

V.D.5 Research and Development of a PEM Fuel Cell, Hydrogen Reformer, and Vehicle Refueling Facility

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Objectives

Design, develop, and demonstrate small on-site H₂ production system for stationary fuel cells and H₂ vehicle fuel stations, including:

- Design, construct, and operate a multipurpose refueling station to dispense H₂/CNG blends and pure H₂.
- Design, construct, install and operate a H₂-fueled stationary 50-kW fuel cell.
- Maintain safety as a top priority for the fueling station and fuel cell.
- Evaluate operability, reliability, and economic feasibility, of integrated power generation and vehicle fueling system.
- Obtain adequate operational data on fuel station to provide basis of future commercial fueling station designs.

Technical Barriers

This project addresses the following technical barriers from Technology Validation section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- B. Storage
- C. Hydrogen Refueling Infrastructure
- D. Maintenance and Training Facilities
- E. Codes & Standards
- I. Hydrogen and Electricity Co-Production

Approach

- Choose hydrogen production technology.
- Base the design of the 50-kW fuel cell stack on existing 7.5-kW reformate-based stack modules developed for residential power generation. Make modifications to allow operation on pure hydrogen.
- Base fuel station design on previous H₂ and H₂/CNG fueling station experience.
- Conduct Extended duration operation of the fully integrated hydrogen generation, fuel cell, fuel station system will be conducted to address robustness, performance, and economic feasibility of this "Energy Station" concept.

Accomplishments

- Several small-scale natural gas based fuel processing technologies under development by others were tested. These included partial oxidation (POX), auto thermal reforming (ATR), and steam methane reforming (SMR) technologies. Based on the experience from testing and the results of an economic analysis, it was decided that SMR was the best technology of the three.
- Achieved satisfactory Hydrogen Generator process operation and product purity capability, with one-button start and load following capability.
- Achieved aggregate Hydrogen Generator operation of over 2800 hours.
- Achieved lower heating value (LHV) efficiency of 68% with hydrogen purity at less than 1 ppm CO.
- Identified and implemented system improvements under real-world performance and durability testing experience.
- Successfully performed over 70 hydrogen/CNG (HCNG) blend vehicle fuelings and approximately 12 pure hydrogen vehicle fuelings.
- The 50-kW stationary fuel cell was operated on hydrogen supplied by the Hydrogen Generator, gaining operational experience.
- Achieved safe operation of the site during operating period to date, attributed to safe engineering, design, fabrication and utilization.

Future Directions

- Conclude current operating period:
 - Continue to provide City of Las Vegas (CLV) vehicle fueling and fueling demonstration testing through conclusion of current project period. Support CLV hydrogen vehicle fleet expansion as applicable.
 - Continue operation of the Hydrogen Generator through conclusion of test operation period, for data collection, analysis and reporting.
- Lessons learned to be incorporated into the Penn State Hydrogen Fueling Station Project.
- Conduct planning with DOE for the continued support of the site beyond the current operating period.

Introduction

Small-scale on-site hydrogen production technology, which can operate on available fuels such as natural gas, will be required to provide hydrogen fuel stations where delivered hydrogen is not readily available. However, small-scale natural gas based hydrogen production units are not fully developed, and will suffer from poor economics due to their small scale and poor utilization rates in the early years of hydrogen vehicle development. One approach to achieving high utilization rates of the hydrogen production unit is to baseload it with a stationary fuel cell that produces electric power while the intermittent vehicle fueling load is handled by diverting a portion of the hydrogen from the fuel cell to the fuel station as and when needed. This co-production of hydrogen and electric power is referred

to as an “Energy Station”. The objective of this project is to demonstrate the technology of an Energy Station that can dispense blends of hydrogen and compressed natural gas (CNG) and pure hydrogen to vehicles, and the co-production of electricity from a stationary fuel cell. A team of three organizations, Air Products and Chemicals Inc., Plug Power Inc., and the City of Las Vegas (CLV), has come together to develop, design, procure, install, and operate this “Energy Station” in Las Vegas, Nevada. The DOE cooperative agreement covers a five-year period (1999-2004) for development, design, installation, startup, and operation of the Energy Station.

Figure 1 is a block diagram of the Energy Station. In addition to the on-site hydrogen generation, a liquid hydrogen supply system was installed to satisfy initial demand for hydrogen at the

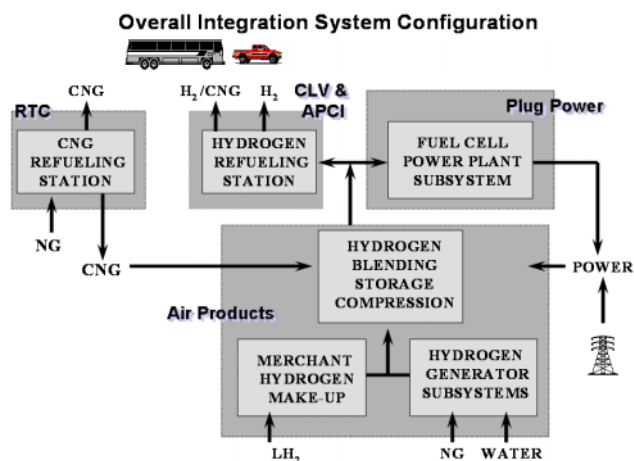


Figure 1. Overall Integration System Configuration

refueling station, and to provide back-up hydrogen supply for additional system reliability. The hydrogen compression, storage, blending and dispensing systems are capable of supplying pre-determined blends of H₂ and CNG to be dispensed to trucks and buses with internal combustion engines (ICEs) converted to run on H₂/CNG mixtures. The station will also be able to dispense pure hydrogen to vehicles. Currently there is one light-duty vehicle (LDV) and one para-transit bus fueled with the H₂/CNG blend.

The original project plan contemplated that upon successful testing/operation of the first H₂/CNG fueled para-transit bus, the CLV would proceed to convert six new CNG fueled buses to H₂/CNG blended fuel operation. They expected to have all six buses converted over a six-month period, nominally one bus per month through December 2003.

The bus conversion is underway, but did not proceed as quickly as originally conceived for the project. The station continues to support the fleet demonstration based on a limited fleet population at this time, with further fleet expansion planned to follow. This aspect of the project demonstration continues to develop.

Approach

Early in the project, Air Products evaluated various small-scale developmental natural gas reformation technologies via extensive laboratory and field-testing. These technologies included

partial oxidation, auto thermal reforming and steam methane reforming. These test results were the basis for technology selection of SMR for the hydrogen generator. The hydrogen generator was integrated with a pressure swing adsorption (PSA) system supplied by QuestAir to produce pure hydrogen.

Plug Power developed and provided a 50-kW fuel cell for the project. The 50-kW fuel cell was built by assembling eight 7.5-kW residential fuel cell stacks which were being developed by Plug Power for the residential power market. The residential system was designed to operate on reformat and thus modifications were required for using pure hydrogen in this project. Extensive testing of the fully assembled module at Plug Power's Latham, NY facility was conducted to qualify individual systems and the final system configuration.

This report covers the operating period of the project, where the Energy Station was operated in the climate extremes of Las Vegas. Hydrogen was provided to produce power from Plug Power's 50-kW fuel cell, and for the fueling of vehicles. This hydrogen was sourced both from the on-site generation of hydrogen by the Air Products Hydrogen Generator, and by liquid hydrogen delivered to the on-site storage system. The generated power was exported to the local Nevada Power grid system. The hydrogen for fueling was directed to both the fueling of hydrogen fuel cell vehicles, on a limited number of occasions, and to CLV's fleet of H₂/CNG ICE vehicles.

Results

Hydrogen Generator

The Hydrogen Generator was installed, commissioned and placed into operation in the summer of 2002 (see Figure 2). On-spec hydrogen production, with purity in excess of 99.95%, was established in August 2002. Successful process operation of the Hydrogen Generator was achieved without process modification to the system after ex-works delivery of the unit to the site for operation. Since the initial establishment of hydrogen production, the unit has achieved an aggregate run-time of over 2800 hours. The integrated Hydrogen



Figure 2. View of the Hydrogen Generator (Left) and Fuel Cell (Right)

Generator system achieved the full range of expected operability control.

During this period, hydrogen production at an efficiency (LHV) of 68% was achieved, at purities of less than 1 ppm CO. The test results to date point to the capability to achieve an efficiency of 70% with the system, meeting the DOE HFCIT Multi-Year Program Plan target for 2003. It should be noted, however, that the unit represents technology decisions and implementation that occurred well in advance of 2003.

Economic analysis of the technology was also performed during this period. Based on the economic assumptions provided by the DOE HFCIT Multi-Year Program Plan and the Las Vegas site specific Hydrogen Generator characteristics (lower hydrogen production capacity [150 kg/day, 75 Nm³/hr], lower production number of units [1 unit], and more conservative capital factor [10 yr term, 10% DCF]), the test results confirm the ability to meet the \$5/kg (GGE) 2003 target for the cost of hydrogen. Further economic analysis was performed to evaluate the integrated co-generation cost of hydrogen and power, with appropriate scaling to economic factors applicable to moderate levels of technology adoption. The analysis was scaled based on higher production capability (400 Nm³/hr) and better economies of scale for larger production volume (100 units). The results of this analysis indicate that the technology is capable of achieving an integrated co-generation cost of hydrogen of less than \$3.60/kg (GGE) and \$0.08/kWh cost of power.



Figure 3. View of the Fuel Station

Las Vegas provides an excellent real-world performance and durability testing environment. Diurnal ambient condition effects on combustion air and process parameters were evaluated. Control system improvements were identified and implemented to dampen undesirable process cycling due to both ambient and process conditions. Additionally, the reformer was dismantled for an in-service inspection of the equipment internals. The reformer components were found to be in excellent condition.

Fueling Station

The fueling station segment of the Energy Station consists of liquid hydrogen storage, gaseous hydrogen storage, product compression, H₂/CNG fuel blending, and H₂/CNG and pure hydrogen dispensing (see Figure 3). Since operation of the fueling station was established, satisfactory vehicle fueling has been demonstrated. Fueling operations have been performed for both hydrogen fuel cell vehicles and H₂/CNG vehicles (see Figure 4). To date, over 70 H₂/CNG vehicle fuelings and 12 pure H₂ vehicle fuelings have been performed. The systems demonstrated an appropriately high level of safety in their engineering, design, fabrication and suitability for functional utilization.

The DOE Safety Panel reviewed the entire Energy Station in March 2004. No material safety deficiencies were identified. The Panel did note some items for consideration. These were reviewed



Figure 4. City of Las Vegas Blend Fuel Bus

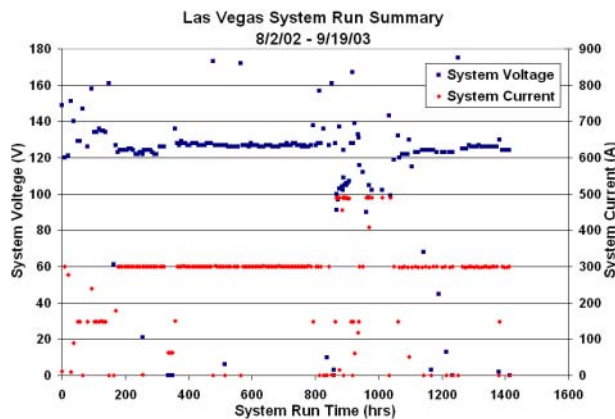


Figure 5. Fuel Cell Power Production Performance

and found to have sufficiently engineered solutions in place.

Stationary PEM Fuel Cell

The 50-kW PEM fuel cell was initially started-up in August 2002. Figure 5 shows the Fuel Cell System run summary from initial startup until September 19, 2003. The system ran for a total of 1414 hours producing approximately 43,500 kWh gross DC Power. Fully integrated operation of the fuel cell within the Energy Station has been demonstrated.

At the 50-kWe set point, the Fuel Cell System consumed 15.3 slm of hydrogen for every kW of electricity produced. Based on the lower heating

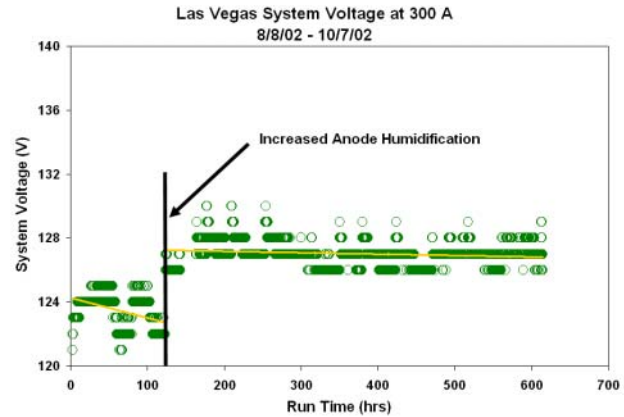


Figure 6. Fuel Cell Power vs. Humidification Effects

value of hydrogen, the total system efficiency was measured at 36.3%, with a fuel cell stack efficiency of 46.8%. System inefficiencies include inverter/transformer losses and the energy required to operate the fuel cell system.

As seen in Figure 6, for the first 125 hours the stacks were experiencing low performance due to low humidification levels. After the anode humidification and temperature were increased a significant increase in stack voltage occurred. Over the next 490 hours the average cell degradation rate was 5 micro-volts/hour. If this degradation rate continued a stack life between 10,000 and 12,000 hours would be expected.

Following these modifications, the unit continued to experience operational issues with cell voltage falloff that made continuous operation problematic. This appears to refute the concept of multiple stacks with no provision to accommodate the need of each stack with respect to voltage output, over stoichiometric flows to both anode and cathode, humidity of both anode and cathode, and temperature of each stack. The fuel cell stack will be replaced the week of July 16, 2004 and restarted.

A potential issue was also identified with timing of electric load shedding on shutdown. The timing will be analyzed and software and/or hardware modifications to eliminate potential ground looping, which may be contributing to stack failures, will be implemented.

Conclusions

- The Energy Station is a viable operational concept. The fuel cell provided a demand for hydrogen during low levels of vehicle fueling demand.
- DOE HFCIT Multi-Year Program Plan targets are obtainable with the technologies used for this demonstration. High volume adoption of the technologies is necessary to realize the economic factors applicable to achieving the targets.
- Vehicle fleet build-up continues to be a primary challenge to satisfactory utilization of hydrogen fueling infrastructure efforts.
- The fuel cell design approach of multiple stacks with no ability to independently manage gas flows, temperature, humidity and power was based on technology that was state-of-the-art in 2001. This project identified the significant barriers to this approach and gained the experience to overcome such barriers in future design activities.
- An excellent list of lessons learned was compiled for a fuel cell design that would include a single fuel cell stack rather than the eight stacks utilized to address integration and cost issues. Other critical areas of experience include inverter integration, water management, and communication.
- The project has provided a significant source of development opportunities, given the applied technology demonstration in a real world environment.

FY 2004 Publications/Presentations

Presentations about this project during this period include:

- Pennsylvania Resources Council, Environmental Award Receipt Presentation – December 4, 2003
- PowerGen 2004, Las Vegas, NV – March 1, 2004 – Tour / description of facility
- International Energy Agency, Las Vegas, NV – March 2, 2004 – Tour and presentation at facility
- DOE Safety Panel, Las Vegas, NV – March 3, 2004 – Presentation at facility
- Fuel Cell Summit VIII, Miami, FL – June 16, 2004 – “Las Vegas Hydrogen Energy Station, Case Study”