# IX.11 Hydrogen Education Curriculum Path at Michigan Technological University

Jason M. Keith (Primary Contact), Dan Crowl, Dave Caspary, Jeff Naber, Jeff Allen, Abhijit Mukherjee, Dennis Meng, John Lukowski, Barry Solomon, Jay Meldrum
Michigan Technological University
1400 Townsend Dr.
Houghton, MI 49931
Phone: (906) 487-2106
E-mail: jmkeith@mtu.edu

DOE Manager
GO: Gregory Kleen
Phone: (720) 356-1672
E-mail: Greg.Kleen@go.doe.gov

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## Fiscal Year (FY) 2011 Objectives

The objectives of this project are to educate university students on the advantages, disadvantages, challenges, and opportunities of hydrogen and hydrogen fuel cells within the United States energy economy. In particular, this project will:

- Develop and/or refine courses in hydrogen technology.
- Develop curriculum programs in hydrogen technology.
- Develop modules for core and elective engineering courses.
- Develop modules to supplement commonly used chemical engineering texts.
- Meet all Department of Energy project management and reporting requirements.

## Technical Barriers

This project addresses the following technical barriers from Education section (3.9) of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Lack of Readily Available, Objective, and Technically Accurate Information

(B) Mixed Messages

(C) Disconnect between Information and Dissemination Networks

## Contribution to Achievement of DOE Education Milestones

This project will contribute to achievement of the following DOE milestones from the Education section (3.9) of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 21:** Launch new university hydrogen education program. (4Q, 2009)

## FY 2011 Accomplishments

The major accomplishments of this project to date are listed as follows:

- We have developed and taught one lecture and one laboratory course in hydrogen energy and two courses in fuel cells.
- Over 40 modules have been developed to introduce students in core chemical engineering courses to hydrogen and fuel cell technology; similar efforts have been accomplished for core mechanical engineering (20 modules) and electrical engineering (6 modules) courses.
- 90 example problems have been created as supplementary material to be used in the sophomore level introductory chemical engineering course.
- Over 70 example problems have been created as supplementary material to be used in the junior level courses in fluid mechanics, heat transfer, and mass transfer fundamentals and their associated unit operations.
- Over the entire project, fifteen oral presentations have been given and seven conference proceedings have been published, with six oral presentations and two conference proceedings during the past year.



## Introduction

There is a strong need for a transformative curriculum to train the next generation of engineers who will help design, construct, and operate fuel cell vehicles and the associated hydrogen fueling infrastructure. In this project, we build upon the project-based, hands-on learning that has been a cornerstone of engineering education at Michigan Technological University (MTU). This teaching and learning style is supported by the engineering education literature which indicates that students learn by doing, particularly through team-based interactive projects with a real-world flavor.

This project has resulted in the formation of an "Interdisciplinary Minor in Hydrogen Technology" at MTU. We focus on student centered design projects, and add additional technical material through elective courses, modules for core courses, and textbook supplements. As a final note, aggressive dissemination of the project results will occur through presentations at the annual meetings of several professional societies.

## Approach

The ultimate goal for the hydrogen education program should be to establish an educational infrastructure and database of hydrogen and fuel cell related educational materials, particularly projects and problem sets. The efforts of this project support this mission.

At MTU, we have embraced the concept of hands-on learning as the cornerstone of a newly approved "Interdisciplinary Minor in Hydrogen Technology." Students that obtain this minor are also required to take newly developed elective courses in fuel cells and hydrogen technology. Focusing on a subset of graduates who choose these options is not enough. In order to reach a wider audience at MTU, modules are being developed for the core curricula in chemical engineering, mechanical engineering, and electrical engineering. Each module stands alone and can be assigned to students as an in-class problem, a homework assignment, or a project. The modules use the fundamental concepts taught within the core course and apply them to hydrogen generation, distribution, storage, or use within a fuel cell. Thus, students are able to see the applications of the fundamentals from their courses. Finally, we are creating supplements to two of the most popular chemical engineering textbooks as another way to introduce hydrogen technology and fuel cells to university students.

The core course modules are to be tested throughout the nation. The results of this curriculum project and testing results are to be disseminated through professional societies in chemical engineering, mechanical engineering, electrical engineering, and engineering education. Course materials, modules, and textbook supplements will be available for use by engineering educators worldwide.

## Results

Results for Task 1.0, Develop and/or Refine Courses in Hydrogen Technology:

- To date, we have created two new courses, "Fundamentals of Hydrogen as an Energy Carrier" to be taught in fall semesters and "Hydrogen Measurements Laboratory" to be taught in spring semesters. We also modified two fuel cell courses. The hydrogen as an energy carrier course and both fuel cell courses were taught during the most recent academic year and were well received by students.

Results for Task 2.0, Develop Curriculum Programs in Hydrogen Technology:

- The "Interdisciplinary Minor in Hydrogen Technology" was approved by the university effective April 2009.
- The "Graduate Certificate in Hybrid and Electric Vehicles" was approved by the university effective May 2010.
- During the 2010-2011 academic year, there were several group projects in the "Alternative Fuels Group" Enterprise. This enterprise consisted of undergraduate students in chemical, mechanical, and electrical engineering, as well as materials science and engineering. Students were in their sophomore, junior, or senior year of study. By participating in the group projects, students earned credit towards their degree and (if desired) towards the new minor mentioned above. Student projects included:
  - Design of methanol production facility for use in direct methanol fuel cell (DMFC) applications (Figures 1 and 2) and analysis of DMFC membrane materials.
  - Integration of Bloom Box solid oxide fuel cells (SOFCs) into the Michigan Technological University electrical grid.

Results for Task 3.0, Develop Modules for Core and Elective Engineering Courses:

- The third task of this project is to develop modules for core courses in chemical, mechanical, and electrical engineering courses. Up to this point, we have developed over 40 chemical engineering modules, 20 mechanical engineering modules, and six electrical engineering modules. It is noted that the modules are available online at: http://www.chem.mtu.edu/~jmkeith/fuel_cell_curriculum/. Plans have been made to test these modules in the classroom at the following institutions: MTU, University of Michigan, Bucknell University, Illinois Institute of Technology, Michigan State University, Mississippi State University, Tennessee Technological University, University of Kentucky, Rowan University, San Jose State University, Oklahoma State University, University of Wyoming, and the University of Texas at Austin. Student feedback at these other institutions has been very positive.

Results for Task 4.0, Develop Modules to Supplement Commonly Used Chemical Engineering Texts:

- We have developed a set of 90 examples to supplement the textbook *Elementary Principles of Chemical Processes* authored by R. M. Felder and R. W. Rousseau and published by Wiley. The problems are organized in "workbook" format where there are blank spaces for students to insert numbers in order to carry out the solutions. It is noted that this textbook is used in the very first chemical engineering undergraduate course

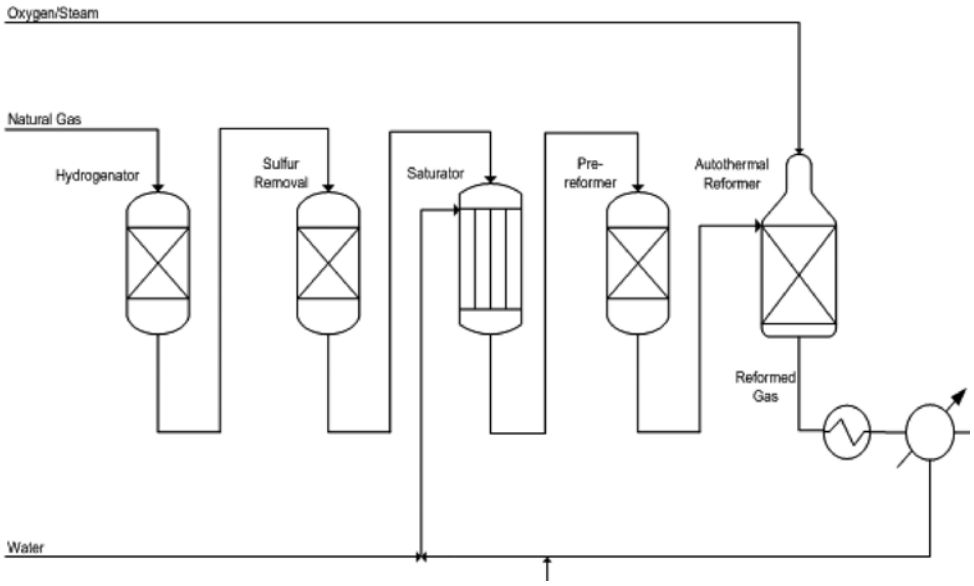


**FIGURE 1.** Process Diagram for Hydrogen Production via Steam Reforming

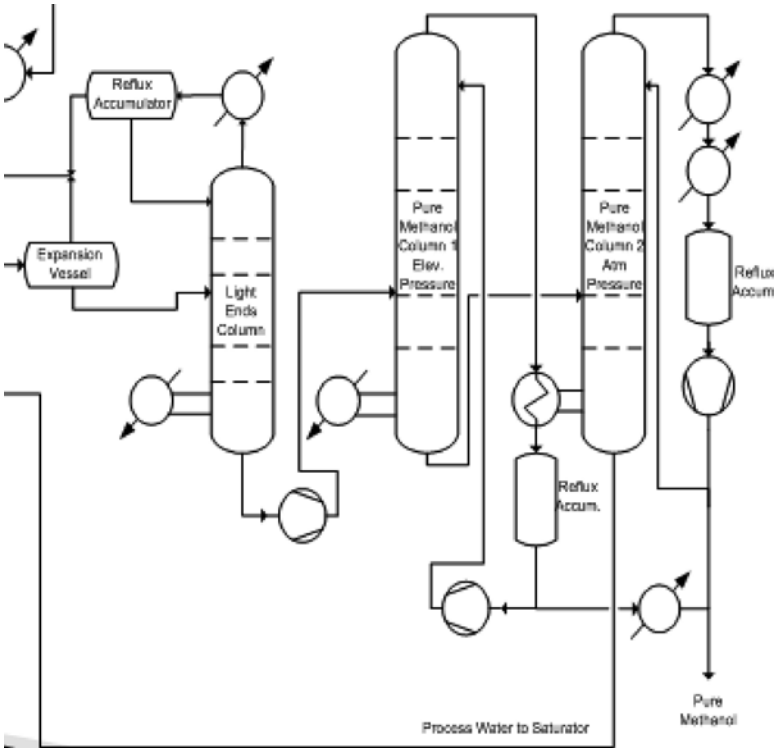


**FIGURE 2.** Process Diagram for Methanol Purification

at most universities in the nation. The main emphasis of the course is on engineering problem solving for chemical engineers. Students learn best by solving a large number of problems. This supplement is intended to meet the student's needs while teaching them about hydrogen technology and fuel cells.

- We have developed a set of over 70 examples to supplement the textbook *Transport Processes and Separation Process Principles* authored by C.J. Geankoplis and published by Prentice Hall. These problems follow the same format as those described above, and can be used to integrate fuel cell and hydrogen production concepts into fluid mechanics, heat transfer, and mass transfer topics and their associated unit operations.

Results for Task 5.0, Project Management and Reporting:

- To date, 10 quarterly reports (out of 12) have been submitted. In addition, a Powerpoint presentation was prepared and an oral presentation was given at the Annual Merit Review.

## Conclusions and Future Directions

The most significant result of this project to date is the approval of a new minor at MTU with title "Interdisciplinary Minor in Hydrogen Technology." The groundwork is in place to teach new courses in hydrogen and fuel cell technology and to introduce these concepts in the core chemical engineering curriculum at MTU.

This project is nearing a close. The remaining modules (Task 3) and reports (Task 5) will be completed by the end of the project.

## FY 2011 Publications/Presentations

**1.** Oral Presentation: J.M. Keith, D.Crowl, D. Caspary, J. Allen, D. Meng, A. Mukherjee, J. Naber, J. Lukowski, J. Meldrum, and B. Solomon, "Hydrogen Curriculum Path at Michigan Technological University," 2011 DOE Hydrogen Program Annual Merit Review, Arlington, VA.

**2.** Web Publication: J.M. Keith, "The Short Term Hydrogen Economy: Fueling Fuel Cells from Natural Gas," Knovel Engineering Cases, 2010.

**3.** Oral Presentation: J.M. Keith, D. Crowl, D. Caspary, J. Allen, D. Meng, A. Mukherjee, J. Naber, J. Lukowski, J. Meldrum, and B. Solomon, "An Interdisciplinary Minor in Hydrogen Technology at Michigan Technological University," 2010 AIChE Annual Meeting, Salt Lake City, UT.

**4.** Oral Presentation: J.M. Keith, T.F. Edger, G.P. Towler, H.S. Fogler, D. Crowl, D. Allen, "Energy Modules for the ChE Curriculum," 2010 AIChE Annual Meeting, Salt Lake City, UT.

**5.** Oral Presentation: D. Lopez Gaxiola and J.M. Keith, "Hydrogen and Fuel Cell Workbook for Material and Energy Balances," 2010 AIChE Annual Meeting, Salt Lake City, UT.

**6.** Oral Presentation and Conference Proceeding: J.M. Keith, D. Lopez Gaxiola, D. Crowl, D. Caspary, D. Meng, J. Naber, J. Allen, A. Mukherjee, J. Lukowski, B. Solomon, J. Meldrum, and T. Edgar, "Development and Assessment of Energy Modules in the Chemical Engineering Curriculum," 2011 ASEE Annual Meeting, Vancouver, BC, Canada.

**7.** Oral Presentation and Conference Proceeding: A. Minerick, J.M. Keith, F. Morrison, M. Tafur, A. Gencoglu, "Connecting Mass and Energy Balances to the Continuum Scale with COMSOL DEMoS," 2011 ASEE Annual Meeting, Vancouver, BC, Canada.