III.15 H2FIRST Consolidation

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Subcontractor:
PDC Machines, Warminster, PA

Project Start Date: October 1, 2015
Project End Date: September 30, 2017

Overall Objectives

- Decrease the contribution of station capital cost towards the levelized cost of hydrogen at fueling stations.
- Reduce the compression contribution (in terms of $/kg$_{H2}$) by approximately 50% (current compressors for large stations ~500 kg/d can cost ~$1,000,000).
- Maximize station performance in terms of back-to-back fills.

Fiscal Year (FY) 2017 Objectives

- Operate the Hydrogen Vehicle Simulator (HyVS) capable of simulating five back-to-back fills at 70 MPa, -40°C conditions.
- Build and integrate the consolidation compressor as designed by PDC Machines.
- Integrate a new 15 hp chiller and triple block at NREL Hydrogen Infrastructure Testing and Research Facility (HITRF) to support back-to-back filling.
- Program and integrate the baseline and consolidation into the NREL HITRF supervisory control and data acquisition system.
- Perform consolidation testing and optimization at the NREL HITRF.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation and Hydrogen Delivery sections of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

Technology Validation

(D) Lack of Hydrogen Refueling Infrastructure Performance and Availability Data

Hydrogen Delivery

(E) Gaseous Hydrogen Storage and Tube Trailer Delivery Costs

FY 2017 Accomplishments

- HITRF station upgrades and integration successfully demonstrated.
  - Low pressure gas management panel design, build and installation.
    - Five banks
    - 189 kg total at 20 MPa
    - Pressure and combustible gas safety systems
  - Medium pressure gas management panel upgrades.
    - Upgrade existing valves and tubing to accommodate larger flow rates.
    - Installed new safety systems to support high pressure to medium pressure cross over.
  - High pressure valve and tubing installation.
    - Tubing size upgraded to 9/16 in outside diameter to accommodate larger flow rates.
    - Second process path added to each high pressure bank to allow for simultaneous filling and dispensing.
- Compressor design, build, installation, and integration.
  - PDC designed and built the compressor at their factory in Warminster, Pennsylvania, to accommodate consolidation the testing of:
    - Multiple flow paths into and out of the compressor.
    - 100 hp motor, two-stage diaphragm.

  - Independent stage operation.
  - Flow rate calculated to be ~1 kg/min nominal.
- NREL and PDC integrated the compressor into the HITRF and confirmed safe operation.

- Baseline and consolidation algorithm development and implementation.
  - NREL has developed the software for control the HITRF and PDC compressor based on algorithms provided by Argonne National Laboratory (ANL).
  - NREL has tested the software and confirmed successful operation.

INTRODUCTION

The project aims to decrease the contribution of hydrogen station capital cost to the levelized cost of hydrogen ($/kg) at fueling stations. The project also aims to maximize station performance in terms of back-to-back fills. These goals will be accomplished through the demonstration of ANL's tube-trailer consolidation concept and its potential to provide significant compression cost reduction at a 700 bar hydrogen refueling station. The project will demonstrate the operation and improve the optimization of refueling station design by utilizing various tube trailer consolidation schemes. The project will instrument and collect operational data to validate ANL's model predictions, identify control issues, and verify the consequent economic benefits.

The proposed concept is projected to reduce the compression contribution to hydrogen cost (in terms of $\$/kg_{H2}$) by approximately 50% (current compressors for large stations ~500 kg/d can cost ~$1,000,000). Deploying 700 bar hydrogen stations capable of multiple back-to-back

T40 vehicle fills involves high capital investment. Low utilization and reliability of installed station equipment in early fuel cell electric vehicle markets escalates the station's contribution to the cost of hydrogen even further. The compression component alone comprises about half of the refueling station installed capital cost across various refueling station capacities. ANL has developed a novel tube trailer consolidation concept and estimated that it can operate the compressor at up to 10 times its rated throughput (in terms of kg/h at supply pressure of 20 bar), and thus can reduce the compressor size dramatically. This enables efficient utilization of the tube trailer payload and compressor capital investments, which can ultimately reduce capital expenditure on stations.

APPROACH

The project takes place in three phases:

- Phase I: Demonstration Setup
- Phase II: Demonstration Preparation
- Phase III: Demonstration Testing

In order to validate the consolidation concept, the project team has upgraded the existing HITRF station at NREL in order accomplish full-scale demonstration of the consolidation concept, as the refueling components at NREL were not sized for optimum performance and cost, but rather research flexibility. Demonstrating the benefits of the consolidation concept using NREL's existing station requires careful sizing of required supplemental components and a proper design of experiment. Such sizing and design must be done with the constraints of the already existing equipment at NREL (e.g., single dispenser and pressure vessels) and the available PDC Machines compressor models, while also minimizing the overall cost of the project.

Phase I, completed January 2016, quantified the capacity of station components necessary to validate the Consolidation concept. ANL ran a matrix of simulations to determine the size requirement of high-pressure vessels required for buffer storage, as well as pressure vessels that will mimic the tube-trailer. The simulations also determined the optimum number of banks, and number of tubes in each bank, for the buffer storage and tube-trailer systems.

Prior to beginning this project, the station capacity at NREL was limited to 20 kg/d with no back-to-back fast fill capability. As noted above, the promise of the consolidation concept lies in its ability to improve the number of back-to-back fast fills, and to satisfy large station daily demands by enhancing the compressor throughput during peak demand periods. ANL sized the tube trailer vessels (considering vessels already available at NREL) to satisfy 100 kg/d demand, and also adjusted the demand profile to simulate the number back-to-back fills (during peak hours) for a 300 kg/d station.

Once the sizing and configuration of the refueling components were established, and the operation of the different operation strategies (i.e., with and without consolidation), NREL and PDC developed a process flow diagram, piping and instrumentation diagram, control strategy flow chart, and detailed bill of material.

Phase II, completed May 2017, required NREL and PDC to build out the HITRF station and compressor to meet the design specifications from Phase I. Upgrades included additional storage tanks and valves, increasing tubing diameter and valve orifice, and installation of the PDC compressor. NREL also modified the HITRF supervisory control and data acquisition system to control and log data

for all of the new components according to the algorithm provided by ANL.

The PDC compressor is a novel design that allows for operation either as two independent single stage compressors or one dual stage compressor, as show in Figure 1.

Phase III, currently active, requires NREL to perform the baseline (without consolidation) and consolidation tests according to the ANL algorithm. The HyVS will be used to create station demand according to a typical hourly filling profile (shown in FY 2016 annual report). The test results will be evaluated by NREL, PDC and ANL, and changes to optimize the station operation will be made. Additional testing will take place at the HITRF station to maximize number of back-to-back fills.

RESULTS

Phase I and Phase II are completed by NREL and ANL (see also FY 2016 annual progress report). Simulations were conducted to show expected results from consolidation and baseline testing. A process hazards analysis was also completed by NREL based on the station design.

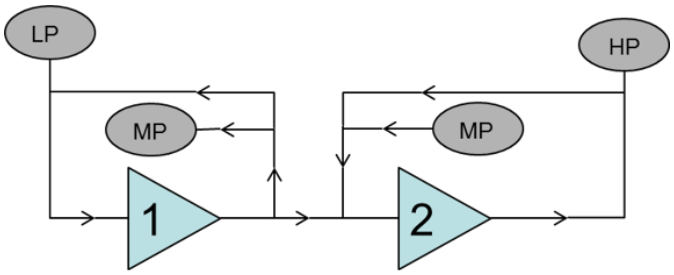

FIGURE 1. PDC compressor flow diagram. The compressor heads (1 and 2) are shown by triangles. The low, medium, and high pressure storage banks (LP, MP, and HP) are shown by the ovals.

In 2017, NREL made major modifications to the HITRF to support the consolidation testing. The images in Figure 2 show the HITRF in 2014 and today. The piping and instrumentation diagram for the station, as configured today is shown in Figure 3 with various flow paths.

NREL and PDC have tested manual operation of the compressor with the station control software, and have shown that the valves were sequenced correctly. The station will consolidate and dispense autonomously according to vehicle demand with the full implementation of the software. NREL is currently in the process of testing the baseline and consolidation algorithms. Results and analysis are expected by September 2017.

CONCLUSIONS AND UPCOMING ACTIVITIES

NREL, ANL, and PDC have worked together in FY 2017 to upgrade the HITRF to support hardware validation of the consolidation concept. This work includes installing new station equipment, programming the control software, and validating the operation. In the coming months, NREL will perform the automated baseline and consolidation tests, and will collect data for further analysis. The data will be evaluated by the team and compared to the modeling results from Phase I. The project team may make changes to the control software to optimize the algorithm.

FY 2017 PUBLICATIONS/PRESENTATIONS

1. Terlip, D., et al, "H2FIRST Tube Trailer Consolidation," Golden, CO, Hydrogen Delivery Technology Team, November 2016.

2. Terlip, D., et al, "H2FIRST Tube Trailer Consolidation," Washington D.C., DOE Annual Merit Review, June 2017.

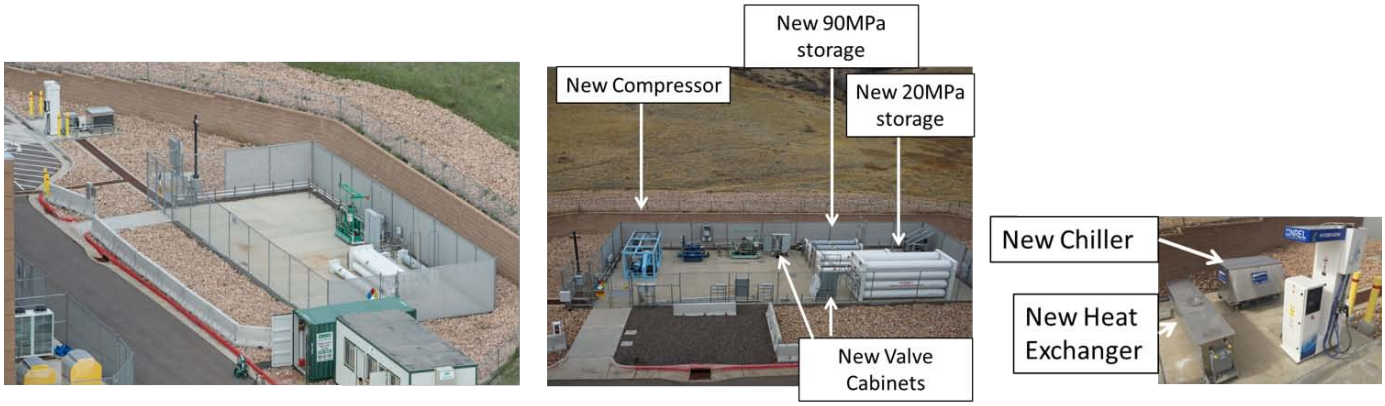

FIGURE 2. Hydrogen Infrastructure Testing and Research Facility shown before (left) and after (right) consolidation upgrades. There were eight new major station components added to the HITRF.

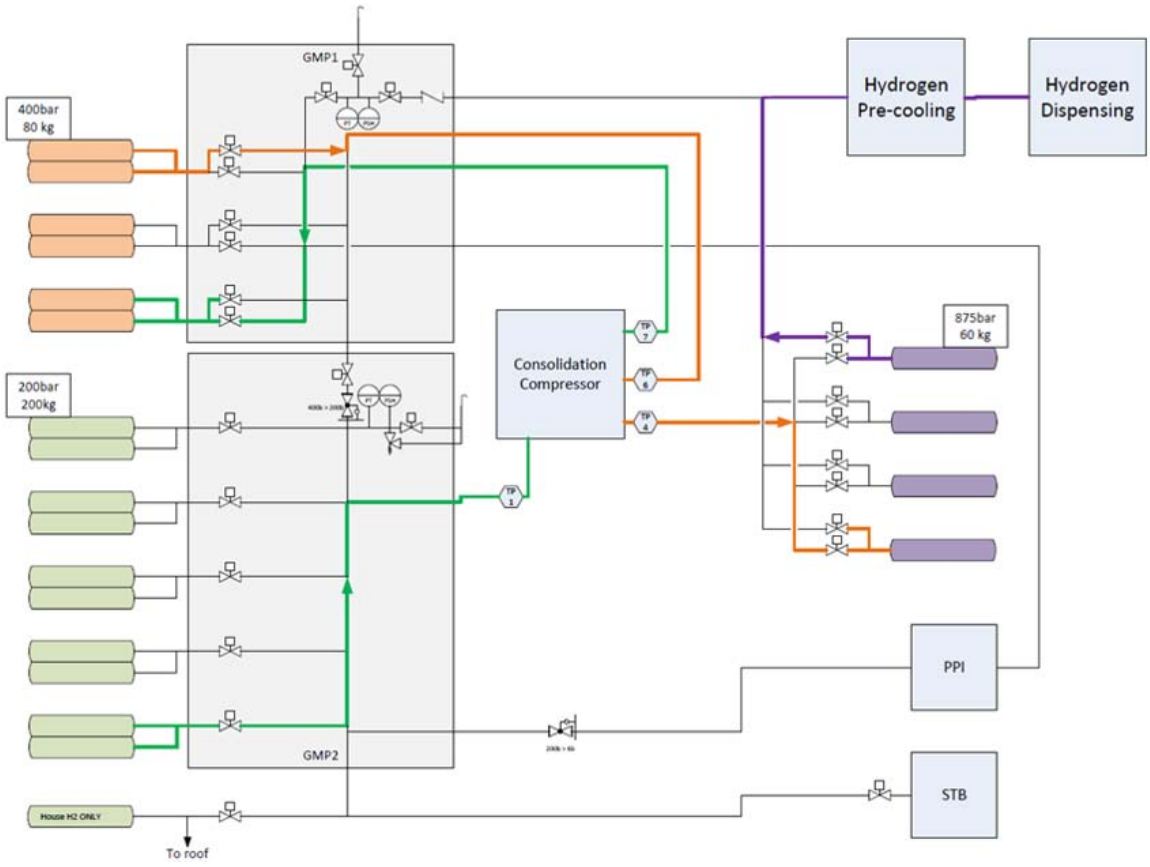

FIGURE 3. The HITRF as configured for consolidation testing. The green path shows consolidation within the tube trailer. The orange path indicates compression from the tube trailer to the station ground storage. The purple path indicates vehicle filling from the station ground storage.