III.14 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 cost contribution of station capital to the cost per kilogram of hydrogen at fueling stations.
- 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).
- Maximize station performance in terms of back-to-back fills.

Fiscal Year (FY) 2016 Objectives

- Design and build vehicle simulator capable of simulating five back-to-back fills at H70-T40 conditions.
- Evaluate the system design, ensure it is deemed both effective (capable of storing 200 kg of hydrogen at 240 bar, 40 kg at 900 bar, and of completing five back-to-back fills of 4.5–5 kg in an hour).
- Evaluate safety via a process hazards analysis (relative to National Fire Protection Agency 2, NREL Environmental Health and Safety requirements, and other relevant standards) by industry and internal stakeholders reviewing the design.
- Procure long lead items such as ground storage and vehicle tanks.
- Design controls strategy.
- Perform operation simulations and optimization with actual performance specifications.

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

Delivery

(E) Gaseous Hydrogen Storage and Tube Trailer Delivery Costs

Technical Targets

TABLE 1. Relevant DOE Cost Targets for Uninstalled Hydrogen Compression

Characteristic	Units	DOE 2020 Targets	Project Status
Uninstalled Capital Cost ($)	$ (Based on 750 kg/d Station [~100 kg/hr peak Compression Flow])	90,000	TBD, Too Early in Project to Evaluate

TBD – To be determined

FY 2016 Accomplishments

Hydrogen Infrastructure Test and Research Facility Buildout

- Low pressure storage 200 bar, 189 kg
- Medium pressure storage 400 bar, 103 kg
- High pressure storage 875 bar, 62 kg
- Precooling 16 hp, triple block R404a refrigerant (H70, T40 capability)
- Dual hose dispenser 350/700 bar SAE J2601

Vehicle Simulator

- 875 bar, 1.45 kg each times 15 tanks, Type IV
- Infrared Data Association communications for SAE J2799 and Canadian Standards Association Hydrogen Gaseous Vehicle 4.3 tests
- Back-to-back fill capability three tanks per fill line, simultaneous fill and vent
- Class I, Division II, Group B

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INTRODUCTION

The project aims to decrease the cost contribution of hydrogen station capital to the cost per kilogram of hydrogen at fueling stations. The project also aims to maximize station performance in terms of back-to-back fills. These aims will be accomplished through demonstration of Argonne National Laboratory's (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 refueling 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 approximately 10 times its rated throughput (in terms of kg/hr 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 operation, which ultimately will result in reduce capital expenditure on stations based on this concept.

APPROACH

The project takes place in three phases:

Phase I: Demonstration Setup

Phase II: Demonstration Preparation

Phase III: Demonstration Testing

Phase I was just completed as of July 2016. The general approach is as follows. In order to validate the consolidation concept, the project team will upgrade the existing Hydrogen Infrastructure Testing and Research Facility station at NREL in order accomplish full-scale operation 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 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 the available PDC Machines compressor models, while also minimizing the overall cost of the project. ANL ran a matrix of simulations to determine the size requirement of high-pressure vessels required for buffer storage, as well as 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 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) understood by the project team, NREL and PDC developed a process flow diagram, piping and instrumentation diagram, control strategy flow chart, and detailed bill of material.

RESULTS

In order to quantify the improvements possible from the consolidation concept, a detailed simulation was completed. The results can be seen in Figure 1. This simulation shows the performance of a consolidation-enabled station compared to a station without such capability. As can be seen in the figure, the consolidation station is able to maintain a 4–5X increase in number of fills until the final state of charge of the vehicle drops below an unacceptable 90%.

The performance of the two stages of the PDC compressor has been validated as being sufficient for the overall concept validation. See Figures 2 and 3. The machine is capable of discharging 999 bar hydrogen with an inlet pressure of 52 bar. The first stage discharge is 200 bar, consistent with the storage pressure of a tube trailer.

For the process hazards analysis, five nodes were defined. The new PDC compressor was broken in to two separate systems, medium pressure compression and high pressure compression. See Figure 4. The five nodes include:

- Low pressure system
- Gas management panel to PDC compressor second stage inlet
- Medium pressure to low pressure cross over
- High pressure system

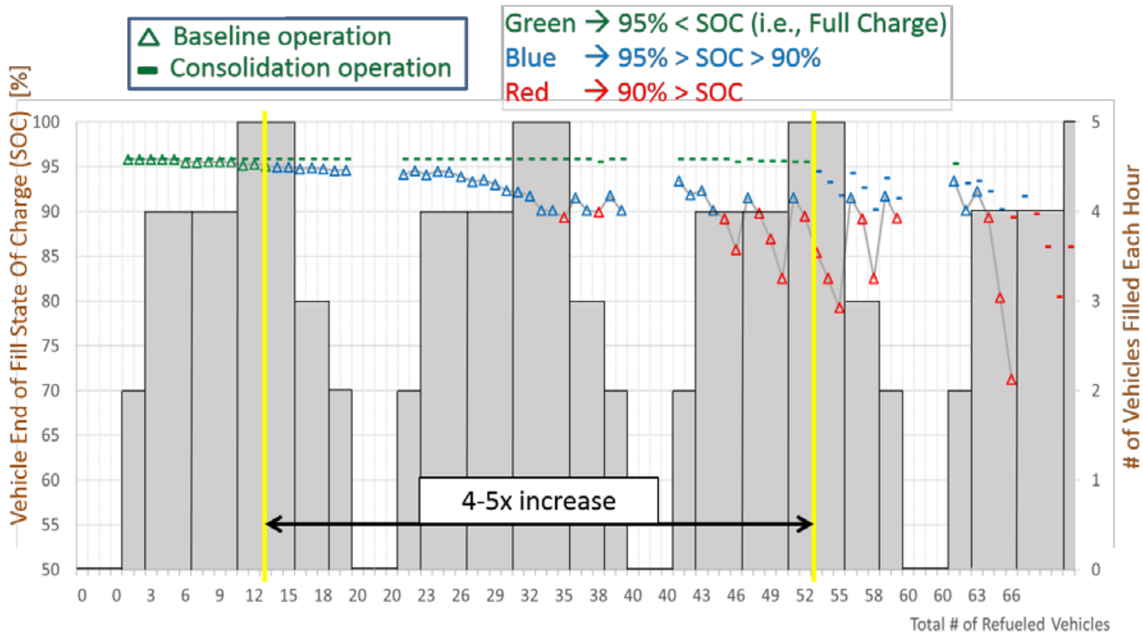


FIGURE 1. Simulated station performance shows 4–5X increase in vehicle fills, fill operation with 3.7 kg fills and two-bank buffer storage (one hose)

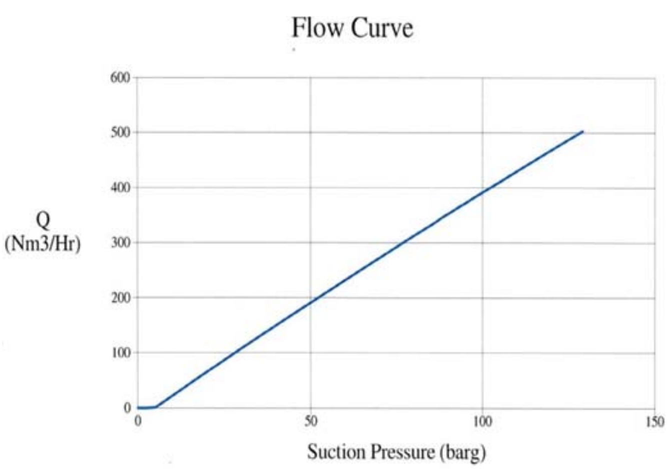


FIGURE 2. Flow curves satisfactory for algorithm validation: Stage 1 inlet 52 bar, discharge 200 bar, flow 198 Nm^3/hr

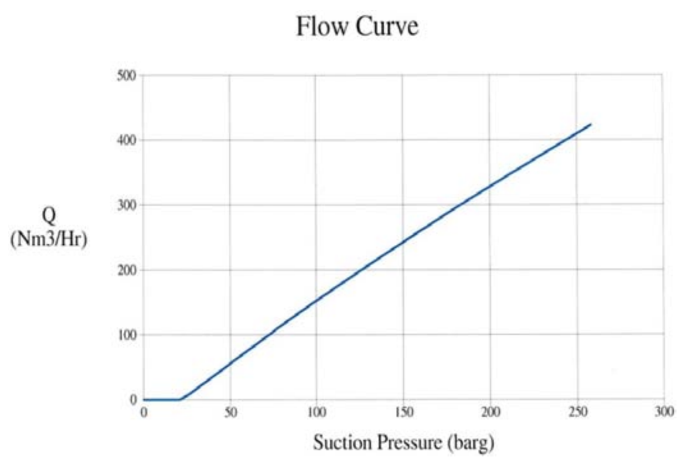


FIGURE 3. Stage 2 Flow curves satisfactory for algorithm validation: inlet 200 bar, discharge 999 bar, flow: 328 Nm^3/hr

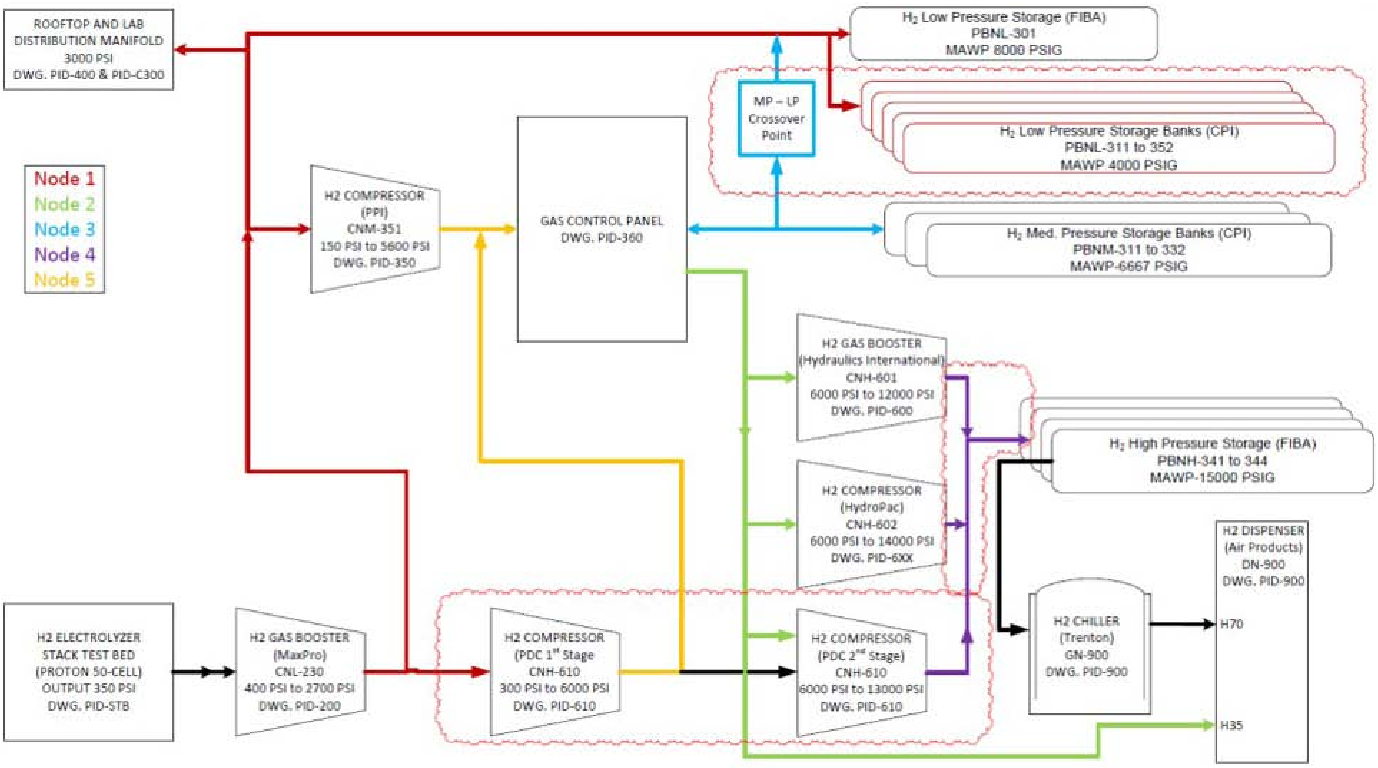
- PDC compressor first stage discharge to gas management panel

CONCLUSIONS AND FUTURE DIRECTIONS

The process hazards analysis generated 12 recommendations for the system. Those recommendations will be implemented prior to operation. Two long lead items remain to be received, the triple block chiller and the compressor. The next year's plan will involve finishing the controls implementation and placing all the equipment. Validation testing will begin in January 2017.

FY 2016 PUBLICATIONS/PRESENTATIONS

1. Terlip, D., et al., *Consolidation,* Washington, D.C.: U.S. Department of Energy, 2016.



MAWP – Maximum allowable working pressure

FIGURE 4. Process Hazard Analysis nodes