# 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 "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 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 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 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

- Three new case studies targeting 1) freshman introductory engineering courses, 2) chemical engineering mass and energy balances, and 3) chemical engineering thermodynamics are under development for use in the Fall, 2009.
- The course content in EE 522-Renewable Energy Systems, taught Fall 2008 was modified to increase the content related to fuel cells and electrolysis.
- Two new courses will be offered during the 2009-2010 academic year. The first course will cover hydrogen production and storage. The second course will focus on hydrogen utilization.
- Two undergraduate students have been placed for internships as the Energy & Environmental Research Center's National Center for Hydrogen Technology.

- Two new experimental setups were designed and implemented into chemical and electrical engineering undergraduate laboratories.
- The student organization, PowerOn, developed experiments that will be incorporated into a mobile laboratory that will be taken to middle schools as a part of a program to stimulate interest in science, technology, engineering, and mathematics (STEM) areas.

## 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, 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 the 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 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, brining 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 the UND Energy & Environmental Research Center (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

Work was initiated to develop three new case studies. These will target 1) freshman introductory engineering courses, 2) chemical engineering mass and energy balances; and 3) chemical engineering thermodynamics. These case studies will serve to introduce all chemical and electrical engineering students at UND to the basics of hydrogen and fuel cell technology.

A new course is under development that will cover hydrogen production and storage. Topic areas include an overview on "why hydrogen" followed by sections on hydrogen production from fossil fuel and biomass, hydrogen from water, and hydrogen distribution and storage. The current texts that are being adopted for the course are "Hydrogen Energy: Challenges and Prospects" by Rand and Dell, and "Hydrogen Fuel: Production, Transport and Storage" edited by R. Gupta. An outline has been developed and work was initiated on developing the first teaching modules.

During the past year, the school has encouraged the development of hydrogen-based projects for the senior

capstone design course. The Renewable Hydrogen Electrolyzer project focused on taking energy from a renewable source, and storing that energy in the form of hydrogen to later be used in a fuel cell. To do this an alkaline electrolyzer was designed and built to produce hydrogen through the process of electrolysis. The overall project goal was to integrate the electrolyzer with an existing wind and photovoltaic power supply, and deliver produced hydrogen to a miniature fuel cell car. Figure 1 depicts the overall system, where the electrolyzer was the system being developed for this project.

The goal of a second project, Combining Alternative Energy Power Sources, was to combine and control the output of unregulated direct current (DC) sources such as fuel cells into a single regulated output to match the load. The purpose of combining sources is to increase the usefulness of alternative energy fuel cell generators which commonly produce unregulated DC output. The solution proposed utilizes a DC to AC (alternating current) converter, a multi-winding transformer, and an AC to DC inverter. In a three-stage system the incoming DC is converted via a full H-bridge to AC, where it is then passed over a two input one output transformer. The power combines in the magnetic spectrum on the transformer core, and the output of the transformer is then converted back into a single DC output. A copy of the circuit design is presented in Figure 2.

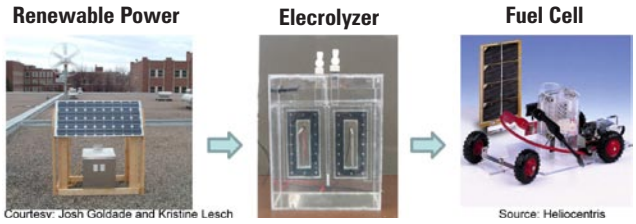


**FIGURE 1.** System overview of renewable power system designed as a senior capstone project.

During the fall 2008 semester, students from EE 522 performed experiments using a Hydro-Geniuses laboratory experimental setup. This equipment contains a solar cell, a single cell PEM electrolyzer, two single cell PEM fuel cells, and a small resistive load. Students generated 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. During the spring 2008 semester, students from ChE 332 performed experiments using the Hydro-Geniuses laboratory experimental setup. Students generated the current-voltage characteristic curves of the fuel cell and the electrolyzer and analyzed system efficiencies. In this lab, the students are given a memo from their "boss" asking them to design a system to supply 100 kW of electricity. The students need to determine system efficiencies and power curves to propose a design to their boss.

Two new experimental setups were purchased from Heliocentrics. The HP 600 includes a 600 watt water-cooled PEM fuel cell stack, a DC/DC and DC/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 set of laboratories has been developed that will be implemented in to the undergraduate curriculum during the 2009-2010 academic year. Photos of the equipment are given in Figure 3.

Two undergraduate students have been placed for internships as the EERC's National Center for Hydrogen Technology.

Nilesh Dale, PhD candidate, successfully defended his thesis entitled "Characterization of PEM Electrolyzer and PEM Fuel Cell Stacks using Electrochemical Impedance Spectroscopy" in November 2008. Mr. Dale presented an open seminar on his work to

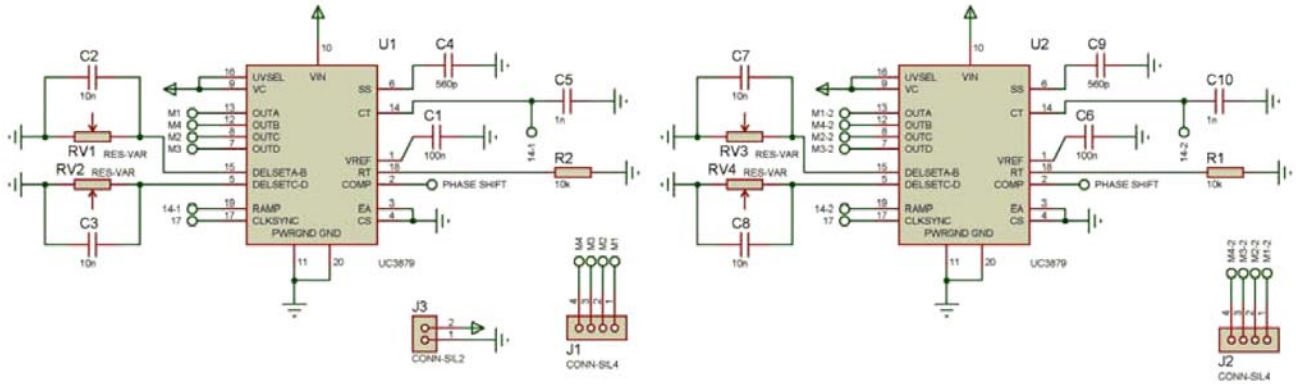


**FIGURE 2.** Circuit design developed as a part of senior capstone project to combine and control output of unregulated DC sources (fuel cells) into single regulated load to match load.

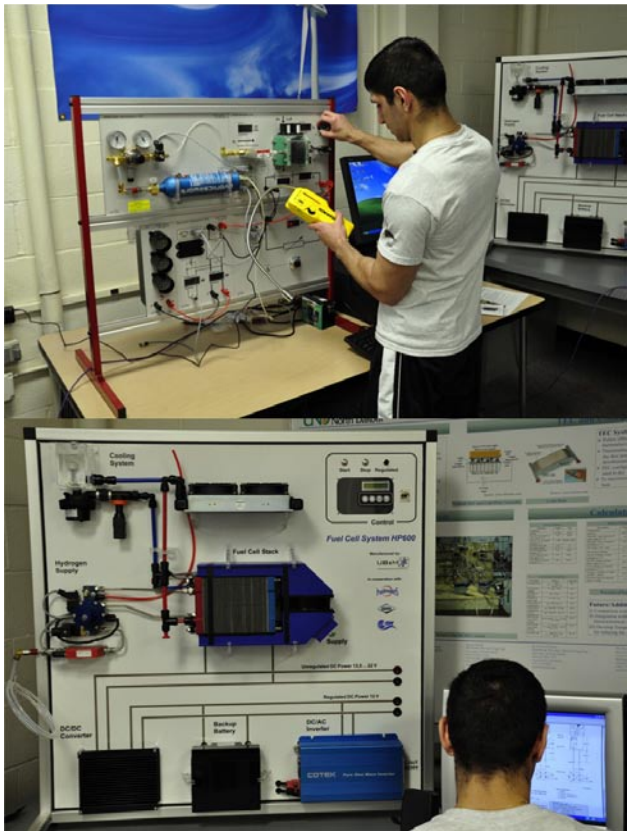


**FIGURE 3.** Laboratory Experiments in Hydrogen Utilization

undergraduate chemical and electrical engineering students.

The student organization, PowerOn, is developing experiments that will be incorporated into a mobile laboratory. This mobile laboratory will be taken to middle schools as a part of a program to stimulate interest in STEM areas. As a part of this DOE program several undergraduate chemical engineering students have developed suitable laboratories on hydrogen production and utilization. Implementation of the PowerOn program will be performed under a separate grant, and is not a part of this project. Undergraduate students also used these experiments as a part of UND's Young Engineers Summer Camp focused on grades fourth through eighth.

## Conclusions and Future Directions

To date this project has impacted approximately 60 students, primarily through the 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 ten students have been fully immersed in hydrogen technology through the capstone design experience.

During the next year work will continue on development of additional case studies. The case studies will be published to provide national access. Work will continue on the development and delivery of the new courses. 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.

## FY 2009 Publications/Presentations

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