X.5 Hydrogen Education Curriculum Path at Michigan Technological University

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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 the Education section (3.9) of the Hydrogen, Fuel Cells and Infrastructure 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 Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

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

Accomplishments

The accomplishments of this project to date are:

- Two new courses were proposed and approved at Michigan Technological University.
- A minor proposal was approved at Michigan Technological University. Effective April 2009, students can receive an "Interdisciplinary Minor in Hydrogen Technology."
- Nearly two dozen modules were developed to introduce students in core chemical engineering courses to hydrogen and fuel cell technology.
- Example problems have been created as supplementary material to a popular chemical engineering textbook.
- Three oral presentations have been given and one conference proceeding has been published.

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. 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. Work is currently underway to prepare the course material. A fuel cell laboratory apparatus was ordered for the laboratory course. The purchase of other laboratory instruments is underway.

Results for Task 2.0, Develop curriculum programs in hydrogen technology:

- A minor proposal was developed and circulated through the curriculum committees at the department, college, and university levels. The proposal for an "Interdisciplinary Minor in Hydrogen Technology" was approved by the university senate and upper administration. Students can now receive this minor effective April 2009.
- During the 2008-2009 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:
  - Hydrogen Economy at Michigan Technological University
  - Analysis of a Hydrogen Powered John Deere e-Gator (see Figure 1)
  - Design and Economic Analysis of a Fuel Cell/Electric Hybrid Fork Lift
  - Hydrogen Economy for the Upper Peninsula of Michigan (see Figure 2)

FIGURE 1. John Deere e-Gator with Hydrogen Power Plant In Vehicle Bed

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, modules have been developed for chemical engineering courses as part of a collaboration between Jason Keith and other faculty external to Michigan Technological University, who are consultants on this project. It is noted that the modules are available online at: http://www.chem.mtu.edu/~jmkeith/fuel_cell_curriculum/.

Results for Task 4.0, Develop modules to supplement commonly used chemical engineering texts:

- We have developed a set of examples to supplement Chapters 2 and 3 of the textbook *Elementary Principles of Chemical Processes* authored by R. M. Felder and R. W. Rousseau and published by Wiley. Each example has at least two problems. 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 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.

Results for Task 5.0, Project management and reporting:

- To date, three 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 Michigan Technological University 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.

Future work will include the following:

- Future work for Task 1.0, Develop and/or refine courses in hydrogen technology: Order experimental units for use in the hydrogen measurements laboratory course; develop laboratory experiments; teach courses.
- Future work for Task 3.0, Develop modules for core and elective engineering courses: Develop modules for core courses in mechanical engineering and electrical engineering curricula; test chemical engineering modules at MTU and other national universities.
- Future work for Task 4.0, Develop modules to supplement commonly used chemical engineering

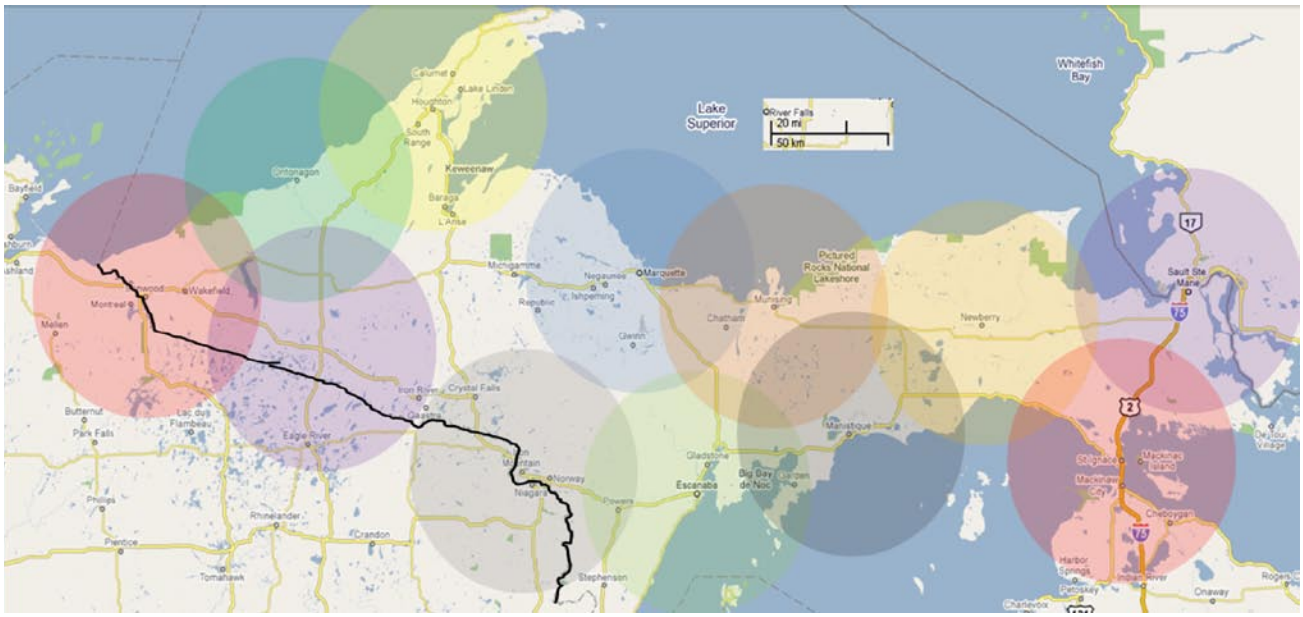

FIGURE 2. Students in the Alternative Fuels Group Enterprise developed this map of Michigan's Upper Peninsula showing optimized locations of twelve hydrogen fueling stations. This result was part of a hydrogen economy project with 10% of total vehicles using hydrogen fuel cells.

texts: Finish supplementary material for Felder & Rousseau textbook; begin supplementary material for Geankoplis textbook (*Transport Processes and Separation Process Principles*, published by Prentice Hall, for junior chemical engineering courses).

- Future work for Task 5.0, Project management and reporting: All quarterly and annual reports will be completed on time.

Special Recognitions & Awards/Patents Issued

1. Jason Keith was named trustee of the CACHE Corporation due to his contributions to the chemical engineering modules.

2. A portion of the material developed on this project was used in a special course MEEM4990 Advanced Propulsion for Hybrid Vehicles, which was offered via distance education to unemployed engineers from the automotive industry during spring semester 2009.

FY 2009 Publications/Presentations

1. Oral Presentation: J.M. Keith, D. Chmielewski, H.S. Fogler, V. Thomas, and M. Gross, "CACHE Module Development for Introducing Energy into the Chemical Engineering Curriculum: Fuel Cells," 2008 American Institute of Chemical Engineers Annual Meeting, Philadelphia, PA.

2. 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," 2009 DOE Vehicle Technologies Program Annual Merit Review, Arlington, VA.

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, "Hydrogen Curriculum at Michigan Technological University," 2009 American Society for Engineering Education Annual Meeting, Austin, TX.

4. Conference Proceedings: J.M. Keith, D. Crowl, D. Caspary, J. Allen, D. Meng, A. Mukherjee, J. Naber, J. Lukowski, J. Meldrum, and B. Solomon, "Hydrogen Curriculum at Michigan Technological University," Proceedings of the 2009 American Society for Engineering Education Annual Meeting & Exposition, Austin, TX.