X.7 Development of a Renewable Hydrogen Production and Fuel Cell Education Program

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Objectives

The objective of this project is to develop a comprehensive university-level education program that will:

- Provide exposure to the basics of hydrogen-based technologies to a large number of students. This exposure will provide a level of training that will allow students to converse and work with other scientists and engineers in this field. It will also serve to spark a level of interest in a subset of students who will then continue with more advanced coursework and/or research.
- Provide a "mid-level" training to a moderate level of students. More detailed and directed education will provide students with the ability to work to support industry and government development of hydrogen technologies. This level of training would be sufficient to work in the industry, but not be a leader in research and development.
- Provide detailed training to a smaller subset of students with a strong interest and propensity to make significant contributions to the technology development. These individuals will have extensive hands-on experience through internships that will allow them to play a major role in industry, government, and academia.

For the purposes of this grant, the terms hydrogen-based technologies, hydrogen energy and hydrogen education are used broadly to include the production, transport, storage, and utilization of hydrogen. This includes both electrolysis and fuel cell applications.

Technical Barriers

This project addresses the following technical barriers from the 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 Hydrogen Information and Dissemination Networks
(D) Lack of Educated Trainers and Training Opportunities

Contribution to Achievement of DOE Education Milestones

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

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

Accomplishments

- Case studies targeting 1) freshman introductory engineering courses, 2) chemical engineering mass and energy balances, and 3) chemical engineering thermodynamics have been implemented into the undergraduate curriculum.
- The course content in EE 522-Renewable Energy Systems was modified to increase the content related to fuel cells and electrolysis. A new course, Hydrogen Production and Storage was developed and taught. Approximately 60 students per semester enroll in these two courses.

Two undergraduate students have been placed for internships as the Energy & Environmental Research Center's (EERC's) National Center for Hydrogen Technology. One intern from last year is now employed there. Two interns have been placed at Oak Ridge National Laboratory.

- Three new experimental setups were designed and implemented into chemical and electrical engineering undergraduate laboratories.
- Two senior design projects were completed focused on various aspects of hydrogen production.
- The student organization, PowerOn developed experiments that will be incorporated into a mobile laboratory that are being presented to middle schools as a part of a program to stimulate interest in science, technology, engineering, and mathematics areas.

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Introduction

The basic concept of the project is to introduce hydrogen education to a broad distribution of students through the use of structured case studies and experiments that are built into the students' required coursework. This guarantees that all undergraduate students will be exposed to the technologies. This level of exposure should generate interest in a subset of these students who would then be interested in taking full semester courses related to hydrogen technologies. This will provide a significant cohort of students that will have a good understanding of the basics making them candidates for entry level jobs in hydrogen-related industries. A smaller subset of these students showing strong interest and aptitude will participate in directed research and internships to produce Bachelor of Science, Master of Science and Doctorate graduates that will play a major role in the future development of the hydrogen technology. UND's distance education experience will be used to reach a large and widely dispersed group of students.

Approach

UND is taking advantage of existing infrastructure and programs to provide a comprehensive renewable hydrogen production and fuel cell education program. This program is comprehensive from the standpoint of the level and number of students that will be involved in the program. It is designed to provide multi-discipline formal training to both undergraduate and graduate level engineers and scientists. This will be accomplished by developing case studies that will be implemented into classes through all four years of the undergraduate curriculum. These case studies will be broadly disseminated though the National Center for Case Studies in Science Teaching Web site making them available to any school in the United States. Two new classes will be generated that will be offered as technical electives at the undergraduate and graduate level. In addition to our on-campus students, the undergraduate class will also be offered though our Distance Education Degree Program (DEDP) to provide access to hundreds of off-campus students across the country and other nations. UND's DEDP program is the nation's only ABET (formerly the Accreditation Board for Engineering and Technology) Engineering Accreditation Commission accredited undergraduate engineering program. Several new hydrogen-related student experiments will be added to our undergraduate laboratory sequence to provide hands-on experience for our students. Additional hands-on experience will be available to selected students through our on-going research at UND, and through summer intern programs to be established with the National Renewable Energy Laboratory (NREL) and Distributed Energy Systems (designer and manufacturer of proton exchange membrane [PEM] hydrogen production systems). UND will develop a hydrogen seminar, bringing in experts in the field from NREL and Distributed Energy Systems to present to UND students. Internships and research opportunities are also available for students at UND EERC.

This program is designed to provide an introduction of hydrogen energy to a large number of students, both on and off the UND campus through the case studies and student laboratories. It will provide more detailed training on the topic to a smaller, but still significant group of students through two new courses that will be added to our curriculum and offered through our distance program. In-depth training will be provided to a select group of undergraduate and graduate students through in-house research and internships with the EERC, NREL, and Distributed Energy Systems. We feel this approach will provide high quality students with the exposure of hydrogen energy required to support research, development, and demonstration activities in the government, industry and academia sectors.

Results

The first in a series of case studies developed for this program were implemented in the freshman Introduction to Chemical Engineering course this spring. The intent is to introduce students to the basics of a fuel cell and its importance and relative place in helping the U.S. meet its future energy needs. This case study will also be used to demonstrate the interactions between electrochemistry and chemical, electrical, and mechanical engineering required to fully develop and deploy fuel cell technology. Other case studies developed for courses such as Chemical Engineering Fundamentals, and Thermodynamics will focus on technical aspects of hydrogen production and use.

A course entitled Hydrogen Production and Storage was developed was taught during the fall semester. The course was being recorded and can be uploaded at a later date in the UND or DOE Web site.

Two new series of laboratory experiments have been developed and implemented into the undergraduate curriculum using new experimental setups purchased from Heliocentris though the support of the DOE. The HP 600 includes a 600 watt water-cooled PEM fuel cell stack, a direct current (DC)/DC and DC/alternating current (AC) converter, metal hydride storage kit, electric load, and an integrated control system. The off-grid instructor includes a 40 watt fuel cell with integrated microprocessor, electronic load, metal hydride storage, and the constructor kit. A Masters student developed the set of laboratories that are being implemented into the undergraduate curriculum during the 2009-2010 academic year.

In addition to performing the basic experiments to generate current-voltage (IV) and power curves, an experiment was added to record individual cell responses to increases in load current. Ambient temperature (approximately 26°C versus stack temperature of approximately 40 degrees) impacts the performance of the outer cells, and therefore, the overall performance of the stack. However, it is assumed that the effect is minimal. Examining the performance of individual cells can help explain the overall behavior of the stack and is a good introduction for student investigation into the more complex reactions occurring in each cell (see Figure 1).

A second set of experiments was developed to demonstrate the effectiveness of the fuel cell as a power source under varying load conditions. Students begin by generating the typical IV curve and power curve to develop an understanding of efficiency as a function of load. Dynamic load tests show the students the lag time between a change in load and the response of the fuel cell. For electrical engineering labs, this can be futher utilized to develop equivalent circuits and to study the time constants related to a dynamic system. Typical results are shown in Figure 2.

ABET requires institutions of higher education to demonstrate that their students achieve a number of program outcomes. Several of these outcomes and objectives address the need for engineers who can apply knowledge from the classroom to real-world problems. The use of hands-on experiments designed to encourage student exploration is one of the ways UND prepares students to be successful engineers. Hands-on experiential learning allows students to supplement their classroom background with actual results and to improve critical thinking skills by developing and solving research problems of their own design. Details of these student laboratories were presented at the 2010 summer meeting of the American Society of Engineering Education.

Two senior design projects were completed. One senior design group from chemical engineering chose to design a process that utilizes a waste gas stream from a biomass to fuel processing plant to produce hydrogen. The waste stream contained small amounts of hydrogen, methane, ethane, propane, with a larger amount of CO

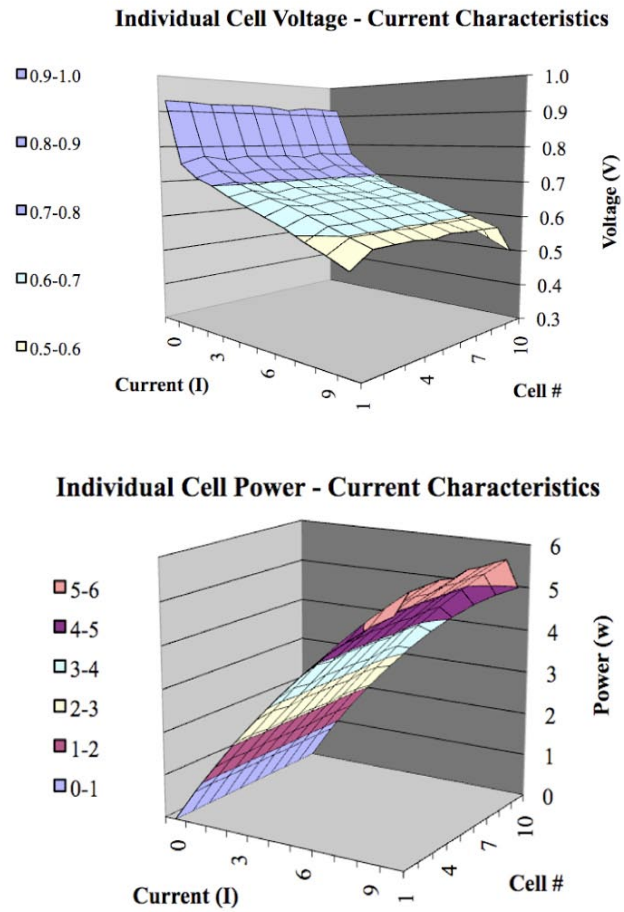

FIGURE 1. Characteristic IV and Power Curves Developed During the Lab for Individual Cells

and the balance of nitrogen and CO_2. Using a steam reforming and high and low shift reactors followed by a Benfield separation plant, the group demonstrated that the process is technically and economically feasible. The group showed that this utilizing this waste stream as a source of hydrogen was technically feasible, and economically feasible (depending upon the assumptions made for the price of hydrogen). A senior design project in Electrical Engineering involved developing a lab-scale electrolyzer system that can be used as a teaching tool, or in applications requiring small hydrogen flows.

Conclusions and Future Directions

To date this project has impacted approximately 120 students, primarily through the classroom and laboratory experiences. When fully implemented, it is expected that approximately 200 students per year will be exposed to case studies and laboratories at UND. A group of approximately 10 students have been fully immersed in hydrogen technology through the capstone design experience.

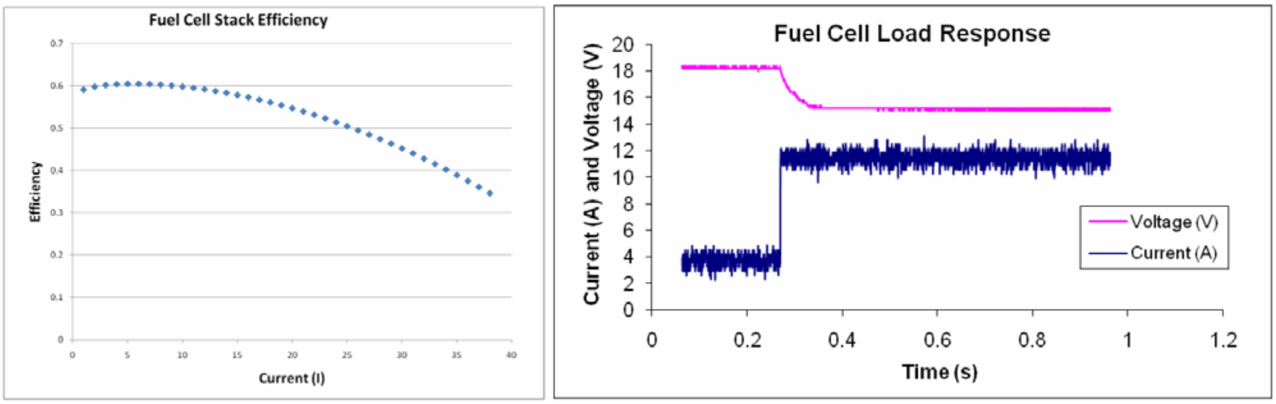

FIGURE 2. Results from Experiments to Demonstrate the Effects of Load Change

During the next year work will continue on development of additional case studies. The case studies will be published to provide national access. Additional experiments and demonstrations will be developed for the new equipment. Recruitment and placement of additional internships will be undertaken. Efforts will be made to bring in an outside speaker for the hydrogen seminar.

Special Recognitions & Awards

1. The paper, "National Hydrogen and Fuel Cell Education Program Part I: Curriculum" received a Best Paper Award at the 2010 American Society for Engineering Education Annual Conference and Exposition.

FY 2010 Publications/Presentations

1. Development of a Renewable Hydrogen Production and Fuel Cell Education Program presented at the 2010 U.S. DOE Hydrogen Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting.

2. Blekhman, D., J. Keith, A. Sleiti, E. Cashman, P. Lehman, R. Engel, M. Mann, and H. Salehfar, 2010, "National Hydrogen and Fuel Cell Education Program Part I: Curriculum," ASEE Annual Conference & Exposition, Louisville, KY.

3. Blekhman, D., J. Keith, A. Sleiti, E. Cashman, P. Lehman, R. Engel, M. Mann, and H. Salehfar, 2010, "National Hydrogen and Fuel Cell Education Program Part II: Laboratory Practicum," ASEE Annual Conference & Exposition, Louisville, KY.

4. Goldade, J., T. Haagenson, H. Salehfar, and M. Mann, 2010, "Design of A Laboratory Experiment to Measure Fuel Cell Stack Efficiency and Load Response," ASEE Annual Conference & Exposition, Louisville, KY.