III.20 Rapid Low-Loss Cryogenic Hydrogen Refueling

Salvador M. Aceves (Primary Contact),
Gene Berry, Guillaume Petitpas, Tim Ross
Lawrence Livermore National Laboratory (LLNL)
7000 East Avenue, L-792
Livermore, CA 94551
Phone: (925) 422 0864
E-mail: saceves@llnl.gov

DOE Technology Development Manager:
Monterey Gardiner
Phone: (202) 586-1758
E-mail: Monterey.Gardiner@ee.doe.gov

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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 barriers from the Delivery section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(J) Other Refueling Site/Terminal Operations

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	95
Installed Capital Cost	k$/(kg/hr)	4	3	5
H_2 Fill Pressure	Peak psi	6,250	12,000	12,000

Accomplishments

- Identified pressurized liquefied hydrogen (LH_2) as a viable solution for cryogenic vessel refueling.
- Identified commercial LH_2 pump that will deliver required performance.
- Acquired LLNL institutional approvals for pump purchase and installation.

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Introduction

Cryogenic pressure vessels have demonstrated highest performance for automotive hydrogen storage, with considerable advantages in terms of weight, volume, and cost [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. The challenge is demonstrating rapid, inexpensive refueling that minimizes evaporative losses regardless of the initial thermodynamic state of the vessel.

Approach

We have identified a promising technology for cryogenic pressure vessel refueling: a liquid hydrogen pump. This pump takes liquid hydrogen at low pressure (near atmospheric) and delivers it as high-pressure (3,000-12,000 psi) low temperature (30-50 K) high-density (>80 kg/m^3) hydrogen that can be directly dispensed into a cryogenic pressure vessel, even when warm and/or pressurized. In this project we plan to purchase a LH_2 pump, install it in the LLNL campus, and demonstrate its virtues for rapid and efficient cryogenic vessel refueling.

Results

Cryogenic vessel temperature and pressure are strong functions of use patterns. After a cryogenic hydrogen fill, pressure vessels will remain cold and unpressurized if frequently driven due to (nearly) isentropic hydrogen expansion during gas extraction, thereby enabling efficient refueling from conventional low pressure (~100 psi) LH_2 Dewars. Extended periods of parking, however, will warm up and pressurize the vessel due to heat transfer from the environment. Refueling warm vessels with low pressure LH_2 is slow and produces considerable evaporative losses. A better solution is needed for practical cryogenic pressure vessel refueling.

Liquid hydrogen pressurization appears a viable solution. A pump may take LH_2 from a low pressure

Dewar and deliver it at 30-50 K and 3,000-10,000 psi, enabling direct dispensing into even warm and/or pressurized vessels while minimizing evaporative losses.

A potential issue with direct dispensing from a LH_2 pump is the variability in the amount of hydrogen in a "full" tank as a function of initial conditions. While a cold tank can be filled to full capacity, a warm vessel can only be refueled to lower capacity to avoid evaporative losses when thermal equilibrium between the hydrogen and the vessel is reached. Fill variability may be acceptable to consumers because it is self-regulating: an infrequently driven vehicle is filled partially, but also requires less fuel because it is typically unused. A frequently driven vehicle has a cold vessel that can be filled to capacity, enabling long driving range.

Pressurized cryogenic refueling may also reduce station capital cost and hydrogen delivery cost. Unlike compressed gas dispensing, pressurized cryogenic dispensing does not require a cascade or refrigeration (Figure 1). The simpler station configuration reduces capital cost and makes the overall cost of liquid hydrogen dispensing comparable to the cost of compressed gas dispensing, even after considering liquefaction cost [3].

We have now identified a pump that satisfies the requirements for rapid cryogenic pressure vessel refueling. The pump takes advantage of LH_2 compressibility to deliver high density H_2 (over 80 kg/m^3, Figure 2) at rapid refuel rates (100 kg/hr) and with low evaporative rates (<3%). Evaporated hydrogen is not vented. Instead, it is recirculated into the station LH_2 Dewar, helping maintain its pressure.

LLNL is currently negotiating a contract with the manufacturer. Current plans call for pump installation (along with a large 3,000 gallon Dewar) at LLNL by early 2012.

Conclusions and Future Directions

- Rapid, low-loss refueling of cryogenic vessels is possible through pressurized LH_2 dispensing.
- Pressurized LH_2 dispensing reduces station cost by avoiding compressor, cascade, and refrigerator.
- Overall delivery cost of pressurized LH_2 is comparable to compressed gas, even after including the cost of liquefaction.
- Future work includes important tasks:

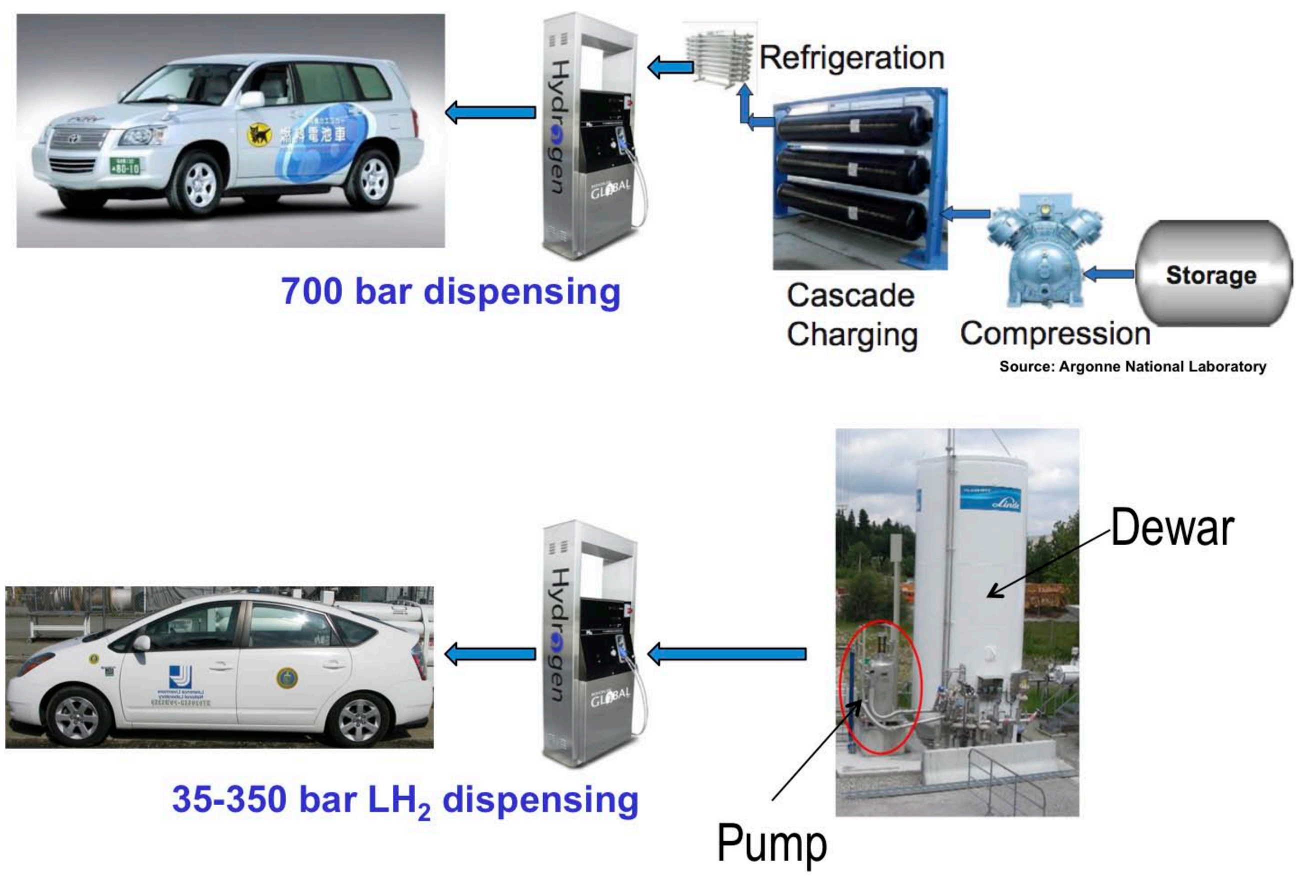

FIGURE 1. Graphical comparison between station equipment needs for 700 bar compressed H_2 dispensing and pressurized LH_2 dispensing (from Argonne National Laboratory [3]).

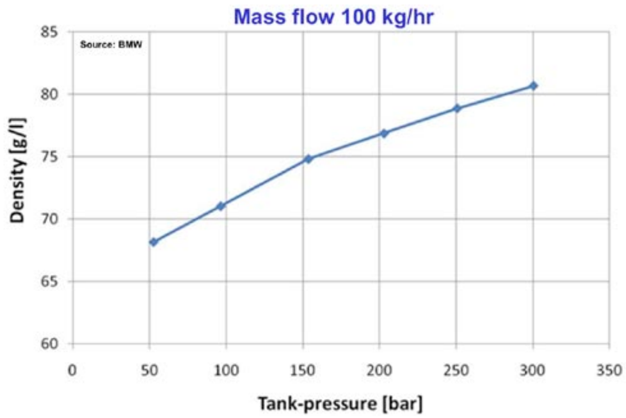

FIGURE 2. Density from Pressurized LH_2 Refueling as a Function of Delivery Pressure (from BMW)

- Purchase and install a pressurized cryogenic pump.
- Demonstrate rapid refueling of (even warm or pressurized) cryogenic pressure vessels with low evaporative losses.
- Explore effect of higher pressure on evaporative losses, refueling speed and maximum vessel capacity.

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