Session 2325

An Interdisciplinary Capstone Design Project in Fuel Cell Development

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Abstract

Since 1996 the University of Washington has maintained an interdisciplinary capstone design project to develop proton exchange membrane fuel cells running on hydrogen and air, along with their applications. Currently, the project involves about 20 chemical and mechanical engineering students. Work is divided into three main areas of fuel cells: development, applications, and manufacturing. Fuel cell development involves fabrication and characterization of individual fuel cells and assembling these together into stacks of up to 40 individual cells. The applications group develops design specifications for the intended applications, which include a 1/3 scale locomotive, modified SAE car, and portable devices such as radios and laptop computers. The manufacturing group investigates cost saving means for producing fuel cell components, especially the membrane electrode assemblies and flow field plates.

To date the students have succeeded in developing a single fuel cell with performance specifications of 0.25 A/cm^2 at 0.6 V, which is within a factor of 2-4 of current industrial standards. Stack development is currently underway. The locomotive and two passenger coaches have already been constructed. The locomotive, which will require a 10 kW fuel cell, rides on 18 inch gauge track and has a 100 V, 13 hp electric motor.

I. Introduction

Today's engineers need to function efficiently in interdisciplinary groups on a daily basis. They still need to specialize in a certain area, but they must also communicate and work efficiently with other group members. Working in interdisciplinary design groups gives students the opportunity to develop those personal and teamwork skills.

The interdisciplinary design experience demands a personal element from the engineering student, who must sort through often confusing and sometimes misleading data in the process of designing a working device. Through participation in an interdisciplinary project that requires a variety of students and their unique talents to design and build a real, complex machine. The students can gain an appreciation of the necessity of working in groups and learn how to do it efficiently.

This paper describes an interdisciplinary project in fuel cell design that has been offered at the University of Washington since 1996. The paper will focus on the skills learned by the students, course design and organization, and how to overcome problems associated with offering and institutionalizing a large interdisciplinary capstone design course.

Why the Fuel Cell Locomotive Project?

Electrochemical fuel cells, or commonly fuel cells, hold the promise of efficient, quiet and pollution-free power generation with wide applicability. Fuel cells have powered all U.S. manned spacecraft except for Mercury, and are the leading energy source for the Partnership for the Next Generation Vehicle (PNGV) sponsored by the Department of Energy and the big three automakers. A number of fuel cell companies, such as International Fuel Cells, Ballard Power Systems, DaimlerChrysler and Siemens have transportation fuel cells in the prototype or near prototype stages.

Except in special cases like spacecraft, today's fuel cells are outperformed by the energy converter they seek to replace, whether it is an internal combustion engine for automobiles or a fossil-fueled electrical generator. However, fuel cells promise great improvements in energy efficiency, by a factor of two to five, over traditional power sources based on heat engines. They achieve the multiple goals of converting energy resources and reducing pollution, emission of greenhouse gases (carbon dioxides and water), and waste heat.

With advantages like these there is little doubt that fuel cells will find their way into the market place in the very near future, perhaps as little as five years from now. It is not an overstatement to say that fuel cell technology will revolutionize fixed and portable power generation as much as the internal combustion engine did more than a century ago. The social and economic benefits of fuel cell related jobs and consumer products based on fuel cells promise to be tremendous.

In addition to the social and economic appeal of the fuel cell we are also drawn to it for interdisciplinary technical reasons. The technical challenges in fuel cell technology encompass a wide range of engineering disciplines. Advances in issues like manufacturability, durability, control, recycling, cost, and safety are needed before fuel cells become common items in every day life.

The history of technology has shown that coupling the energy source to its application is an essential element of success, as in the locomotive, car, airplane, and even the pacemaker. Once that is done, the task of customizing a fuel cell to another application; such as a car, wheelchair, or portable computer is relatively straightforward. On the basis of its broad emotional appeal and technological challenge, we have chosen a fuel cell powered locomotive as our first venture into fuel cell engineering. This is an ideal project for integrating faculty and students of all engineering disciplines to build a device of practical importance and with challenges that go beyond the application as well.

Trains appeal to most everybody's emotions. From a technical standpoint trains are the most efficient form of transportation over land. Combining the most efficient transportation with the most efficient energy converter appeals to the engineer's sense of elegance.

II. Project Goals

Technical Goals

The original goal of this project when it began in the Autumn 1996 was to build a fuel cell powered train capable of carrying about ten people around a loop somewhere on campus during Engineering Open House. This event takes place every second year and attracts a large amount of people to the College of Engineering and it departments. This goal was made more specific by the students during the first quarter. It was decided that the train should consist of one locomotive and two cars capable of riding on 18 inch gauge track. This is approximately one third the scale of a real locomotive, which runs on 54.5 in gauge track. The loop of track should be an oval at the center of campus around a large fountain. The power requirement was computed to be 10 kW (13 hp) assuming a top speed of 7 mph on an oval track laid out at the center of campus. These design goals remain unchanged today.

At the beginning of each new quarter students familiarize themselves with the project by reading the final reports of the previous quarter. The students are divided into groups along their interests and skills and the goals of the coming quarter are discussed. Each group then submits a written proposal outlining the goals of the quarter for faculty approval. The specific goals for a quarter thus depend on the number and distribution of students from the different engineering departments, the progress of past quarters, and the interests of the students.

Educational Goals

The focus on the fuel cell locomotive presents a goal-oriented design to the student. The goal, which is a real engineering system, requires students to have a firm understanding of fundamental concepts and how things work. Students must integrate their classroom instruction as well as their experiences and work within teams to achieve that goal. The history of technology shows that goal oriented design is the most effective, illustrated by Watt's steam engine, Edison's electric light and the Wright Brothers' airplane. In a sense the goal-oriented design constitutes a return to the elements of engineering education, except that the students retain and use their engineering science background obtained in the classroom [1,2].

The fuel cell project gives students the opportunity to work in truly interdisciplinary groups on a complex project. These groups of 2-5 students work on specific parts of the project, yet each group coordinates its activity with the others. The student groups work under direction of an interdisciplinary faculty drawn from five departments of the College of Engineering. The interdisciplinary approach means that different aspects of the project manifest themselves in different and sometimes surprising ways to students and faculty. For example, the drive train designed by mostly mechanical engineers must work with the motor and controls designed by the electrical and mechanical engineers and the fuel cell and related systems designed by the chemical, mechanical, and materials science engineers. From this perspective, one accomplishes the system engineering task only through an interdisciplinary approach.

Faculty/student interactions are the fulcrum for these activities. The most successful designers often cite a personal element, such as some idea of their own coupled with classroom work or personal experience, as fundamental to their approach. Close interactions between faculty and students encourage such personal responses and thus offer a greater likelihood of success. This approach is not new, of course. It constitutes the tradition of apprenticeship in which the student learns a craft or trade with the master [3]. The “apprenticeship” model of design instruction requires that faculty spend more time with the students and actually contribute to the design process themselves. Thus, students learn by example from the teacher just as the teacher learns design instruction by actually doing it. The faculty time requirements of this model may appear unreasonable at first, but consider that the non-contact time spent preparing lectures and grading student’s reports (typically six hours per student credit hour) could perhaps be better spent in direct interaction with the students. The students certainly appreciate it.

A final point with respect to educational goals is distinguishing different kinds of design. Most engineers are taught “constrained design,” whereby a part or process is designed for lowest cost. If design is defined as the solution of problems with insufficient information, then this form of constrained design is not design at all, rather, it is mapping out the cost function of all possible solutions. The higher forms of design, and those involving the most creativity, can be called “loosely constrained design” and “unconstrained design.” A loosely constrained design relies somewhat on cost, and is most useful in developing replacement technology. Examples of loosely constrained design include the electric light (to replace gas lights), the transistor (to replace vacuum tubes), and compact discs (to replace records). Unconstrained design involves the solution of a problem where no solution existed before. Thus, cost is irrelevant. Examples of unconstrained design include the steam engine, airplane, and many drugs. The fuel cell locomotive project involves all three types of design: the project itself qualifies as unconstrained design, development of lower cost fuel cells requires loosely constrained design at several levels, and staying within budget requires constrained design.

Relationship of Educational Goals to Engineering Education

The educational goals outlined above correspond well with those of the American Society of Engineering Education (ASEE) [4]. Of the 15 action items in that report the fuel cell project relates to 4. The most important of these, reexamination of curriculum includes 12 subtopics, of which 8 bear directly on the project. The relevant action items and subtopics are:

1. a strategic plan
3. faculty awards
4. reexamination of curriculum, including
    a) team skills
    b) communication skills
    c) leadership
    d) system perspective
    e) integration of knowledge through out the curriculum

f) multi-disciplinary activities
g) undergraduate research and engineering work experience
h) societal, economic, and environmental impact
14. resource sharing.

Serving as a case study, the Fuel Cell Locomotive Project is an example of a possible future engineering educational paradigm that could be incorporated into a strategic plan. The issue of faculty rewards arises because the fuel cell project and other like it do not necessarily qualify as primary teaching responsibility; for the most part faculty work on the project is uncompensated.

Public Outreach

The fuel cell locomotive project is a project with very high potential for public outreach. First, having students work on what is really the cutting edge of a new, environmentally friendly form of energy generation is an exciting idea by itself. Coupling that with the romantic appeal of a locomotive has captured the imagination of the public.

Second, the potential for growth in the fuel cell engineering translates directly to entrepreneurship and growth in related jobs, employing the students themselves after college. There is a strong industrial demand for engineers trained in the art of fuel cells, coupled with high student interest. Over 10 of our students have so far been employed by the fuel cell industry.

III. Project Organization and Description

Student Participation

Student recruiting and retention is strongly affected by their department's policy with respect to the project. Chemical engineering students register for the course (Chem E 497) and are asked to commit three quarters at three credits per quarter to the project. In return, five of these credits may be used in place of their second capstone design course. Students apply for the project by submitting a listing of courses completed, courses yet to take, major time commitments, and a one page essay stating their motivation for working on the project, the skills they have to offer, and their assessment of the major challenge of the project. Grades are not used for admission.

Mechanical engineering students work on the project by enrolling in their mechanical engineering capstone design course. The mechanical design course has long been in existence and allows the students a wide choice of design projects, so the fuel cell project was easily accommodated in the curriculum. It is now one of several projects the mechanical engineering students can choose from when signing up for the required capstone design course. A year involvement in the project is encouraged (but nor required) and it is accomplished by the students taking two quarters of independent project after the capstone design course. The total number of earned credits for three quarters of work ranges from 9 to 11.

Material Science and Engineering and Electrical Engineering students have so far used independent project course credits when they enroll in the project. The future goal is that they also will be able to use their capstone design course in the same way as the Mechanical engineering students.

Organization of Student Groups.

Figure 1 shows a group organizational chart in which the interdisciplinary nature of the project is depicted by the large outer circle and the intradisciplinary connections are shown by the interior lines. The primary student groups are the Single Cell and Stack Engineering groups, the Chassis and Drivetrain groups, and the Motor Control Group. The functions of each group will be discussed next.

Single Cell Group

The responsibility of the Single Cell Group is to determine the proper catalyst formulation and preparation to achieve optimum performance of a single fuel cell. The design goal for a single cell is a current density of 1A cm^{-2} at a cell voltage of 0.6 V. Over the project this group has faced a tough challenge as the current densities at the beginning of the project were less than 1 mA cm^{-2}. The single cell group has typically been made up of a mixture of 4-5 chemical engineering students and 1-2 mechanical engineering students.

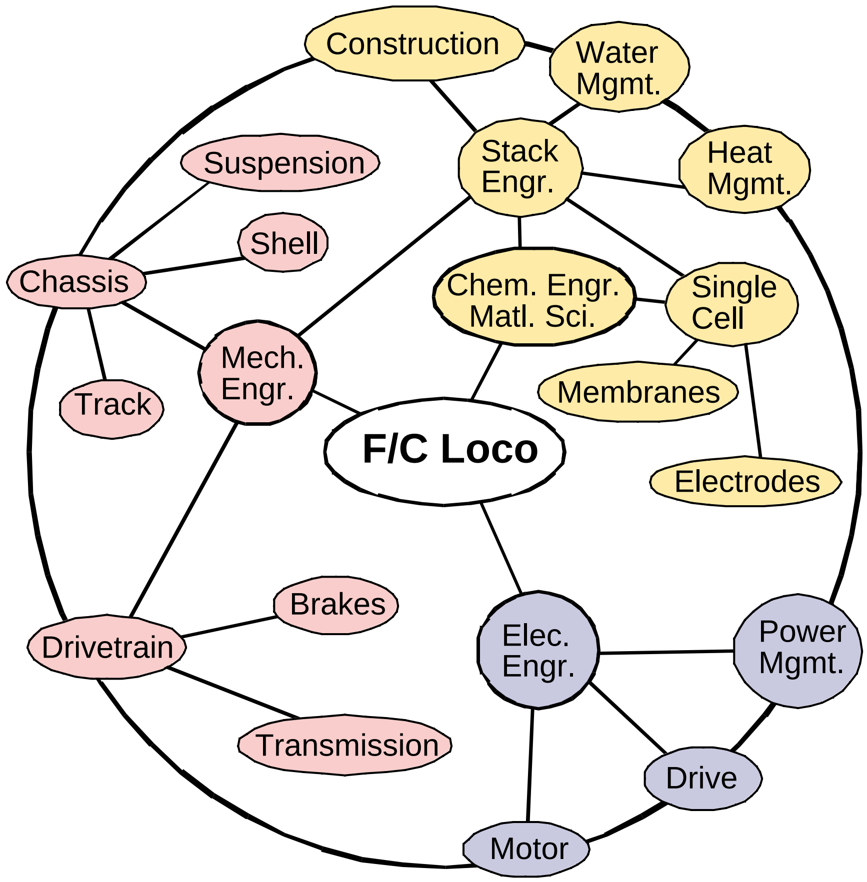
Stack Engineering Group

The Stack Engineering group is charged with grouping the individual cells together to form a fuel cell stack capable of 100 A at 24 V. This requires nominally 36 cells in series with each cell having an active area of 10 x 10 cm^2. The Stack Engineering Group has been responsible for the design of the hydrogen and air flow systems, water management system, thermal management system, material selections, and considerations of manufacturbility of the fuel cell. This group has always been an interdisciplinary group with a mixture of mechanical and chemical engineering students (typically with the mechanically students in majority). The group has also had extensive interdisciplinary interactions with the Chassis and Motor Groups. The fuel cell stack and related components must fit onto the locomotive chassis, and the current/voltage characteristics of the stack must be matched to the motor and the controller.

Chassis Group

The Chassis group designs the locomotive and passenger car frames, suspension, and steering systems. They are also in charge of track design and selection. An important issue for this group is the interaction with the Stack Engineering Group. This group is responsible for making sure that the fuel cell stack can fit onto the locomotive chassis and that the system can operate in an absolutely safe fashion. Hence, ventilation and fail safe systems considerations are of paramount importance to this group. Close interaction with the Drivetrain group is also necessary to design and position the drivetrain components. The Chassis group is typically made up of entirely mechanical engineering students.

Drivetrain Group



The Drivetrain Group designs the motor mounts, transmission, and the braking system for the locomotive and the passenger cars. The group interacts closely with all other groups for

Figure 1. Organizational chart for the Fuel Cell Locomotive project. The outer circle shows interdisciplinary relations and the straight lines show intradisciplinary relations.

coordination of issues concerning the motor and its mounting, reduction gearing, and fuel cell safety systems. The group has always been staffed with mechanical engineering students.

Motor Group

The Motor Group designs the motor and electronic control unit for it. The torque/rpm characteristics of the motor must be matched to the voltage/current characteristics of the fuel cell. In addition, the controller will also include a lead acid battery system to supplement the fuel cell during peak power requirements. In off-peak operation the fuel cell will then be used to charge the battery system. The Motor groups interacts with both the Stack Engineering group, for coordination of the fuel cell output and motor requirements, and the Drivetrain group. Until now only mechanical engineering students, who were also enrolled in the department's Mechatronic thrust area, have been active in the group.

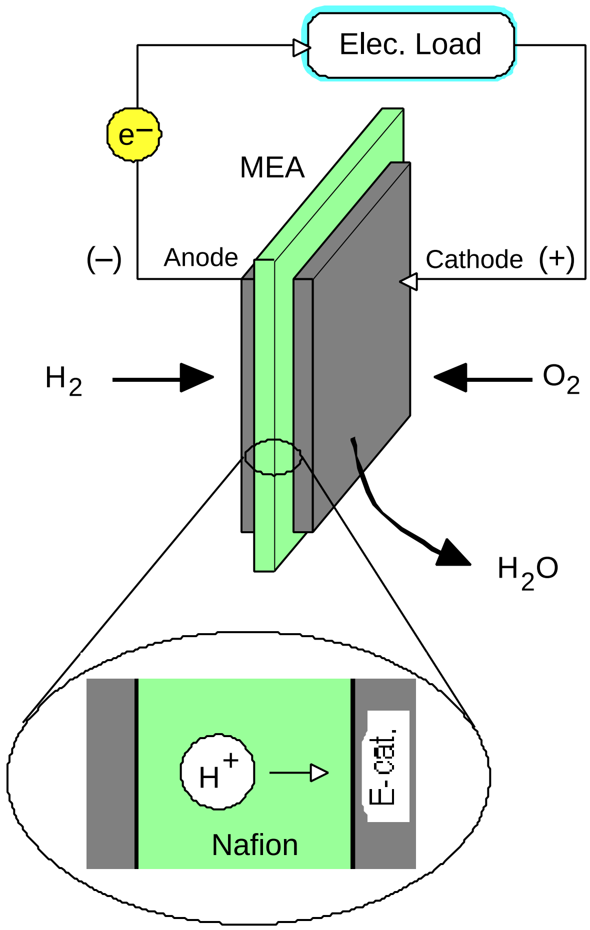


Figure 2. Schematic of solid polymer electrolyte fuel cell.

IV. Accomplishments and Project Status

Fuel Cell

Solid polymer electrode (SPE) fuel cells were chosen for this project on the basis of their simplicity and low temperature operation (80 ^{o}C). Figure 2 shows a schematic of the fuel cell. The solid polymer electrolyte is a perfluorosulfonic acid (Nafion) membrane, which is proton conducting when fully hydrated. Electrocatalyst layers of platinum supported on carbon black are coated onto each side of the membrane to form the membrane electrode assembly (MEA). The MEA itself constitutes the fuel cell; when exposed to hydrogen on one side (the anode) and air or oxygen on the other (the cathode), the cell will develop electricity through the reaction

$$H_2 + 1/2\, O_2 \longrightarrow H_2O.$$

The maximum electrical energy available comes from the free energy change of the reaction, which is 237 kJ per mole of hydrogen at room temperature. The thermodynamic cell voltage is 1.23 V, but nonidealities in the fuel cell and related components result in lower outputs, which become most severe under high loads. In practice, the minimum acceptable cell voltage is 0.6 V, which corresponds to an electrical efficiency of 50%, still considerably higher than heat engines. The unrealized energy is converted to heat that must be removed from the cell. Present technology allows current densities of 1 A cm^{-2} of electrode area at 0.6 V to be achieved with Nafion membranes and even higher values with more specialized membranes [5].

One of the main technological challenges in making fuel cells consists of finding the right procedure for preparing the MEA. The electrocatalyst is composed of Vulcan XC 72-R carbon black powder with 10% (by weight) platinum nanoparticles dispersed on the powder. The electrocatalyst layer is prepared as a mixture of the carbon/platinum powder with binder of solubilized Nafion and a solvent of isopropanol and other alcohols. The mixture is, in fact, an ink, and is applied by an air brush in an adaptation of the Gottesfeld "paste-ink" method [5]. Following application it is then treated with high temperature drying and pressing steps to evaporate the solvent and set the binder. Thus, optimization of the MEA preparation procedure is a complex task itself.

Two operational fuel cell testing stations have been built, one for the Single Cell group and the other for the Stack Engineering group. Both test stands benefit from a number of previous versions that were themselves developed and superseded during the first year of the project. Figure 3 shows a schematic of the stack test stand, which is similar to that of the single cell stand. Hydrogen and air are supplied from pressurized cylinders, humidified by passage through heated water tanks, and sent to the fuel cell anode and cathode, respectively. A recirculating water loop allows for preheating the fuel cell. Both the single cell and the stack stands have flow field plates for directing gas flow over the MEA. A nitrogen purge system allows for complete and safe shutdown of the fuel cell.

The fuel cell performance of the student's latest single cell design operating at 80 ^{o}C is shown by the polarized curve in Figure 4. While the current performance of approximately 0.23 A/cm^2 at 0.6 volts is significantly below our current design goal of 1 A cm^{-2} it represents more than two orders of magnitude improvement over when the students did their first test. Future work will be devoted to improving our fuel cell performance.

The Stack Engineering group has designed and is currently manufacturing a fuel cell stack, a schematic of which is shown in Fig. 5. The flow field plate (FFP), which is made of polymer impregnated graphite, is the main component responsible for proper stack function. It directs the flow of humidified gases (hydrogen and air) over the electrocatalyst layer with the desired flow rate and pressure drop. Further, it assists in the removal of product water from the cathode, conducts electricity between single cells, and conducts waste water heat to cooling plates (not shown) positioned throughout the stack. The alternating arrangement of flow field plates and membrane electrode assemblies are compressed together to make up the stack. In our latest design each system is designed to consist of 40 single cells of 100 cm^2 area each. Thus the stack will have an output of 22 Amps at 24 volts at the current performance level. Fig. 6 shows a photograph of a recent stack.

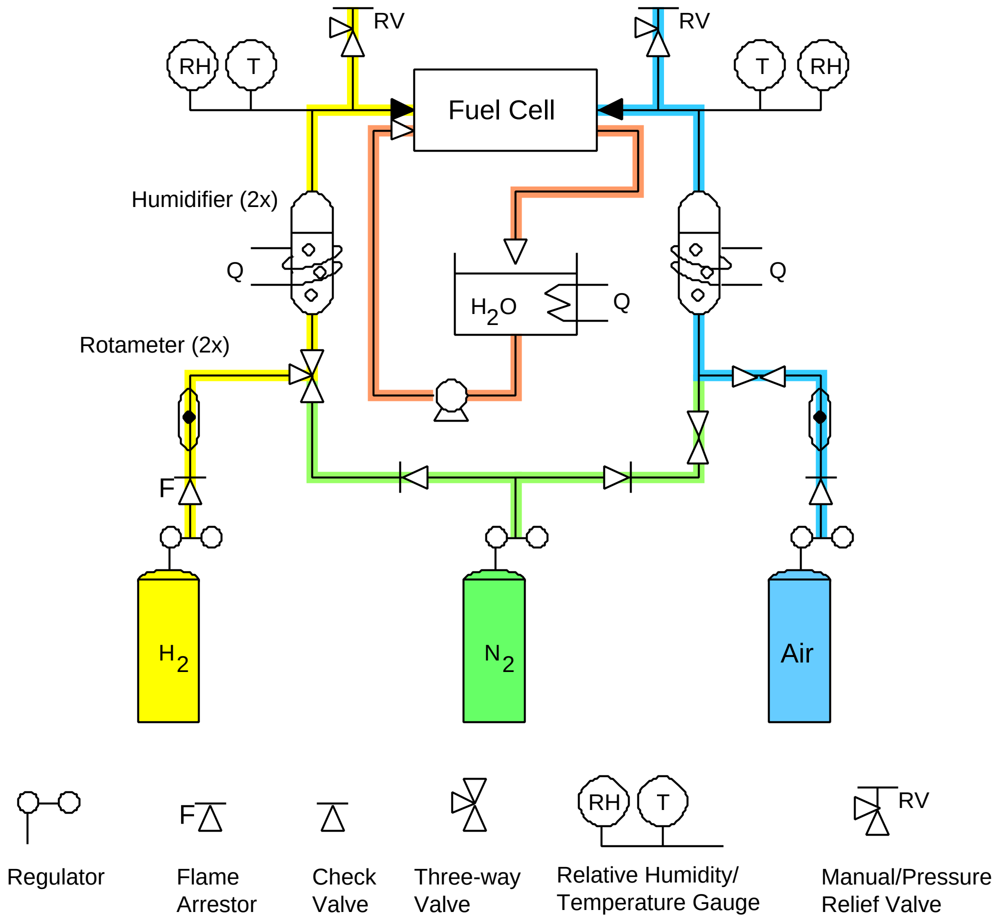


Figure 3. Schematic of test stand.

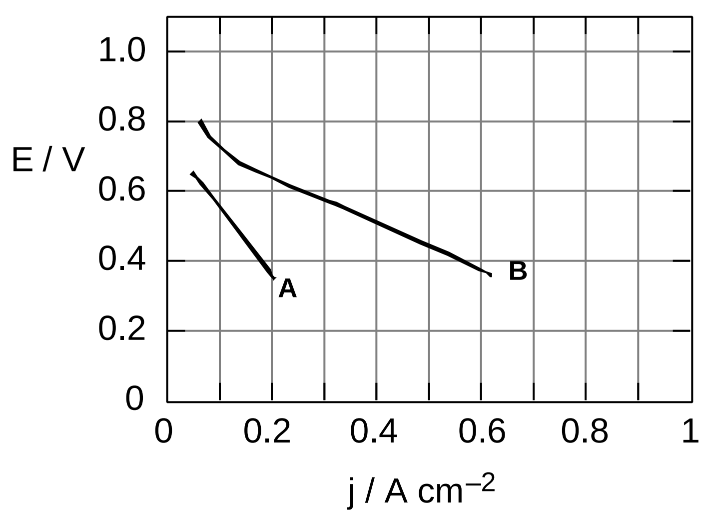


Figure 4. Polarization curve for the single cell: (A) non-optimal flow field plate; (B) serpentine flow field plate. Other conditions: Hydrogen/air: 10 psi; Temp.: 40 °C.

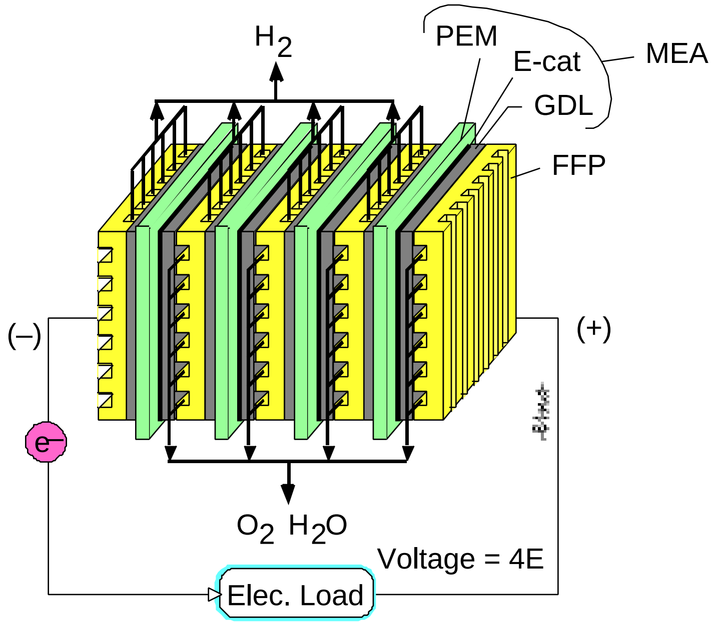


Figure 5. Schematic of four-cell stack.

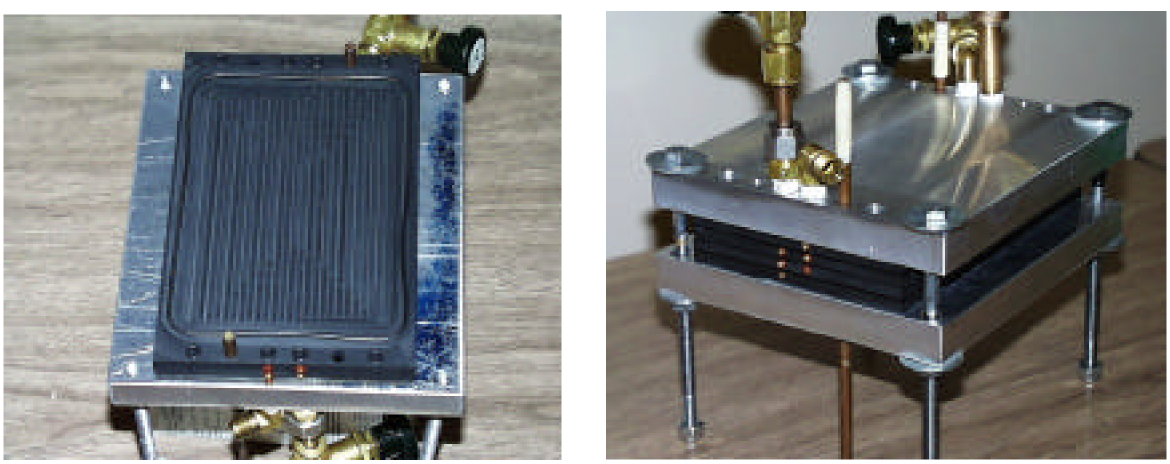


Figure 6. Photographs of recent stack work. Left: a flow field plate. Right: assembled stack.

<u>*Rolling Stock*</u>

Designs for the rolling stock (locomotive and passenger cars) have been completed. The locomotive construction is almost finished. Remaining tasks include some fine-tuning of the brake system and cosmetic work. The locomotive has room for the fuel cell itself, all the related fuel/cooling systems, air compressor, and the hydrogen fuel tank. Power will be initially delivered by a single 96 Volt DC motor rated at 5kW. The plan is to replace this motor with a 200 VAC motor rated at 5 kW to make the system more efficient. Power is delivered to the front and rear axles through flat ribbed belts. Two, open air passenger cars have also been built. Passengers will ride on simple benches in the car. Each car holds four to six passengers. All the passenger cars and the locomotive have brakes have on all axles. The brakes are adapted motorcycle disk brakes. The brakes are activated through a proportioning hydraulic system in which proportioning valves at each coupling determine the amount of braking pressure to each car. A loss of hydraulic pressure will cause automatic application of the brakes.

Track

Several track configurations have been investigated for the train. The most involved is a loop around a green area and a large fountain. This loop poses a challenge in that in places it has a rather steep climb (5% grade). The drivetrain, the motor system, and brakes have been designed so that the locomotive can carry a full load around this loop. Standard amusement park track will be purchased and held by wooden ties.

V. Safety

With the presence of hydrogen, safety is of primary importance. It is essential to avoid mixing hydrogen and air at any time. We have developed a number of nitrogen testing procedures to insure against internal leaks. Hydrogen cannot be treated like other flammable gases (such as natural gas) because of its unusual flame properties. Backflashes are a real danger since hydrogen burns with a flame velocity ten times faster than that of natural gas and has a minimum flame diameter of 0.3 mm, almost one-tenth that of natural gas (2 mm). A high speed flash arrestor is placed on the hydrogen tank. A custom designed burner has been developed by the students to flare off purged hydrogen gas without having the risk of backflashes.

We realized from the beginning that safety needed to be our highest priority. The safety of the participating students and the rest of the university community can, of course, never be compromised. Implementing safety in a large-scale, multi-year senior design project is a difficult challenge. The first action was that each group had to write standard operating procedures (SOPs) for each experiment and equipment that was designed. These SOPs had to be clearly written and fully explain how to handle an emergency situation. All SOPs are now located in well marked locations in the laboratories. No activity can take place in the laboratory without the students indicating on a checklist that they have read the relevant SOP.

Students who are exploring, designing, and building are typically eager and tend to be in a rush. This might be good for getting things done but compromises safety. The tendency is to try the latest idea to see if it works or to try to finish before a report deadline. To avoid this students are told at the beginning that there are no deadlines. They are not judged on how much they get done. They are judged on how well they function in the design group, on the procedures they use and how well documented their activities are in their lab books. No experiment can be done until it has been checked for safety by a faculty member. Dry runs must always be conducted with nitrogen in order to detect leaks before an experiment involving hydrogen can be conducted.

The constant addition of new students to the project also presents a safety risk. In order to overcome this we require that the new students each quarter read all the SOPs that relate directly or indirectly to the activity of their group. New members must also have at least one experienced member present when conducting an experiment. All members are also asked to use their notebooks to document how the safety is incorporated into their activities.

VI. Student Development

Team skills

The ability to work efficiently as a team is continuously emphasized. Each engineering group meets regularly throughout the week and once a week with a faculty member. The group sets goals for the quarter during the first week of the quarter. Individual tasks and responsibilities are also decided then. A group leader is selected at this time. The responsibility of the group leader includes scheduling, faculty interaction, leading the discussions during the group meetings and coordinating the progress and final reports. It is imperative that all groups function properly for this interdisciplinary project to move forward. The students have, in general, responded very well to this fact. They quickly realize that the only way to achieve the goals is to work together and to keep deadlines within the group.

Interdisciplinary Issues

The interdisciplinary nature of the project is simultaneously its most challenging and interesting aspect. Since primarily chemical and mechanical engineering students have been involved, this project has brought to fore the differences in their respective training. Chemical engineers rarely build something during there academic career, while mechanical engineers are asked repeatedly to build and design systems and components throughout their last two years. The capstone design course in a mechanical engineering department usually gives the students a well organized, hands-on experience leading to the design of functional device or system. The capstone design in a chemical engineering department typically gives the students the opportunity to design an entire chemical plant by computer. This course is obviously of great value, but the designs are not real and lack any hands-on experience.

So it is our experience that the typical chemical engineering student is very good in computer simulations and in analyzing and optimizing processes. The mechanical engineering student is good at designing functional systems and making things. This fundamental difference in educational emphasis causes interesting, but maybe not so surprising, effects when the students are asked to work together. The students choose the path of least resistance. The chemical engineering student wants to do process analysis and the mechanical engineering student wants to design and build things. Left to themselves there would be no interplay and no interdisciplinary work. One can not blame them – they are simply sticking to the engineering flavor that they have been exposed to so far.

We have tried to overcome this problem by encouraging group membership from both departments. The Single Cell Group has always had at least one mechanical engineering student as a member. Similarly, we have made an effort to make sure that the Stack Engineering group is almost equally staffed. But we have observed that more has to be done to overcome the segregation between chemical and mechanical engineering students. First, the individual assignments for each group member has to be "steered" to encourage the student to get involved with issues that might seem slightly uncomfortable at first. Second, to encourage the interdisciplinary aspects of the project and student participation in a wide range of issues all students and faculty meet weekly. These large meetings provide an opportunity for students to see the big picture and to be exposed to the technical issues that are being addressed by the other groups.

Communication and Leadership skills

The project provides amble opportunity for the students to improve their communication and leadership skills. Each group is required to make 2 to 3 oral/written reports each quarter to all students and faculty. The weekly meetings with the students involve short oral reports from all groups that result in lively discussions. All students are encouraged to participate. The importance of participating during the meetings is emphasized by including it in the student assessment procedure.

The students have also presented the project several times at engineering open house, student conferences, and fundraising activities. Other communication activities include the development of web and promotional material to obtain technical and financial assistance from fuel cell companies as well as job placement.

The students are expected to take leadership in their assigned tasks. If they do not do it, the task will not get done and the group and whole project suffer. The students have in general responded very well to this responsibility. Leadership skills are also honed by the many management roles within the project, such as group leader and committee chair (concerning safety, public relations, fundraising, grading policy, open house, and web design).

VII. Faculty Development

Impact on curriculum

Over 80 students have so far participated in the project, and the departments of Chemical Engineering and Mechanical Engineering have institutionalized it as a permanent capstone design course. Fuel cell technology has started to get a more pronounced role in the lower level thermodynamics and material science courses. The goal for both departments is to establish elective undergraduate thrust areas in fuel cell engineering.

After initiation of the project the need for formal training in fuel cell engineering soon became apparent. An elective chemical engineering course (ChemE 445, Fuel Cell Engineering) open to all engineering students was developed in 1998 to fill this need. The course covers the four aspects of fuel cell systems (single cell, stack, system, and safety) using traditional chemical engineering concepts to develop engineering design heuristics. This course is also given by distance learning through televised instruction and over the web with streaming video. In the Spring of 2000 the class was given to 30 UW students and 25 distance learning students. Industrial demand is so strong that the course will be offered twice in the 2000/2001 school year.

Fuel cell research

Creating new courses and additional teaching duties at large research institutions are always met with a certain amount of skepticism among the faculty. Without additional incentives it is hard to motivate faculty over new teaching initiatives. This has not been the case for the fuel cell project. Why? It is because fuel cell engineering is a very active research area with plenty of room for new innovations. So we are in essence establishing a research program with the help of an undergraduate design program. It is a program where the endless stream of seniors is actually expanding the knowledge base to the benefit of the institution and the faculty. Much has been written lately about getting undergraduates involved in research programs. In the fuel cell train program we have taken this a step further: The undergraduates are doing the research to establish the program.

VIII. Course Assessment and Student Evaluation

Course assessment

The primary assessment tool is the student's response to project and their course evaluations. Other assessment tools will be those used for our ABET accreditation evaluation. These include: the progress and final reports, the lab books themselves, an annual faculty peer review of the courses, end of program surveys of the students, alumni/employer surveys, and employer statistics.

Student evaluation

At the end of each quarter there is ample material to evaluate the performance of each group: three oral presentations, progress and final reports, faculty/group discussions, quality of work done, and their safety record. In order to help us evaluate the performance of each student we use: 1) the personal logbook that each student is required to keep, 2) meeting participation, 3) safety record, 4) peer effort evaluations (students evaluate each other's efforts), and 5) peer review (students evaluate each other's characteristics as group members).

One of the most difficult aspects in grading group work is evaluating the contributions of each group member. We have found that the personal logbook is especially helpful in this task. It is easy to spot if a group member is not carrying his or her weight on a team by a rather quick inspection of these books. In addition, we have found them a crucial component of our safety system in that the student needs to record what safety precautions were taken for each experiment. We have also found the peer effort evaluation and peer review forms that were developed by a student/faculty committee for this project useful.

IX. Conclusions

We feel that the project has been a success on several fronts. The students have become excited about fuel cell engineering and the potential benefits of fuel cell technology. The technological challenges in fuel cell engineering are many and cover a wide spectrum of engineering fields. This has attracted a large number of students from a diverse student population to the project.

We feel that the project gives the students a true sense of what it means to work in interdisciplinary teams and to design complex functioning systems. The project also provides undergraduates with the chance to participate in research at the frontiers of technology in an area that is currently getting industry attention. The excitement from this project is starting to have a positive effect on lower level chemical and mechanical engineering courses in thermodynamics, operations research, materials, and manufacturing. Along with the obvious technical challenge of the project, students have gained valuable experience in teamwork, communication skills, safety, project planning, procurement, and public relations.

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