

AC 2010-747: INTERDISCIPLINARY MINOR IN HYDROGEN TECHNOLOGY AT MICHIGAN TECHNOLOGICAL UNIVERSITY

Jason Keith, Michigan Technological University

Jason Keith is an Associate Professor of Chemical Engineering at Michigan Technological University.

Daniel Crowl, Michigan Technological University

Dan Crowl is the Herbert H. Dow Professor of Chemical Engineering at Michigan Technological University.

David Caspary, Michigan Technological University

Dave Caspary is the Manager of Laboratory Facilities in the Department of Chemical Engineering at Michigan Technological University.

Jeffrey Allen, Michigan Technological University

Jeff Allen is an Associate Professor of Mechanical Engineering at Michigan Technological University.

Jeff Naber, Michigan Technological University

Jeff Naber is an Associate Professor of Mechanical Engineering at Michigan Technological University.

Dennis Meng, Michigan Technological University

Dennis Meng is an Assistant Professor of Mechanical Engineering at Michigan Technological University.

Abhijit Mukherjee, Michigan Technological University

Abhijit Mukherjee is an Assistant Professor of Mechanical Engineering at Michigan Technological University.

John Lukowski, Michigan Technological University

John Lukowski is an Associate Professor of Electrical Engineering at Michigan Technological University.

Jay Meldrum, Michigan Technological University

Jay Meldrum is the Director of the Keweenaw Research Center at Michigan Technological University.

Barry Solomon, Michigan Technological University

Barry Solomon is a Professor of Geography and Environmental Policy in the Department of Social Sciences at Michigan Technological University.

Interdisciplinary Minor in Hydrogen Technology at Michigan Technological University

Abstract

In this paper we describe the formation and administration of a new minor in hydrogen and fuel cell technology at Michigan Technological University. To receive the 16 credit minor, students are required to satisfy requirements in four areas, which are:

- Participation in multiple semesters of the Alternative Fuels Group Enterprise, where students work on hands-on integration, design, and/or research projects in hydrogen and fuel cells
- Taking a fuel cell course
- Taking a lecture or laboratory course on hydrogen energy
- Taking discipline-specific elective courses

In addition to describing the minor, the paper will also describe the content of the Alternative Fuels Group Enterprise as well as the fuel cell and hydrogen energy courses.

Introduction

The search for alternative energy sources is an area that has received great attention in the last few years, beginning with the January 2003 State of the Union address by President George W. Bush, approving federal funding for hydrogen fuel cell research for passenger vehicles. Similar announcements were made by state governors, most notably Michigan Governor Jennifer Granholm, 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.”

Inherent within the nation’s initiative should be the development of educational programs related to fuel cells and other aspects of the hydrogen economy, including advantages and disadvantages. This is important since hydrogen has been proposed for use in transportation applications as a replacement fuel for gasoline, with fuel cells replacing the internal combustion engine. As such, the Energy Policy Act of 2005 was passed by the 109th Congress¹ as Public Law 109–58. This bill contained the Spark M. Matsunaga Hydrogen Act of 2005 (cf Sections 801-816)¹. One aspect of this bill was to fund the development of university education programs. These programs are described in more detail in the Department of Energy Multi-Year Research, Development, and Demonstration Plan².

Michigan Technological University is receiving federal support under this act, with an emphasis on new course development, development of an interdisciplinary minor, and development of modules that can be used to supplement the traditional curriculum with information about hydrogen and fuel cell technology. The focus of this paper is on the courses and projects associated with the minor.

Formation of an Interdisciplinary Minor in Hydrogen Technology

Beginning in the fall semester of 2008, a draft proposal for an “Interdisciplinary Minor in Hydrogen Technology” was created by the authors of this paper. The home for the minor was in

the Department Chemical Engineering, and the proposal was reviewed and approved by the department curriculum committee, Dean of Engineering, University Senate, Provost, and President, effective April 2009.

The catalog description for the minor reads as follows:

“This interdisciplinary minor focuses on hydrogen technology as an alternative to fossil fuels for stationary and transportation applications. One component is participation in the Alternative Fuels Group Enterprise with project work based upon hydrogen fuel cells and/or other hydrogen technologies, such as hydrogen production or storage. Students will also enroll in hydrogen related elective course modules to receive the appropriate training. Students will also be exposed to the broader, societal impacts of hydrogen technology. Although the minor is open to all students, targeted majors are chemical engineering, electrical engineering, mechanical engineering, materials science and engineering, electrical engineering technology, and mechanical engineering technology.”

It is noted that all minors at Michigan Technological University require at least 6 semester credit hours of 3000 level or higher courses which are not required for the Major degree program except as free electives, and that a minimum cumulative grade point average of 2.0 is required for courses in the minors.

The implications of the above statement in regards to the double-counting of free elective credits will now be described. To obtain a Bachelor of Science degree in Chemical Engineering, 131 semester credit hours are required, of which three semester credit hours are available as free electives. Thus, it is possible for a student to obtain a B.S. in chemical engineering with the hydrogen minor with a minimum of 134 semester credit hours.

The requirements for this 16 semester credit hour minor are for students to obtain credits in four areas:

- Alternative Fuels Group Enterprise Project work (between 4 to 6 credits)
- Fuel Cells (1 to 3 credits)
 - CM/ENT3974 Fuel Cell Fundamentals (1 credit) OR
 - MEEM4990/5990 Fuel Cell Technology (3 credits)
- Hydrogen Fundamentals (1 to 2 credits)
 - CM/ENT3977 Fundamentals of Hydrogen as an Energy Carrier (1 credit)
 - CM/ENT3978 Hydrogen Measurements Laboratory (1 credit)
- Approved Electives (remainder of credits)
 - Common elective credits for chemical engineering students
 - CM3110 Transport / Unit Operations 1 (3 credits)
 - CM3120 Transport / Unit Operations 2 (3 credits)
 - CM4000 Chemical Engineering Research (1-3 credits)
 - CM4310 Chemical Process Safety / Environment (3 credits)
 - Common elective credits for electrical engineering students
 - EE2110 Electrical Circuits (3 credits)
 - EE3120 Introduction to Energy Systems (3 credits)
 - EE3221 Introduction to Motor Drives (4 credits)

- EE4000 Electrical Engineering Undergraduate Research (1-4 credits)
- Common elective credits for electrical engineering technology students
 - EET2120 Circuits II (4 credits)
 - EET3131 Instrumentation (3 credits)
 - EET3390 Power Systems (3 credits)
- Common elective credits for mechanical engineering students
 - MEEM3210 Fluid Mechanics (3 credits)
 - MEEM3230 Heat Transfer (3 credits)
 - MEEM3999 ME Undergrad Research Project (3 credits)
 - MEEM4220 Internal Combustion Engines 1 (3 credits)
 - MEEM4990/5990 Micro- and Nanofabrication for Energy Applications (3 credits)
- Common elective credits for mechanical engineering technology students
 - MET3250 Applied Fluid Mechanics (4 credits)
 - MET4300 Applied Heat Transfer (3 credits)
 - MET4390 Internal Combustion Engines (3 credits)
 - MET4900 Alternative Energy Systems (3 credits)
- Typical elective credits for materials science and engineering students
 - MY3100 Materials Processing I (4 credits)
 - MY3110 Materials Processing II (4 credits)
 - MY4140 Science of Ceramic Materials (3 credits)
 - MY4990 Materials Science and Engineering Undergraduate Research (1-6 credits)
 - MY5410 Materials for Energy Applications (3 credits)
- In addition, the following elective courses are related to societal impacts of hydrogen technology
 - EC4620 Energy Economics (3 credits)
 - ENG5510 Sustainable Futures I (3 credits)
 - ENG5520 Sustainable Futures II (3 credits)
 - ENT3956 Industrial Health and Safety (1 credit)
 - SS3800 Energy Technology and Policy (3 credits)

It is noted that some of the elective courses are required courses within their discipline (e.g. for chemical engineering students electives include both of the transport / unit operations courses in addition to the safety / environment course). Courses in transport were chosen as electives as they (fluid mechanics and heat / mass transfer) are common to the degree requirements for students in chemical and mechanical engineering and materials science and engineering. To round out the electives, courses in circuits and power / energy systems were listed for electrical engineering students. These elective courses often have particular application to the necessary skills required to be successful in the fuel cell and hydrogen energy industry. The use of the elective courses also make the minor attractive to undergraduate students.

Alternative Fuels Group Enterprise

The structure of the minor has an emphasis on project work through the Alternative Fuels Group Enterprise program. Project-based, hands-on learning has been a cornerstone of engineering

education at Michigan Technological University, and the engineering education literature has proven that students learn by doing, through team-based interactive projects³⁻⁸.

It is noted that the Alternative Fuels Group Enterprise is one of over twenty enterprises on campus. The Enterprise program is an opportunity for teams of students from various disciplines (such as chemical, electrical, and mechanical engineering, as well as business) and different levels of their academic careers (sophomore, junior, and senior) to work in a business-like setting to solve real-world problems. Each Enterprise is intended to operate like a real company in the private sector and is run by the students with faculty supervision.

The Alternative Fuels Group has been in existence since fall 2002. Students can enroll in enterprise project work courses in the fall and spring semesters beginning in the second semester of their freshman year. All courses are 1 credit with the exception of the senior level courses which are for 2 credits. The group typically consists of students in chemical engineering, mechanical engineering, electrical engineering, materials science and engineering, mechanical engineering technology, and electrical engineering technology majors. Students that are enrolled in the course attend a weekly business meeting and meet outside of class with their teammates. Each student is part of a sub-team which is assigned a group project. There are usually two or three projects each semester.

Students that participate in this experience also gain experience in the “softer skills” for ABET accreditation. An emphasis is placed on communication skills within the team (via team meetings), with the advisor (via team meetings, end-of-semester team written report, and an end-of-semester individual summary), and with the project sponsor (as needed). Strong emphasis is also placed on the need for life-long learning, as the project emphasis is outside the disciplinary area of the students. Students are reminded that knowledge of fuel cells and hydrogen energy systems will educate them on the advantages and disadvantages of the technology, but the fundamental concepts that they learn can certainly aid them in solving future energy challenges, whether the predominant energy sources are coal, natural gas, nuclear, or renewables for electricity and gasoline, natural gas, hydrogen, or batteries for transportation applications.

Secondary emphasis is placed on understanding professional and ethical responsibility, understanding the global and social impact of engineering solutions, and demonstrating knowledge of contemporary issues. These are addressed by working on a project to find an affordable future energy source. More details will be provided in the next section.

It is noted that the final grade is determined from attendance (10%), individual summaries (10%), and a team report (80%) which is weighted by peer evaluations.

Sample Enterprise Projects

The following is a brief summary of Alternative Fuels Group Enterprise projects related to hydrogen and fuel cells. Each semester there are at least three projects for students to choose from.

- Analysis of a Hydrogen Powered John Deere e-Gator: The purpose of this project was to gain a better understanding of the electrical system of a hydrogen-powered John Deere e-Gator that was designed and constructed by students in the Alternative Fuels Group during a prior semester. Design requirements were provided by the enterprise advisors. Major goals of the testing included characterization of electrical flow in the system:
 - Hydrogen is fed in parallel to two Ballard Nexa fuel cell units (with a maximum electrical power output of 1.2 kW)
 - Electricity from the fuel cells is combined using a battery isolator which acts as a diode to allow for load leveling and to prevent backflow into the fuel cells
 - Electricity from the battery isolator flows through a deep cycle 12 V battery to boost the voltage to be in the proper range for the e-Gator motor controller to move the vehicle
 - The circuit is closed via electrical flow back into the fuel cells.
- Hydrogen Economy for the Upper Peninsula of Michigan: The main objective of this project is to explore the feasibility and obstacles of developing a hydrogen fueling infrastructure in a remote part of the country. Several assumptions were made based upon the recent report titled “The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs” report published in 2004 by the National Research Council and the National Academy of Engineering⁹.

For their project, the students were told to consider the hypothetical scenario in the year 2025, when 10% of all vehicles have fuel cells for propulsion. The students estimated that 250,000 vehicles would require hydrogen fuel. The total fuel demand would be 4.5 million kg of hydrogen (note that a full-scale hydrogen economy in the United States would require 100 billion kg of hydrogen). The students made a recommendation to produce the hydrogen from natural gas via steam reforming in a centralized location with hydrogen transportation as a compressed gas to twelve fueling stations as seen in Figure 1 below.

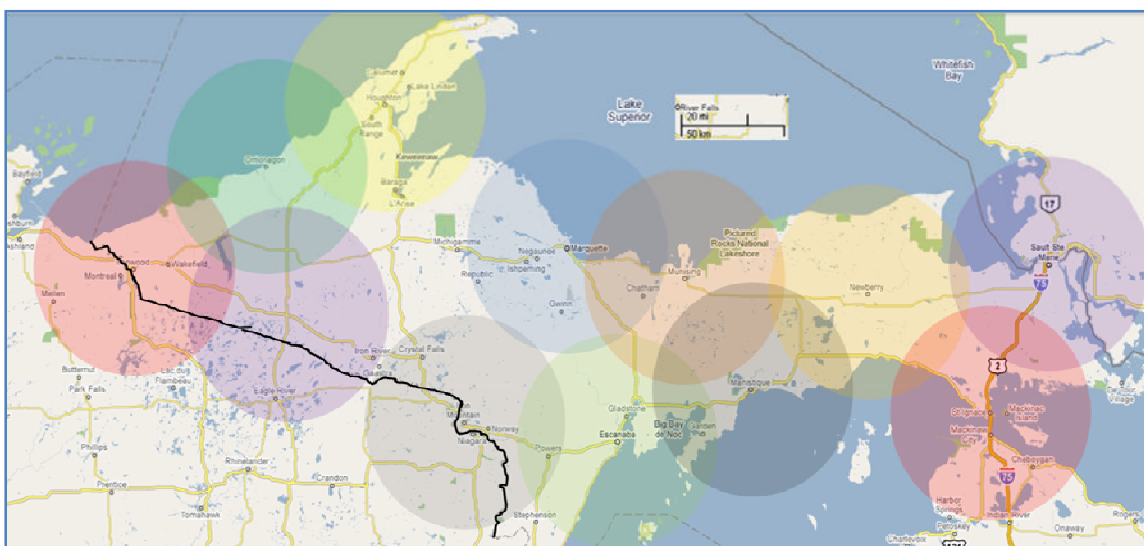


Figure 1. Proposed Hydrogen Fueling Station Locations

- Design and Economic Analysis of a Fuel Cell / Electric Hybrid Fork Lift

The “Clean Lift” performed an economic analysis of a large distribution facility that used a large number of forklifts. If a hydrogen production facility capable of producing 50 kg H₂ per day were used, and if the cost of hydrogen production was \$6 / kg, the economics of using hydrogen powered forklifts was favorable when compared with propane. However, the cheapest option remained using battery powered forklifts charged by electricity.

It is noted that the students also estimated greenhouse gas emissions as well as other environmental impact factors including chlorofluorocarbon, heavy metal, and carcinogenic emissions as well as acidification and eutrophication effects.

Additional details of prior projects can be obtained in the literature^{7,8}.

Fuel Cell Courses

To receive the hydrogen minor, students are required to take a course in fuel cells. The components of these courses will now be described.

In CM / ENT 3974: Fuel Cell Fundamentals (1 semester credit hour), mostly undergraduate students are introduced to fuel cells and how to use concepts from their core curriculum to predict fuel cell operation. An emphasis is placed on proton exchange membrane fuel cells. Students completing the course should be able to:

- Explain what a fuel cell is and how it works
- Describe the chemistry involved in fuel cell systems
- Describe sources of loss in fuel cell systems
- Explain how to integrate fuel cells onto vehicles
- Perform simple mass and energy balance calculations on fuel cell systems

The topics taught within the course, taught in fall semesters from 2004-2007 and 2009, include:

- Types of Fuel Cells
- Components of a Fuel Cell
- Fuel Cell Efficiency
- Effect of Pressure and Gas Concentration
- Losses in Fuel Cells
- Fuel Cell Mass Balances
- Humidity and Water Management
- Thermal Management of Fuel Cells
- Hydrogen Economy

The course grade is determined from performance on nine homework assignments (50%) which includes a create-your-own homework problem assignment and performance on two midterm exams (25% each).

In MEEM 4260/5990: Fuel Cell Technology (3 semester credit hours), mostly graduate students

gain sufficient knowledge for working in a fuel cell industry or research and development organization. The focus is on all fuel cell types, and students completing the course should be able to:

- Learn design and analysis of fuel cells using thermodynamics and electrochemistry.
- Understand the performance and design characteristics and operating issues for various fuel cells.
- Discuss impact of fuels and fuel cell power plants on environment and society
- Obtain thorough understanding and advancement of performance characteristics of fuel cell power plant and its components.
- Learn to prepare a formal technical report and make presentations in the class.

The topics taught within the course, taught in fall semesters since 2007, include:

- Basics of Fuel Cell Technology
- Efficiency and Open Circuit Voltage
- Operational Fuel Cell Voltages
- PEM Fuel Cells
- Alkaline Fuel Cells
- Direct Methanol Fuel Cells
- Phosphoric Acid Fuel Cells
- Molten Carbonate Fuel Cells
- Solid Oxide Fuel Cells
- Fuels and Fuel Reforming
- Balance of Plant / Delivering Fuel Cell Power
- Fuel Cell Systems

The course grade is determined from performance on six homework assignments (10%), a semester project on the fuel cell research literature (20%), performance on two midterm exams (20% each), and performance on a cumulative final exam (30%).

Hydrogen Courses

In CM / ENT 3977: Fundamentals of Hydrogen as an Energy Carrier (1 semester credit hour), mostly undergraduate students are introduced to different energy sources and how to produce hydrogen from them. Added emphasis is placed on obtaining hydrogen from natural gas and coal as they are mature technologies. Students completing the course should be able to:

- Describe sources, reserves, and emissions from various energy sources
- Describe electric, fuel cell, and hybrid vehicles
- Explain how to convert natural gas into hydrogen
- Explain how to convert coal into hydrogen
- Explain how to obtain hydrogen from biomass, electrolysis, wind energy, solar energy, and nuclear energy
- Perform simple calculations on converting energy sources into hydrogen
- Describe basic public and government policies in regards to hydrogen

The topics taught within this course, taught for the first time in the fall 2009 semester, include:

- History of energy production
- Energy sources and emissions
- Electric and hybrid vehicles
- Fuel cells and fuel cell vehicles
- Energy / Hydrogen from natural gas
- Energy / Hydrogen from coal
- Energy / Hydrogen from biomass
- Energy / Hydrogen from electrolysis / wind
- Energy / Hydrogen from solar
- Energy / Hydrogen from nuclear
- Hydrogen public policy

The course grade is determined from performance on ten homework assignments (50%) and performance on two midterm exams (25% each).

In CM / ENT 3978: Hydrogen Measurements Laboratory (1 semester credit hour), mostly undergraduate students are introduced to different experiments in hydrogen energy. Students completing the course should be able to:

- Measure characteristic curves for solar cells and fuel cells
- Use Faraday's law for electrolysis and fuel cell operation
- Exhibit mastery of basic fuel cell voltage, current, power, and hydrogen consumption calculations
- Be familiar with efficiency in energy systems

Within the laboratory, four separate experimental setups are available. These were purchased from Heliocentris¹⁰ and include a *Dr. Fuel Cell Professional* solar electrolyzer and fuel cell (1.7 W maximum power output), a 50 W *Instructor Basic Kit* fuel cell, a 1.2 kW *Nexa Fuel Cell* with a *Variable Resistance Load*, and a *Dr. Fuel Cell Model Car*.

The eight laboratory experiments in the course (and the setup to be used) include:

- Solar Panel Characteristic Curve (Two-Cell Fuel Cell)
- Faraday's Law for Electrolysis (Two-Cell Fuel Cell)
- Fuel Cell Characteristic Curve (Two-Cell Fuel Cell)
- Current, Voltage, and Power in a Fuel Cell (50 W Fuel Cell)
- Faraday's Law for the Fuel Cell (50 W Fuel Cell)
- Efficiency of the Fuel Cell Stack (50 W Fuel Cell)
- Determine voltage, current, hydrogen consumption (1.2 kW Fuel Cell)
- Hydrogen Fuel Economy (Fuel Cell Car)

The course is to be taught in two sections (Tuesday and Thursday afternoon for two hours) with each section having a maximum enrollment of two teams of four students each. In the first week of the course, students will receive a laboratory tour and a lecture on hydrogen safety. The remainder of the course will be taught in cycles. Within each cycle are two experiments followed by a week to write up the laboratory reports. Thus, in one cycle the first team of students will perform experiment A in week one followed by experiment B in week two, and the other team of students will perform experiment B in week one followed by experiment A in week two.

The course grade is determined from performance on laboratory reports (80%) and performance on a midterm exam (20%). The course will be taught for the first time in the spring 2010 semester.

Progress in the Initial Year

During the first year of the minor, the enrollment in the appropriate courses (described in the preceding sections) are summarized in Table 1 below. Also, the enrollment in courses that have been taught before are summarized in Table 2.

Table 1. Course Enrollments During 2009-2010 Academic Year

Course	Term	Enrollment
Alternative Fuels Group Enterprise	Fall 2009	27
Alternative Fuels Group Enterprise	Spring 2010	25
Fuel Cell Fundamentals	Fall 2009	41
Fuel Cell Technology	Fall 2009	23
Fundamentals of Hydrogen as an Energy Carrier	Fall 2009	27
Hydrogen Measurements Laboratory	Spring 2010	12

Table 2. Course Enrollments During Prior Academic Years

Course → ↓ Year	Alternative Fuels Group Fall / Spring	Fuel Cell Fundamentals Fall Only	Fuel Cell Technology Fall Only
2008-2009	11 / 20	N/A	22
2007-2008	16 / 14	24	25
2006-2007	25 / 25	21	N/A
2005-2006	23 / 40	10	N/A
2004-2005	34 / 35	20	N/A

Conclusions

This paper has described the formation and structure of an interdisciplinary minor in hydrogen technology. The minor requires participation in the Alternative Fuels Group Enterprise and taking courses in fuel cells and hydrogen technology. Student interest in the enterprise project work courses and technical courses has been very positive. It is expected that the first students to receive the minor will graduate in May of 2010.

Acknowledgments

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