under construction. In particular, DC motors, ultracapacitors, batteries, and components of drive trains will be illustrated.

IVY Tech Coursework

29. Hybrid and Electric Vehicle Technologies (Auto 210) - This course provides an overview of the fundamentals of operation, diagnosis and repair of electric and gas-electric hybrid vehicles. Topics to be covered will include batteries, fuel cells, electric motor controllers, invertors and auxiliary accessories utilized in the Electric (EV) and Hybrid Electric Vehicles (HEV).
30. Advanced Hybrid and Electric Vehicle Technologies- (Auto 260) - This Course presents advanced theory, diagnosis and repair of BEV and HEV type of vehicles using manufacture specific diagnostic tools and equipment. Installation and application of PHEV conversions will also be an integral part of this course.
31. Principles of Alternative and Renewable Energies (Auto 103) - This Course presents basic theory, diagnosis and repair of BEV and HEV type of vehicles using manufacture

specific diagnostic tools and equipment. Installation and application of PHEV conversions will also be an integral part of this course.

32. Engine Performance I (Auto 109) - This is the first in a series of three courses that introduces the operating systems of an internal combustion engine. The basic theory and operation of ignition, fuel, emission, and mechanical systems will be presented. Basic test procedures will be introduced. Computer engine control basics will be explained. Basic service and replacement procedures and techniques will also be covered.
33. Electrical and Electronics II (Auto 123) - This first of second electrical classes introduces the fundamentals of electricity and automotive electronics. Extensive use of digital multimeters and circuit troubleshooting is covered. Emphasis is placed on understanding and utilizing electrical diagrams. Starting and charging systems are presented.
34. Electrical and Electronics I (Auto 113) - This first of three electrical classes introduces the fundamentals of electricity and automotive electronics. Extensive use of digital multimeters and circuit troubleshooting is covered. Emphasis is placed on understanding and utilizing electrical diagrams. Starting and charging systems are presented.

Purdue Calumet / North Carolina Central University Coursework

35. Modules for BS Chemistry Courses - Both schools developed modules that have been included into general and advance chemistry courses. These modules were 2 -3 week long events including both lab activities and lectures for all levels of students. They further steps these activities down such that they have been incorporated into the K-12 science classroom.

3.3 Task 3. Deliver Educational Programs to a Diverse Group of Students

The courses developed in Task 2 were delivered to a diverse group of students enrolled at the various educational institutions over the course of the DoE grant. A summary of the student enrollment in the various courses is provided in Table 1. Now that these courses have been developed, they are continuing as part of the regular curriculum of the I-AEVtec partner institutions.

Table 1. Course Offerings During the I-AEVtec Program

	FY2010 10/1/09 - 12/31/09	FY2010 1/1/10 - 3/31/10	FY2010 4/1/10 - 6/30/10	FY2010 7/1/10 - 9/30/10	FY2010 10/1/10 - 12/31/10	FY2011 1/1/11 - 3/31/11	FY2011 4/1/11 - 6/30/11	FY2011 7/1/11 - 9/30/11	FY2011 10/1/11 - 12/31/11	FY2012 1/1/12 - 3/31/12	FY2012 4/1/12 - 6/30/12	FY2012 7/1/12 - 9/30/12	FY2012 10/1/12 - 12/31/12	Q2 FY 2013 TOTAL
597 - Automotive Prime Movers Technology					10				36	16				52
590 - Reenergizing Society through Battery Technology					11								15	25
300 - EVGP Sustainability					16	15								26
500 - Design and Sim. Batteries					4				15					16
597 Design & Analysis HEV Drivetrain					23									19
610 - Intro to Energy Storage Systems														23
399 - EV Systems, Design & Fabrication		24				24								48
321 - Electromechanical Motion Devices									9					9
433 - Power Electronics						10			21					31
595 - Electric Vehicle Systems					5	8								8
501 Electric & Hybrid Vehicle Systems					22									5
301 - Intro to EV technology					5									22
597 - EV System Controls										16				21
300 - EPICS - EVEI-1 Infrastructure	10	15			21	23	15		23	18			15	121
399 event Planning													19	21
101 - Eng Intro to EV technology					22									56
300 - EPICS - EVEI-2- Out Reach		17			11	13			18	16			4	7
300 - EPICS-EVEI-3- Education					7	6			12	13			4	86
400 - Senior Design Project		5			2	6			13				4	7
500 Battery Lab						17							3	32
500 - Automotive Control									34				12	29
500 - Modeling, analysis, and control of EV & Hybrid Vehicles													32	66
500 - Renewable Energy and Fuel Cells						21							5	5
500 - Powertrain Integration						15			21					43
400 - Hybrid and Electric Transportation														36
500 - Topics in Energy Systems, Grid & Market														0
300 - Energy Storage Devices & Systems													10	10
595 - 26. Hybrid Electric Propulsion Systems and Control									4					4
400 - Electrochemical Energy Conversion & Storage		7					9						8	8
400 - Electric and Hybrid Vehicles														
210 - Auto #1		15			6	8			0				46	23
260 - Auto #2						8							25	100
Auto 103										15			6	14
Auto 109													7	15
Auto 123													24	31
auto 113													20	16
Auto 107													20	36
First Responder Train-the-Trainer		7			52					24			26	109
NCCU Lab Module						15							35	50
PU Cal Support Modules		20				30								50
Total		110	0	0	217	243	0	0	228	136	0	0	301	1457

3.4 Task 4. Establish Electric Vehicle Hub

Utilizing the Purdue's HUBzero™ infrastructure the SmartEnergyHub was created to deliver the course material, including lectures, homework, videos, tests, syllabus, and other associated materials. The delivery system not only includes state-of-the-art simulation tools, but also an Learning Management System that allows students easy access to the. The SmartEnergyHub is segmented into the following operating parts: one for course materials including PowerPoint, video, tests, etc. and a second for general outreach links. An easy to select course catalog allows the user to select courses by topic or by university. The Hub environment was also used as a file sharing and group work area for the teachers and staff developing K-12 materials. There have been discussion with educational institutions outside the I-AEVtec partnership concerning use of the SmartEnergyHub for their content, but no formal relationships have been established to date.

3.5 Task 5. Partner with the regional industries that manufacture advanced electric vehicles and/or components to ensure that the graduates of the education/training programs meet the needs of this evolving industry.

Industry representatives from companies involved in various aspects of electric vehicle technology were engaged to provide input on their perspective of workforce needs. Using this information the coursework programs were evaluated to determine that anticipated needs were being met. From these meetings two specific industrial outreach programs were developed:

1. Energy Storage MS Program. A major focus of the Indiana industries in this space is batteries. In particular, the Naval Surface Warfare Center – Crane (NSWC-Crane) is a large DoD facility in southern Indiana that has the DoD lead in battery operation, maintenance, testing and safety. In addition, the State of Indiana has recently established the Battery Innovation Center (BIC) at the Crane West Gate. BIC is a not-for-profit entity that is designed to support commercial and DoD battery research, development and deployment with a special focus on manufacturing. Because of the presence of NSWC-Crane and BIC, Purdue developed a special Chemical Engineering MS degree with a focus on Energy Storage (see Section 3.4.1 for program details). This MS program is distance enabled and delivered directly to employees at Crane. This program uses many of the courses developed as part of the DoE sponsored I-AEVtec grant; however, the I-AEVtec grant did have resources for delivering courses at distance. The cost for distance delivery was paid for by (i) NSWC-Crane and (ii) the Indiana Economic Development Corp.
2. HEV101 – Introduction to Electric Vehicle Systems. Immediately upon announcement of the DoE I-AEVtec grant we were contacted by Delphi Corporation who is a leading supplier of electronics to the auto industry. Delphi Corp. wanted a course to help re-tool their workforce from a micro-electronics focus to a power electronic focus in order to address the emerging EV and PHEV markets. Purdue develop an industrial short course with 11 educational modules ranging from vehicle performance to motor performance to

batteries. The cost for delivery was paid for by Indiana Department of Workforce Development via a Dept. of Labor training grant. The various modules were videotaped and are now available for distance learning from Purdue College of Engineering's Engineering Professional Education program.

The two programs illustrate how the educational materials developed as part of the DoE sponsored I-AEVtec project are being used in a wider arena, with sustainable resources in order to address the needs of regional industry concerned with electric vehicles and the associated technology.

3.6 Task 6. Develop a program appropriate for secondary school students and have community outreach concerning EVs, PHEVs and FCVs.

There were significant activities as part of the I-AEVtec program with respect to both community outreach and K12 education. With respect to community outreach the various activities are listed in Table 2. Several activities of particular importance are:

1. Purdue Spring Fest. Spring Fest is when the Purdue campus is open up to the public every spring, where more than 10,000 children, parents and community members visit a variety of fun activities over a two day weekend. In 2010, 2011 and 2012 the I-AEVtec program had a large tent in the central mall area of Spring Fest, where we had a variety of age appropriate hands-on activities concerning electric vehicles as well as a number of EV and PHEVs vehicles on display. There were thousands of children and adults who participated in this outreach activity.
2. Indiana State Fair. We had a display at the Indiana State Fair both on the main mall and in the Our Land Pavilion showcasing electric vehicle technology. In the Our Land Pavilion we had an electric go-kart video game simulator, where students could virtually race against each other. Thousands of young people and their parents were exposed to the emerging electric vehicle technology.
3. Go-Kids at the Bauer Community Center. As part of the DoE grant we developed an afterschool outreach program to at-risk upper elementary and middle school students at the Bauer Community Center. The program was centered on hands-on building projects, where the students built small science/technology projects related to electric vehicle technology. In addition, the student built an electric drill powered go-kart that they drove around the gymnasium. This activity was very well received by the K12 students, but in addition it provided an excellent introduction to community service for the college students that participated as the program mentors.

These three projects illustrate the type of outreach activities that were part of the DoE I-AEVtec grant, where a complete listing of activities is given in Table 2. Via these events large number of individuals were exposed to the electric vehicle technology, e.g. major supercomputer conventions (15,000 attendees), National Science Teachers conventions (20,000 attendees), Indiana and Ohio State fair (1.5 million attendees), various car shows, displays at local malls and countless presentations to high school students in the Midwest.

With respect to the K12 education program, a significant opportunity arose that caused a major change in direction. After considerable interaction with middle school and high school teachers and administrators, it became clear that isolated projects, no matter how technically interesting, could not sustain unless they were an integrated part of a larger curricula that satisfies the state/national teaching requirements like the Core Curriculum. Thus, isolated projects on electric vehicle technology will be difficult for sustained use in the K12 environments. However, based upon this understanding a new opportunity has occurred. Because of the high visibility of the evGrandPrix (see next Section) with the IndyCar racing community at the Indianapolis Motor Speedway (IMS), Purdue has been able to establish very strong relationships with the leaders of the IndyCar community, including race teams, Dallara (the manufacturer of the IndyCars) and the Indianapolis Motor Speedway (home of the Indy 500). A partnership has now formed between Purdue, Dallara, IMS and several local school districts to develop a motorsports based STEM program (i.e. M-STEM), that has broad support from the Indiana based motorsports, manufacturing, local business and educational communities. The initial focus is on developing a complete middle school physical science program that uses motorsports cool to bring along young people into STEM. We have also begun discussion on what a high school program might look like, where an electric go-kart race like the collegiate evGrandPrix would be a very attractive program for high school students. Although the current focus of the M-STEM program is not electric vehicle technology, it is important to acknowledge that the genesis of this significant K12 STEM education program was the DoE I-AEVtec grant, where electric vehicle technology may become part of this STEM program as it matures.

Table 2. Electric Vehicle Outreach Events

Purdue Spring Fest - Spring 2010
Karting News radio show - Spring 2010
IMS - Out reach program Spring 2010.
Student Recruitment Program - Local Mall Energy Day Spring 2010
K - 12 Secondary School Program - HS presentation Spring 2010
Electric Grand Prix Go-Kart Race - 4/18/2010
Student Recruitment Program - Indiana State Fair summer 2010
Student Recruitment Program 4H Summer Program 2010
K-12 Navy JR ROTC - Summer 2010
Auto Sports Radio - fall 2010
K-12 Teachers Summer Program - 4H instructor program fall 2010
K - 12 Secondary School Program - HS Presentation Fall 2010
K - 12 Secondary School Program - Back to Class - Fall 2010
Purdue Florida Event Winter 2010
Electric Grand Prix Go-Kart Race -5/7/2011
Student Recruitment Program - Purdue students spring 2011
Student Recruitment Program - Local Mall Energy Day Spring 2011
K - 12 Secondary School Program - go Kids spring - 2011
K - 12 Secondary School Program - HS presentation Spring 2011
EvGrandPrix 2011 - at Indianapolis Motor Speedway spring 2011
Electric Grand Prix Go-Kart Race - spring 2011
HAAS Technical Education Conference - Summer 2011
Student Recruitment Program - 4h summer 2011
Student Recruitment Program - Indiana state fair summer 2011
Student Recruitment Program - Htec North American Conference Summer 2011
K-12 Navy JR ROTC - Summer 2011
K - 12 Secondary School Program - go Kids spring - 2012
Student Recruitment Program - Local Mall Energy Day Fall 2011
Student Recruitment Program at Ivy Tech Fall 2011
IMS - Out reach program Fall 2011
Purdue Chem Eng Centennial Event - Out reach effort Fall 2011
International Super Computing Conference 2011
International Super Computing Conference 2010
Bauer Community Outreach efforts Fall/Spring 2011, 2012
Purdue Campus Fall Car Show Fall 2011, 2012
3rd Annual Michigan Electric Vehicle Show and Rally Schoolcraft College, Livonia Michigan Spring 2012
Bowling Green Car Cruise, Downtown Bowling Green, Ohio Summer 2011, 2012
Project Lead The Way Secondary Education Teacher Workshop, Eastern Michigan University Fall 2012
Flag City Balloon Fest and Car show, Findlay Ohio Fall 2011, 2012
HEV Michigan Group Networking, Poster presentation at the Westin Southfield Detroit mi. Fall 2011, 2012
Charging Forward: EV Showcase, Ohio 4-H Center, Columbus, Ohio
BGSU Campus Fest, BGSU Spring 2011
National Science Teachers Convention Spring 2012
National After School Convention Spring 2012
Boy Scouts Presentation Summer 2012
Student Recruitment Program 4H Summer Program 2012

3.7 Task 7. Initiate the Electric Vehicle Grand Prix Go-Kart Race

Over the last three years the Electric Vehicle Grand Prix, i.e. the evGrandPrix, go-kart race has become a huge success. The evGrandPrix has occurred three times on Purdue University's GrandPrix go-kart track. The International Collegiate evGrandPrix has occurred twice at the Indianapolis Motor Speedway and it will occur in 2013 on Open Day Weekend for the Indy500. The International Collegiate evGrandPrix has teams from across the US as well as from Europe. The evGrandPrix provides college student with the opportunity to integrate their technical coursework in a real project, where the outcome is not just a grade from a professor, but a head-to-head public competition with other college students. The design and building of the electric powered go-karts requires the students to integrate different types of technical knowledge in order to make a working electric vehicle. The scoring for the evGrandPrix has four components:

1. Placement in the evGrandPrix race;
2. Engineering design of the go-kart, including (i) a written design report and (ii) a presentation to industrial and faculty experts explaining the features of the design and how it relates to the performance of the go-kart;
3. Energy efficiency of the electric go-kart. The total energy consumed by the go-kart is measured and the efficiency is computed from the total power used divided by the number of laps completed. This requires the students to develop a drive strategy, where they must optimize your power utilization while still actively competing in the race;
4. Community Outreach where each team must have a project where expand the base of knowledge concerning electric vehicles or some aspect of electric vehicle technology in the community. The students prepare both a written report and an oral presentation.

In summary, the evGrandPrix is an event that both a hands-on, integrated design and building experience for college students, where they then compete against other collegiate teams in both a race and in an engineering design and community engagement. This is one of those activities that students love to do and learn real technical skills at the same time. The evGrandPrix was initiated with funding from the DoE I-AEVtec grant, but now is being sustained by a number of significant industrial sponsors – in particular by Autodesk which is the lead sponsor for the 2013 evGrandPrix.

The evGrandPrix has significant national visibility, including numerous TV interviews, press releases that have been pickup by over 500 media sites in both the US and Europe. All this media exposure has provided an excellent vehicle for informing the public about electric vehicle technology.

4. Jobs Created or Retained

This DOE sponsored project help create and retain a number of jobs as summarized in Table 3, including professors, instructors, staff members, graduate and undergraduate students. In the original I-AEVtec proposal is was projected that a total of 50 individuals would be supported by the I-AEVtec project across the six educational institutions as shown in Table 3. The actual number of new positions or positions that received funding from the grant is 71, which are also shown in Table 3.

Table 3. Job Creation/Retention Projection

	Professor/ Instructor	Actual	Staff	Actual	Graduate Students	Actual	Undergrad Students	Actual
Purdue	10	12	3	6	6	10	4	10
Ivy Tech	6	6	6	6	0	0	0	1
IUPUI	3	3	2	2	0	0	0	0
Notre Dame	2	2	0	0	1	1	1	1
Calumet	1	3	1	1	0	3	2	2
IU-Northwest	1	1	0	0	0	0	2	2
North Carolina	0	1	0	0	0	2	0	0
Total	23	27	11	14	7	14	9	16

Appendix

Course Work Content

As part of the I-AEVtec grant 35 courses were developed. Purdue developed 21 courses, Notre Dame delivered 2 courses, IUPUI developed 9 courses, Ivy Tech created 7 courses and Indiana University Northwest (North Central Carolina state) and Purdue Calumet developed electrochemistry modules that were part of their general chemistry coursework. Because of the extensive length of this material, the course material will be forward under separate cover.