III.11 LLNL/Linde 875 bar Liquid Hydrogen Pump for High Density Cryogenic Vessel Refueling

Salvador M. Aceves (Primary Contact), Gene Berry, Francisco Espinosa-Loza, Guillaume Petitpas, Vernon Switzer, Stan Tuholski
Lawrence Livermore National Laboratory (LLNL)
7000 East Avenue, L-792
Livermore, CA 94551
Phone: (925) 422 0864
Email: saceves@llnl.gov

DOE Manager
HQ: Erika Sutherland
Phone: (202) 586-3152
Email: Erika.Sutherland@ee.doe.gov

Subcontractors:
Linde LLC, Hayward, CA
Engineering, Procurement & Construction (EPC), Lakewood, CO

Start Date: October 1, 2009
Project End Date: Project continuation and direction determined annually by DOE

Fiscal Year (FY) 2012 Objectives

- Demonstrate rapid refueling of cryogenic vessels
- Refuel cryogenic vessels even when warm and/or pressurized
- Refuel at high density (>80 kgH_2/m^3)

Technical Barriers

This project addresses the following technical barrier from the Delivery section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(J) Refueling Site Operations

FY 2012 Accomplishments

- Developed a vessel fill model and demonstrated agreement with BMW experimental data
- Located an appropriate site for liquid hydrogen (LH_2) pump installation at LLNL
- Completed topographical, soil, and utility scans of selected location
- Received institutional approval for pump installation

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Introduction

Cryogenic pressure vessels have demonstrated highest performance for automotive hydrogen storage, with storage density (43 gH_2/L), weight fraction (7.3%), cost ($11.3/kWh), and safety advantages (~8X lower expansion energy than compressed gas and secondary protection from vacuum jacket) [1,2]. One of the outstanding challenges for cryogenic pressure vessels is refueling. Today's hydrogen storage technologies (compressed and liquid hydrogen) operate at fixed temperature. Cryogenic pressure vessels, however, drift across the phase diagram depending on the level of use, cooling down and depressurizing when driven and heating up and pressurizing when parked. The challenge is demonstrating rapid, inexpensive refueling that minimizes evaporative losses regardless of the initial thermodynamic state of the vessel.

Approach

LLNL has identified a promising technology for cryogenic pressure vessel refueling: a liquid hydrogen (LH_2) pump. Manufactured by Linde, a leading supplier of cryogenic equipment, this pump takes liquid hydrogen at low pressure (near atmospheric) and delivers it at high pressure (up to 875 bar), high flow rate (100 kg/hour), low temperature (30-60 K), high density (>80 g/L), and low evaporative losses

TABLE 1. Progress toward Meeting DOE Hydrogen Delivery Technical Targets

Pressurized LH_2 pump				
DOE targets for forecourt compressors	**Units**	**2010 Target**	**2015 Target**	**Pressurized LH_2 pump**
Reliability	-	Improved	High	High
Compression energy efficiency	%	94	95	99
Installed capital cost	k$/(kg/hr)	4	3	5
H_2 fill pressure	Peak psi	6,250	12,000	12,700

(less than 3% of dispensed H_2). Pumped hydrogen can be directly dispensed into a cryogenic pressure vessel, even when warm and/or pressurized. In this project we plan to install a LH_2 pump in the LLNL campus and demonstrate its virtues for rapid and efficient cryogenic vessel refueling.

Results

In an effort to evaluate the potential for future LH_2 pump high density refueling, LLNL has developed a model for vessel fill processes. Based on REFPROP [3], the model considers real gas hydrogen properties and enables quick calculation of relevant thermodynamic properties. The model is based on experimental measurements of outlet temperature vs. pressure performed at Linde, and has been validated against experimental BMW data for an existing 300 bar pump, demonstrating good agreement for a wide range of experimental conditions (Figure 1).

Aside from model validation, FY 2012 effort has mainly focused on site location and institutional approvals for LH_2 pump installation. The LH_2 pump and dewar (3,000 gallons, 800 kg LH_2 storage capacity) make a large package (12-m long by 4-m wide, Figure 2) and need to be installed in a location that permits access by LH_2 delivery truck.

With assistance from LLNL's facilities group, an appropriate location for the pump in the southern end of the LLNL campus has been identified. The site is within the future Livermore Valley Open Campus, a joint LLNL-Sandia partnership established to enhance industrial collaboration. The pump may therefore be publicly accessible in the future if so decided by laboratory/DOE management. A soil study and a topographical survey has been conducted (Figure 3).

All institutional approvals have been granted, and detailed design is about to start. Detailed design will include plans for demolition, tree removal, fence removal and rebuild, electric supply (480 and 120 volts), telephone line, foundation, bollard installation, road construction, grading, and paving.

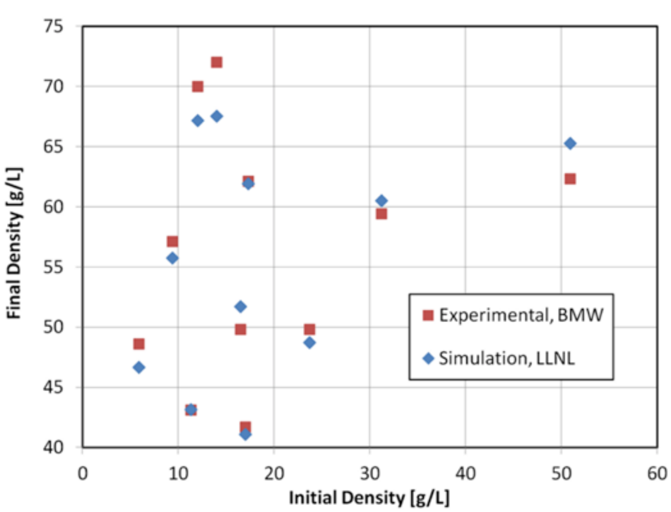

FIGURE 1. Validation of REFPROP-based model for Linde's LH_2 pump vs. experimental data from BMW

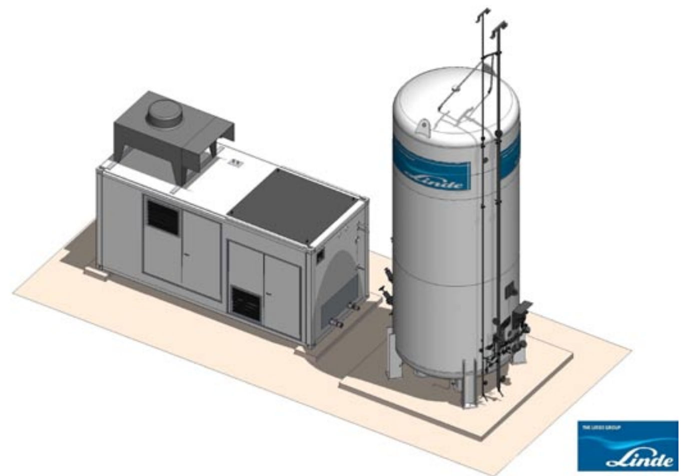

FIGURE 2. Rendering of the future LLNL LH_2 pump fabricated by Linde

The design was conducted during the month of August. The design package will then be approved by LLNL in September, immediately followed by construction. Pump installation by Linde is finally expected for January of 2013.

Conclusions and Future Directions

- Rapid, low-loss refueling of cryogenic vessels is possible through pressurized LH_2 dispensing
- LH_2 pump model has been developed and validated against BMW experimental data
- LLNL facilities program has approved the proposed plan
- Detailed design is under way, to be quickly followed by construction
- Pump installation is planned for January 2013
- LH_2 pump will enable up to 30% higher density refueling and will open to research a large region of the H_2 phase diagram (Figure 4)

References

1. Aceves, S.M., Espinosa-Loza, F., Ledesma-Orozco, E., Ross, T.O., Weisberg, A.H., Brunner, T.C., Kircher, O., "High-density automotive hydrogen storage with cryogenic capable pressure vessels," International Journal of Hydrogen Energy, Vol. 35, pp. 1219-1226, 2010.

2. Ahluwalia, R.K. Hua, T.Q. Peng, J.-K. Lasher. S, McKenney. K. Sinha, J., Gardiner. M. "Technical assessment of cryo-compressed hydrogen storage tank systems for automotive applications," International journal of hydrogen energy, Vol. 35, pp. 4171–4184, 2010.

FIGURE 3. Topographical area of the construction site indicating the future location of the LH_2 pump (red rectangle near the middle of the figure)

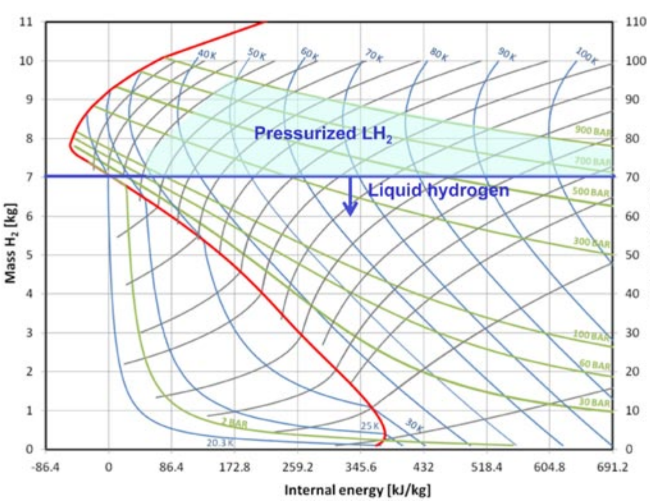

FIGURE 4. Hydrogen phase diagram indicating the operating region for LH_2 (below 70 g/L) and the region opened to research by the LH_2 pump

3. Lemmon, E.W., McLinden, M.O., Huber, M.L., "REFPROP: NIST reference fluid thermodynamic and transport properties," National Institute of Standards and Technology, 2004. NIST Standard reference database 23, version 7.1.

FY 2012 Publications/Presentations

1. Cryogenic Hydrogen Storage, Delivery, and Safety, Salvador Aceves, Invited Presentation, Annual Congress of the Mexican Society of Mechanical Engineers, San Luis Potosi, Mexico, September 2011.

2. Compact Hydrogen Storage in Cryogenic Pressure Vessels, Salvador M. Aceves, Francisco Espinosa-Loza, Elias Ledesma-Orozco, Guillaume Petitpas, in Handbook of Hydrogen Energy, Edited by S.A. Sherif, E.K. Stefanakos, and D.Y. Goswami, CRC Press, Taylor & Francis, 2012.

3. Web-Based Resources Enhance Hydrogen Safety Knowledge, Weiner, S.C., Fassbender, L.L., Blake, C., Aceves, S.M., Someday, B.P., and Ruiz, A., Accepted for Publication, International Journal of Hydrogen Energy, 2012.

4. Hydrogen Safety Training for Researchers And Technical Personnel, Aceves, S.M., Espinosa-Loza, F., Petitpas, G., Ross, T.O and Switzer, V.A., International Journal of Hydrogen Energy, 2012.

5. Modeling of sudden hydrogen expansion from cryogenic pressure vessel failure, Petitpas, G. and Aceves, S.M., International Journal of Hydrogen Energy, 2012.

6. Vehicle refueling with liquid hydrogen thermal compression, Guillaume Petitpas, Salvador M. Aceves, Nikunj Gupta, International Journal of Hydrogen Energy, Vol. 37, Issue 15, pp. 11448-11457, 2012.