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A Student-Driven Enterprise in Fuel Cells and Alternative Fuels

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Abstract

This paper describes an interdisciplinary, research-oriented student project in alternative energy at Michigan Technological University (MTU), currently funded by the United States Army Tank Automotive and Armaments Command (TACOM). Students can participate in the project as an elective or in pursuit of an "enterprise minor" over a period of three years.

The Alternative Fuels and Fuel Cell Enterprise (AFE) is run as a business with student management and faculty oversight. The students have arranged themselves into sub-teams that are active in the following projects:

- Development of a hybrid diesel / fuel cell military transport
- AIChE Chem-E-Car competition
- Recruting, public relations, and fundraising
- Business plan and accounting

The paper will further illustrate the structure of Michigan Tech's enterprise program and how AFE is helping students learn to solve real-world energy problems, work in teams, and communicate with other students, faculty, and industry.

Motivation for Alternative Energy

The search for alternative energy sources is an area that has received great attention in the last few years. This has been brought to light recently in the January 2003 State of the Union address by President George W. Bush, who requested that Congress approve $1.2 billion in federal funds over a five year period for hydrogen fuel cell research for passenger vehicles. Furthermore, in her State of the State address in February 2003, Michigan Governor Jennifer Granholm made her own commitment by stating "not only will we build these cars in Michigan, our Automotive Technology Corridor will help develop the fuel cell technology those cars will run on."

Student Interest in Studying Alternative Energy

Students became interested in alternative energy by participating in a hands-on design course for chemical engineers, which has been described in previous ASEE proceedings[1,2]. The main idea behind this course was that students learn best by doing. This type of learning is well documented in the mechanical engineering design literature, and excellent papers on the subject have been written by Steven Batill at the University of Notre Dame[3-5]. The author of this paper worked with Prof. Batill while in graduate school and used some of his ideas to develop a course using the LEGO Mindstorms kit for process control[1-2]. There are several web sites[6-10] and books[11-13] dedicated to using LEGO Mindstorms to do just about anything. Additional references describing the use of the LEGO Mindstorms in the chemical engineering curriculum are also available[14].

At their own initiative, students that took the hands-on design course integrated the LEGO Mindstorms into their AIChE Student Chapter Chem-E-Car to win the 2002 regional competition. The students then became interested in working with the author of this paper in developing the AFE alternative energy project as part of MTU's Enterprise Program. By the end of summer 2002, funding had been secured from the United States Army. After a brief description of MTU's enterprise program, the alternative fuels enterprise will be discussed in detail.

The MTU Enterprise Program

The Enterprise program is available to undergraduate students at MTU as a minor or as a concentration as part of their respective accredited degree program. The uniqueness of the Enterprise Program is that it integrates students at the sophomore, junior, and senior level, from different engineering and business disciplines into a company-like setting to work on a project supplied by industry. Currently in its third year, over 400 students (in an engineering college with about 3000 students) are participating in over 20 Enterprises, ranging from Pavement Design, Wireless Communications, and Ground Water Supply Evaluation, to Formula SAE Car, Future Truck, and Consumer Product Manufacturing. Each Enterprise is intended to operate like a real company in the private sector and is run by the students. For further information about MTU's Enterprise Program, consult the references available in the engineering education literature[15-18].

Students are eligible to enroll in the Enterprise project courses (such as AFE) at any point after the start of their second year. Credits earned from Enterprise project courses can be applied as electives or towards fulfilling the requirements for the Enterprise minor (20 credits) or concentration (12 credits), as shown in table 1. To obtain a minor or concentration, several technical and business courses (formally called "modules") are required. Currently available communication, business, and elective modules are listed in table 2.

The core enterprise experience occurs in the project work course. 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.

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

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)

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

Most enterprises have a weekly "business meeting" that all members attend. Students working on an enterprise project are usually grouped into sub-teams. This is also the case for AFE, which has its "business meeting" on Wednesday nights from 6-7pm. Each sub-team meets once a week for about an hour to discuss progress or work on the specific tasks assigned to them. Students choose the sub-team they want to work with.

The Alternative Fuels and Fuel Cell (AFE) Enterprise

The AFE Enterprise is a multidisciplinary group (of about 40) MTU students with the following mission statement:

> *"To provide an opportunity for young professionals in multiple academic disciplines to interact with industry and faculty and to provide viable solutions to real world energy problems."*

The sponsor of the three year project is the United States Army Tank Automotive and Armaments Command (TACOM). The predominant goal of the AFE Enterprise is to completely design and construct a military ground transport vehicle called a MULE. The Army's broad-based initiative describes a MULE as a versatile military transport that is about the size of small truck, weighs about 1000 pounds, and can carry over half its weight in mission-specific military or communications equipment. The MULE designed by AFE will be powered using hybrid diesel / electric / fuel cell technology. The diesel power will be used for moving large distances in short time periods, and the fuel cell power will be used for silent propulsion for about 30 to 40 minutes. The application that TACOM has in mind is for the silent operation capability of the MULE is to carry combat gear for several soldiers while they are moving at walking speeds, possibly to "sneak up on the enemy."

A secondary project for AFE revolves around the American Institute of Chemical Engineers (AIChE) Chem-E-Car competition. 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.

AFE members are also aware that the focus of the Enterprise may change over time, and it would be expected as the enrollment grows and becomes more diverse, that projects in other alternative energy areas will be explored. The author of this paper is working with several other professors and industries towards securing funding for additional projects.

There are currently four sub-teams within AFE, which will now be described.

- Development of a hybrid diesel / fuel cell military transport – This is the largest of the sub-teams within AFE. This project was discussed with and proposed to the project sponsor. Students working in this sub-team are involved in one of several smaller projects, including:
    - Integration of a fuel cell onto a Chrysler Global Electric Motorcar (GEM)

- Integration of a fuel cell onto a John Deere Electric Utility Vehicle
- Conceptual design of the military transport
- Drivetrain design

The projects that involve integration of the fuel cell into the electric vehicles are a key milestone in the development of the hybrid military ground transport. This is because most AFE students (and the faculty advisor) do not have much experience with hybrid vehicles. Rather than start by putting together a vehicle that has a diesel engine, fuel cell, and batteries, it was decided to develop two intermediate vehicles, where the fuel cell will be used to charge the batteries (through some electrical energy conversion devices) that directly run the vehicle. The operating time of the vehicle with and without the fuel cell will be determined. The statement of work for this phase is given in Appendix 1.

- AIChE Chem-E-Car – The goal of this sub-team is to develop new, alternative energy technologies and implement them onto a small vehicle for use in the AIChE Chem-E-Car competition. The spirit of this competition revolves around using chemical reactions to power a vehicle, which is a perfect fit with the AFE enterprise. The Chem-E-Car sub-team also does extensive testing and calibration of the vehicle and takes it to the regional and national competitions. The sub-team's car placed 5th at the 2002 national competition and improved upon its success with a 2nd place finish and "Most Consistent" award at the 2003 national competition. A new car design is expected in 2004.

- Recruiting, public relations, and fundraising – The goals of this small sub-team are to ensure that AFE can replace its graduating members with new ones. In addition to generating promotional posters, they organize informal meetings for prospective members, complete with pizza and soda. It is also planned that this group will become more active in searching for funds for additional projects.

- Business plan and accounting – The goals of this small sub-team are to set the direction of the enterprise by writing a formal business plan, and to keep the enterprise "in the black" financially by balancing the books and working as an interface between the sub-teams and the university purchasing department. It is also planned that members of this group will work with the public relations sub-team in searching for funds for additional projects.

There is also a "corporate structure" to the AFE enterprise. There is a president who is elected on an annual basis. Each sub-team also has a leader, usually a returning senior who was asked by the course instructor to serve in such a leadership role. Sub-team leaders get "extra credit" for their service to the enterprise and additional extra credit if their sub-team is successful.

Evaluation Tools

Student grades are determined according to the following criteria:

Item	*Weight*
Meeting Attendance and Participation	10 %
Individual Memo Reports	10 %
Sub-team Final Semester Report	60 % (weighted by peer evaluations)
Instructor / Sponsor Evaluations	20 %

As mentioned before, there is a weekly business meeting. Students need to attend these meetings to know what is going on outside of their sub-team. As a result, attendance is taken at these weekly meetings. Counting attendance for 10% of the course grade motivates students to attend the meeting. However, since the project involves students at the senior, junior, and sophomore level and in chemical, mechanical, and electrical engineering departments, the business meeting has to be held in the evening. MTU generally schedules evening exams in their courses. Therefore, students can miss the business meeting for conflicts such as exams.

To ensure that the students develop good communication skills, they are required to write periodic progress memos throughout the semester. In their first memo, students are asked to describe the goals of their sub-team and their own personal goals. In their last memo, students are asked to evaluate whether or not they met the goals set forth in the first memo and describe any challenges that they overcame in attaining them. These memos are used as part of the assessment plan for the AFE enterprise, which will be described in a future ASEE paper.

The culmination of the semester is summarized by each sub-team in a final report. This report is submitted in both electronic and hard copy formats. The reports are used to ensure that the students are effectively communicating with the faculty advisor and the project sponsor. In addition, since students graduate and move on to the real world, the reports are used to get new students "up to speed" as to what is going on in the AFE enterprise and on their project. The reports are graded by the instructor and a contact person who works for the project sponsor.

Following a suggestion from Professor Rich Felder of the Department of Chemical Engineering at North Carolina State University, students' individual grades for the sub-team report are weighted by peer evaluations. If a student does put enough effort onto the project, this student does not get the grade earned by their teammates. Students are told this at the beginning of the semester, and it serves as motivation to "be a team player," especially since the sub-team report is worth 60% of the course grade.

The final evaluation tool is the instructor evaluation of the student, worth 20% of the grade. Discussion with instructors from other enterprises revealed that the peer weighting system does not always work. Students could possibly arrange a deal with each other to give everyone a 100% evaluation. By making the instructor evaluation a significant portion of the grade, the instructor has discretion to give a student who did not appear to work as hard a lower grade. This method works well if the instructor knows all of the students and can take the time to attend one or two sub-team meetings throughout the semester.

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. However, there is still a missing link between the standard curricula for AFE's student population (students come from chemical engineering, electrical engineering, mechanical engineering, and materials science of engineering majors) and alternative energy. Therefore, a one credit-module course will be developed (and taught for the first time in Fall 2004) to help students gain a better understanding of fuel cell fundamentals that they can apply to their project work. This module will cover the following topics:

1. History of fuel cells
2. Overview of fuel cell technology, advantages and disadvantages of fuel cell types
    a. Fundamentals
    b. Proton Exchange Membrane fuel cells
    c. Alkaline Electrolyte fuel cells
    d. Direct Methanol fuel cells
    e. Phosphoric Acid fuel cells
    f. Molten Carbonate fuel cells
    g. Solid Oxide fuel cells
3. Review of electrochemistry
4. Fuel Cell Efficiency and Fuel Cell losses
5. Concepts of fuel processing and reforming
6. Characteristics of fuel cells
7. Fuel cell catalysts, "platinum problem", sulfur / CO poisoning of electrodes
8. Research and development efforts in fuel cells
9. Fuel cell system economics and market

A good introductory book on fuel cells (that will be recommended, but not required) has been written by Larminie and Dicks[19]. Supporting laboratory experiments will also be developed in future years. These experiments can easily be integrated into the chemical engineering curriculum.

What Went Right / What Went Wrong

Working with a large number of undergraduate students on a research project is a challenging task. This section will highlight some of the things that were a success and some of the things that could be improved upon.

Student evaluations of the instructor were excellent. This may be because the instructor took a "hands off"approach to teaching the course. Students had the freedom to do what they wanted to, with some guidance. Nevertheless, the students definitely have a lot more ownership in this course than in others. Students are also very creative. They did a lot of things different that the instructor would have, but the result was the same (or sometimes better).

During the fall 2003 semester, the instructor had several major life events occurring at the same time. These include having a very young baby boy in the house and the instructor's wife finishing up her Master's thesis. The instructor did not have the time to go to sub-team meetings. This may be a reason why the sub-teams did not "play together" as well as the sub-teams in the pre-baby, pre-thesis era. Some students received low grades because of poor peer evaluations. However, the sub-team leader is expected to contact the instructor and/or the AFE enterprise president when there is a problem with sub-team dynamics. This point will be made more clear in subsequent semesters.

Future Directions

Funds are currently being solicited by the author and his colleagues to study alternative energy development from animal waste and to study heat and mass transfer fundamentals within specific fuel cell components to improve their performance. These projects will involve both graduate students and the AFE enterprise. In addition, assessment of the AFE enterprise is currently underway and will be reported at a future ASEE conference.

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Appendix 1: AFE Statement of Work to U. S. Army TACOM

Background: With increasing concern for energy related conservation issues, the precedent has been set for the future necessity of development in the area of alternative fuels, specifically in the field of fuel cell research. The military, long reliant on fossil fuel energy, has become specifically interested in this type of alternative energy source for possible integration into lightweight surface transport vehicles. Superior fuel efficiency and noise reduction result in distinct benefits desirable for military applications.

Scope: The Alternative Fuels Enterprise (AFE) of Michigan Technological University (MTU) shall design, develop and implement a hybrid diesel/fuel cell powertrain, for a military ground transport vehicle called a MULE.

AFE is a multidisciplinary group of MTU students with the mission of providing an opportunity for young professionals in multiple academic disciplines to interact with industry and faculty and to provide viable solutions to real world energy problems.

Tasks: The following tasks will be completed by AFE:

1. AFE shall develop and implement a fuel cell based power train into a provided John Deere electric utility vehicle (e-Gator). This vehicle will be an intermediate for the completed project, and will be available for examination prior to construction of the MULE.

2. AFE shall design a combined diesel/fuel cell power train for a MULE prototype including the development of a complete cost analysis, powertrain, and vehicle design specifications prior to initial construction of the prototype for the MULE