2006-191: ENGINEERING EDUCATION IN ALTERNATIVE ENERGY

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Engineering Education in Alternative Energy

Abstract

This paper describes education and research efforts in alternative energy at Michigan Technological University (MTU). A particular emphasis will be placed on the multidisciplinary education of chemical engineering undergraduate students in alternative energy. Experiences can involve enrollment in an interdisciplinary design project, an elective fuel cell course, a hydrogen fuel cell "electrochemical engineering" laboratory, or performing basic or applied research with university faculty and staff. Teaching and mentoring opportunities are also available to doctoral students.

The major aspect of the experience is the Alternative Fuels and Fuel Cell Enterprise (AFE). This is a multidisciplinary, research-oriented undergraduate research project which is run as a business with student management and faculty / staff oversight. The students are currently working on the development of a hybrid, alternative fuel military transport and a transportable alternative energy demonstration unit. Furthermore, these students are involved in minor projects studying other forms of alternative energy, alternative energy applications, or energy integration. This project is in its fourth year and typically enrolls about thirty chemical, mechanical, and electrical engineering undergraduates.

Introduction

Alternative energy is a topic of current interest due to rising oil costs due to increased worldwide demand and political instability in the Middle East. During the 2004 election campaigns, both President George W. Bush and Senator John Kerry discussed as part of their platforms an increased focus on alternative energy research and development. Furthermore, within the State of Michigan there has been increased emphasis on fuel cell applications to motor vehicles. To prepare our students to create the future, faculty and staff at MTU have developed a wide range of interdisciplinary courses and projects in alternative energy.

After describing the structure of the MTU enterprise program, the AFE enterprise and its projects will be presented. This program allows for a unique, multidisciplinary integration of research into teaching. Following this will be a description of the elective course, laboratory, and focused research projects.

The MTU Enterprise Program

MTU students can pursue a minor or concentration (curriculum shown in Table 1 with elective modules listed in Table 2) in the Enterprise program as part of their respective accredited degree program. A vertical (sophomores, juniors, and seniors) and horizontal (various engineering and business disciplines) integration makes the program a unique experience for students. Over 10% of students enrolled in the College of Engineering are involved in (mostly) industry-sponsored enterprise projects, in one of twenty enterprises.

For further information about the MTU Enterprise Program, consult the references available in the engineering education literature[1-5].

Enterprise Concentration (12 total credits)	**Enterprise Minor (20 total credits)**
	Teamwork (2 credits)
Project work (6 credits)	Project work (7 credits)
Communication and/or Business (3 credits)	Communication (2 credits)
	Business (5 credits)
Elective Modules (3 credits)	Elective Modules (4 credits)

Table 1. Enterprise minor and concentration curriculum. Project work credits can also be used as electives for students not pursuing the minor or concentration.

Course #	**Course Title (number of credits)**	**Course #**	**Course Title (number of credits)**
ENG2961	Teamwork (2)	ENG2962	Communications Contexts (1)
ENG3962	Complex Communication (1)	ENG4953	Writing / Societal Context (1)
ENG3954	Enterprise Market Principles (1)	ENG3961	Enterprise Strategic Leadership (1)
ENG3963	Enterprise Entrepreneurship (1)	ENG3964	Project Management (1)
ENG3971	Seven Habits (1)	ENG4951	Budgeting (1)
ENG 4951	Global Competition (1)	ENG2963	Electric Circuit Design & Fab (1)
ENG3955	Conceptual Design / Problem Solving (1)	ENG3956	Industrial Health and Safety (1)
ENG3957 / 3967	Product and Process Development (1)	ENG3958	Engineering Ethics in Design (1)
ENG3966	Design for Manufacturing (1)	ENG3968	Manufacturing Processes (1)
ENG3969	Project Phases of Design (1)	ENG4955	Concurrent Engineering (1)
ENG3974	Fuel Cell Fundamentals (1)		

Table 2. Listing of Business, Communication and Elective Modules for MTU Enterprise Program

The core enterprise experience occurs in the project work courses. During each semester of the sophomore and junior years, students sign up for 1 credit of project work. At this point the students are becoming acquainted with the enterprise project and become more involved as they progress through their academic career. The experience culminates when students sign up for 2 credits of project work per semester during their senior year. At this time these students are often expected to take a leadership role within their respective enterprise. The seniors are also expected to work twice as long on the project. Project work credits beyond the 6 or 7 listed in Table 1 are optional.

It is noted that the courses listed in Table 2 are co-listed in other departments at the University. Courses are taught by

- faculty with affiliations in the School of Business and Economics
- engineering faculty who also advise engineering enterprises
- instructors in the Engineering Fundamentals department who focus only on teaching

Students pursuing a Chemical Engineering undergraduate degree use the project work courses as electives in the degree program. They are excused from one credit of the traditional curriculum, a design laboratory where the students typically work on the AIChE contest problem. The enterprise advisor typically assigns a design problem to the students who are not enrolled in this course.

The Alternative Fuels and Fuel Cell (AFE) Enterprise: Past, Present, and Future

The AFE Enterprise (advised by Keith, Meldrum, and Green with significant input from Gwaltney and Bradley) is one of twenty enterprises on the MTU campus and has been described previously in the engineering education literature.[5] Other enterprises include Clean Snowmobile Challenge, Future Truck, Campus Planning, Aerospace Enterprise, and Consumer Product Manufacturing. It is noted that there is a one-hour weekly "business meeting" between the faculty and staff mentors and all enrolled students. The main goals and accomplishments during the past years will be briefly summarized here.

Project work AFE Enterprise courses were first offered during the fall semester of 2002. Over the course of four years, an average of thirty students have been enrolled per semester (~ 40% Chemical Engineering). The original project was funded by the United States Army Tank Automotive and Armaments Command (TACOM) with the goal of taking an electric vehicle and operating it with a hydrogen proton exchange membrane fuel cell to extend the operating range of the vehicle. TACOM also donated two Ballard Nexa 1.2 kW fuel cells for use by AFE. Safety considerations require students to fill out Job Safety Assessment forms and go through a review with faculty and staff before operating laboratory equipment. Separate safety training is provided for machine shop use.

AFE purchased a John Deere e-Gator electric utility vehicle that operates at 48 V on eight batteries. At full load, the Ballard Nexa fuel cell produces direct current electricity at a voltage of 25 V and a current of 50 A. This power source was connected to a DC/AC inverter to produce 110 V electricity. The battery charger from the e-Gator was plugged into the power inverter (instead of the wall of the garage). A small Q hydrogen cylinder (with an internal volume of 14.7 L filled with compressed hydrogen at 2000 psi) was used to power the fuel cell for slightly less than one hour. This power was adequate to power the e-Gator and prevent the batteries from losing charge. Pictures of the vehicle are shown in figure 3 below.

Figure 3. John Deere e-Gator with fuel cell power unit as the payload.

At this point the TACOM funding period expired and the students began to seek additional funding. With the guidance of the faculty advisor, students contacted companies to initiate discussion. The majority of the minor project teams were paper studies of alternative energy areas. If the contact seemed promising, a proposal was developed. The areas studied included:

- Wind power – the goal of this sub-project is to install a wind turbine on the MTU campus to power a small building and/or improve the visibility of alternative energy technology. A potential industrial partner was found; however, the installed cost of the 600 kW turbine was too high to make the turbine profitable for the industrial partner or the university. AFE is currently looking at smaller wind turbines that may alleviate these cost issues.
- Ice resurfacer – the goal of this sub-project is to power an ice resurfacer using a fuel cell or with the existing internal combustion engine modified for hydrogen combustion. A potential partner was located that was willing to donate an ice resurfacer; however, funds were not provided to purchase a fuel cell. AFE is currently looking in more detail at hydrogen combustion with the aid of a mechanical engineering faculty member.
- Heat integration studies – the goal of this sub-project is to study a steel plant and find ways for them to save money on utility bills. This project has been understaffed by students; a greater emphasis will be placed upon it next year.
- AIChE Chem-E-Car Project – a secondary project for students involved in AFE revolves around the American Institute of Chemical Engineers (AIChE) Chem-E-Car competition. Typically a subset of 5 to 6 AFE students work with additional students not enrolled in AFE on the project. Non-AFE students often sign up for AFE after the experiences of working with on the Chem-E-Car project. The

purpose of this competition is to give students experience in powering and stopping a shoebox-sized vehicle using principles of chemical reaction engineering and alternative energy sources. Additional information about how the Chem-E-Car project has been integrated into chemical engineering curricula around the country has been described in the engineering education literature.[5-9]

- Alternative Energy Demonstrator – the goal of this sub-project is to add a fuel cell to a Global Electric Motorcar (GEM vehicle) donated by Daimler Chrysler and use the vehicle as an alternative energy demonstration unit for recruiting and publicity.

In summer 2005, a new cooperative agreement between MTU and the Army Research Laboratory was funded. The goal of the project is to design and develop a vehicle that can run on a traditional diesel engine and an alternative fuel source for "silent propulsion." With the new funding, a new approach was taken that gave the students less "freedom" on the project by giving intermediate homework assignments (as described in Appendix 1). This helped the authors meet particular project goals and deliverables.

The students enrolled in the AFE enterprise have participated fully in the design process, working with faculty in chemical engineering (CM) and research staff at the Keweenaw Research Center (KRC). This group has expertise in vehicle design, simulation, and testing. The CM/KRC collaboration helps satisfy the multidisciplinary mission of the enterprise program and gives the students exposure to diverse levels of expertise.

Description of Fuel Cells Module

With the formation of the AFE Enterprise, students could take up to 8 credits of project work in the area of alternative energy. To provide students core material in one form of alternative energy, a one credit-module course was developed and taught during the fall semester of 2004 (by Keith and Opella) and 2005 (by Keith and Miller). This course used the book by Larminie and Dicks[10] and met one hour per week.

It is noted that this course is completely unrelated to the AFE enterprise. Thus, the module was open to any student; 20 students enrolled in 2004 and 10 students enrolled in 2005. However, half of these students were or became involved in the AFE enterprise as a result of the course. It is noted that taking the module would count as one credit towards the concentration or minor requirements.

The following schedule was followed when teaching the class:

Week 1: Introduction; Types of Fuel Cells; Fuel Cell Stack Components
Week 2: Open time for problem solving
Week 3: Fuel Cell Efficiency
Week 4: Effect of Pressure and Concentration on Fuel Cell Performance
Week 5: Operational Fuel Cell Voltages
Week 6: Fuel Cell Mass Balances
Week 7: Humidity and Water Management in Fuel Cells

Week 8: In Class Exam
Week 9: Thermal Management of Fuel Cells
Week 10: Fueling Fuel Cells (guest lecture by teaching assistant)
Week 11: Fundamental Research in Fuel Cells (guest lecture by teaching assistant)
Week 12: Effect of Operating Pressure; Compressors, Turbines, and Fans; Analyzing a Fuel Cell System; Electrical Issues
Week 13: In Class Exam
Week 14: FEMLAB Modeling of Fuel Cell Systems (computer exercise)

Lectures ranged in length from 30 to 45 minutes. The remaining time was used by students to work in teams on a homework or in-class problem. Students were expected to meet again outside of class to finish it. The assignment was due at the next class meeting.

As seen in the description, during weeks 10 and 11 a graduate student was asked to develop and present course material to the class. The graduate student also helped write the second in class exam with the lead instructor. This experience helped these students evaluate the balance between research and teaching in an academic setting.

Fuel Cell Laboratory Experiment

Chemical Engineering seniors at MTU enroll in a three credit, required course called "Unit Operations Laboratory." Each group of four students performs five experiments during the semester. Each group is required to do an experiment on polymer extrusion, heat exchanger, and pumping. The final two experiments are assigned based upon how each group prioritizes the ten remaining experiments in the laboratory. New for Fall 2005 was the "Proton Exchange Membrane Fuel Cell" with a chemical engineering faculty member as the instructor (Keith). It is noted that this experiment is completely unrelated to the AFE enterprise.

In this laboratory experiment students were to operate a Ballard Nexa fuel cell unit with the capability of producing a DC power supply of 1200 W at an output voltage of 26 V. This unit is powered by a nearly pure supply of hydrogen gas.

The goals for the students were to produce a polarization plot (of stack voltage (V) vs. stack current (A)). The data was recorded using software developed by Ballard run on a computer in the laboratory. After following the startup procedure, students varied the load on the fuel cell by turning on a bank of switches on a load cart. The students recorded the stack current and voltage at each of the 30 settings, and also determined the power in watts (W) for each setting. Finally, the students were required to estimate the efficiency of the fuel cell based on the lower heating value (LHV) and the hydrogen consumption rate for each load level assuming a fuel leak of 3%. The polarization data was also compared to vendor data.

Undergraduate Research Opportunities

Two chemical engineering faculty (King and Keith) have been collaborating on a research project to develop improved materials for use in fuel cell bipolar plates. These plates have channels to carry the reactant and product gases (and liquids) and constitute a large fraction of the total weight of a fuel cell stack. MTU is investigating the use of multiple carbon fillers (carbon black, synthetic graphite, and carbon fiber) into a liquid crystal polymer to make recyclable bipolar plates that meet Department of Energy targets for thermal (for heat removal) and electrical conductivity (to minimize ohmic losses).

The chemical engineering faculty (King and Keith) are currently supervising three doctoral students on this project. They have worked with about 20 undergraduate students on the project in the last calendar year. Students often enroll for one to three research credits during the academic year. They will work in the laboratory about three hours per week per credit hour enrolled. Another two are paid to perform summer research (about 30 hrs / week). The research students are not necessarily affiliated with the AFE enterprise, although they are often recruited from this group.

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Appendix 1: Homework Assignments For AFE Enterprise During 2005-2006 Academic Year

In the first business meeting of the fall 2005 semester a KRC engineer presented detailed information about a class of military vehicles called a MULE (Mulitfunctional Utility / Logistics and Equipment Vehicle). This included a rough idea of performance specifications set forth in a Boeing Broad Agency Announcement. Following this another presentation was given on the prescriptive model of the design process and how to rank design options using methods such as objectives trees and pairwise comparison charts. Students were given an assignment to use the performance specifications to bracket vehicle requirements (including dimemsions, vehicle and payload weights, horsepower, and tractive coefficient). Answers from the students were collected a week later.

The second homework assignment was broken into several parts. The first part required the students to look at a diagram of a proposed vehicle design architecture, with major system groups of powerplant, drivetrain / suspension, chassis / mission equipment package, and command / control. Each major system group had various levels of subsystem responsibility. The students were then tasked to determine which system group had major responsibility for various components of the vehicle (such as tires / tracks, exhaust, fuel tank, engine mounts). The second part required the students to either compare drawbacks and benefits of purchasing an existing vehicle and modifying it versus designing and building a new vehicle, or identifying five potential alternative fuel sources for use.

On the third homework assignment, students worked with a partner to investigate an available hybrid vehicle, the Toyota Prius, in terms of the size, weight, horsepower, drive mechanism, motor and battery weight, and power density. Furthermore, students were required to study two particular propulsion technologies (including traditional engines, stirling engines, capacitors, fuel cells, and batteries) and determine weight, volume, specific energy, nominal power, peak power, startup time, and power density. These results were specifically used to show the project sponsor the viable alternative energy sources for the project.

The fourth homework assignment required students to study scalability of the proton exchange membrane fuel cell (over a range from 10 W to 1 kW to 100 kW) by determining the weight, volume, specific energy, nominal power, peak power, startup time, and power density.

The fifth assignment required students to fill out a data sheet for an unmanned ground vehicle. A database was developed with about 60 vehicles, in terms of manufacturer, time frame of construction, number built, cost, size, empty weight, payload capacity, power source, power, maximum speed, method of propulsion, and unique features of the vehicle.

It is noted here that the grading structure was changed to account for the added emphasis the advisors placed on the homework problems and individual written communication (now equal to 45% of class grade). The rest of the class grade is computed based upon attendance (10%), participation in recruiting activities for future years (5%), and the final major and minor sub-team reports (40%).

During the spring semester of 2006, AFE students will continue to be given intermediate assignments to keep a good project pace. For the first assignment, AFG students (working in teams of three) will rank a list of over forty possible vehicle requirements to be essential, very important, somewhat important, or desirable. The groups will be constructed to introduce new and old AFG members. After student presentation, the results will be discussed and the key requirements will be agreed upon.

Students (in the same groups of three) will then develop downselect criteria for the vehicle project. Topics to be considered in developing downselect criteria include:

- Capabilities vs. Requirements
- Schedule (Design Effort, Component Availability)
- Cost (Design, Components, Fabrication)
- Risks (Meeting Schedule, Within Budget, Performance)

The criteria will be presented by the students at the following AFG meeting. After discussion, the downselect criteria will be agreed upon.

During the ensuing week(s) AFG students (in the same groups of three) develop a weighting system to evaluate possible vehicles or designs. These will be presented, discussed, and agreed upon.

The AFG group will then be subdivided into five subteams. Two or three of the teams that worked on the first three assignments will be combined together. To study the initial vehicle concepts developed in fall 2005 and "score" the concept using the downselect criteria. Each team is also expected to consider an additional vehicle concept and score it as well. The designs will then be presented by each group at an AFG general meeting. After a discussion the top design will be identified.

As a semester goal, all students will work together to develop a detailed design and 1/4th or similar scale prototype of one of the concepts, to be completed by the end of the spring semester.