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THE PALM DESERT RENEWABLE TRANSPORTATION SYSTEM

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Abstract

This paper describes the Schatz Energy Research Center (SERC) progress on the Palm Desert Renewable Hydrogen Transportation System Project for the period June 1997 through May 1998. The project began in March 1996.

The goal of the Palm Desert Project is to develop a clean and sustainable transportation system for a community. The project demonstrates the practical utility of hydrogen as a transportation fuel and the proton exchange membrane (PEM) fuel cell as a vehicle power system. The project includes designing and building 4 fuel cell powered vehicles, a solar hydrogen generating and refueling station, and a fuel cell vehicle diagnostic center.

Over this last year, SERC has built a fuel cell powered neighborhood electric vehicle and delivered it to the City of Palm Desert. The design of the hydrogen refueling station is near completion and it is anticipated that construction will be complete in the fall of 1998. The vehicles are currently being refueled at a temporary refueling station. The diagnostic center is being designed and maintenance procedures as well as computer diagnostic programs for the fuel cell vehicles are being developed.

City employees are driving the vehicles daily and monitoring data are being collected. The drivers are pleased with the performance of the vehicles.

Objective

The objective of this project is to develop a clean and sustainable transportation system for the City of Palm Desert in Southern California and to demonstrate the practical utility of hydrogen as a transportation fuel and proton exchange membrane (PEM) fuel cells as vehicle power plants.

The outcome of this project will be a complete, operating model transportation system based on hydrogen and fuel cell powered vehicles. This is the first time that solar derived hydrogen will be produced and used in fuel cells to power motor vehicles. The project provides the opportunity to collect data to help understand how differences in system components can influence overall performance, thus gaining information directly relevant to the nation's future transportation system.

Technical Goals

In order to achieve the project objective, the following specific technical objectives must be met:

- Design and construct 3 personal utility vehicles (PUVs) and 1 neighborhood electric vehicle (NEV) and deliver them to the City of Palm Desert. These fuel cell powered vehicles will be driven around the City for normal day-to-day activities and their performance will be recorded and evaluated.

- Design and construct a solar hydrogen generation facility and a hydrogen dispensing station in the City. The generation facility will use photovoltaic electrolysis to produce the hydrogen, which will be compressed and stored. Fuel dispensing to the vehicles will occur at a refueling island in the City and will be convenient and safe.

- Equip a fuel cell vehicle maintenance facility which will have diagnostic capability; personnel will be trained to maintain and service the vehicles.

Major Barriers to Meeting Technical Goals

Several technical and societal barriers have slowed progress in achieving the technical goals of this project:

- Permitting - A conditional use permit and a building permit will be required for the solar hydrogen generation facility. The generation building and gas dispenser will have to meet building, electric, plumbing, and fire codes. The demands on employee time and the length of this process are largely unknown and could delay the delivery of the station.

- Insurance - SERC PUVs are covered under the Humboldt State University Foundation's general policy, even though they use an unconventional power source. Currently the NEV is insured with a conventional insurance agent. Coverage is very expensive.

- Hindenburg Syndrome and Ignorance about Hydrogen - A percentage of the public holds irrational fears about hydrogen and is not knowledgeable of the properties of hydrogen. At a civic meeting, one representative of the College of the Desert responded to a transparency of 5th graders at SERC's solar hydrogen facility with: "How can you even think about having children involved in this technology in light of the Hindenburg accident?" In another situation, an insurance agent asked for indemnification against the possibility of a "toxic hydrogen spill."

- Availability of appropriate and certified system components - Many of the components for the NEV and solar hydrogen station will be integrated in such systems for the first time. Off-the-shelf items sometimes have lead times exceeding 6 weeks while other items have to be modified or custom-made and extensively tested. Certification is another issue; finding components certified for hydrogen use is sometimes difficult, costly, and/or time consuming.

Approach/Background

The creation of this project was motivated by several social, technical and environmental conditions:

- Smoggy air lowers the quality of life of the over 75% of Americans who live in large cities. A 1993 study using Harvard and American Cancer Society research and linking deaths to air pollution showed that the Riverside-San Bernardino region topped the nation in the death rate per capita blamed on particulates. The study linked 17% of cardiopulmonary deaths in the greater Los Angeles area to pollution. This number exceeds the number of people who died from auto accidents.

  In the District, smoggy air is also responsible for millions of dollars of agricultural losses, as well as damage to forests, range, and pastureland in addition to the human health effects.

  In the South Coast Air Quality Management District (SCAQMD), poor air quality is primarily linked to motor vehicles. Development of a clean, sustainable transportation system would eliminate criteria pollutants, decrease reliance on imported petroleum, and improve public health.

- Zero emission vehicles (ZEVs) are currently required in New York and will in the near future be required in California. Massachusetts and other states could soon follow suit. The research and development on fuel cell technology and its integration into a user ready, street safe vehicle will aid in producing ZEVs to meet these mandates.

- In order for this technology to be integrated into our society, people must overcome their fear of hydrogen (see Hindenburg Syndrome above) and learn its benefits. A complete hydrogen fuel cell powered transportation system operating in a community will go far to dispel these fears and educate citizens.

Past Results

In the 1990-1995 period prior to the start of the Palm Desert Renewable Hydrogen Transportation System Project, the Schatz Energy Research Center (SERC) designed and built an automatic solar hydrogen-fuel cell energy system which powers an air compressor at the Humboldt State University Telonicher Marine Laboratory. The first system of its kind in the U.S., it continues to operate today. In addition, SERC developed a fully equipped fuel cell laboratory and production facility and built its first fuel cells, as well as a proof-of-concept fuel cell powered PUV. The proof-of-concept PUV was completed on schedule and debuted on November 5, 1995 at the Palm Desert Golf Cart Parade. The cart performed well and met our initial goals.

SERC began the three-year, $3.9M Palm Desert Renewable Hydrogen Transportation System Project in January of 1996. By May 1997, SERC had:

- completed the design and assembly of the first PUV, including: writing new software, designing new electronic controls, completing a hazards analysis, assembling fuel storage/delivery/refueling, water circulation, and air delivery systems, and installing and testing of the 5 kW fuel cell stack. The PUV was delivered in early September 1996 and remains in day-to-day use in the City.

- designed and installed a temporary hydrogen refueling station at the College of the Desert (COD) and trained the station operators.

- assembled, tested, and delivered two additional fuel cell powered PUVs that incorporate numerous engineering and safety improvements over the first PUV. These PUVs are equipped with pickup beds so they can be used by City personnel for gardening and maintenance work.

- begun negotiations with COD and City officials and their attorneys to secure a site for the solar hydrogen generation facility and the hydrogen dispensing station in Palm Desert.

- begun the design of the solar hydrogen generating facility and hydrogen dispensing station. This included completion of a PV system simulation and sizing of the array, a hazards analysis, a site plan, a floor plan of the generation building, preliminary landscaping plan, and architectural rough sketches.

- acquired, instrumented, and tested an NEV, begun the design of a fuel cell power system appropriate to the NEV, and initiated fuel cell testing necessary to determine the configuration of the NEV stack.

- coordinated activities with Sandia National Laboratory to develop an on-board metal hydride storage system for a PUV and conducted tests on a possible hydride module.

Current Year Accomplishments/Status

During the past year, SERC has:

- completed the design, assembly, testing, and delivery of the first fuel cell powered Neighborhood Electric Vehicle (NEV) which incorporated numerous engineering and safety improvements over the PUVs, including higher cruising speed (35 mph), greater range (30 miles), and greater fuel cell power (9 kW fuel cell stack utilizing Gore PRIMEA membrane electrode assemblies (MEAs)). The NEV was delivered in April 1998 and debuted at the 1998 Palm Desert Clean Cities Celebration and is now in day-to-day use in the City.

- monitored, refueled, and maintained the three fuel cell vehicles in Palm Desert. For more than a year, the PUVs have been in day-to-day use by City employees for gardening, maintenance work, and other activities. The temporary hydrogen refueling station was relocated to City property and a new refueling and maintenance technician was trained.

- secured a site for the solar hydrogen generation facility on the property of SunLine Transit and a site for the hydrogen dispensing station near Palm Desert City Hall. This followed a lengthy and involved negotiation with COD and City officials and their attorneys that ultimately proved unproductive.

- completed the site plans and the architectural plans for the generation and dispensing facilities and submitted review packages to County planning and fire departments to begin the permitting process. Completed the sizing and specification of the grid-connected photovoltaic system and negotiated power purchase agreements with Southern California Edison. Completed the design of the hydrogen plumbing and control system and the development of the schematics, parts lists, and systems descriptions. Begun the development of the control software for the generation facility.

- acquired major components for the solar hydrogen generating and refueling facilities, including an electrolyzer, diaphragm compressor, and computer control system for the generation facility.

- begun the design of a fuel cell vehicle service and diagnostic center.

Design and Production of the Neighborhood Electric Vehicle (NEV)

The design and production of the neighborhood electric vehicle (NEV) began in May 1997, immediately following delivery of PUV2 and PUV3.

Prior to that date, SERC had purchased the original, battery powered Kewet El-Jet 3 that would be the vehicle to be retrofitted with the SERC fuel cell system. The Kewet was selected because it could be purchased in the U.S. and licensed for use on California roads. The retofit was executed in the following discrete steps:

- The original Kewet with its 48 V lead-acid battery pack was instrumented to permit monitoring and recording battery voltage and current over time. The Kewet was then road tested to determine the voltage, current , and power input to the motor controller under highway cruising and city use conditions. The maximum speed and range were verified to be 35 mph and 25 miles.

- Individual subsystems were designed and tested. These subsystems included the fuel cell, hydrogen storage and delivery, air delivery, water circulation and cooling, the high current electrical system for the traction bus, the sensor and actuator system, and the on-board computer hardware and software. The air blower motor was modified to run at the 48 V traction bus voltage and the water pump was retrofitted with a more efficient motor.

- The fuel cell parts were fabricated and the stack was assembled and tested on a test bench fitted with a programmable load to mimic driving cycles developed from Kewet testing data.

- Other separate components were also assembled and tested on the test bench independently and in conjunction with the fuel cell and other components. In response to test results, the control algorithm was iteratively modified to correct bugs and improve system performance.

- Alternative layouts of system components in the Kewet were developed and evaluated and the component layout was finalized.

- The Kewet was structurally augmented to provide adequate protection for the hydrogen storage and delivery system and appropriate heat exchanger area. The dashboard was rebuilt and the seats were replaced.

- The subsystems were installed, including the hydrogen storage and delivery system, air delivery system, water circulation and cooling system, the high current traction bus electrical system, the sensor and actuator system, and the on-board computer hardware and software. Following testing of these subsystems, the fuel cell was installed and tested.

- The NEV was first operated on a static test stand and was then road tested and final adjustments were made.

- The NEV was delivered to Palm Desert on April 22, 1998 (Earth Day) and debuted at the 1998 Palm Desert Clean Cities Celebration.

Figure 1 shows the completed NEV just before shipment to Palm Desert. A rear view of the NEV is presented in Figure 2 and shows the fuel cell compartment with the cover removed.

Table 1 lists the specifications of the NEV. The maximum speed of the NEV is 35 mph and the cruising range of the vehicle is 30 miles. The NEV fuel cell contains 96 Gore PRIMEA MEAs and can produce 9 kW at 600 mV/cell.

Table 1. Specifications of the SERC Neighborhood Electric Vehicle (NEV)

Item	Specification
Fuel Cell Type	Proton Exchange Membrane
Fuel Cell Power	9 kW @ 600 mV/cell (12.2 hp)
Number of Cells	96
Fuel Cell Operating Temperature	50-65°C (120-150°F)
Body and Chassis	Kewet El-Jet 3 (Denmark)
Traction Bus Voltage	48 Volts (nominal)
Electric Motor Size	7.5 kW (10 hp)
Hybrid Battery Size	80 Amp-hrs
Cruising Speed	35 mph
Range (on Full Tank)	30 miles
Hydrogen Tank Volume	31.1 liters
Hydrogen Gas Storage Pressure	3000 psig
Refueling Time	2 minutes

Performance of Personal Utility Vehicles (PUVs)

The three SERC fuel cell personal utility vehicles (PUVs) have been in day-to-day use in Palm Desert for more than a year. Each vehicle is capable of recording operational data for later analysis. PUV1 records data on a lap-top computer while PUV2 and PUV3 store the recorded data on-board until it can be downloaded to a lap-top computer later.

Table 2 summarizes the accumulated performance data for the three PUVs.

Table 2. Summary of PUV Performance in Palm Desert

Vehicle	Delivery Date	Total Miles	Total Run Hours	Maximum Speed (mph)	Mileage (mpg equivalent) City	Mileage (mpg equivalent) Highway
PUV1	Sept. 1996	350	70	13	65	110
PUV2	May 1997	300	120	15	95	120
PUV3	May 1997	300	120	15	90	120

Plans for Future Work

In the coming and final year of the Palm Desert Project, SERC intends to:

- construct, test, and operate the solar hydrogen generation facility on the property of SunLine Transit and the hydrogen dispensing station near Palm Desert City Hall.
- continue monitoring, refueling, and maintaining the four fuel cell vehicles in Palm Desert.
- design and outfit the fuel cell vehicle service and diagnostic center.

Status of Economic Evaluation

This is a research and demonstration project. An economic evaluation is not appropriate for our prototype vehicles and solar hydrogen generating system.

Acknowledgments

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There are seven students (one graduate and six undergraduate) involved with this project. All are studying Environmental Resources Engineering at Humboldt State University. They are indicated with an asterisk in the list above.

SERC has contacts in the following companies, which are partners in the project:

Teledyne /Brown Engineering - Energy Systems
DuPont
W. L. Gore & Associates
ASE Americas
SunLine Transit

Publications/Awards/Events

At the request of DOE, PUV3 was exhibited in Las Vegas at Preview 98 in January 1998.

Videos about the project have appeared on:

Tomorrow's World (produced by the BBC, the most watched science program in the world), May 1996

Understanding Cars, The Learning Channel, May 1997

Articles about the project have appeared in:

CNN – OnLine, http://cnn.com/EARTH/9804/29/fuel.cell.car, April 29, 1998

Positive Alternatives, Winter 1998

H_2 Digest, January/February 1998

Motorland Magazine (publication of the northern California AAA), November/December 1996

NHA Advocate, Fall 1996.

Popular Science, September 1996 and October 1996

Scientific American, December 1995

Peter Lehman and Charles Chamberlin made the following project related presentations in 1996, 1997, and 1998:

- Lehman, P.A., "Recent Progress in the Palm Desert Project," 9th Annual National Hydrogen Association Meeting, Alexandria, VA, March 1998.

- Lehman, P.A., "The Palm Desert Project," Symposium at South Coast Air Quality Management District, December 1997

- Lehman, P.A., "The Palm Desert Project," DOE Annual Review Meeting, Alexandria, VA, May 1997.

- Lehman, P.A., "The Palm Desert Project," Meeting at the City of Palm Springs to discuss clean transportation in the Coachella Valley, April 1997.

- Lehman, P.A., "Fuel Cell Powered Electric Vehicles," Monthly Meeting of the HSU Society of Sigma Xi, April 1997.

- Lehman, P.A., "The Palm Desert Project," 8th Annual National Hydrogen Association Meeting, Alexandria, VA, March 1997.

- Lehman, P.A., "Fuel Cell Powered Electric Vehicles," Monthly Meeting of the California Section of the American Chemical Society, February 1997

- Lehman, P.A., "Fuel Cell Basics," South Coast Air Quality Management District, February 1997

- Lehman, P.A., "Recent Progress in the Palm Desert Project," World Car Conference, Riverside, CA, January 1997. Also session chairman for "Fuel Cells and Infrastructure I and II."

- Lehman, P.A. and Chamberlin, C.E., "Design and Performance of SERC's Prototype Fuel Cell Powered Vehicle," Fuel Cell Seminar, Orlando, November 1996.

- Lehman, P.A., "Using Hydrogen Technology: Codes and Standards, Safety, and Common Practice," City of Palm Desert, November 1996.

- Lehman, P.A., "Design and Performance of SERC's Prototype Fuel Cell Powered Vehicle," Commercializing Fuel Cell Vehicles Conference, Chicago, September 1996.

- Lehman, P.A., "The Palm Desert Project," DOE Annual Review Meeting, Miami Beach, May 1996.

- Chamberlin, C.E. and Lehman, P.A., "Design and Performance of SERC's Prototype Fuel Cell Vehicle," 7th Annual National Hydrogen Association Meeting, Alexandria, VA, April 1996.

- Lehman, P.A., "Design and Performance of SERC's Fuel Cell Powered Vehicle," World Car Conference, Riverside, CA, January 1996.

SERC personnel also gave lectures, talks, and tours in our facilities and on campus to university students, secondary school students, emeritus faculty, business people, and community organizations.

Figure Titles

Figure 1: **The SERC Neighborhood Electric Vehicle (NEV)**

Figure 2: **Rear View of NEV Showing the Fuel Cell (Compartment Cover Removed)**

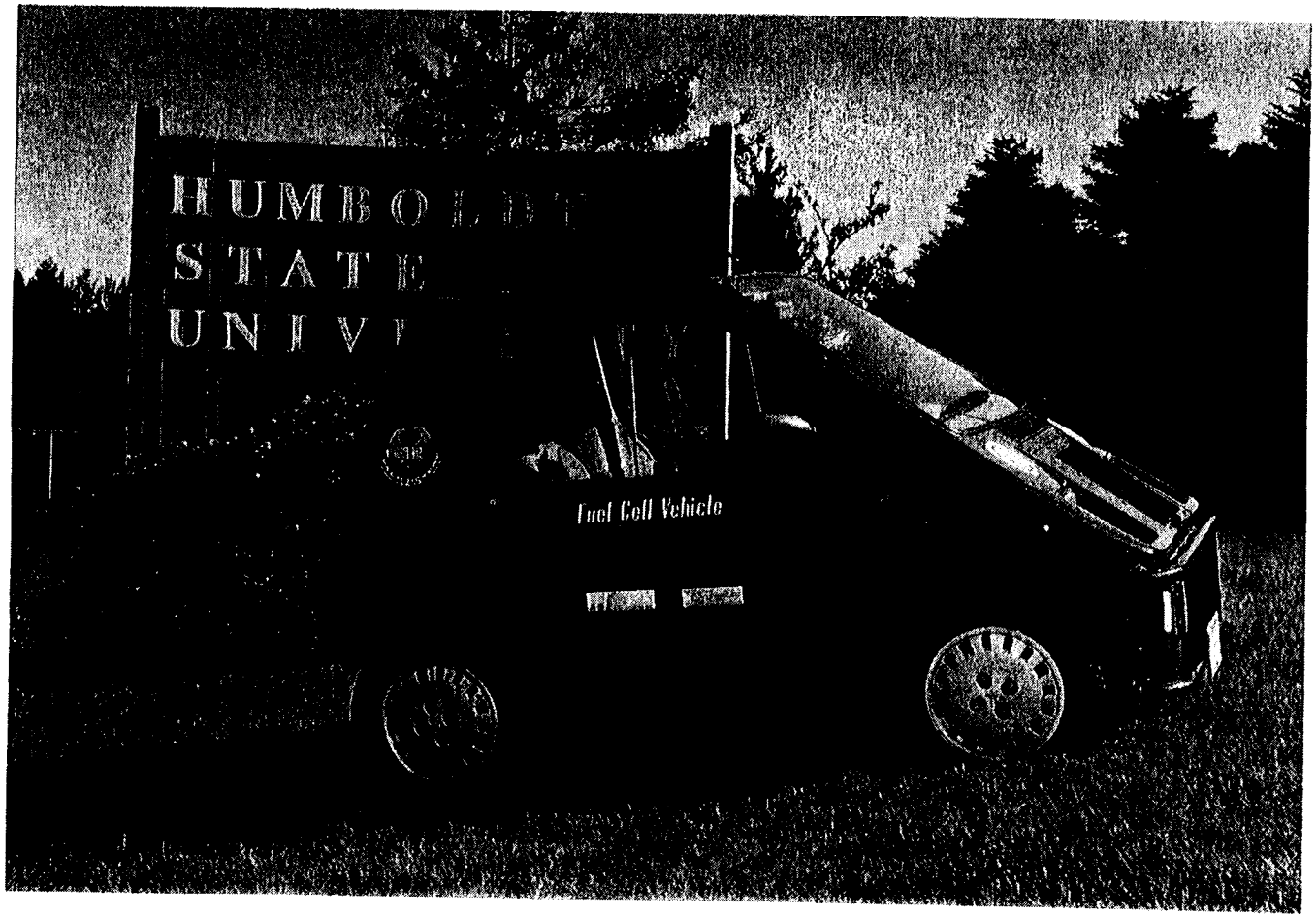

Figure 1

Figure 2