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## **AC 2011-959: DEVELOPMENT AND ASSESSMENT OF ENERGY MODULES IN THE CHEMICAL ENGINEERING CURRICULUM**

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## Development and Assessment of Energy Modules in the Chemical Engineering Curriculum

### Abstract

As part of a curriculum development project, a set of hydrogen and fuel cell modules has been developed for use in core chemical, mechanical, and electrical engineering courses. These modules have been supplemented with energy modules. The formation of the modules centers about the principle that students learn best by doing. Each module contains an introduction, problem motivation and background, example problem statement, example problem solution, and a homework problem statement. Instructors can obtain the solutions from the lead author by email.

The fuel cell and energy modules have been used at Michigan Technological University in the following manner:

- There is a short lecture on a chemical engineering (or energy) topic
- The students are given a module to serve as an in-class problem
- The students work through the example problem in the module during class
- The students begin solution of the homework problem during class
- The instructor circulates around the room and assists students if they have any questions
- The homework problem is due at a future class meeting

There are also alternative ways to use the modules, such as being given them for out of class assignments, which was often the case when the modules were tested at other institutions.

In this paper we report on the development, testing, and assessment of these modules and report future directions.

### Objectives and Motivation

Research and development in alternative energy sources has received great attention in the last few years, beginning with the January 2003 State of the Union address by President George W. Bush, in which he described federal funding efforts for hydrogen fuel cell research for passenger vehicles. Shortly following that announcement, similar announcements were made by state governors, particularly in automotive industry focused states such as Michigan.

The development of the fuel cell funding came about with the Energy Policy Act of 2005 which was passed by the 109<sup>th</sup> Congress<sup>1</sup> as Public Law 109-58. This bill contained the Spark M. Matsunaga Hydrogen Act of 2005 (cf Sections 801-816)<sup>1</sup>. 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 Plan<sup>2</sup>.

Michigan Technological University is funded from a grant proposal related to 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<sup>3</sup>.

### Hydrogen as an Energy Carrier Course and Module Assignments

One aspect of this program is the teaching of an elective course titled Fundamentals of Hydrogen as an Energy Carrier (1 semester credit hour). In this course, mostly undergraduate students are introduced to different energy sources. To align with Department of Energy program goals, the course also describes methods to produce hydrogen from these different energy sources. 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, and again in the fall 2010 semester, include (with homework assignment also listed):

- Week 1: History of energy production (Energy Consumption Analysis module)
- Week 2: Energy sources and emissions (Energy Emissions Analysis module)
- Week 3: Electric and hybrid vehicles (Battery Energy Analysis module)
- Week 4: Fuel cells and fuel cell vehicles (Battery / Fuel Cell Vehicle Range module)
- Week 5: Energy / Hydrogen from natural gas: steam reforming (Equilibrium Simulation of a Methane Steam Reformer module)
- Week 6: In-class quiz
- Week 7: Energy / Hydrogen from natural gas: separations (Hydrogen Purification module)
- Week 8: Energy / Hydrogen from coal (Coal Gasification problem)
- Week 9: Energy / Hydrogen from biomass (Biomass Gasification problem)
- Week 10: Energy / Hydrogen from electrolysis / wind (Wind Energy problem)
- Week 11: Energy / Hydrogen from solar (Solar Panel Design problem)
- Week 12: In-class quiz
- Week 13: Energy / Hydrogen from nuclear (no problem)
- Week 14: Hydrogen public policy (no problem)

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

## Module Design

We have reported on the development of fuel cell modules at a prior ASEE conference<sup>4</sup>. As a point of reference, online modules can be found at the bioengineering educational materials bank<sup>5</sup>: (<http://www.bioemb.net>) the materials digital library pathway<sup>6</sup>: (<http://matdl.org>), the Massachusetts Institute of Technology open courseware site<sup>7</sup> (<http://ocw.mit.edu>), and the Multimedia Educational Resource for Learning and Online Teaching site<sup>8</sup> (<http://www.merlot.org>).

To be most effective in teaching the students, each module is designed to contain a problem motivation, example problem statement, example problem solution, home problem statement, and home problem solution (the solutions are kept secure and any faculty wishing to obtain solutions should contact the lead author of this paper). The modules also list the chemical engineering course that the problem can be used in and the most pertinent sections of chemical engineering textbooks to suggest to instructors when to use the problems. The fuel cell modules are currently online at the following site<sup>9</sup>: [http://www.chem.mtu.edu/~jmkeith/fuel\\_cell\\_curriculum/](http://www.chem.mtu.edu/~jmkeith/fuel_cell_curriculum/).

The modules can be quickly downloaded and used in any chemical engineering undergraduate course. At Michigan Technological University, we have used the modules in the following manner:

- There is a short lecture on a chemical engineering (or energy) topic
- The students are given a module to serve as an in-class problem
- The students work through the example problem in the module during class
- The students begin solution of the homework problem during class
- The instructor circulates around the room and assists students if they have any questions
- The homework problem is due at a future class meeting

In a later section, we will show assessment results on this strategy. Other forms of using the modules include providing only the example problem statement (as either an in-class or homework problem), providing only the homework problem statement (as either an in-class or homework problem), and providing the entire module (which does not include the homework problem solution) to the students to work on outside of class.

In addition, we are in the process of developing modules with a broader energy emphasis. This project is co-sponsored by the CACHE Corporation<sup>10</sup> and the AIChE Center for Energy Initiatives<sup>11</sup>, with J. Keith as project leader. Current modules are available at the following site<sup>12</sup>: <http://www.chem.mtu.edu/~jmkeith/energy/>.

As of January 2011, there are eleven modules for general energy analysis (as used in weeks 1-4 of the Hydrogen as an Energy Carrier Course). Additional modules are to be developed in wind energy, water energy, solar energy, biomass energy, and coal energy. Some of the modules will replace existing homework assignments (see week 8 – 11 of

the course outline in a prior section of this paper). There is an example module shown in the appendix at the end of this paper.

### Preliminary Assessment

During fall of 2010, fifteen students enrolled in the Fundamentals of Hydrogen as an Energy Carrier course at Michigan Technological University. There were ten homework assignments for this course. In six of these assignments, the full module was given (with the exception of the home problem solution). In four of the homework assignments, only a problem statement was provided. The rationale behind assigning the problem only was to assess the value of providing an example problem and solution.

Institutional Review Board approval was granted (MTU protocol # M0277, Hydrogen Education at Michigan Technological University) to use human subjects in the classroom. A survey instrument was developed and distributed during the final class meeting. Participation in the survey was voluntary. Twelve students participated out of an enrollment of fifteen students. The questions on the survey and survey results, which were very positive, are summarized below.

1. I felt that the instructional material helped facilitate my learning.

Strongly Agree	Agree	Ambivalent	Disagree	Strongly Disagree
7 responses	5 responses	0 responses	0 responses	0 responses

2. I felt that the lecture showed me how to apply engineering principles to alternative energy / hydrogen technology systems.

Strongly Agree	Agree	Ambivalent	Disagree	Strongly Disagree
7 responses	5 responses	0 responses	0 responses	0 responses

3. I felt that the homework problems allowed me to apply my engineering principles to alternative energy / hydrogen technology systems.

Strongly Agree	Agree	Ambivalent	Disagree	Strongly Disagree
7 responses	5 responses	0 responses	0 responses	0 responses

4. Please provide any additional comments you may have on this course and/or the instructional modules:

#### Sample responses:

- “The modules allowed us to understand the problems being asked. They provided examples for how to complete the problem without giving away the answers.”
- “I liked how the h.w. assignments were set up as real-world problems so we could see how this would / is actually applied.”
- “Although interesting, they were easy and failed to engage me.”

Overall, the students seem to enjoy the course content and teaching methods, including homework problem assignment.

In addition, Institutional Review Board approval was granted (MTU protocol # M0639, Energy Knowledge Survey) to use human subjects in the classroom. A pre-test survey instrument was developed and distributed during the first class meeting, and a post-test survey (identical to the pre-test survey) was distributed during the final class meeting. Participation in the survey was voluntary. Fourteen students participated in the pre-test and ten students participated in the post-test, out of an enrollment of fifteen students. The questions on the survey and survey results are summarized below. The first five questions came from the tenth national report card survey on energy knowledge<sup>13</sup>.

1. How is most electricity in the United States generated? Is it...
  - a. By burning oil, coal, and wood                      Correct Answer; Pretest 71%, Posttest 100%
  - b. With nuclear power                                      Pretest 14%, Posttest 0%
  - c. Through solar energy, or                                Pretest 0%, Posttest 0%
  - d. At hydro electric power plants?                      Pretest 14%, Posttest 0%
  - e. Don't know    Pretest 0%, Posttest 0%
  
2. Which of the following uses the most energy in the average home? Is it...
  - a. Lighting rooms    Pretest 0%, Posttest 10%
  - b. Heating water    Pretest 21%, Posttest 0%
  - c. Heating and cooling rooms, or                          Correct Answer; Pretest 64%, Posttest 90%
  - d. Refrigerating food?                                      Pretest 7%, Posttest 0%
  - e. Don't know    Pretest 7%, Posttest 0%
  
3. Which fuel is used to generate the most energy in the U.S. each year? Is it...
  - a. Petroleum    Correct Answer; Pretest 21%, Posttest 50%
  - b. Coal    Pretest 43%, Posttest 40%
  - c. Natural gas, or    Pretest 7%, Posttest 10%
  - d. Nuclear?    Pretest 14%, Posttest 0%
  - e. Don't know    Pretest 14%, Posttest 0%
  
4. Though the U.S. has only four percent of the world's population, what percentage of the world's energy does it consume? Is it...
  - a. 5 percent    Pretest 0%, Posttest 0%
  - b. 15 percent    Pretest 21%, Posttest 10%
  - c. 20 percent, or    Pretest 43%, Posttest 30%
  - d. 25 percent?    Correct Answer; Pretest 14%, Posttest 60%
  - e. Don't know    Pretest 21%, Posttest 0%
  
5. In the past ten years, has the average miles per gallon of gasoline used by vehicles in the U.S. ...
  - a. Increased    Pretest 71%, Posttest 90%
  - b. Remained the same                                      Pretest 7%, Posttest 0%

- |                      |  |
|----------------------|--|
| c. Gone down, or     | Correct Answer; Pretest 14%, Posttest 0% |
| d. Not been tracked? | Pretest 0%, Posttest 0%                  |
| e. Don't know        | Pretest 7%, Posttest 10%                 |

Please also show any work for the following questions:

1. Estimate the pounds of carbon dioxide emissions per gallon of gasoline.
 

a. 2	Pretest 21%, Posttest 10%
b. 3	Pretest 7%, Posttest 40%
c. 20	Correct Answer; Pretest 14%, Posttest 10%
d. 200	Pretest 14%, Posttest 20%
e. Don't know	Pretest 57%, Posttest 20%
  
2. How many kg of hydrogen are needed to provide the same amount of energy as one gallon of gasoline?
 

a. 0.5	Pretest 14%, Posttest 10%
b. 1	Correct Answer; Pretest 21%, Posttest 30%
c. 2	Pretest 7%, Posttest 10%
d. 5	Pretest 14%, Posttest 30%
e. Don't know	Pretest 43%, Posttest 20%
  
3. During a 10 hour period (8am – 6pm) what is the incident solar energy over a 50 m<sup>2</sup> collection area in kW-hr in the US Southwest?
 

a. 50	Pretest 7%, Posttest 10%
b. 100	Pretest 7%, Posttest 0%
c. 200	Pretest 7%, Posttest 20%
d. 300	Correct Answer; Pretest 14%, Posttest 30%
e. Don't know	Pretest 64%, Posttest 40%
  
4. Power from the wind is proportional to the wind speed raised to what exponent?
 

a. 1/2	Pretest 36%, Posttest 20%
b. 1	Pretest 0%, Posttest 0%
c. 2	Pretest 14%, Posttest 50%
d. 3	Correct Answer; Pretest 0%, Posttest 20%
e. Don't know	Pretest 50%, Posttest 10%

The energy report<sup>13</sup> lists national averages for correct answers on the first five questions of this survey are 36%, 66%, 36%, 50%, and 17%, respectively. Therefore, the students taking the pretest did better than the national average on one question, average on two questions, and below average on two questions. When the students took the posttest, they were above average on four of the five questions. The only one that was below average was for the fifth question on fuel economy. This is likely due to class discussions on improvements in internal combustion engine operation and aftertreatment.

The last four questions on the quiz were based upon course content. It was expected students would have no knowledge prior to the pretest and some knowledge for the

posttest. There are two observations to be made on these questions. First of all, the students did not show much improvement in obtaining the correct answer from taking the course. Also, on the pretest there was a higher fraction of students answering “Don’t know.” By taking the course, the students felt more confident in providing an answer. However, it is noted that the students did not show any work for any of the problems. Rather, they just guessed. Next year’s version of the survey will be open ended problems asking the students for a numerical answer.

## Conclusions and Future Directions

This paper has described modules to introduce energy technology into the undergraduate chemical engineering curriculum. Each module contains a problem motivation, example problem statement, example problem solution, home problem statement, and home problem solution. Preliminary assessment of the modules indicates that students enjoy using the modules. They also performed well both years that the class has been offered. Two sets of student surveys were generated. Students enjoyed learning the course material in the module format. A pretest and posttest indicated that they gained general energy knowledge from the course, but still struggled with some concepts. Two of the concepts (solar energy and wind energy) did not have a related module, but only a homework problem. The survey will be modified in the future to have short, open -ended energy questions, to better discern any improvement.

## Acknowledgments

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**CACHE / AIChE Modules on Energy in the Curriculum**

**Module Title:** Battery / Fuel Cell Vehicle Range

**Module Author:** Jason Keith

**Author Affiliation:** Michigan Technological University

**Concepts:** Energy usage for transportation

**Problem Motivation:** The availability of energy has become an important part of our society. In this and related problems, we will discuss issues of energy consumption, energy reserves, and energy related emissions. Furthermore, we will analyze conventional and alternative energy systems. A particular emphasis will be placed on the generation of hydrogen for use in fuel cells for transportation and/or stationary applications.

**Problem Information**

**Example Problem Statement:** Consider a fuel cell / battery hybrid system. The fuel cell has 400 cells and the electric motor operates at 300 V.

- a) The vehicle consumes 2.1 kW power from the battery alone at 20 miles per hour. If the battery has 1.1 kW-hr of energy storage, determine the driving range in miles.
- b) The vehicle consumes 15 kW power from the fuel cell alone at 60 miles per hour. If the vehicle carries 4 kg hydrogen, determine the driving range in miles.

**Example Problem Solution:**

- a. Battery energy ( $E$ , in kW-hr) is equal to the product of operation time ( $t$ , hr) and power consumption rate ( $P$ , kW):

$$E = Pt \tag{1}$$

As such, the time of operation is given as:

$$t = \frac{1.1 \text{ kW-hr}}{2.1 \text{ kW}} = 0.52 \text{ hr}$$

The driving range ( $R$ , mi) is equal to the product of the speed ( $v$ , mph) and the operation time ( $t$ , hr):

$$R = vt \tag{2}$$

From which the driving range can be calculated as:

$$R = (20 \text{ mph})(0.52 \text{ hr}) = 10.5 \text{ mi}$$

- b. For a fuel cell, we first need to relate the power consumption and the voltage to the current flow. The current flow will then be related to the hydrogen consumption rate. Once this is known, the vehicle range can be determined.

The current ( $I$ , A) is equal to the power ( $P$ , W) divided by the voltage ( $V$ , V):

$$I = \frac{P}{V} \quad (3)$$

Thus,

$$I = \frac{15 \text{ kW}}{1 \text{ kW}} \frac{1000 \text{ W}}{300 \text{ V}} = 50 \text{ A}$$

For a hydrogen fuel cell, the current can be used to determine the hydrogen consumption rate ( $\xi_{\text{H}_2}$ , mol/s), the number of cells ( $N$ ), and Faraday's constant ( $F = 96485 \text{ C/mol e}^-$ ):

$$\xi_{\text{H}_2} = \frac{IN}{2F} \quad (4)$$

Note that in this equation, 2 represents that for every mole of hydrogen fuel ( $\text{H}_2$ ) there are 2 moles of electrons produced (from the anode reaction  $\text{H}_2 \rightarrow 2 \text{H}^+ + 2\text{e}^-$ ).

Thus,

$$\xi_{\text{H}_2} = \frac{50 \text{ A}}{2 \text{ mol e}^-} \frac{400 \text{ cells}}{96485 \text{ C}} \frac{\text{C/s}}{\text{A}} = 0.104 \frac{\text{mol H}_2}{\text{s}}$$

The molecular weight ( $M = 2 \text{ g/mol}$ ) can be used to give the hydrogen consumption rate as:

$$\dot{m}_{\text{H}_2} = M \xi_{\text{H}_2} = 0.207 \frac{\text{g H}_2}{\text{s}}$$

Next, the total hydrogen supply ( $M_{\text{tank}}$ , g) can be used to determine the total operation time for the fuel cell ( $t_{\text{fuelcell}}$ , s).

$$t_{\text{fuelcell}} = \frac{M_{\text{tank}}}{\dot{m}_{\text{H}_2}} \quad (5)$$

Since the problem statement gives the hydrogen supply as 4 kg, we must first convert to 4000 g to have consistent units. Thus,

$$t_{\text{fuelcell}} = \frac{4000 \text{ g}}{0.207 \frac{\text{g}}{\text{s}}} = 19300 \text{ s} = 5.36 \text{ hr}$$

Finally, we can use equation 2 to determine the range:

$$R = (60 \text{ mph})(5.36 \text{ hr}) = 320 \text{ mi}$$

**Home Problem Statement:** Consider a fuel cell / battery hybrid system. The fuel cell has 375 cells and the electric motor operates at 300 V.

- a) The vehicle consumes 3 kW power from the battery alone at 35 miles per hour, traveling 50 miles. If the total energy in the battery is 16 kW-hr (as it is in the Chevy Volt), determine the fraction of the available energy in the battery that is consumed. Note that it is typical that only a fraction of the battery energy is used to allow for thousands of charge/discharge cycles.
- b) The vehicle consumes 10 kW power from the fuel cell alone for 4 hours at 40 miles per hour. Determine the fuel economy of the vehicle in miles per kg hydrogen.

For the solution, please contact the lead author of this paper.