Hydrogen Education Curriculum Path at Michigan Technological University

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Overview

Timeline

- Project Start Date: 09/01/2008
- Project End Date: 07/31/2011
- Percent Complete: 25%

Budget

- Total Project Funding $482,244
  - DOE $375,000
  - MTU $107,244
- Funding Received FY08 $166,208
- Funding for FY09 $152,000

Education Barriers Addressed

- Lack of information (A)
- Mixed messages (B)
- Disconnect between information and dissemination (C)

Partners

Michigan Technological University

- Chemical Eng., Mechanical Eng., Electrical Eng., Social Sciences, Keweenaw Research Center

Collaboration with Other National

Institutions

DOE Field Office & Headquarters

Broad Objectives of this Project

- **Task 1.0** *Develop and/or Refine Courses in Hydrogen Technology*
- **Task 2.0** *Develop Curriculum Programs in Hydrogen Technology*
- **Task 3.0** *Develop Modules for Core and Elective Engineering Courses*
- **Task 4.0** *Develop Modules to Supplement Commonly Used Chemical Engineering Texts*
- **Task 5.0** *Project Management and Reporting*

Relevance to DOE Hydrogen Program: Education Objectives

- Expand existing university programs in fuel cell and hydrogen technologies
  - How: Develop new courses and content (Tasks 1, 3, 4)
  - How: Develop hydrogen and fuel cell student projects (Task 2)
  - How: Disseminate to other academic institutions (Task 5)
- Goal: Produce graduates for careers in research, development, and demonstration

Year 1 (FY09) Objectives

- **Subtask 1.1** *Develop Fundamentals of Hydrogen as an Energy Carrier Course*
- **Subtask 1.2** *Develop Hydrogen Measurements Laboratory*
- **Subtask 1.3** *Refine Existing Fuel Cell Courses*
- **Subtask 2.1** *Develop Minor in Hydrogen Technology*
- **Subtask 3.1** *Develop Modules for Chemical Engineering Courses*
- **Subtask 4.1** *Develop Modules to Supplement Introductory Chemical Engineering Text*

Milestones for FY08/FY09

Month/Yr	Milestone
Sept. 08	Students in Alternative Fuels Group Enterprise work on hydrogen projects
Sept. 08	Begin development of modules for chemical engineering courses
Jan. 09	Students in Alternative Fuels Group Enterprise work on hydrogen projects
Jan. 09	Submit proposal for undergraduate minor
Jan. 09	Begin national testing of existing chemical engineering modules

Milestones for FY08/FY09

Month/Yr	Milestone
Jan. 09	Begin development of modules for Felder & Rousseau text
May 09	Begin development of modules for electrical and mechanical engineering courses
May 09	Begin development of new course material
July 09	Refine existing hydrogen courses

Approach: Project

Unique Curriculum Development

Module and Supplement Testing

Michigan Tech
Michigan Technological University

Chem Eng | Mech Eng | Elec Eng

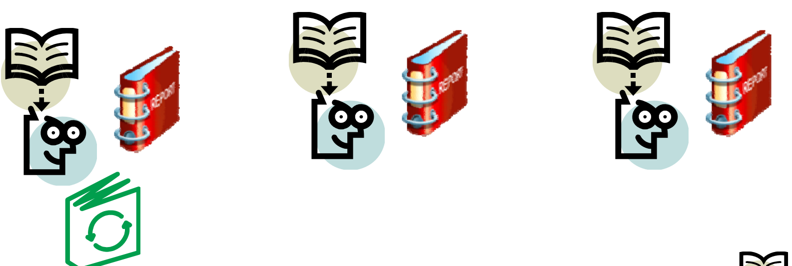
Hydrogen Courses & Curriculum
Modules
Text Supplements

Approach: Broad Impacts

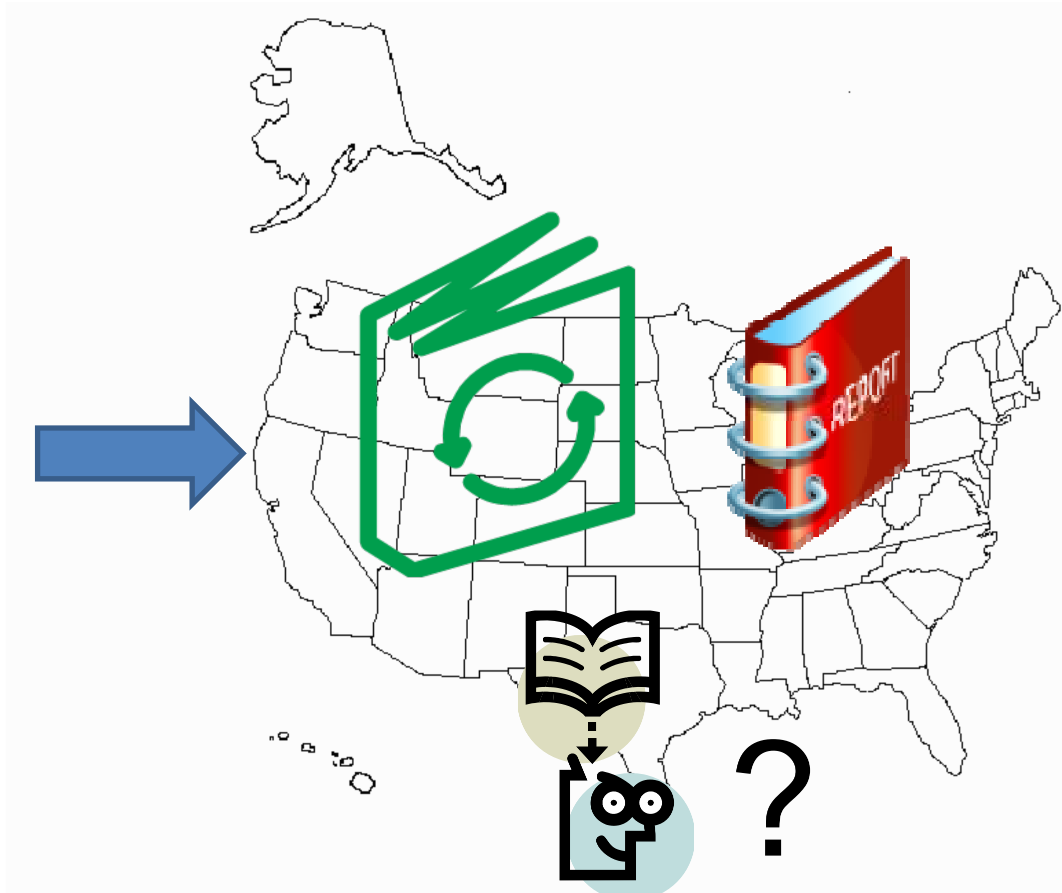
National Dissemination

Michigan Tech
Michigan Technological University

Chem Eng Mech Eng Elec Eng



Hydrogen Courses & Curriculum
Modules
Text Supplements



Technical Accomplishments & Progress: June 08 – May 09

Task 1.0 *Develop and/or Refine Courses in Hydrogen Technology*

- Two new courses proposed and approved:
  - Fundamentals of Hydrogen as an Energy Carrier (Fall 2009)
  - Hydrogen Measurements Laboratory (Spring 2010)
- Two existing fuel cell courses will also be taught (Fall 2009) adding hydrogen economy case studies
- Barriers Addressed: ABC
- Relevance: Provide accurate technical information on hydrogen and fuel cells to students

Technical Accomplishments & Progress: June 08 – May 09

Task 2.0 *Develop Curriculum Programs in Hydrogen Technology*

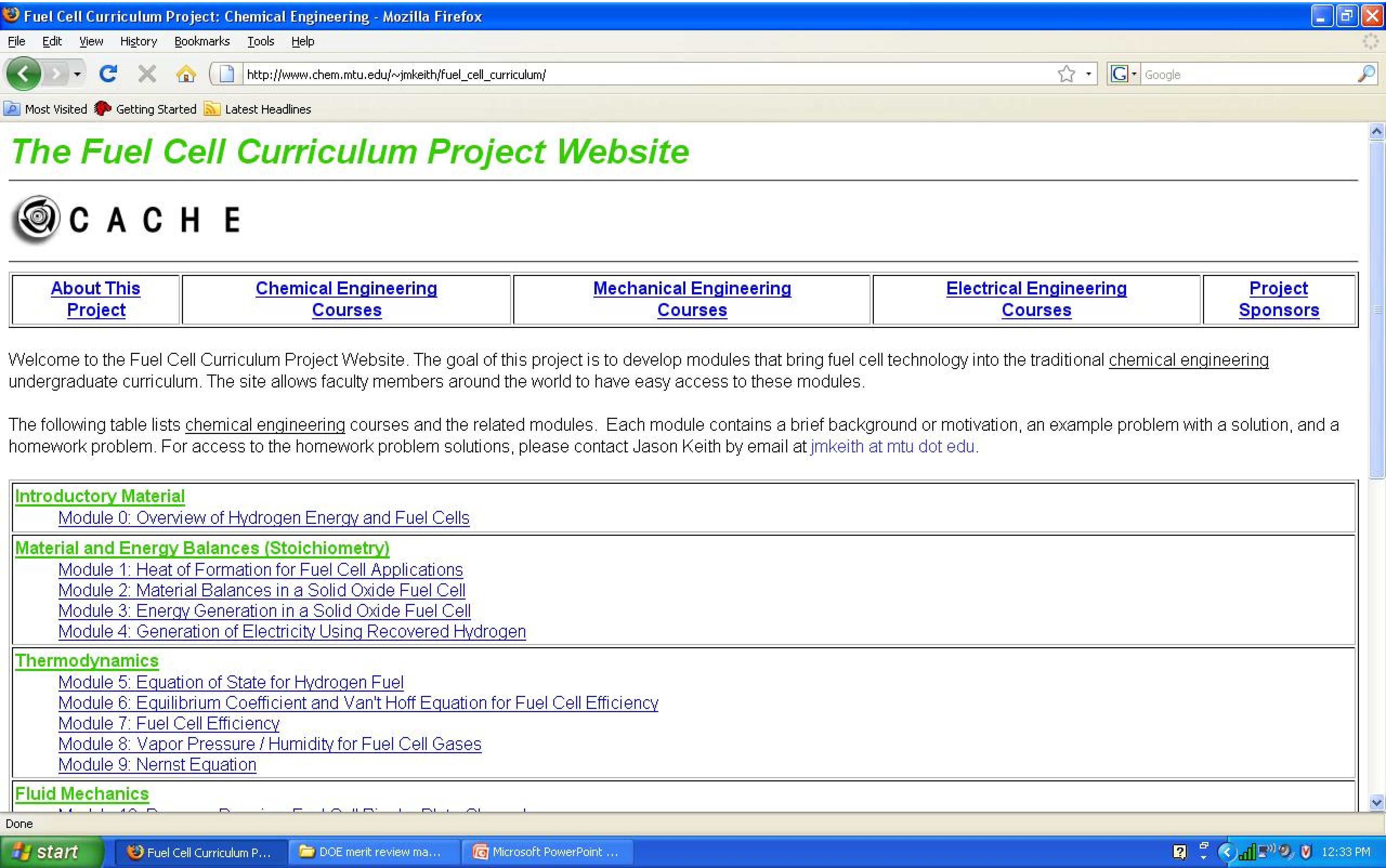
- Integration of hydrogen projects into Alternative Fuels Group project work courses
  - Hands-on project to integrate fuel cells into electric vehicle
  - Paper project to design hydrogen economy at local and regional level
- Hydrogen Technology Minor proposal under review
- Barriers Addressed: ABC
- Relevance: Provide hydrogen / fuel cell experience

Technical Accomplishments & Progress: June 08 – May 09

Task 3.0 *Develop Modules for Core and Elective Engineering Courses*

- Integration of hydrogen / fuel cell technology into core chemical engineering undergraduate courses
  - Stand-alone "module" format includes problem motivation, background, example problem statement and solution, and homework problem
  - Homework solution separate
- Barriers Addressed: ABC
- Relevance: Ease of use by faculty at other institutions

Technical Accomplishments & Progress: June 08 – May 09: Curriculum Website



Technical Accomplishments & Progress: June 08 – May 09: Sample Module

CACHE Modules on Energy in the Curriculum

Fuel Cells
Module 5 (Final Draft): Equation of State for Hydrogen Fuel
Module Author: Jason Keith
Author Affiliation: Michigan Technological University
Module Secondary Author: Michael Gross
Author Affiliation: Bucknell University

Course: Thermodynamics

Text Reference: Sandler (2nd ed.), Section 4.4
Smith, Van Ness, and Abbott (7th ed.), Section 3.5

Concepts: Gas law, equation of state

Problem Motivation:
Fuel cells are a promising alternative energy conversion technology. One type of fuel cell, a proton exchange membrane fuel cell (PEMFC) reacts hydrogen fuel with oxygen to produce electricity. Fundamental to the design of fuel cells is an understanding of nonideal equations of state, as hydrogen fuel is often stored at high pressure. We are interested in determining the impact of the nonideal behavior of the compressed hydrogen has on fuel cell performance. After completing this module, you will be able to size compressed fuel tanks for fuel cell applications. One example of a fuel cell application would be powering a laptop as shown below.

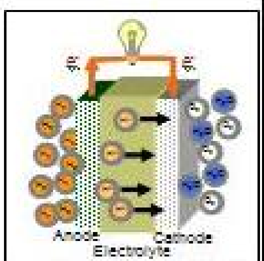


Figure 1. Reactions with PEMFC

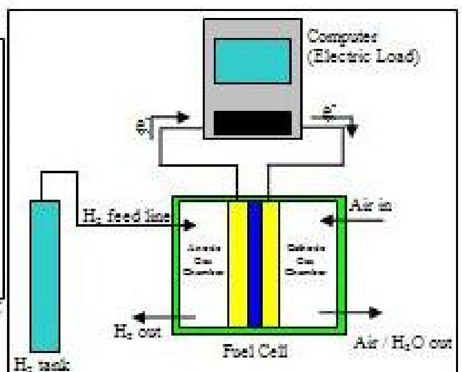


Figure 2. Diagram for Fueling a Laptop

The PEMFC reactions are:

Anode:	$H_2 \rightarrow 2H^+ + 2e^-$	
Cathode:	$\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$	
Overall:	$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$	

For each mole of hydrogen consumed, two moles of electrons are passed through the electric load. To convert electron flow (moles of electrons/s) to electrical current (coulombs/s or amps), one would use Faraday's constant, $F = 96{,}485$ coulombs / mole of electrons. The primary objective of a fuel cell is to deliver energy to the electric load. To calculate the energy delivery rate (also know as power) one would multiply the current times the cell voltage: $Power = Current \cdot Voltage$. (Recall the unit conversions: $Coulomb \cdot Volt = Joule$ and $Joule/s = Watt$).

Problem Information
Example Problem Statement: A gas cartridge contains hydrogen gas at room temperature and 500 psi pressure. This cartridge has been proposed as a fuel tank for a fuel cell powered laptop computer. Note that the volume of the cylinder is 2 L.

a. Determine the number of moles of hydrogen in the tank utilizing the Peng-Robinson equation of state and compare this result with the ideal gas law result, which is 2.78 moles of hydrogen.

b. Calculate and compare the operating time of a laptop running on this cartridge of H_2 using the Peng-Robinson equation of state and the ideal gas law. The laptop requires 35 W of power at 0.7 V.

To solve this problem, note that the Peng-Robinson equation of state is given by:

$$P = \frac{\rho RT}{1-b\rho} - \frac{a\rho^2}{1+2b\rho-b^2\rho^2}$$

where P is the pressure, ρ is the density, R is the gas constant, T is the absolute temperature, and a and b are coefficients for the Peng-Robinson equation of state. They can be calculated knowing the critical temperature T_c and pressure P_c of the gas under pressure, and are given by the following relationships (see, for example, Section 4.7 in Sandler):

$a = a_c \alpha$
$a_c = 0.45724\ R^2 T_c^2 / P_c$
$\alpha = [1 + \kappa(1 - T_r^{1/2})]^2$
$T_r = T / T_c$
$b = 0.07780\ RT_c / P_c$
$\kappa = 0.37464 + 1.54226\ \omega - 0.26993\ \omega^2$.

Note that ω is the acentric factor and relates to the compressibility of the gas (for example, see Table 4.6-1 in Sandler for values of T_c, P_c, and ω).

Technical Accomplishments: June 08 – May 09

Task 4.0 *Develop Modules to Supplement Commonly Used Chemical Engineering Texts*

- Integration of hydrogen / fuel cell technology into most relevant undergraduate chemical engineering courses
  - Introductory Chemical Engineering Course: Felder and Rousseau, *Elementary Principles of Chemical Processes*
  - Progress for Chapters 2-3, >10 problems per chapter
- Barriers Addressed: ABC
- Relevance: Ease of use by faculty at other institutions

Technical Accomplishments: June 08 – May 09

Task 5.0 *Project Management and Reporting*

- 1st quarterly report submitted Jan. 2009
- 2nd quarterly report to be submitted Apr. 2009
- Project dissemination at American Institute of Chemical Engineers annual meeting Nov. 2008
- Project dissemination planned for American Society for Engineering Education Jun. 2009

Listing of National Collaborators

Module Tests: Chemical Engineering Programs

H. Scott Fogler, University of Michigan

Michael Gross, Bucknell University

Don Chmielewski, Illinois Institute of Technology

Pat Walton, Michigan State University

Adrienne Minerick, Mississippi State University

Don Visco, Tennessee Technological University

David Silverstein, University of Kentucky

Kevin Dahm, Rowan University

Claire Komives, San Jose State University

Future Work: Rest of FY09

- Module development: Mechanical Engineering and Electrical Engineering courses
- Course development
  - Fundamentals of Hydrogen as an Energy Carrier course
  - Fuel Cell courses
- Continue module development for Felder & Rousseau supplement

Future Work: FY10

- Continue student projects in Alternative Fuels Group Enterprise
- Teach Fuel Cell courses
- Teach Hydrogen as an Energy Carrier course
- Develop / Teach Hydrogen Lab course
- Test modules
  - Chemical Engineering courses
  - Felder & Rousseau supplement
- Develop modules for Geankoplis supplement
- Submit graduate course proposals

Summary

- This work will help educate students on the advantages, disadvantages, challenges, and opportunities of hydrogen and hydrogen fuel cells within the nation's energy economy
  - Hydrogen Technology Course Development
  - Hands-on Project Work Through Alternative Fuels Group Enterprise
  - Modules developed for chemical engineering courses
  - Modules developed to supplement introductory chemical engineering text
  - National dissemination : American Institute of Chemical Engineers and American Society for Engineering Education

Acknowledgment

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- Thank you for your attention!