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THE PALM DESERT FUEL CELL VEHICLE PROJECT

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Abstract

For the past three years, the Schatz Energy Research Center (SERC) has been involved in the development and production of proton exchange membrane (PEM) fuel cells. During this time, we have: 1) built a fuel cell laboratory and production facility, 2) designed, constructed, and installed a 1.5 kW PEM fuel cell for use as a stand-by power source at the Schatz Solar Hydrogen Project, and 3) conducted research to improve power density and lower manufacturing costs of fuel cells.

SERC has now turned its focus to the Palm Desert Fuel Cell Vehicle Project. The goal of this project is to develop a clean and sustainable transportation system for a community. The project involves a consortium which includes the City of Palm Desert, DuPont, SERC, and Lawrence Livermore National Laboratory (LLNL). The goal will be accomplished by:

- Designing, building, and operating a fleet of personal utility vehicles (PUV's) and neighborhood electric vehicles (NEV's) powered by hydrogen fueled PEM fuel cells. Various modes of on-board storage of hydrogen will be investigated in a companion project undertaken by Sandia National Laboratory (SNL).

- Designing, building, and operating a refueling infrastructure relevant to future hydrogen based transportation systems. This will include two hydrogen refueling stations. One station will be wind powered; the second will be solar powered.

- Conducting research into the details of PEM fuel cell production, with particular emphasis on developing materials and manufacturing techniques which will lower costs.

- Designing and constructing a PEM fuel cell service and diagnostic center. The center will be located in a refurbished building in the City of Palm Desert corporation yard and service personnel will be trained through this project. The center will serve as an incubator to attract fuel cell manufacturing industry to the City.

Major funding sources for the $4.1M project are expected to include the U.S. Department of Energy and the South Coast Air Quality Management District. The City of Palm Desert and SERC, as well as industrial partners DuPont, Teledyne Brown Engineering, ASE Americas, and Wintec, will provide matching funds and/or in-kind donations.

Background

A major national long-term goal is to produce highway vehicles powered by PEM fuel cells. Currently PEM fuel cells suffer from two key problems that limit their commercialization in highway vehicles. First, the power density required (≈ 1 kW/liter) is approximately 5 times greater than currently achievable. Second, the cost of PEM fuel cells ($5,000-$20,000/kW) is an even greater barrier to commercialization when compared with the ≈$50/kW of an internal combustion engine (ICE). Simple economies of scale will help reduce PEM production costs somewhat, but developments are still required to drive the manufacturing and materials costs to the point where they are competitive. Thus, the time is not yet ripe for the introduction of fuel cell power plants to highway vehicles.

There are, however, other transportation applications which have a greater tolerance for the high cost of power and would benefit from the use of PEM fuel cells as primary power plants. Small, battery-powered electric utility vehicles generally require 3-10 kW of maximum power and carry a battery bank worth $500-$1000. These battery banks generally need replacement several times during the vehicle's lifetime. The result is that power systems for these small utility vehicles can cost as much as an order of magnitude more per kW than does the ICE for a passenger car. Power density and acceleration requirements are also smaller for these vehicles so that present PEM technology can easily meet their needs. Furthermore and perhaps most importantly, building and operating small fuel cell vehicles will offer a unique and valuable opportunity to accelerate the process of learning how best to improve upon PEM fuel cell materials and manufacturing processes and will serve as an important stepping stone towards eventual production of PEM power plants for highway vehicles. Doing this in a real fleet application will also generate immediate, positive awareness of hydrogen and fuel cells for transportation.

Fuel cell vehicles will have two additional distinct advantages over battery powered, small utility vehicles. Range is significantly improved, by approximately 400%. This could be improved even further with an advanced hydrogen storage system. Best of all, refueling time is reduced to minutes from the hours required to recharge batteries. Both these advantages will make fuel cell vehicles much more attractive to users.

Location

An important factor in producing technological progress is a venue where the technology can be usefully employed, effectively demonstrated, and rigorously tested. The City of Palm Desert is such a venue. The City has exhibited, through its legislation and its policies, a commitment to promote the development of environmentally benign technologies. This commitment has already manifested itself in several ways: 1) The City Council, on December 22nd, 1994, passed resolutions supporting the participation of the City and its staff in this project and committing the City to a cash contribution of $300k and an in-kind contribution of the City's corporation yard and a building (valued at $350k); 2) The California legislature, through Assembly Bill #1229, has established Palm Desert as a test locale in which golf carts used as PUV's are street legal;
3) Resolution number 94-63 was passed by the City Council in order to encourage research and development in the areas of alternative energy and alternative transportation and to attract related industry; 4) The public transportation system servicing the City, SunLine Transit, is the only one in the U.S. that is completely fueled by compressed natural gas; and 5) The local community college, College of the Desert, has the only compressed natural gas mechanics training program in the nation.

Moreover, one of the main motivations to implement a clean and sustainable transportation system is poor air quality. This is an important concern for the City since it is located in the South Coast Air Quality Management District (SCAQMD), a 13,350 square mile area consisting of Los Angeles, Orange, and parts of Riverside and San Bernardino Counties. The area is the smoggiest in the nation despite California's strict air pollution control program. Most of this pollution originates in and around the city of Los Angeles, where the air quality failed to meet federal standards for ozone, carbon monoxide, or PM10 (particulates smaller than 10 microns) on about one out of every two days in 1993.

The population in the SCAQMD has grown from 5 million in 1950 to the present 13 million, and is projected to reach 18 million by the year 2010. At present there are 9 million registered motor vehicles, which travel nearly 300 million miles, consuming 13 million gallons of gasoline and 1.5 million gallons of diesel fuel each and every day. These vehicles are the predominant cause of poor air quality; approximately 60% of the air pollution in the area is due to motor vehicles.

In order to improve the air quality in California and especially in the SCAQMD, the California Air Resources Board (CARB) has mandated that by the year 1998, 2% of all new passenger vehicles sold in California must be zero emission vehicles (ZEV's). By the year 2003, this number will increase to 10%. For golf carts, the regulations are more stringent. In January 1994, CARB passed a regulation requiring that: "All golf carts produced for sale after January 1st, 1997 in federal ozone non-attainment areas in the State of California must be zero emission." Since the City is in such a non-attainment area, its new golf carts/PUV's must be zero emission by that date. Thus, there are strong regulatory pressures to develop clean vehicles.

During the summer of 1994 the City initiated plans to invest in the development of a PEM fuel cell industry and to support development of prototype fuel cell powered PUV's operating on the streets of Palm Desert. On August 25, 1994 the City held a special workshop entitled "Proton Exchange Membrane Technology: Fueling Economic Development." Presentations were given to the City Council by Hank Wedaa, then chairman of the SCAQMD; Dr. Peter Lehman, director of SERC; and Glenn Rambach of LLNL. The extremely positive response of the Council led to the formation of a consortium whose members include the City, SERC, and LLNL.

Subsequent to the August meeting, Lehman and Rambach presented an outline of the project at the meeting of the Hydrogen Technical Advisory Panel in Los Angeles. Since that time, DuPont has joined the consortium via discussions with Dr. Shoibal Banerjee, Program Manager for Fuel Cell Membranes at DuPont.

Project Description

Fuel Cell Research

As mentioned above, the major impediment to utilization of fuel cells for transportation is their high cost. The objective of the proposed collaborative research effort between SERC, DuPont, and LLNL will be to examine details of PEM fuel cells so that less costly materials can be utilized and mass production techniques can be employed. Specifically, the research will focus on:

- Materials and advanced production techniques for electrodes and subsequently, membrane-electrode assemblies
- Materials and advanced production techniques for bipolar current collector plates
- Techniques for stack assembly which minimize labor and are amenable to automation

Working together, SERC, DuPont and LLNL will explore alternatives to the carbon cloth or paper electrodes presently used. In particular, the carbon aerogel technology already developed by LLNL is an attractive possibility. This material is a foam whose porosity and density can be engineered to satisfy the needs of an application. In addition, it promises to be able to be applied to the membrane in a continuous coating process resulting in a thinner electrode than is now used and allowing for eventual mass production. Carbon aerogel electrodes also lend themselves to alternate methods of catalyst application. Various MEA's will be produced using this material and their performance will be tested in single cells and realistic PEM stacks. Based on performance results, the process will be optimized.

The current collectors in PEM stacks are generally fashioned from graphite sheets. Other materials are sometimes utilized but they suffer from high cost (such as titanium) or undesirable properties (such as the high contact resistance of stainless steel). Graphite current collectors are machinable, inert, and have excellent conductivity and low contact resistance. These materials, however, are not inexpensive to begin with and their machining is costly. Molded graphite has been used but suffers from much higher resistance. Our plans are to investigate aerogels for current collectors as well as electrodes. An intriguing possibility is to have the electrode and current collector be a single piece with properties of the aerogel engineered to change with distance from the membrane in the proper fashion. If this is possible, inexpensive mass production may be realized with this graded-density form of carbon aerogel. Other novel methods are also being considered for more cost effective production of current collectors. In particular, materials will be investigated which have a formable state and can then be transformed to a dense, conductive state.

The LLNL Manufacturing, Materials Science, and Engineering Divisions, in conjunction with SERC, will develop cell and stack production methods to replace the present time-consuming and costly assembly by hand. The goal of this activity is to identify and develop an assembly process amenable to automation so as to reduce production cost.

Fuel Cell Vehicles

Central to this project is the design, construction, testing, and operation of fuel cell PUV's and NEV's. We propose to produce 5 PUV's and 3 NEV's to be used within the City of Palm Desert. They will be used by City personnel, by City officials, and by public citizens for normal work and leisure activities. The intent is to integrate them fully into the regular, day-to-day life of the community.

Each PUV and NEV prototype produced in this project will be equipped with an on-board data logging system to record details of the PEM stack and subsystem performance. Information gathered on earlier PUV's and NEV's will be used to refine the design of later ones.

The first tasks in designing the power plant and associated subsystems for the PUV are to record performance of similarly powered battery electric vehicles and analyze power needs. Engineers at SERC have already accomplished these tasks for an E-Z-Go Golf Cart. This has allowed sizing of the PEM fuel cell stack that will be necessary for the first phase of the project--the golf-cart-like PUV. Based on tests, a 5 kW stack has been chosen and is already under development. Our plans are to refine and develop this stack as the project progresses and the remaining four PUV prototypes are built. Developments resulting from the fuel cell research described above will be integrated into later 5 kW stacks as these improvements become available.

The PEM stacks which have been developed and operated at SERC have been designed to be simple and have high *net* efficiency. As such, they are designed to run on air at very low pressure. This means that stack performance is less than achieved with pressurized systems, but that a simple blower (and not a compressor) is required for the air supply. This is turn significantly reduces parasitic energy requirements.

Ancillary subsystems in the PUV's will be designed and built so that vehicle operation is smooth, reliable, responsive, and transparent to the driver. Subsystems will include a heat removal system utilizing water circulation and a radiator, a variable speed blower for air supply, an air purification system upstream of the blower, a water recovery and purification system, numerous safety interlocks, and a computer-based control system. The hydrogen storage system will be developed in conjunction with SNL in a companion research project which will address safety and certification, as well as engineering design issues. The first prototype will use an off-the-shelf, pressurized hydrogen tank, with other modes of storage such as hydride or cryogenic tanks addressed in subsequent vehicles.

The NEV prototypes will be based on an existing, commercially available battery powered vehicle. Its performance will be measured and used as the basis for design. It is anticipated that the 5 kW stack built and optimized during the PUV stage of the project will be utilized for the NEV's. The plan is to employ two 5 kW stacks in the NEV. As with the PUV's, the NEV's produced will be attractive, responsive, and reliable.

The first PUV prototype will be powered solely by the fuel cell stack (with the exception of a small battery to "wake-up" the system). The reasoning behind this decision is to avoid any ambiguity in the minds of (perhaps skeptical) media and interested citizens about the source of power driving the vehicle. However, from an engineering design standpoint, a hybrid vehicle is more desirable and will likely result in enhanced performance and lower cost. Thus, hybrid designs will be considered and implemented in subsequent PUV's and NEV's. Control hardware and software will be developed to enable the hybrid battery-fuel cell vehicles to function smoothly.

Every effort will be made to insure that the prototypes will be attractive, safe, and newsworthy. Participation in the City's annual electric vehicle parade (each November) and other public events will serve to popularize this technology and to acquaint citizens with the safety and cleanliness of hydrogen transportation technology. In addition, all operational details and performance history will be extensively documented throughout the project.

Wind-Hydrogen Refueling Station

Hydrogen produced from wind generated electricity and electrolysis is currently the lowest cost of the developed renewable systems. Wind electrolysis benefits from the maturity of the wind industry and excellent geographic distribution of reliable wind resources. To date, production of electrolytic hydrogen from wind has not been demonstrated as has been done using solar photovoltaics in several large-scale installations.

The San Gorgonio Pass, about 15 miles from Palm Desert is one of the nation's leading areas for wind generated electricity. There are regions between the Pass and Palm Desert that are adequate for the production of electrolytic hydrogen for this project. A 65 kW wind turbine, electrolyzer, compressor and storage system will be installed in an area adjacent to the City where the wind quality and capacity factor are sufficient to supply abundant quantities of hydrogen fuel for this project.

Conservative estimates show that a wind-hydrogen production system with the following components and properties should be sufficient for fueling the fleet of vehicles built in this project for 15 - 30 miles per day for each vehicle, depending on capacity factor:

- 65 kW wind turbine
- 9 - 17% wind capacity factor
- 62% efficient electrolysis
- 85% efficient compression to 3600 psi
- 2 - 4 kg of H_2 per day

The design and construction of the wind-hydrogen system for this project will be managed by LLNL. LLNL will work with the wind turbine and electrolyzer suppliers to design the overall system and establish the best method for electrically integrating the two primary components. Site selection and preparation will be carried out with the wind turbine supplier and the City of Palm Desert. An equipment shed, hydrogen compressor and storage tanks will be installed at the site. All pertinent codes and standards will be met by this facility.

LLNL will work with SNL and SERC on the design and construction of the hydrogen refueling station. Design criteria will include the safest user-friendly method of connecting the station's hydrogen supply to the vehicle. Interfaces currently in use elsewhere will be evaluated as input to the design.

Photovoltaic-Hydrogen Refueling Station

Photovoltaic (PV) electrolysis has been demonstrated as a safe, reliable, and effective method of generating hydrogen from solar energy. SERC has successfully operated the Schatz Solar Hydrogen Project for a year and a half, producing solar hydrogen automatically and efficiently. The experience gained in designing and operating this system will aid greatly in the design and construction of a like system in the City of Palm Desert. The work will be managed by SERC in collaboration with LLNL and in matters of refueling, with SNL.

Preliminary design of the system calls for the following components:

- A photovoltaic array consisting of 176 ASE-300-DG-50 power modules manufactured by ASE Americas, yielding 50.2 kW of power at 200 volts
- A 50 kW bipolar, alkaline electrolyzer manufactured by Teledyne-Brown
- A compressor for compression to 3600 psi
- A computer based control system
- High pressure storage and refueling hardware
- Low pressure buffer storage between the electrolyzer and the compressor

Working together with Teledyne, SERC has developed a detailed simulation model which predicts electrolyzer behavior based on environmental conditions and PV array characteristics. This model will be used to size system components accurately and to engineer their integration. The system will be designed to run automatically and will conform to all applicable wiring and compressed gas codes. If performance is similar to the SERC system, hydrogen fuel with the energy equivalent of approximately 6-8 gallons of gasoline will be produced on a sunny day. Since the City is located in an area blessed with abundant sunshine, this amount of fuel will be produced nearly every day.

Once design is complete, the work of installing the array and building a small, electrolyzer building will be contracted out locally. SERC engineers will oversee the work and install and debug the control system. We plan to build this refueling station close to City Hall, in the center of town. The City also has plans to make the station into a demonstration center and tourist attraction. This will insure that the technology gets maximum exposure and that many people have the opportunity to acquaint themselves with hydrogen technology and begin to feel comfortable around it. This educational feature is an important aspect of this project and is crucial if hydrogen technology is to make real contributions to transportation.

Fuel Cell Service and Diagnostic Center

An important component of an infrastructure supporting a fleet of hydrogen fuel cell vehicles is a center capable of diagnosing problems and completing necessary repairs. We plan to develop such a center at the City's corporation yard by refurbishing an existing 6000 square foot building for this purpose. The building and land are being contributed by the City. The building is large enough to permit significant expansion of the original center as the fleet expands and needs for service increase.

The center will be modeled after the SERC Fuel Cell Laboratory at Humboldt State University. It will be equipped with two completely automated test stations capable of testing PEM fuel cell stacks up to a power rating of 5 kW. The stations will be capable of all measurements necessary to diagnose stack performance including current, voltage, temperature, and reactant gas flow rates as well as being able to automatically record polarization curves. An additional feature, important for stacks used in vehicles, is the ability to put the stack through a simulated urban or highway driving cycle. Data will be logged continuously and data analysis software will be supplied. The stations will be equipped with interlocks connected to the building's safety systems which include hydrogen sensors, fire alarms, and ventilation sensors. Should any safety component indicate a dangerous condition, the system would effect a shutdown. These features will allow the stations to run unattended so that long term performance can easily be measured.

The center will be supplied with electronic test equipment and hardware, a complete hand tool set, and appropriate laboratory furniture. Personnel will be trained to operate the equipment and diagnose problems. The training program will be designed and implemented by SERC personnel. Having the capability to measure fuel cell performance and trained personnel to handle the task will serve as an impetus to the development of a fuel cell industry in the Palm Desert area. From the City's perspective, this incubator-like facility is an important step in their economic development plan.

Time Line

The time line for this project is shown in Figure 1. As can be seen in the figure, work at SERC has already begun. A golf cart has been obtained and its performance measured. Development of the 5 kW stack has also begun with the testing of smaller format stacks and the construction of the first cells of the larger format which will be used in the final stack. Work has also begun on obtaining and testing subsystem components.

The prototype 5 kW stack will be completed by May 1995 and will be installed in the first PUV along with subsystems in June. Testing and refinement will occur and this first vehicle will be delivered to the City in late October 1995 so that it can participate (as a featured attraction) in the City's electric vehicle parade in early November. The additional 4 PUV's will be built and delivered during the next year.

In late 1995, the first NEV will be obtained and tested. Subsystem development and stack installation will occur during the first half and testing during the second half of 1996. Delivery of the first NEV will be late in 1996 with the two additional NEV's during the last year of the project. Monitoring of all vehicles will occur as soon as they are in use and continue for the duration of the project.

Design of the wind-hydrogen refueling station will begin during May 1995, with installation and debugging completed by June 1996. At that time and thereafter, all vehicles in this project will be fueled with renewably generated hydrogen. As soon as the wind-hydrogen station is operating, work will begin on the PV-hydrogen station. Design and installation will require a year's time with operation scheduled for June 1997.

Design of the fuel cell service and diagnostic center will begin in July 1996 and installation will be complete one year later, in June 1997. The training course for personnel will occur during the autumn of 1997 and by the end of that year, complete responsibility for the center will be turned over to local technicians and administrators.

Research on fuel cell components and stacks, manufacturing processes, and assembly techniques will be ongoing throughout this project. Work will begin in July 1995, coinciding with the anticipated onset of funding. Coordination between DuPont, LLNL, SNL, and SERC will be close and continuous so as to expedite progress and efficiently coordinate schedules.