IX.13 Development of a Renewable Hydrogen Production and Fuel Cell Education Program

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Contract Number: DE-FG36-08GO18110

Project Start Date: August 30, 2008
Project End Date: September 1, 2011

Fiscal Year (FY) 2011 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 2009 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 2009 Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

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

FY 2011 Accomplishments

There were seven tasks in this project. Major accomplishments include:

- Task 1 – Case Study Development: Case studies were developed and implemented into the undergraduate curriculum. The most successful of these case studies were presented for publication in the National Science Foundation (NSF) National Center for Case Study Teaching in Science.
- Task 2 – Development of New Courses: A new course, Hydrogen Production and Storage was developed. The content of our Renewable Energy Systems course was modified to highlight fuel cells and electrolysis and Fuels Technology was modified to highlight hydrogen production technologies. All courses were taught simultaneously to undergraduate, graduate and distance students
- Task 3 – Laboratory Experiments in Hydrogen: Experiments were developed for undergraduate chemical and electrical engineering laboratory classes. The experiments are accomplished using three sets of equipment – a single-cell electrolzer/fuel cell combination, a 40-watt fuel cell system, and a 600 watt fuel cell system. A set of experiments was designed to demonstration fuel cell membrane design, construction and testing.

- Task 4 – MS/PhD Teaching Experience: Doctoral (PhD) and Masters of Science (MS) students developed laboratory experiments, provided input for case studies, and participated in summer outreach programs for undergraduate students.
- Task 5 – Summer Internship: The project helped place summer interns at the National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory, and the DOE National Center for Hydrogen Technology.
- Task 6 – Hydrogen Seminary Series: Students were exposed to various aspects of hydrogen technology through a series of seminars that were offered each semester. Students were provided with the opportunity to attend the annual UND Energy & Environmental Research Center Hydrogen Summit.
- Task 7 – Develop Modules for PowerOn!: PowerOn provides hands on demonstrations for students in grades 4-9. A special topics class engaged students in the development and presentation of these modules.

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 in the program 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, MS, and PhD 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 website 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 EAC 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 summer intern programs to be established with NREL and Proton Energy Systems (designer and manufacturer of proton exchange membrane [PEM] hydrogen production systems). UND will develop a hydrogen seminar, brining in experts in the field from NREL and Proton to present to UND students. Internships and research opportunities are also available for students at UND Energy & Environmental Research Center.

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 new courses 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. 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

A variety of case studies were developed for the undergraduate curriculum, designed to fit into specific courses with the intent of reinforcing fundamental concepts using hydrogen production and/or utilization examples. While these were found to provide a good introduction to hydrogen, there was some difficulty incorporating these into core courses. While most faculty like new problems for application in their courses, they have limited time within the semester schedule to add significant content. They found it difficult to implement a case study that required a whole class period. A better approach was found to be utilizing the problem-based learning concept implemented in the Michigan Tech program, where shorter directed-problems were developed.

Case studies were found to be successful in survey courses where faculty are looking to expose students to examples of how technology can meet the needs of today's society. These courses are good places to introduce "non-technical" aspects of engineering to students, such as political and social constraints in making engineering

decisions. The most successful case studies were presented for publication in NSF National Center for Case Study Teaching in Science.

A new course, Hydrogen Production and Storage was developed and added to the curriculum. In addition, the content of our Renewable Energy Systems course was modified to highlight fuel cells and electrolysis and our Fuels Technology course was modified to highlight gasification and other hydrogen production technologies. These courses were effective in stimulating interest in hydrogen related technologies. An indication of this interest is the number of students choosing hydrogen related projects for their senior design. All courses were taught simultaneously to undergraduate, graduate and distance students to help maximize exposure.

An existing Hydro-Geniuses laboratory experimental setup consisting of a solar cell, a single-cell PEM electrolyzer, two single-cell PEM fuel cells, and a small resistive load is used by students to generate the current-voltage characteristic curves of the fuel cell and the electrolyzer and analyzed system efficiencies. The two fuel cells were operated both in series and in parallel. 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 Hydrogen Education Program. 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 were implemented into the undergraduate curriculum.

To help improve the depth of knowledge and skills of our MS and PhD candidates, a variety of teaching experience opportunities were provided. PhD and MS students developed the laboratory experiments for implementation in the undergraduate labs. This provided the opportunity to test the equipment and determine which of its capabilities could be best utilized to demonstrate the fundamentals of hydrogen based energy. These students also provided input for case studies and participated in the summer outreach programs for undergraduate students.

One of the goals of this program was to provide internship opportunities for students that received training through a combination of their laboratory experience and the hydrogen related classes. This training was expected to add value to the student, making it easier for them to obtain internships. Students were placed in summer internships at NREL, Oak Ridge National Laboratory, and the DOE National Center for Hydrogen Technology.

Students were exposed to various aspects of hydrogen technology through a series of seminars that were offered each semester. Students were also provided with the opportunity to attend the annual UND Energy & Environmental Research Center Hydrogen Summit.

PowerOn is an outreach activity that provides hands on demonstrations for students primarily in the grades 4-9. The demonstrations and the infrastructure to support PowerOn are provided from other non-project funds. A special topics class engaged students in the development and presentation of these modules. Having students develop these modules on a “for credit basis” rather than for pay allowed projects to be developed without any monetary contributions from the project. Presentation of the PowerOn demonstrations allows students to gain practice in presenting engineering related concepts to the general public. While the general audience in middle school, experience has been that kids of all ages have a strong interest. The program also indirectly educates parents, as they often accompany their children in these public events.

Conclusions and Future Directions

Over 200 students were directly impacted by program.

- Over 150 chemical and electrical engineering undergraduate students were exposed to various aspects of hydrogen through in-class case studies and laboratory experiments.
- Twenty-seven students were involved in senior design projects related to hydrogen.
- Three hydrogen related courses were developed and taught, with enrollment of 73 students.
- Twenty-one undergraduate students were involved with PowerOn to develop modules to demonstrate hydrogen and other renewable energy technologies. Demonstrations were made to over 1,000 youth.
- Two PhD and two MS students were trained through the development of instructional material for this program. Nine interns were placed working in hydrogen related fields.
- Two undergraduates were placed at the DOE National Hydrogen Center and one at NREL. Two PhD graduates were placed with Nissan in their fuel cell division in Detroit.
- Results of this work have been presented at the 2010 annual American Society for Engineering Education meeting in addition to the DOE annual merit review meetings.

The final activities of this project will be to publish selected case studies and to publish a paper that summarizes the lessons learned during this program.

Special Recognitions

The paper, “National Hydrogen and Fuel Cell Education Program Part I: Curriculum” received the Best Paper Award at the ASEE Annual Conference and Exposition.

FY 2011 Publications/Presentations

1. Development of a Renewable Hydrogen Production and Fuel Cell Education Program presented at the 2009, 2010 and 2011 U.S. DOE Hydrogen Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meetings.

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.