DISTRIBUTED H₂ SUPPLY FOR FUEL CELL UTILITY VEHICLES

Year 6 – Activity 3.5 – Development of a National Center for Hydrogen Technology

Topical Report

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ABSTRACT

The Energy & Environmental Research Center (EERC) has developed a high-pressure hydrogen production system that reforms a liquid organic feedstock and water at operating pressures up to 800 bar (~12,000 psig). The advantages of this system include the elimination of energy-intensive hydrogen compression, a smaller process footprint, and the elimination of gaseous or liquid hydrogen transport. This system could also potentially enable distributed hydrogen production from centralized coal. Processes have been investigated to gasify coal and then convert the syngas into alcohol or alkanes. These alcohols and alkanes could then be easily transported in bulk to distributed high-pressure water-reforming (HPWR)-based systems to deliver hydrogen economically.

The intent of this activity was to utilize the EERC's existing HPWR hydrogen production process, previously designed and constructed in a prior project phase, as a basis to improve operational and production performance of an existing demonstration unit. Parameters to be pursued included higher hydrogen delivery pressure, higher hydrogen production rates, and the ability to refill within a 5-minute time frame.

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EXECUTIVE SUMMARY

This activity is a continuation of work done previously under the National Center for Hydrogen Technology[®] Program (NCHT[®]) Cooperative Agreement. Details of progress made during NCHT Years 1–5 were previously presented in a final report written to encompass only those years. The present report focuses on the results of Year 6 of the NCHT contract, but repeats enough of previously reported results to aid in understanding of Year 6 results.

The Energy & Environmental Research Center (EERC) has developed a high-pressure hydrogen production system that reforms a liquid organic feedstock and water at operating pressures up to 800 bar (~12,000 psig). Details of this production system can be found in the NCHT Years 1–5 final technical report, filed with DOE in 2011. The advantages of this system include the elimination of energy-intensive hydrogen compression, a smaller process footprint, and the elimination of gaseous or liquid hydrogen transport.

This system could also potentially enable distributed hydrogen production from centralized coal. Processes have been investigated to gasify coal, then convert the syngas into alcohol or alkanes. These alcohols and alkanes could then be easily transported in bulk to distributed high-pressure water-reforming (HPWR)-based systems to deliver hydrogen economically.

The intent of this activity was to utilize the EERC's existing HPWR hydrogen production process, designed and constructed in a prior project phase, as a basis to improve operational and production performance of its existing demonstration unit. Parameters that were to be pursued included higher hydrogen delivery pressure, higher hydrogen production rates, and the ability to refill within a 5-minute time frame, as summarized in Table ES-1.

This demonstration was to provide valuable information regarding the real cost of hydrogen production. The work in these activities would focus on optimization of the process variables in order to meet the target goals of the system. Other variables tested would include reactor aspect ratio, pressures, feed rates, temperatures, and residence times for the given delivery parameters. The process was to be integrated with 700-bar hydrogen storage tank(s) and a fueling dispenser, previously supplied by Krauss Global, Inc., to make a complete and functional hydrogen fueling system for small-scale demonstration purposes. From the demonstration unit, hydrogen production costs would be obtained along with the identification of applicable target markets.

Table ES-1. Performance Characteristics

Fill Time	Delivery Rate, kg/min	Pressure, bar	H ₂ Purity/Compatibility
5 minutes	1.0	700	PEM* fuel cell (99.99% purity)

* Proton exchange membrane.

Initial hydrogen production results at 350 bar were reported in the NCHT Years 1–5 final technical report. Initial experiments produced a hydrogen-rich reformat at approximately 350 bar (~5000 psig), which is the design onboard storage fill pressure for many fuel cell-powered vehicles. Methanol experiments produced a 350-bar (~5000 psig) product gas consisting of 73 mol% hydrogen, 25 mol% carbon dioxide, 1 mol% methane, and 1 mol% carbon monoxide. Conversion ranged from 74% to 100%, depending on methanol flow rate. A methanol flow rate of 0.09 kg/hr resulted in 100% conversion, while a methanol flow rate of 0.23 kg/hr resulted in 74% conversion. Pressure swing adsorber tests proved the subsystem’s capability to purify the reformat to ICE (internal combustion engine) quality or better.

These results served as lower-pressure validation of the system design. Higher-pressure validation at 700 bar was somewhat dependent upon acquisition of and integration of a high-pressure hydrogen storage subsystem that would permit full functional checkout of the integrated system. The high-pressure tank acquisition process had been started with Lincoln Composites during the previous phase of the project.

The acquisition and approval for use of the high-pressure tank proved much more challenging than originally anticipated. The EERC attempted to procure a 300-liter, 700-bar, Type IV composite hydrogen fuel tank directly from Lincoln Composites, an industry leader in this cutting-edge hydrogen storage technology. After months of unsuccessful negotiations to contract purchase of these tanks, the EERC discontinued negotiations with Lincoln Composites in January 2011.

The EERC instead found an alternate outlet for identical tanks. Powertech Labs in Vancouver, British Columbia, had stock of at least two of these Lincoln Composites tanks. Powertech was also uniquely qualified to test these tanks and work with local permitting authorities to resolve issues pertaining to lack of adequate ASME codes to govern these cutting-edge tanks. Powertech had been responsible for negotiations with the California Department of Industrial Relations for approval to use identical tanks in California.

The EERC contracted with Powertech Labs to provide one tank and appropriate system integration hardware. The EERC also contracted for a comprehensive report on Powertech Lab’s negotiations with the North Dakota State Boiler Inspector, the local authority with authority to approve this tank for use with the HPWR system. In December 2011, the tank was received from Powertech Labs after the EERC received authorization from the North Dakota State Boiler Inspector’s office, in the form of a variance letter. This tank is shown in Figure ES-1.

Powertech Labs is currently working toward resolution of approval issues with the North Dakota State Boiler Inspector. However, this process was complicated by the fact that ASME Section X had not been formally drafted when the purchased high-pressure tank was manufactured. ASME Section X is the formal pressure vessel code governing ground installation of this new type of high-pressure hydrogen fuel tank. Additionally, at the time of this report, inspection checklists used by pressure vessel inspectors nationwide for these types of high-pressure tanks are still under development, and no inspection procedures have yet been ratified.

The North Dakota State Boiler Inspector had consistently stated his office's position from the beginning of negotiations for installation approval that North Dakota approval of ground installation of this Type IV tank would come in the form of a variance and was contingent upon approval of a nearly identical installation in California by the pressure vessel approval authority in California, a recognized expert in this field. Although this nearly identical installation in California was originally granted a variance after the draft of ASME Section X was published, that California variance was recently revoked after it was discovered that prescribed acoustic tests on these tanks had not been performed, as previously indicated by Lincoln Composites.

Absence of approval to use the purchased high-pressure tank prevented integration of the tank into the HPWR system. Integration and demonstration of the complete system will be pursued in subsequent projects requiring high-pressure storage. It is interesting to note that these types of high-pressure composite tanks are formally approved for use in transport applications by the U.S. Department of Transportation (DOT).¹ It is, therefore, expected that, with time, the ASME code governing use of these tanks in ground storage applications will mature to a point allowing use of these tanks in applications such as the one discussed here.

Figure ES-1. 700-bar Type IV tank delivered to the EERC by Powertech Labs.

¹CSA America Inc.'s NGV2, *Basic Requirements for Compressed Natural Gas Vehicle (NGV) Fuel Containers*, ISO 11439, *Gas Cylinders – High Pressure Cylinders for the On-Board Storage of Natural Gas as a Fuel for Automotive Vehicles*, and FMVSS 304, *Compressed Natural Gas Fuel Container Integrity* are currently used as guidelines for approval of mobile hydrogen storage. SAE J2579, *Technical Information Report for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles*, is in the early stages of development, but will further refine DOT's approach to approval of mobile hydrogen storage tanks.

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INTRODUCTION

This activity is a continuation of work done previously under the National Center for Hydrogen Technology[®] Program (NCHT[®]) Cooperative Agreement. Details of progress made during NCHT Years 1–5 were previously presented in a final report written to encompass only those years. The present report focuses on the results of Year 6 of the NCHT contract, but repeats enough of previously reported results to aid in understanding of Year 6 results.

APPROACH

The intent of this activity was to utilize the Energy & Environmental Research Center's (EERC's) existing high-pressure water-reforming (HPWR) hydrogen production process, designed and constructed in a prior project phase, as a basis to improve operational and production performance of its existing demonstration unit. Parameters that were to be pursued included higher hydrogen delivery pressure, higher hydrogen production rates, and the ability to refill within a 5-minute time frame.

This demonstration was to provide valuable information regarding the real cost of hydrogen production. The work in these activities would focus on optimization of the process variables in order to meet the target goals of the system. Other variables tested would include reactor aspect ratio, pressures, feed rates, temperatures, and residence times for the given delivery parameters. The process was to be integrated with 700-bar hydrogen storage tank(s) and a fueling dispenser, previously supplied by Krauss Global, Inc., to make a complete and functional hydrogen-fueling system for small-scale demonstration purposes. From the demonstration unit, hydrogen production costs would be obtained along with the identification of applicable target markets.

BACKGROUND

The EERC has developed a high-pressure hydrogen production system that reforms a liquid organic feedstock and water at operating pressures up to 800 bar (~12,000 psig). Details of this production system can be found in the NCHT Years 1–5 final technical report, filed with the U.S. Department of Energy (DOE) in 2011. The advantages of this system include the elimination of energy-intensive hydrogen compression, a smaller process footprint, and the elimination of gaseous or liquid hydrogen transport.

Hydrogen fuel cell-powered vehicles are an attractive alternative to traditional hydrocarbon fuel combustion engines because they emit only water vapor as exhaust and because the hydrogen fuel can originate from a variety of sources. Although alternative sources of hydrogen

are being investigated, natural gas remains the number one source of hydrogen in the United States. Currently, 95% of the hydrogen produced in the United States is produced via steam methane reforming (1). This process converts methane and water into hydrogen and carbon dioxide. Hydrogen production facilities are often large and located at centralized locations. Therefore, compression and transportation are required to bring hydrogen to end users. It has been estimated that hydrogen transportation costs \$4–\$9/gge (gallon of gasoline equivalent) and hydrogen compression, storage, and dispensing costs \$2–\$3/gge (2).

Transporting hydrogen from large production facilities to a dispersed network of fuel stations would require many tube trailers or an extensive hydrogen pipeline. Tube trailers have an upper pressure limit of approximately 220 bar (3200 psig) and would require on-site compression and storage, in order to provide a 700-bar (~10,000-psig) hydrogen fill to vehicles. A suitable hydrogen pipeline would require an enormous infrastructure investment. There are currently about 1900 km (~1200 miles) of hydrogen pipeline in the United States, compared to over 1 million miles of pipeline for natural gas (3). Because of hydrogen embrittlement and other issues, specialized pipes must be constructed for hydrogen transport.

As an alternative to traditional hydrogen production and transportation methods, the EERC has developed a system that pumps liquid products into a high-pressure reactor. The reactor continuously produces a high-pressure, hydrogen-rich gas stream that is purified at pressure and dispensed into vehicles. This design eliminates hydrogen transportation and hydrogen compression. Liquid feedstock would be brought to, and stored in, existing tanks at fueling stations, and the high-pressure hydrogen reformer would be located out of the way.

Liquid reforming also provides cost savings by operating at reduced temperatures compared with traditional methods. Other operational advantages such as the ability for small scale and distributed production of hydrogen make liquid reforming an attractive option for transportation-grade hydrogen generation.

RESULTS AND DISCUSSION

Summary of Scaled-Up Demonstration System Design

The overall scaled-up demonstration system design was approached as three separate subsystem design efforts. This separation was mandated by the need to incorporate one of two purification subsystem designs dependent upon test results achieved simultaneously to the scaled-up demonstration system design phase. A 3-D model of the integrated system and its configuration within the test facility is shown in Figure 1. The two designs are as follows:

- Reformer subsystem design
 - The design for the reformer subsystem was derived directly from the final configuration of the lab-scale unit, but scaled up to achieve the hydrogen production rates demanded by the demonstration goals. The design included a nearly identical preheater, a larger catalytic reforming reactor, improved heat exchange to minimize external heating, additional water knockouts, a larger CO₂ stripper column

(employing the same liquid CO₂ adsorbent that achieved promising results during lab-scale testing), and a larger methanation reactor. The reformer subsystem design is shown in Figure 2.

- Gas purification system design
 - A purification subsystem design was required to complete the integrated design of the scaled-up demonstration system because the goal of this project was to produce PEM-grade hydrogen. The reformer alone produces a relatively pure hydrogen stream, but not pure enough to meet hydrogen fuel standards for PEM fuel cells. The pressure swing adsorption (PSA) design consisted of three trains, each with two beds of adsorption media. One vessel in each train contained only powdered activated carbon. The other vessel in each train contained both powdered activated carbon and zeolite-based molecular sieve material. The gas purification subsystem designed for use in the integrated scaled-up demonstration system is shown in Figure 3.

Summary of Scaled-Up Demonstration System Testing

Initial hydrogen production results at 350 bar were reported in the NCHT Years 1–5 final technical report. The integrated hydrogen production and purification system was subsequently tested with a methanol feedstock and water. Methanol and water were fed to the scaled-up reformer at flow rates of 4 and 14 lb/hr, respectively. The entire methanol feed was converted to a hydrogen-rich gas (100% conversion). At complete conversion, these flow rates result in a hydrogen product flow of 8 kg/day (0.34 kg/hr). Reactor temperature was 396°C, and reactor pressure was 5017 psig. The dry product gas coming from the reformer is shown in Table 1. This high-pressure gas was then routed to the CO₂ removal vessel where the CO₂ concentration was reduced from 20.8 to 0.03 vol%. Table 1 summarizes gas composition at various stages in the liquid reforming process. No additional PSA subsystem testing was completed during Year 6. PSA tests proved the subsystem’s capability to purify the reformat to internal combustion engine (ICE) quality or better.

These results served as lower-pressure validation of the system design. Higher-pressure validation at 700 bar was somewhat dependent upon acquisition of and integration of a high-pressure hydrogen storage subsystem that would permit full functional checkout of the integrated system. The high-pressure tank acquisition process had been started with Lincoln Composites in late 2009, during the previous phase of the project.

Table 1. Gas Cleanup at Various Stages of the Liquid Reforming Process

	H ₂	CO ₂	CO	CH ₄
After Reformer	72.9	20.8	1.5	1.4
After CO ₂ Removal	96.6	0.03	1.8	1.4
After Methanation	96.1	0.02	0	3.5
Final Product	100	0 (<100 ppm)	0 (<100 ppm)	0 (<100 ppm)

Figure 1. 3-D model of the EERC scaled-up hydrogen on-demand system.

Summary of Efforts to Integrate High-Pressure Storage Tank, Focus of NCHT Year 6 Project Activities

During NCHT Year 6, the project team focused on completion of hydrogen storage subsystem integration design and subsequent installation of storage subsystem integration equipment and computer control programming. This included procurement and installation of high-pressure storage tanks, but also included the safety equipment (proper pressure relief, gas detection system, storage tank enclosure, dispenser island standoff guards, lightning protection, etc.) required to support a successful installation of the high-pressure storage subsystem and achieve permitting and insurance approval from local authorities.

The acquisition of and approval for use of the high-pressure tank proved much more challenging than originally anticipated. The EERC attempted to procure a 300-liter, 700-bar, Type IV composite hydrogen fuel tank directly from Lincoln Composites, an industry leader in this cutting-edge hydrogen storage technology. After months of unsuccessful negotiations to contract purchase of these tanks, the EERC discontinued negotiations with Lincoln Composites in January 2011.

The EERC instead found an alternate outlet for identical tanks. Powertech Labs in Vancouver, British Columbia, had stock of at least two of these Lincoln Composites tanks. Powertech was also uniquely qualified to test these tanks and work with local permitting authorities to resolve issues pertaining to lack of adequate ASME codes to govern these cutting-edge tanks. Powertech had been responsible for negotiations with the California Department of Industrial Relations for approval to use identical tanks in California.

Figure 3. Purification subsystem design schematic.

The EERC contracted with Powertech Labs to provide one tank and appropriate system integration hardware. The EERC also contracted for a comprehensive report on Powertech Lab's negotiations with the North Dakota State Boiler Inspector, the local authority with authority to approve this tank for use with the HPWR system. In December 2011, the tank was received from Powertech Labs after the EERC received authorization from the North Dakota State Boiler Inspector's office, in the form of a variance letter. This tank is shown in Figure 4.

Powertech Labs is working toward resolution of approval issues with the North Dakota State Boiler Inspector. However, this process was complicated by the fact that ASME Section X had not been formally drafted when the purchased high-pressure tank was manufactured. ASME Section X is the formal pressure vessel code governing ground installation of this new type of high-pressure hydrogen fuel tank. Additionally, at the time of this report, inspection checklists used by pressure vessel inspectors nationwide for these types of high-pressure tanks are still under development, and no inspection procedures have yet been ratified.

The North Dakota State Boiler Inspector had consistently stated his office's position from the beginning of negotiations for installation approval that North Dakota approval of ground installation of this Type IV tank would come in the form of a variance and was contingent upon approval of a nearly identical installation in California by the pressure vessel approval authority in California, a recognized expert in this field. Although this nearly identical installation in California was originally granted a variance after the draft of ASME Section X was published, that California variance was recently revoked after it was discovered that prescribed acoustic tests on these tanks had not been performed, as previously indicated by Lincoln Composites.

Figure 4. 700-bar Type IV tank delivered to the EERC by Powertech Labs.

The North Dakota State Boiler Inspector continues to work with Powertech Labs to determine an appropriate path toward approval for use. The inspector's office performed an on-site inspection in January 2012 using an early draft of an inspection procedure under development by an ASME team (NB11-1901, "Installation of High Pressure Composite Pressure Vessels"). This inspection revealed eight issues to be addressed prior to issuance of the variance. Powertech and the inspector's office are currently negotiating resolution to this list of issues. Many of the issues are minor and have been addressed already. The principle issue of contention is in regard to the proposed, but not-yet-ratified, demand for a pressurized acoustic test of the tank upon manufacture and again every 3 years.

Absence of approval to use the purchased high-pressure tank prevented integration of the tank into the HPWR system. Integration and demonstration of the complete system will be pursued in subsequent projects requiring high-pressure storage. It is interesting to note that these types of high-pressure composite tanks are formally approved for use in transport applications by the U.S. Department of Transportation (DOT).² It is, therefore, expected that, with time, the ASME code governing use of these tanks in ground storage applications will mature to a point allowing use of these tanks in applications such as the one discussed here. This type of tank is critical for hydrogen systems because the higher pressure and resulting hydrogen gas density enable a higher energy density. This energy density, ultimately, has direct impact on hydrogen delivery system economics.

CONCLUSIONS

Despite successful design and testing of the reformer subsystem and purification subsystem at lower pressures (350 bar), the EERC was unable to adequately test the integrated system at higher pressures. This effort was impeded by an inability to obtain permitting and insurance approval to use new Type IV high-pressure, plastic-lined, carbon composite tank technology.

At the inception of this project, it was understood that extremely high pressure storage and dispensing of hydrogen was at the cutting edge of technology. However, it was believed that any issues could be resolved as the project progressed. A new breed of plastic-lined, carbon fiber-wound, composite tanks capable of 700-bar storage were newly offered in the market. Although they were not yet formally approved by ASME as viable pressure vessels, ASME was quickly writing codes to address this new technology. In fact, ASME was catching up to code already approved by the U.S. Department of Transportation for use in mobile applications.

²CSA America Inc.'s NGV2, *Basic Requirements for Compressed Natural Gas Vehicle(NGV) Fuel Containers*, ISO 11439, *Gas Cylinders – High Pressure Cylinders for the On-Board Storage of Natural Gas as a Fuel for Automotive Vehicles*, and FMVSS 304, *Compressed Natural Gas Fuel Container Integrity*, are currently used as guidelines for approval of mobile hydrogen storage. SAE J2579, *Technical Information Report for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles*, is in the early stages of development, but will further refine DOT's approach to approval of mobile hydrogen storage tanks.

Efforts to resolve permitting issues with the installed Type IV tank continued to the end of the project. At the time of this report, the North Dakota State Boiler Inspector has not signed the variance to permit use of this tank. The goal to incorporate the high-pressure hydrogen storage subsystem to permit high-pressure fueling demonstration and exploration of process improvements at higher pressure will need to be reached in subsequent testing of the HPWR system once use permits have been obtained.

The resolution to issues pertaining to ground installations of Type IV hydrogen storage tanks will continue to develop nationwide. It is the EERC's hope that this project's use of these tanks in its design and subsequent pressure on regulatory authorities in North Dakota and California have served to move these issues toward resolution more quickly.

REFERENCES

1. U.S. Department of Energy Hydrogen Program. *FY2006 Annual Progress Report*; 2006.
2. Schneider, J.; Richard, M.; Gambone, L.; McDougall, M.; Powers, C.; Patel, D.; Veenstra, M.; Barth, F.; Pregassame, J.; Damiani, C.; Webb, J.; Lynch, F. Evaluation of Fueling Performance Targets for Onboard 70-MPa Gaseous Hydrogen Storage Containers. In *Proceedings of the National Hydrogen Association 2006 Annual Meeting*; 2006.
3. U.S. Department of Energy – Hydrogen Program. Hydrogen Distribution and Delivery Infrastructure. www1.eere.energy.gov/hydrogenandfuelcells/pdfs/doe_h2_delivery.pdf (accessed 2011).