# AC 2010-635: NATIONAL HYDROGEN AND FUEL CELL EDUCATION PROGRAM PART I: CURRICULUM

**David Blekhman, California State University Los Angeles**

David Blekhman is an Associate Professor in the Power, Energy and Transportation program in the Department of Technology at CSULA. Dr. Blekhman received his B.S.-M.S., in Thermal Physics and Engineering from St. Petersburg State Technical University, Russia, and a Ph.D. in Mechanical Engineering in 2002 from SUNY Buffalo. Prior to joining CSULA in 2007, he was an Assistant Professor of Mechanical Engineering at Grand Valley State University. Currently, Dr. Blekhman is a PI for the Department of Energy "Hydrogen and Fuel Cell Education at CSULA" grant, Co-PI for California Air Resources Board grant to built a Hydrogen Refueling Station at the CSULA campus, and senior personnel on NSF funded Research Experience for Undergraduates and Center for Energy and Sustainability under the Centers of Research Excellence in Science and Technology. Bringing emerging "green jobs" opportunities to his students, Dr. Blekhman is actively developing the program by offering new courses such as Fuel Cell Technologies, Photovoltaics, Smart Grid, Electric and Hybrid Vehicles etc.

**Jason Keith, Michigan Technological University**

Jason Keith is an Associate Professor of Chemical Engineering at Michigan Technological University. He received his B.S.ChE from the University of Akron in 1995, and his Ph.D from the University of Notre Dame in 2001. His current research interests include reactor stability, alternative energy, and engineering education. He is the 2008 recipient of the Raymond W. Fahien Award for Outstanding Teaching Effectiveness and Educational Scholarship. He has served ASEE as program chair and awards co-chair of the Chemical Engineering Division.

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Ahmad Sleiti is an Assistant Professor in Mechanical Engineering Technology and Mechanical Engineering Departments at the University of North Carolina at Charlotte (UNCC) and a member of Energy Production and Infrastructure Center (EPIC). He obtained his PhD from the University of Central Florida (UCF), USA. He also holds two MS degrees in mechanical engineering. He has taught at UCF, UNCC and at University of Jordan (UJ). Prior to coming to UNCC, he was an Assistant Professor and Research Associate at UCF. He also worked for several years as a mechanical engineer in various consulting, R&D and contracting firms on industrial, commercial and residential projects. His research interests include energy systems, fuel cells, thermal management and thermal transport phenomena, nanofluids, heat transfer and aerodynamics for gas turbines and other turbomachinery.

**Eileen Cashman, Humboldt State University**

Eileen Cashman is a professor of Environmental Resources Engineering at Humboldt State University and a Faculty Research Associate at SERC. She is an alumna of HSU where she received her B.S. degree in Environmental Resources Engineering. She received an M.S. in Energy Policy and Analysis and a Ph.D. in Civil and Environmental Engineering from the University of Wisconsin, Madison. Dr. Cashman currently teaches courses in engineering design, water quality, computational methods and environmental fluid hydraulics. At SERC, Cashman is currently involved in a feasibility study for hydroelectric resources for the Yurok tribe and the H2E3 university curriculum project.

**Peter Lehman, Humboldt State University**

Peter Lehman is Director of Schatz Energy Research Center and Professor of Environmental Resources Engineering at Humboldt State University. Lehman's research focuses on renewable energy and hydrogen technologies. Under his direction, the Schatz Energy Research Center has: built and operated a solar-hydrogen energy system for 20 years; designed and built a fleet of fuel

cell vehicles for SunLine Transit Agency, including the first PEM fuel cell vehicle licensed to drive in the U.S; installed the first hydrogen fueling station, also at SunLine; designed and built numerous integrated stationary PEM fuel cell power systems; designed and built a modern hydrogen fueling station at HSU. Lehman's current work includes producing a national hydrogen energy curriculum for high school students in collaboration with Lawrence Hall of Science at UC Berkeley, studying gasification of woody biomass, and photovoltaic module durability and degradation testing.

**Richard Engel, Schatz Energy Research Center**

Richard Engel is a Senior Research Engineer at SERC. He graduated from Humboldt State University with a B.S. in Environmental Resources Engineering. Engel's work at SERC has included technical, development of educational materials for high school and university level students, hydrogen and fuel cell system maintenance and repair, energy program development for local communities and Tribes, and feasibility research on emerging energy technologies. Engel is currently a Fulbright Scholar at Universidad Don Bosco in El Salvador during the 2009-2010 academic year where he will help the university create a degree program in renewable energy and energy efficiency.

**Michael Mann, University of North Dakota**

Dr. Mann is a Professor and Chair of the Chemical Engineering Department, and the Associate Dean for Research in the School of Engineering and Mines at the University of North Dakota (UND). He has a Ph.D. in Energy Engineering and a M.S. in Chemical Engineering. Dr. Mann has served in several research and supervisory capacities within the Energy & Environmental Research Center between 1981 and 1999 when he joined the faculty in the Department of Chemical Engineering. Dr. Mann was recognized as a Chester Fritz Distinguished Professor in 2009, the highest honor bestowed by UND. He is a NSF Career Award winner. Dr. Mann's principal areas of interest and expertise include performance issues in advanced energy systems firing coal and biomass; renewable and sustainable energy systems with a focus on integration of fuel cells with renewable resources through electrolysis; production of fuel and specialty chemicals from crop oils; and development of energy strategies coupling thermodynamics with political, social, and economic factors. He has authored or coauthored over 90 peer-reviewed publications and over 200 publications in total.

**Hossein Salehfar, University of North Dakota**

Hossein Salehfar received his Bachelor of Science (B.S.) degree in electrical engineering from the University of Texas at Austin, and his Master of Science (M.S.) and Doctorate (Ph.D.) degrees in electrical engineering from the Texas A&M University in College Station. He was an Assistant Professor of Electrical Engineering at Clarkson University in New York during 1990-1995. Since 1995 he has been with the Department of Electrical Engineering at University of North Dakota, Grand Forks, where he is now a full Professor, Department Vice-Chair, and the Director of Engineering Ph.D. Programs. Dr. Salehfar has worked as a consultant for the New York Power Pool, electric utilities and coal industries in the State of North Dakota, and the North Dakota Energy and Environmental Research Center (EERC). He is currently working on a number of projects funded by the National Science Foundation (NSF), and the U.S. Department of Energy (DOE). Some of the projects that he has worked on include alternative and renewable energy systems, fuel cell technologies, power electronics, electric drives, neuro-fuzzy intelligent systems, electric power and energy systems, power systems reliability, engineering systems reliability, power systems production costing, energy and load management, and energy efficiency. Dr. Salehfar is an active reviewer of proposals and manuscripts for the National Science Foundation (NSF), IEEE, Power Electronics Specialist Conference (PESC) and various other international journals, conferences, and publications. He is a professional member of the American Society for Engineering Education (ASEE) and a senior member of the IEEE.

# National Hydrogen and Fuel Cell Education Program Part I: Curriculum


## Abstract

In 2008, the U.S. Department of Energy (DOE) made five awards to university programs seeking to develop and expand education programs in Hydrogen and Fuel Cells. The main objective of the DOE program was to train graduates who will "comprise the next generation workforce needed for research, development, and demonstration activities in government, industry, and academia."

Hydrogen and fuel cell technologies (HFCT) are considered strong components in the future suite of technologies enabling energy independence and a cleaner environment for stationary and transportation applications. However, HFCT are inherently complex and require contribution from most of the engineering and technology disciplines. At the same time, HFCT topics are rare in university programs and few engineering students receive adequate training.

The paper will present the educational efforts and models being developed under this funding. The program is offered through California State University Los Angeles, Humboldt State University, Michigan Technological University, University of North Carolina Charlotte and University of North Dakota. With collaborations, the list of participating colleges is even larger. The authors' intent is to share the wealth of approaches taken to and the challenges and accomplishments of developing HFCT curriculum, which range from designing short modules for existing courses to dedicating majors and minors to the topic. More than twenty courses are modified or developed as part of the activities. As a result, HFCT is introduced to technology and chemical, mechanical, electrical, and environmental engineering majors. The activities undertaken also include outreach to non-major student population and school programs.


## Introduction

In fall 2008, the U.S. Department of Energy (DOE) made five awards to university programs seeking to develop and expand Hydrogen and Fuel Cells Education. The original solicitation sought to expand hydrogen and fuel cell technology awareness among the general public, decision makers and also develop professional educational programs. Five academic institutions throughout the country were selected to further expand the latter. The main objective of this section of the program was to train graduates who will "comprise the next generation workforce needed for research, development, and demonstration activities in government, industry, and academia."[1] The program is offered through awards to California State University Los Angeles, Humboldt State University, Michigan Technological University, University of North Carolina Charlotte and the University of North Dakota.

The first year of executing the educational program has overlapped with interesting developments in the government and industry. The 2010 FY DOE budget proposal significantly reduced the funding for the DOE's hydrogen programs following Secretary Chu's skepticism in the readiness of HFCTs to reach the mass market in the near future. The DOE website[2] cites "Dr. Steven Chu, distinguished scientist and co-winner of the Nobel Prize for Physics (1997), was appointed by President Obama as the 12th Secretary of Energy and sworn into office on January 21, 2009." Several challenges for HFCT were voiced especially in the transportation area. Among them were fuel cell durability, availability of hydrogen dispensing infrastructure, insufficient onboard compressed storage and reliance on hydrogen production from natural gas[3]. Active lobbying ensued, for example, the reader is referred to the statement by Jerome Hinkle, the Vice President of the National Hydrogen Association[4]. As such, the $150M 2010 FY budget was effectively restored to the previous year's level of funding. Indeed, the industry has shown remarkable achievements in 2009 to support its claims for viability and progress. For example, several new publicly accessible hydrogen stations were open in the New York area, Charleston WV, and Los Angeles; Vehicle Projects Inc. of Denver, Colorado unveiled the very first full size 240kW fuel cell switch locomotive to be deployed on the BNSF site in Commerce CA; but the most noted was the Toyota Highlander Fuel Cell Hybrid Vehicle Advanced which achieved an estimated range of 431 miles of mixed driving on southern California roads on the full charge of 6.29 kg (15 °C) of 70 MPa compressed hydrogen. A total of 163 fuel cell vehicles have been introduced in CA by June 2009[5] mainly comprised of the Honda FCX Clarity and the GM Equinox.

The 2008 DOE's report to Congress[6] estimates from 361,000 to 675,000 jobs to be created in the fuel cell industry by 2050. The majority of those jobs are expected in dealerships and service. However, 10,000 white collar jobs are expected by 2035. HFCT is a very specialized multidisciplinary area of science and engineering requiring creative solutions or program redesigns to introduce the topics in the respective curriculums[7-11]. The five awarded institutions welcome DOE's efforts to support creation of new and expansion of existing HFCT programs. Combined, the institutions have taken a multitude of solutions to accomplish DOE's call for training the future professional workforce which will be prepared to meet the challenges currently ahead of HFCT.

The approaches range from designing short modules for existing courses to dedicating majors and minors to the topic. More than twenty courses are modified or developed as part of the activities. As a result, HFCT is introduced to technology and chemical, mechanical, electrical and environmental engineering majors. The activities undertaken also include collaborations with other institutions, industry partnerships, outreach to non-major student population and school programs. The paper will give an overview of each institution tasks/goals and progress report of meeting them after one and a half years of executing the program. The authors also share the challenges and accomplishments of developing HFCT curriculum. The main intent of the paper is to aid other institutions in developing their strategies and approaches in introducing HFCT. Those interested in obtaining materials are welcome to contact the authors. Laboratory curriculum development is reflected in a companion paper offered through the same forum[12].

For convenience, Table 1 illustrates a summary of the curriculum and courses developed at each institution, as well as enrollment data for the most recent offering. It is expected that future enrollments will be about the same or larger with advances in research and development in hydrogen and fuel cell technology. Table 2 illustrates the degrees, minors, or concentrations that can be obtained as a result of this project. We note that each institution has independent objectives which are described in the following sections. The institutions, facilitated by the program manager at the United States Department of Energy, meet annually and share best practices through telephone and email. This contribution and its companion paper[12] are an example of the collaborative efforts towards program dissemination. Overall program assessment and impact will be discussed in a future paper.

Table 1. HFCT Course Enrollments During 2009-2010 Academic Year

| **Institution** | **Course** | **Coverage ( F = Full Course, I = Introduction)** | **Enrollment** |
|---|---|---|---|
| California State University Los Angeles | Fuel Cell Applications, Technology Dept. | F | 12 |
| California State University Los Angeles | Fuel Cell Systems, grad course in ME | F | 8 |
| California State University Los Angeles | The Impact of Technology on the Individual and Society, Tech | I | ~ 330 |
| California State University Los Angeles | Renewable Energy and Sustainability, ME | I | 26 |
| California State University Los Angeles | Electric, Hybrid and Alternatively Fueled Vehicles, Tech | I | 20 |
| California State University Los Angeles | Power, Energy and Transportation Technologies, Tech | I | 45 |
| Humboldt State University | Introduction to Environmental Science and Engineering | I | 115 |
| Humboldt State University | Thermodynamics and Energy Systems I | I | 60 |
| Humboldt State University | Thermodynamics and Energy Systems II | I | 25 |
| Humboldt State University | Engineering Design and Analysis (at the University of California, Berkeley) | I | 25 |
| Michigan Technological University | Alternative Fuels Group Enterprise | F | 27 |
| Michigan Technological University | Fuel Cell Fundamentals | F | 41 |
| Michigan Technological University | Fuel Cell Technology | F | 24 |
| Michigan Technological | Fundamentals of Hydrogen | F | 27 |

| | | | |
|---|---|---|---|
| University | as an Energy Carrier | | |
| Michigan Technological University | Hydrogen Measurements Laboratory | F | 12 |
| University of North Carolina Charlotte | H2 I - Physical Hydrogen Storage and Handling | F | To be offered |
| University of North Carolina Charlotte | Fuel Cell Technologies I | F | To be offered |
| University of North Carolina Charlotte | Fuel Cell Technologies II | F | To be offered |
| University of North Carolina Charlotte | H2 II – Hydrogen Production | F | To be offered |
| University of North Carolina Charlotte | Thermo-Fluid-Heat Transfer Topics in HFCT | F | To be offered |
| University of North Carolina Charlotte | Energy Management | I | 34 |
| University of North Carolina Charlotte | Analysis of Renewable Energy Systems | I | 21 |
| University of North Dakota | Methods of Hydrogen Production and Storage | F | 20 |
| University of North Dakota | Renewable Energy Systems | I | 20 |
| University of North Dakota | Chemical Engineering Lab III | I | 30 |

Table 2. HFCT Degrees, Minors, or Concentrations

| **Institution** | **Activity** |
|---|---|
| California State University Los Angeles | Power, Energy, and Transportation Concentration (part of Technology degree) and Mechanical Engineering |
| Michigan Technological University | Interdisciplinary Minor in Hydrogen Technology |
| University of North Carolina Charlotte | Hydrogen and Fuel Cell Technology Concentration (part of Engineering Technology degree) |
| University of North Dakota | Concentration in Sustainable Energy Engineering |
| University of North Dakota | M. S. in Sustainable Energy Engineering |

**California State University Los Angeles**

Objectives

The main goal of the DOE program at CSULA is to establish an effective educational program in HFCT to work with the local industry and support university efforts in green technology leadership. This includes bringing a hydrogen fueling station on campus. The comprehensive nature of the university, its strategic location in the hydrogen and fuel cell abundant industrial region and a historically minority-serving charter make it an ideal candidate to carry out the project. The approach used is multidisciplinary and a combination of full fledged courses and lecture modules. The latter is applied to both hard core engineering courses as well as to a general education course reaching wider university audience. The funding is also used to establish a "Zero Emissions Laboratory" with both purchased and custom built experiments.

Curriculum, Course, and Laboratory Descriptions

Two full-fledged courses solely concentrating on fuel cells were developed. One of the courses was offered as an undergraduate technology course and the other as a graduate course in Mechanical Engineering.

The undergraduate course was offered in the Power, Energy and Transportation (PET) concentration of the Technology program. The program is designed in such a way that it has a 3 credit senior course titled Emerging Technologies in PET. It allows teaching any related topic in depth. Thus, a Fuel Cell Applications course was offered in the context of Emerging Technologies in PET. The course aims to deliver cutting edge information on fuel cells at the junior/senior undergraduate level. After review of alternative and renewable energy technologies, it continues with fundamental principles of electrochemistry and thermodynamics as it applies to Polymer Electrolyte Membrane fuel cells. Balance of plant and ancillary equipment are also covered. A special emphasis in the course is placed on system integration of fuel cells into common applications like fuel cell vehicles, stationary distributed and military portable energy generators. Lectures are paralleled by hands-on activities and experiments in the laboratory. The course is also open to undergraduate ME students as an elective.

In the 2009 offering of the course, students attended the 2009 ASME Fuel Cell conference which was available locally. Honda Clarity FCX team gave a lecture and a demonstration on Honda fuel cell vehicles. At other occasions, General Motors fuel cell vehicle center in Burbank, CA, as well as the Southern California Edison Electrical Vehicle Center in Pomona, CA, hosted CSULA students for tours. Attending the ASME conference and vehicle manufacturers participation greatly contributed to one of the program goals of fostering partnerships with the industry and providing students with quality training.

The Fuel Cell Systems is a graduate course in Mechanical Engineering preparing students through advanced coverage of fuel cell systems and hydrogen production. It addresses the operating principles, electrochemistry and thermodynamics of Proton-Exchange, Phosphoric Acid, Alkaline, Molten-Carbonate, and Solid-Oxide Fuel Cells. On-board electrical systems, inverters, and grid connection are included. The course is offered with some laboratory demonstrations.

A single large power point presentation addressing HFCT was prepared as a one week module that could be used with appropriate adjustments in a variety of courses. Two video lectures were recorded based on the presentation, one concentrated on fuel cells and the other on hydrogen technologies[13-14]. The materials are used to train faculty and also as a support resource when the HFCT is covered.

TECH 250-The Impact of Technology on the Individual and Society course is a general education required course, which contains a one week module on fuel cells and hydrogen economy. It is open to all majors in the university and is selected to deliver our message to the university-wide student body. A total of eleven sections of the course were offered in four quarters from fall to fall with an average of 30 students per section. Six technology faculty, who are traditionally assigned to teaching the course, were trained in HFCT using a lecture and module training materials.

In addition, one week of HFCT topics was integrated in the following courses: ME 454-Renewable Energy and Sustainability (enrollment 26); TECH 470-Electric, Hybrid and Alternatively Fueled Vehicles (enrollment 20), and TECH 370-Power, Energy and Transportation Technologies (enrollment 45).

Concurrently, significant effort was dedicated to establishing the “Zero Emissions Fuel Cell and Hydrogen Laboratory.” The laboratory is designed to provide hands-on activities supporting fuel cell courses and students’ teaching and research experiences. The following major equipment has been acquired: Heliocentris’ -- Dr. Fuel Cell, Nexa Training System Complete, Nexa Integration Kit; and Proton’s-Hogen GC600 Electrolyzer. Two graduate students work in the lab on educational and research projects. A four-student multidisciplinary senior design team designed and built a Hydrogen Safety demonstrator that allows experimentation with the comparative flammability limits of hydrogen and other explosive gases. Another multidisciplinary senior design team installed 21 solar panels (1.8 kW total power) donated by Southern California Edison. The solar power should provide the emissions free generation of hydrogen in the lab for the true zero-emissions performance. The work will be continued to complete wiring and connection to the equipment in the lab. A total of nine students participated in two projects: six EE, two ME and one Technology.

CSULA has actively pursued public outreach and educational activities through which the HFCT curriculum at CSULA is promoted. During the summer of 2008, a team of six summer undergraduate researchers representing four different states built a 25-$cm^2$ fuel cell test stand. The test stand was taken to the Hydrogen Road Tour Day at the California Science Center in Los Angeles in August 2008. It was displayed at the Santa Monica Alternative Car Show in September 2008. During the fall of 2008, ECST hosted two open house events for middle and high-school students, about two hundred of whom toured the Zero-Emissions Fuel Cell laboratory. In February 2009, the stand was a part of the Southern California Edison Black History Month event. In April 2009, CSULA participated in the first annual “Green Valley Expo” organized by Lookin' Green Magazine, Pasadena, CA.

CSULA partnered with Sempra Energy to work on a senior design project related to hydrogen technologies. Students are to design a device which will allow measuring the amount of hydrogen dispensed by a hydrogen station. This project is of significance to California because currently the payment for hydrogen is per fill service and not by the actual amount of hydrogen dispensed.

CSULA offered a workshop combining alternative energy and programming with fourteen students from a local community college. Lego Mindstorms was selected to serve for both purposes. The topic for alternative energy was HFCT. Students utilized Horizon's H-20 fuel cells to power a Lego Mindstorm vehicle, as seen in Figure 1 below, which is believed to be the very first application of fuel cells to powering Lego Mindstorm. Fourteen students participated in this activity. Horizon Fuel Cells has partnered with CSULA to further promote such an application of its product.

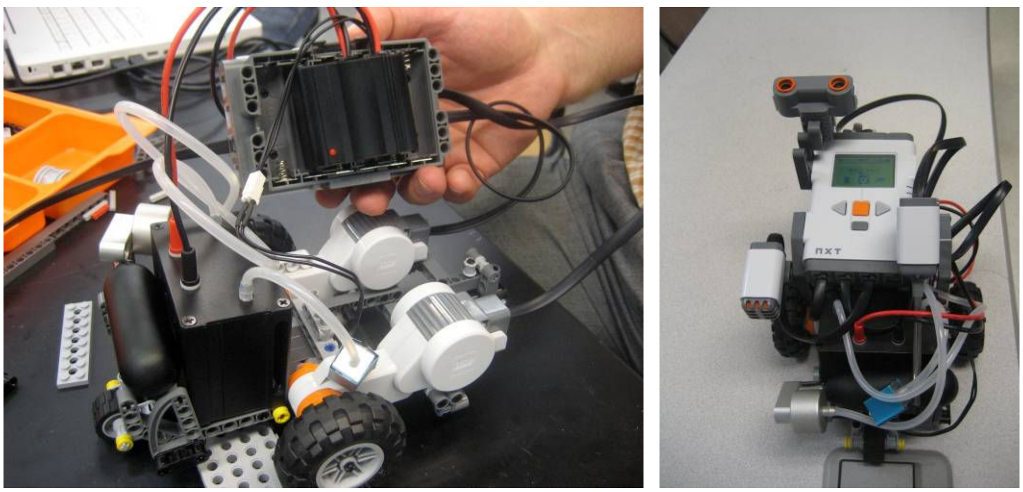

Figure 1. Horizon H-20 fuel cell is being installed onto a Lego Mindstorm vehicle platform (left) and completed fuel-cell-powered robot (right).

**Humboldt State University**

<u>Objectives</u>

The “Hydrogen Energy in Engineering Education” ($H_2E^3$) project is a three-year effort being led by the Schatz Energy Research Center (SERC), affiliated with Humboldt State University (HSU). SERC is teaming with the Institute of Transportation Studies (ITS) at the University of California, Berkeley (UCB) to develop a hydrogen energy and fuel cell curriculum and associated teaching tools aimed primarily at undergraduate engineering programs in the California State University and University of California systems. SERC and ITS are working with faculty at HSU and UCB and fuel cell industry partners. When fully distributed through the two university systems, the curriculum has the potential to reach thousands of California engineering students each year.

SERC researchers and their partners on this effort bring 20 years of relevant experience in teaching about hydrogen energy and developing fuel cell technology. SERC built the first PEM fuel car licensed in the U.S. and a solar powered hydrogen fueling station as part of the Palm Desert Renewable Hydrogen Transportation Project. In partnership with the Lawrence Hall of Science at UCB, SERC developed the Hydrogen Technology and Energy Curriculum (HyTEC) designed for high school chemistry and environmental science students. HyTEC is being distributed nationwide. Over the years, many HSU graduate and undergraduate students have obtained hands-on experience with cutting edge energy technologies by being research assistants at SERC. This DOE $H_2E^3$ project is an attempt to bring these opportunities to students statewide.

The objectives of the $H_2E^3$ project are:

- to develop commercializable hydrogen teaching tools including a benchtop fuel cell/electrolyzer kit and a basic fuel cell test station suitable for use in university engineering laboratory classes,
- to deliver effective, hands-on hydrogen energy and fuel cell learning experiences to a large number of undergraduate engineering students at multiple campuses in the California State University (CSU) and University of California (UC); and
- to provide follow-on internship opportunities for students at hydrogen and fuel cell companies.

Curriculum, Course, and Laboratory Descriptions

Project activities began with the development of curriculum modules and fuel cell laboratory hardware. The curriculum modules and lab hardware are designed for use in existing engineering courses and use hydrogen and fuel cell technologies to teach concepts and principles already integral to the course curricula. The goal is to allow instructors to replace existing lessons rather than add lectures or activities to already tightly scheduled courses constrained by department and the Accreditation Board for Engineering and Technology (ABET) requirements. The lead investigators of this project are working closely with engineering faculty to develop lesson plans that can be integrated seamlessly with existing courses, including introductory engineering, introductory and advanced thermodynamics, manufacturing engineering, upper-division engineering laboratories, and in courses on the general topic of energy and society.

During year one of the project (beginning in Fall 2008), SERC engineers designed and built 30 benchtop fuel cell/electrolyzer kits. With these benchtop kits, students use electric power to generate hydrogen gas through water electrolysis, then use the hydrogen to power a fuel cell connected to a mechanical load. The kit is instrumented so students can measure the efficiency of each energy conversion step. We have developed curriculum for the lab activities, including a benchtop fuel cell/electrolyzer users guide, lab safety guidelines, wiring diagrams and several experimental lesson plans that utilize the kits.

Also in year one, two fuel cell test stations have been built that allow the operator to directly observe and record data on a fuel cell stack while adjusting a number of operating parameters, including load current, temperature, air/fuel stoichiometry, and frequency and duration of hydrogen purges. Each test station is supplied with an 8-cell, 500-Watt fuel cell stack designed and built by SERC.

In the second (current) year of the project, the laboratory hardware was delivered to HSU and UCB (Figure 2) and the initial curriculum was implemented in an introductory engineering and a thermodynamics course at HSU (Figure 2). Additionally, curricular material to demonstrate the use of the test station was developed and implemented through a guest lecture at UCB in the Energy and Society course. Monitoring and evaluation activities aimed at closing the feedback loop to improve both the written curricular material and the lab hardware have included pre and post surveys in courses and focus group discussions with faculty, teaching assistants and students. The pre and post surveys have been used to evaluate the effectiveness of the activities in presenting learning objectives. The focus group discussions have provided useful suggestions on improving the function of the laboratory hardware itself and the curriculum. SERC will continue to work with faculty at both HSU and UCB throughout the remainder of this year to deliver additional lab sessions in the spring semester and improve the equipment and curriculum based on assessment results.

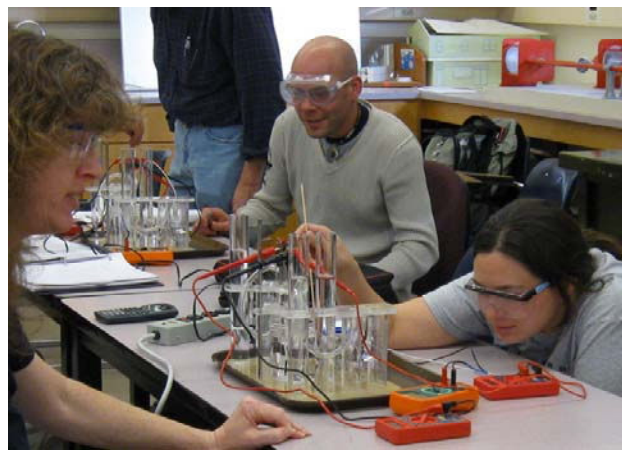

Figure 2. (left) SERC delivers a fuel cell test station to UC Berkeley. Pictured left to right are Richard Engel (SERC), Peter Lehman (SERC), Tim Lipman (ITS UCB), and Dan Kammen (UCB). (right) HSU students in the HSU Thermodynamics and Energy Systems I class using the fuel cell kits in the laboratory. Photos by Eileen Cashman.

During the last year of the project, SERC will facilitate hydrogen and fuel cell-related internships for students who have participated in the curriculum with industry partners Jadoo Power Systems, Inc., Protonex Technology Corporation, UTC Power, and IdaTech LLC. The curriculum will be disseminated more widely to interested CSU/UC engineering programs. Several faculty members have already expressed interest in using the curriculum.

Current dissemination activities include personal contacts with UCB and HSU faculty, guest lectures at HSU and UCB, the development of a website where curriculum will be posted (www.hydrogencurriculum.org) and presentation in conferences such as this one (ASEE).

Program Accomplishments

In summary, the first half of this three-year project has been productive, with the establishment of working relationships with faculty at the two pilot campuses, UCB and HSU, and completion of planned hardware development. Several course lesson plans have been developed and successfully piloted in undergraduate engineering classes. We are currently working to refine the course materials based on student and instructor feedback. We will work with our industry partners to secure internships for students who have participated in courses that include $H_2E$ material and will monitor outcomes for these interns and their industry hosts. In the final year of the project we will recruit other UC and CSU campuses to participate in the project and monitor and report on their learning outcomes. Students from these campuses will also have the opportunity to apply for industry partner internships during the project's final year. We continue to look for relationships with interested educators and the opportunities they bring to share the project's deliverables with a wider audience.

**Michigan Technological University**

Objectives

Michigan Technological University is developing a hydrogen curriculum with the main objectives to develop an educational infrastructure and database of hydrogen and fuel cell related educational materials, particularly projects and problem sets. The overarching tasks for this project are to:

Task 1. Develop and/or refine courses in hydrogen technology
Task 2. Develop curriculum programs in hydrogen technology
Task 3. Develop modules for core and elective engineering courses
Task 4. Develop modules to supplement commonly used chemical engineering texts

A brief description describing completion towards the project tasks will now be provided.

Curriculum, Course, and Laboratory Descriptions

The hydrogen curriculum and new courses are parts of the first two tasks of this project.

Task 1. Two new courses have been created:

- "Fundamentals of Hydrogen as an Energy Carrier" was first taught in the fall semester of 2009 with an enrollment of 27 students. Topic areas for the course included: history of energy production; energy sources and emissions; electric and hybrid vehicles; fuel cells and fuel cell vehicles; energy / hydrogen from: natural gas, coal, biomass, electrolysis / wind, solar, and nuclear; and hydrogen public policy.
- "Hydrogen Measurements Laboratory" is to be taught beginning in the spring semester 2010 with a projected enrollment of 12 students (enrollment limit is 16). The course will consist of eight laboratory experiments using four different fuel cell apparatus and will cover the topics on solar panel characteristic curve; Faraday's law for electrolysis and fuel cells; fuel cell characteristic curve; fuel cell efficiency; and hydrogen vehicle fuel economy. The laboratory course will be described in more detail in a companion paper to the 2010 ASEE meeting.

Furthermore, an existing course titled "Fuel Cell Fundamentals" was refined to include information about hydrogen production, transportation, storage, and delivery. This course was taught in the fall semester of 2009 with an enrollment of 41 students.

Task 2. Effective April 2009, Michigan Technological University offers an "Interdisciplinary Minor in Hydrogen Technology." To obtain this 16 credit minor, a student needs to satisfy requirements in four areas:

- Alternative Fuels Group Enterprise Project work (between 4 to 6 credits)
- Fuel Cells course (1 to 3 credits)
- Hydrogen Fundamentals course (1 to 2 credits)
- Approved Electives (remainder of credits)
    - Core courses in transport phenomena (fluid mechanics, heat / mass transfer) for chemical engineering, mechanical engineering, and materials science and engineering students
    - Core courses in circuits and energy / power systems courses for electrical engineering students

A central theme of the minor is participation in the "Alternative Fuels Group" Enterprise. This is one of over twenty enterprises at the university. The Alternative Fuels Group Enterprise consists of undergraduate students in chemical, mechanical, and electrical engineering, as well as materials science and engineering. Students are 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. During the past year, student projects with a hydrogen focus have included:

- Hydrogen Economy for the University Motor Pool
- Experimental Analysis of a Hydrogen Powered John Deere e-Gator
- Design and Economic Analysis of a Fuel Cell / Electric Hybrid Fork Lift
- Hydrogen Economy for a Remote Region of the United States

It is noted that during each semester there are at least three projects focused on fuel cells and hydrogen technology. In the fall 2009 semester, there were five total projects with 27 enrolled students.

<u>Module Descriptions</u>

The other two tasks of this project involve the development of modules for use in the core engineering courses, and will now be described.

Task 3. It is our opinion that focusing efforts on a subset of students who choose to enroll in the fuel cell or hydrogen elective or enterprise courses is not enough. In order to reach a wider audience, 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. As such, course materials, modules, and textbook supplements will be available for use by engineering educators worldwide through an online database at http://www.chem.mtu.edu/~jmkeith/h2ed.

The most mature collection of modules are for the chemical engineering curriculum. The modules developed so far, arranged by core chemical engineering course, are listed below:

*Introductory Material:*
Module 0: Heat of Formation for Fuel Cell Applications

*Material and Energy Balances:*
Module 1: Heat of Formation for Fuel Cell Applications
Module 2: Material Balances in a Solid Oxide Fuel Cell
Module 3: Energy Balances in a Solid Oxide Fuel Cell
Module 4: Generation of Electricity Using Recovered Hydrogen

*Thermodynamics:*
Module 5: Equation of State for Hydrogen Fuel
Module 6: Equilibrium Coefficient and Van't Hoff Equation for Fuel Cell Efficiency
Module 7: Fuel Cell Efficiency
Module 8: Vapor Pressure / Humidity of Gases
Module 9: Nernst Equation

*Fluid Mechanics:*
Module 10: Pressure Drop in Fuel Cell Bipolar Plate Channel
Module 11: Finite Difference Method for Flow in a Fuel Cell Bipolar Plate

*Heat and Mass Transfer:*
Module 12: Conduction and Convection Heat Transfer
Module 13: Microscopic Balances Applied to Fuel Cells
Module 14: Diffusion Coefficients for Fuel Cell Gases

*Kinetics and Reaction Engineering:*
Module 15: Tafel Equation and Fuel Cell Kinetic Losses
Module 16: Hydrogen Adsorption and Catalyst Surface Coverage

*Separations:*
Module 17: Hydrogen Purification
Module 18: Air Separation for Coal Gasification
Module 19: Hydrogen Production by Electrolysis with a Fuel Cell
Module 20: Hydrogen Production by Natural Gas Assisted Steam Electrolysis

Module development is underway for modules for courses in mechanical engineering (courses include: Heat Transfer, Failure of Material in Mechanics, Principles of Energy Conversion, Internal Combustion Engines, Combustion and Air Pollution, Metal Forming Processes, and Nonlinear Systems Analysis and Control) and electrical engineering (courses include: Circuits and Instrumentation, Electric Energy Systems, and Introduction to Motor Drives).

Task 4. 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.

**University of North Carolina Charlotte**

Objectives

The HFCT program at the University of North Carolina Charlotte is designed to serve the needs of students intending to enhance their education from the Associate of Science or Associate of Arts level, of undergraduates entering UNCC directly and wishing to pursue a degree in HFCT, or of current professionals wishing to advance their technical skills to meet the needs of the future technology in HFCT. The program includes the development and delivery of undergraduate courses in the Engineering Technology Department within the ABET accredited Bachelor of Science in Engineering Technology program. The mode of course offering is both in class and on line, which will increase the number of students in the program.

The HFCT program takes advantage of UNCC's geographic location, HFCT-related companies, and local governments that are in need of HFCT professionals in the area. The program also helps address the growing need for properly trained workforce in the HFCT field. The curriculum includes courses on technical writing, project management, and administration. Also, there are courses which require team efforts. All of the required courses for the HFCT program will be taught at the main campus and on-line. This allows access by non-traditional students to a quality program. The program will use industry experts in the HFCT field in some of the courses to provide the latest developments to students. This supports UNCC's emphasis on academic diversity. The HFCT program will build on the strong, relevant undergraduate education, and will foster many partnerships, locally, nationally, and internationally.

The program includes an evaluation process, which engages multiple perspectives, uses a wide range of qualitative and quantitative methods, and triangulation procedures to assess and interpret a multiplicity of information. The focus of the evaluation at the end of each year is on summative outcome measures based on the stated program objectives plus formative feedback for the following year.

In addition to supporting the missions of the College and University, the implementation of this program will strengthen UNCC by helping to accomplish the following goals: offer the best undergraduate education, achieve international prominence in key programs of graduate study and research, provide international focus to the curricula and research programs, become more inclusive and diverse, and be leading partnership university.

Curriculum, Course, and Laboratory Descriptions

Currently, UNCC's Bachelor of Science of Engineering Technology is accredited by the Technology Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET) (111 Market Place, Suite 1050, Baltimore, Maryland 21202 - Telephone 410/347-7700). The new HFCT concentration will be a part of the accredited program. The Bachelor of Science in Engineering Technology – Hydrogen and Fuel Cell Technology (HFCT) Concentration Program curriculum consists of the following components:

| Credits: | |
|---|---|
| General Education | 36 |
| Lower Level Courses | 24 |
| Required Core Courses | 27 |
| HFCT Core Courses | 30 |
| HFCT Technical Electives | 11 |
| Total | 128 |

The Engineering Technology – HFCT Concentration Program first requires that 36 hours of the General Education Program be completed, along with certain specific required courses (College Algebra or Math for Calculus, Approved Programming, Economics, Physics, General Science, Communications, Cultural and Historical, and Social Foundations courses). This includes 24 hours of lower level technical courses, which is important for students in order to learn the basics concepts of HFCT.

After students have acquired the general education and lower level technical courses, they will then be required to take the 27 hours of the Core to satisfy Engineering Technology degree requirements since HFCT is a concentration in the program. Then 30 hours of HFCT core courses are required. The major HFCT courses are:

- H2 I - Physical Hydrogen Storage and Handling — 3 Credit Hours
- Fuel Cell Technologies I — 3 Credit Hours
- Fuel Cell Technologies II — 3 Credit Hours
- H2 II – Hydrogen Production — 3 Credit Hours
- Thermo-Fluid-Heat Transfer Topics in HFCT — 3 Credit Hours
- Energy Management — 3 Credit Hours
- Analysis of Renewable Energy Systems — 3 Credit Hours

Upon completion of these courses, students will choose four additional courses from a list of technical electives in order to gain their specialization skills. It is critical to note that every one of these courses is highly critical in the training of quality graduates as they all address a broad range of diverse learning objectives unique to this program. In order to ensure that the graduates are aptly prepared for employment, students coming into the program with A.S. degrees are required to take the upper level coursework shown above.

The following is a description of the core HFCT courses:

- Hydrogen I: Basic concepts and principles of hydrogen technologies to include chemical and physical properties, concept of a hydrogen economy and applications, and fundamental technologies for understanding hydrogen safety, storage, production and delivery and transport.
- Fuel Cell I: Basic concepts and principles of fuel cell technologies to include basic chemical and thermodynamic properties as applied to fuel cells, basic electrochemistry concepts of fuel cells and undserstanding cell components, materials properties, processes and operating conditions.
- Hydrogen II: Fundamental understanding of hydrogen storage and production technologies. Topics include chemical and mechanical fundamentals as applied to hydrogen storage and production, industrial processes for manufacturing hydrogen storage options, industrial processes for producing hydrogen from fossil, nuclear and renewable feedstocks, fundamental technologies for hydrogen safety, standards and codes and appreciate the use of hydrogen in the future world economy.
- Fuel Cell II: Fundamental understanding of fuel cell technologies stack design, modeling, diagnostics, system design and applications. Topics include basic principles of fuel cell stack operation, industrial processes for manufacturing fuel cells, basic modeling and diagnostics methods, system level issues for different applications and ppreciate the use of fuel cell in the future transportation applications.
- Analysis of Renewable Energy Systems: Higher level course looking at system analysis of renewable energy systems: Well-to-wheels analysis, lifecycle energy and emissions, total cost, skill sets, methodologies and tool kits needed to analyze various technologies on a consistent basis for a given application.

Program Accomplishments

The HFCT program has started in Fall 2008, since then the program has successfully attracted students from exisiting programs as observed from course registration records and direct contact with HFCT faculty. For example, for the first time offering of the Analysis of Renewable Energy Systems course the number of registered students reached 24 students. Currently, four faculty members are directly involved in the HFCT program as course and lab instructors. Several lab experiments have been developed including six hydrogen labs and six Fuel Cell labs. The hydrogen labs include: Lab Safety and Gas Cylinder Safety & Handling, Instrumentation – Gas Chromatograph (GC), Instrumentation – Thermo Gravimetric Analyses, Material Balance (calibration of mass flow controller & humidifier), Characterization of Chemical Hydride Materials, Hydrogen Liquefaction Experiments and Hydrogen Production Student Project. The Fuel Cell labs include: Instrumentation, Fuel Cell Chemistry and Efficiency, Electrochemistry, Fuel Cell Components and Assembly, Operating Conditions (pressure, temperature, humidity, flow rates) and Diagnostics.

At UNCC, in Spring 2010 we are offering the ETGR3000-001 Analysis of Renewable Energy Systems where 21 engineering and engineering technology students are taking the course. We are planning to offer the ETGR3000-002 Hydrogen I course in Summer of 2010 and we expect that 14-22 students will take the course. In the Fall of 2010, the ETGR3000-003 Fuel Cell I course will be offered to both graduate and undergraduate students and we expect to have 18-26 students. The Hydrogen II and Fuel Cell II courses are still in the approval process but we expect to have about 20 students in each course. All courses mentioned above will be offered to students from engineering, engineering technology and other departments. There are plans to offer certificates in HFCT in the future but they are still in the approval process.

In summary, a program focused on HFCT in Engineering Technology Department at University of University of North Carolina Charlotte is developed. The HFCT Program intends to support the need for educated graduates that comprise the next generation workforce needed for research, development, and demonstration activities in government, industry, and academia. The program includes the development and delivery of undergraduate courses within the ABET accredited Bachelor of Science in Engineering Technology program. The mode of course offering is both in class and on line, which will increase the number of students.

**University of North Dakota**

Objectives

The University of North Dakota (UND) has developed a strong research program in sustainable and renewable energy. SUNRISE (SUstainable eNergy Research, Infrastructure, and Supporting Education), UND's sustainable energy initiative includes a focus on hydrogen. UND developed a PhD program in Energy Engineering in 1992 to take advantage of the strong interest in energy within the School of Engineering and Mines (SEM) and UND's Energy & Environmental Research Center (EERC). Through this program, UND has been able to attract high quality students whose primary interests are in sustainable and renewable energy. Departments within SEM have developed energy related courses that are taught at both the undergraduate and graduate level, and SEM has developed a hydrogen laboratory focused on PEM electrolysis and fuel cell research, education, and applications.

UND has taken advantage of existing infrastructure and programs to provide a comprehensive renewable hydrogen production and fuel cell education program in support of DOE's Hydrogen Education Program. UND's program is designed to provide multi-discipline formal training to both undergraduate and graduate level engineers and scientists. This is being accomplished by developing case studies that are implemented into classes through all four years of the undergraduate curriculum. Two new classes 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 allows off campus students to obtain an ABET EAC accredited undergraduate engineering degree. Several new hydrogen-related student experiments were added to our undergraduate laboratory sequence to provide hands-on experience for our students. Additional hands-on experience is available to selected students through our on-going research at UND, and through summer intern programs. A hydrogen seminar has been added, brining in experts to present to UND students.

The objective of this project is to develop a comprehensive 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.

Curriculum, Course, and Laboratory Descriptions

*Development of Case Studies:* Faculty buy-in is important for implementation of case studies in a broad spectrum of classes. Case studies were outlined and reviewed with course instructors. Those to be implemented in the Chemical Engineering program were reviewed with the entire faculty during their Annual Assessment and Curriculum Review Retreat. Initial work focused on development of three new case studies targeting freshman introductory engineering courses; the sophomore mass and energy balance course; and junior-level chemical engineering thermodynamics. Once these case studies are fully developed they will be broadly disseminated though the National Center for Case Studies in Science Teaching web site.

*New Course Development:* Several courses in renewable energy technologies are offered including Methods of Hydrogen Production and Storage through the chemical engineering department, as well as an electrical engineering elective titled Renewable Energy Systems. Both are open to upper level undergraduates and graduate students and both feature fuel cell education. Topical areas cover include "why hydrogen" followed by sections on hydrogen production form fossil fuels and biomass, hydrogen from water, and hydrogen distribution and storage. The fundamentals of electrolysis and fuel cells are discussed, followed by implementation and the long-term perspective on the future of hydrogen as an energy carrier. Rather than teaching from a single text, the courses utilize a variety of documents available from DOE, IEA, and various publishers. This exposes students to the most current literature available on the subject, and allows the instructor to be more selective in material presented.

UND has encouraged the development of hydrogen-based projects for the senior capstone design. 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. 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. The goal of a second project, Combining Alternative energy Power Sources (CAPS) project was to combine and control the output of unregulated direct current (DC) sources such as fuel cells into a single regulated output to match 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 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 converted back into a single DC output.

*Laboratory Experiments in Hydrogen: S*tudents from ChE 332-Chemical Engineering Lab III and EE 552-Renwable Energy Systems performed experiments using the 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 I-V 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.

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 Masters student has been developing a set of laboratories that will be implemented in to the undergraduate curriculum during the 2009-2010 academic year. Details of this equipment are discussed in another paper presented at this conference.

*Summer Internships:* Undergraduate students have been placed for internships as the Energy & Environmental Research Center's National Center for Hydrogen Technology. These internships provide students with in-depth hands-on experience in various aspects of hydrogen production and/or utilization.

*Hydrogen Seminary Series:* Nilesh Dale, currently with Nissan's Fuel Cell Laboratory presented as seminar entitled "Characterization of PEM Electrolyzer and PEM Fuel Cell Stacks using Electrochemical Impedance Spectroscopy". This seminar focused on new techniques to characterize the performance of electrolyzers and fuel cells. UND students with an interest in hydrogen also attended the technical sessions of the UND Energy & Environmental Research Center Hydrogen Summit free of charge.

Each of these educational offerings provides increased student exposure to hydrogen technologies. In addition to the specific activities focused on expanding the educational opportunities for students specific to hydrogen, an undergraduate concentration and a master's program in Sustainable Energy Engineering have been established.

**Conclusions**

As a result of DOE funding, HFCT has made significant progress toward our goal of establishing effective HFCT programs. The programs have demonstrated a variety of approaches taken to developing HFCT curriculum, which range from designing short modules for existing courses to dedicating majors and minors to the topic. HFCT is introduced to a wide spectrum of disciplines such as technology and chemical, mechanical, electrical, and environmental engineering.

Industry support and collaboration have facilitated student learning. In addition, wider university audiences and general public have been introduced to HFCT through grant related activities. Funding under the grant will continue for another year and a half. During that time the teams will make progress toward meeting the goals of individual programs.


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