Advancing Hydrogen Dispenser Technology by Using Innovative Intelligent Networks

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Subcontractors:

- Air Liquide Advanced Technologies (U.S.), Houston, TX
- Rheonik GmbH, Oldehausen, Germany
- National Renewable Energy Laboratory, Golden, CO

Project Start Date: June 1, 2016
Project End Date: DOE June 13, 2020 (pending no-cost extension)

Overall Objectives

- Improve reliability of vehicle-to-dispenser communication with the use of emerging connected-vehicle-to-infrastructure wireless communication technologies employed for intelligent transportation systems using the secure Institute of Electrical and Electronics Engineers (IEEE) 1609 vehicle communications protocol.
- Achieve consistent 2% or better metering accuracy of the dispenser system through tight design control of flow dynamics and thermal response of the meter, as well as improved thermal mass flow regulation enabled by advanced fueling event notification.
- Reduce cost and complexity of dispenser hardware, such as hydrogen precooling systems, via intelligent and predictive controls incorporating individual vehicle data and, where possible, wide-area fleet data, to allow more appropriately sized equipment.

Fiscal Year (FY) 2019 Objectives

- Complete safety review and training of National Renewable Energy Laboratory (NREL) employees for testing of innovative dispenser system at NREL's Hydrogen Infrastructure Testing and Research Facility (HITRF).
- Validate innovative dispenser hardware and heat exchanger to the requirements in SAE J2601 (2016) using test procedures defined in CSA HGV 4.3 as guidance over a minimum of 27 fills.
- Upgrade NREL's vehicle simulator to accept dedicated short-range communication (DSRC) radios and successfully demonstrate DSRC's ability to transmit IrDA messages with less than 500 ms latency.
- Demonstrate meter accuracy of less than or equal to 4% using NREL's hydrogen meter accuracy measurement system.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Delivery section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration (MYRD&D) Plan[1]:

- (I) Other Fueling Site/Terminal Operations.

Technical Targets

This project will develop and test an SAE J2601-compliant dispenser system designed to address reliability concerns with vehicle to dispenser communication, compliance with weights and measures standards for commercial fueling, and dispenser cost and complexity. Specifically, the project team will develop, test, and demonstrate DSRC hardware for vehicle-to-station communication as opposed to the current infrared communication standard, as well as engineering a new high-accuracy Coriolis flow meter specifically designed to maintain an accuracy of 4% or better in automotive hydrogen refueling application

[1] https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

conditions. This meter will be integrated with the prototype dispenser in an optimized way to ensure accuracy is maintained over the entire fueling event, enabling a pathway for NIST Handbook 44 compliance of dispenser systems. In addition, the project will engineer and develop novel methods for hydrogen pre-cooling, flow control and predictive control algorithms to decrease system complexity and cost. Technical targets are detailed in Table 1.

FY 2019 Accomplishments

- Completed manufacturing and factory testing of SAE J2601 H70-T40-compliant dispenser system that integrates innovative technologies, including low-cost hydrogen cooling, high accuracy metering, and DSRC wireless communication.
- Completed design and manufacturing of low-cost, high-U_A heat exchanger that leverages glycol thermal mass, reducing the overall cooling system volume by 1.45X when compared to aluminum block heat exchangers.
- Successfully installed all dispenser and cooling hardware at NREL's HITRF testing facility, enabling validation of meter accuracy, fueling protocol capability, and DSRC communication.
- Initiated partnership with industry leader in DSRC technology and development of full-scale prototype IEEE 1609 DSRC wireless communication hardware and software, capable of interfacing with simulated or real vehicle controller area networks (CAN).
- Presented DSRC technology capabilities to SAE Interface Task Force and solicited industry feedback.
- Published DSRC white paper for industry review.
- Performed initial cost assessment of dispenser and heat exchanger hardware to DOE's MYRD&D targets.

Table 1. Hydrogen Dispenser Targets Compared to Corresponding MYRD&D Targets

Category	Project Target	MYRD&D	Project Status
Dispenser Capital Cost	$150,000 at low volume	$40,000 by 2020 at high volume	Less than $200,000 at prototype stage
Communication Method	DSRC using IEEE 1609 protocols	Nozzle IR alternative	Demonstrated capability at bench scale
Meter Accuracy	≤ ± 2% accuracy at temperatures between -40°C and 85°C and flow rates between 0.6 and 60 g/s	≤ ± 4% Commercial goal of ± 1.5%	≤2% accuracy with 95% confidence
Cooling System Cost	≤$100,000 at low volume	$70,000 by 2020	In progress—will be determined after prototype build

INTRODUCTION

This project aims to improve early adoption of fuel cell electric vehicles (FCEVs) by addressing technical obstacles and high cost associated with SAE J2601/1-compliant hydrogen dispenser systems. The team is focusing on three main areas: robustness of vehicle-to-dispenser (SAE J2799) communication, ability to comply with NIST Handbook 44 for weights and measures, and complexity of system design associated with hydrogen cooling and flow control. The team intends to address these issues by improving hydrogen meter accuracy, replacing infrared communication with wireless technology based on existing automotive standard systems, and implementing improved hardware, modeling, and controls for dispenser thermal and flow management.

APPROACH

The project includes design, development, and testing of an advanced hydrogen dispenser that incorporates DSRC wireless communication and improved hydrogen meter accuracy to a level of ≤4%. During the beginning phases of the project, demonstration of core technologies was performed at the bench level, along with detailed system modeling. Testing included wireless communication of refueling protocol messages using DSRC hardware and bench scale demonstration of hydrogen meter accuracy better than 4% over varying temperatures, pressures, and flow conditions.

For the next phase, a full-scale prototype dispenser has been designed and manufactured for testing at the NREL HITRF. This phase's goals are to validate compliance with SAE J2601/1 (2016), demonstrate hydrogen meter accuracy of ≤4% when integrated in a dispenser, show wireless communication of refueling messages from a simulated vehicle to the dispenser control unit, and demonstrate the cost reductions associated with improved thermal system and flow design.

RESULTS

The team has successfully built and installed the innovative dispenser system, integrating several key technologies such as DSRC wireless communication, high-U_A heat exchanger, and high-accuracy flow metering, at NREL's HITRF, as shown in Figure 1. Testing is now underway; by the end of 2019, the team will demonstrate the capabilities of key technologies developed under this program.

Figure 1. Dispenser and hydrogen cooling system installed at NREL's HITRF

To demonstrate full-scale hardware, the team manufactured a single nozzle H70-T40 SAE J2601-capable hydrogen dispenser. This dispenser was built according to the design documentation developed under Phase 1 of the program and leveraged U.S.-based manufacturing and assembly within New England. In addition to high-accuracy metering, the system integrates improved pneumatic valves to address low-temperature leakage and a fast response servo flow control valve. This system consists of two components: an aircraft-style, high-accuracy, high-RPM servo controller and custom throttling valve. These components allow the flow control device (FCD) to respond at speeds up to 150 rpm with an accuracy of ±1° (±0.001" orifice diameter). The rapid response and high accuracy allow the system to respond to rapid changes in supply pressure such as switching from low- to high-pressure storage systems, minimizing the need for pauses in fueling. Additionally, the servo provides positional feedback via an encoder allowing for closed loop control as compared to typical open loop control of pressure regulators. Closed loop control of the FCD increases safety of fueling by comparing expected flow rates of the flow control device via positional feedback and C_V curves to the high accuracy flow meter.

A cost assessment of all technologies developed under this program was completed. As shown in Figure 2, the dispenser CAPEX cost, including high-accuracy metering and flow control, has been reduced by approximately 25% from the 2014 industry status,[2] even for the prototype build at a quantity of one. A cost

[2] 2014 status for dispenser costs from the following reference: G. Parks, R. Boyd, J. Cornish, and R. Remick "Hydrogen Station Compression, Storage, and Dispensing Technical Status and Costs," Technical Report: NREL/BK-6A10-58564, May 2014.

breakdown for the prototype build is also included in Figure 2. Due to the nature of prototype manufacturing, labor costs are significantly higher than standard production costs. Based on internal modeling of volume production, as well as design for manufacturing in the largest cost segments (dispenser housing, electrical system, and balance of plant), CAPEX can be reduced by up to 40% compared to current dispenser technologies, resulting in a volume cost to the station developer of approximately $150,000 for a single-nozzle dispenser.

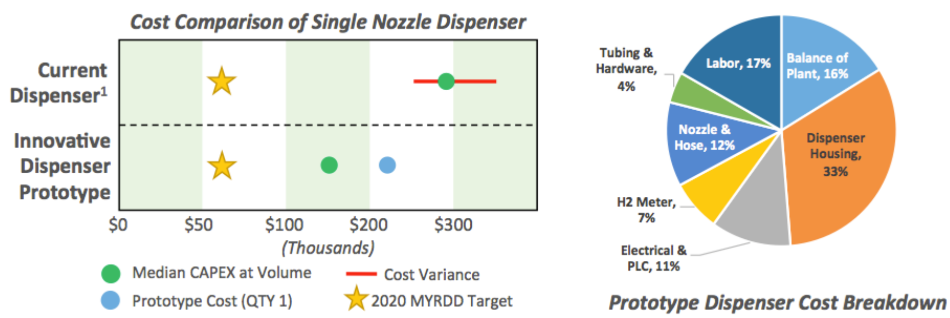

Figure 2. Cost information for dispenser at prototype level (actual production cost) and medium volume production (cost projection) as compared to the current cost status

For the hydrogen cooling system, as designed in Phase 1, a low-cost finned coil heat exchanger was developed and manufactured in the United States to the requirements of American Society of Mechanical Engineers Boiler Pressure Vessel Code and installed at NREL's facility for testing. The system consists of a free-floating coiled tube and shell heat exchanger, glycol reservoir, circulation pump, and cooling source. Using this cooling strategy overall volume and weight of the heat exchanger is reduced while increasing the total specific energy available for cooling.

Modeling was used to estimate performance of the cooling system over various usage cases to assess performance and trade off of capital cost[3] versus operating cost. Simulations show with 15.8 kilowatts of heat rejection capacity, the station can support up to 50 kilograms per hour dispensed, or 10 vehicles per hour at 5 kilograms, for 6 hours using only 100 gallons of brine coolant. Reduction in station heat rejection capacity slightly increases recovery time if glycol volume is fixed; but if the glycol reservoir is increased recovery times can be maintained while reducing overall operating costs up to 30%. These modeling results will be validated during testing at NREL.

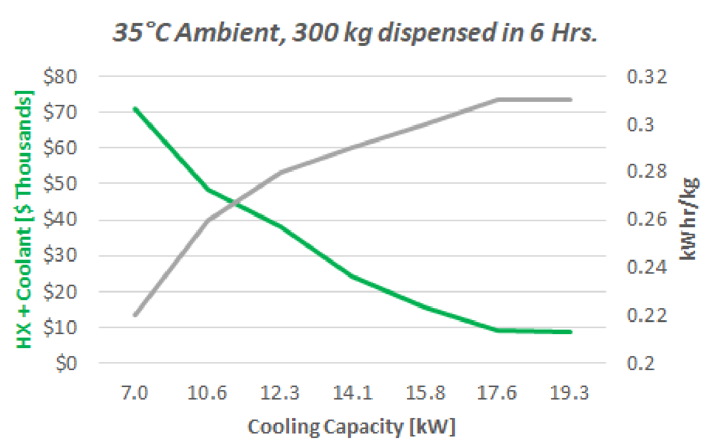

Figure 3. Modeling of capital cost (heat exchanger plus brine coolant) and operating cost (kWh per kg hydrogen dispensed) versus chiller capacity, based on a single-nozzle installation

[3] Capital cost includes the hydrogen heat exchanger, glycol and associated reservoir, balance of plant, and chiller.

Manufacturing of the heat exchanger does not require heavy industry techniques such as casting or specialty techniques like diffusion bonding, allowing it to be manufactured in the United States at low cost. When compared to an aluminum triple block heat exchanger, this heat exchanger and glycol reservoir system reduces capital cost by 31% at low volumes. Higher volume manufacturing in the scale of tens per year can reduce cost further to meet DOE's MYRD&D Plan goal of $70,000 for the complete hydrogen cooling system. This low-cost and highly scalable approach is poised to benefit medium-duty and heavy-duty markets as well by allowing various configurations such as single large glycol reservoirs with multiple heat exchangers.

To develop DSRC hardware for full-scale testing, the project team partnered with a leader in DSRC programming and trial deployments. Industry feedback on testing and possible integration methods was gathered via industry forums such as SAE International. Feedback from these forums recommended the vehicle onboard unit (OBU) radio communicate via CAN protocols. Because direct access to a vehicle's network creates security concerns, several industry representatives suggested simulating the interface for initial testing.

To simulate a full vehicle environment, software has been developed to convert various CAN messages with SAE J2799 information from the NREL vehicle simulator device to WAVE format, thus allowing the messages to be wirelessly transmitted via IEEE 1609 protocols. The dispenser unit receives this information and translates the WAVE message into an Ethernet protocol. Most commonly used industrial controllers can receive information in these protocols quickly and reliably. This system is now being tested with the prototype dispenser and vehicle simulator at NREL to demonstrate that it can meet and exceed the data transfer requirements of the SAE J2799 communication protocol.

CONCLUSIONS AND UPCOMING ACTIVITIES

In the second year of the project, progress was made toward full-scale testing of the technologies developed in this program. The innovative hydrogen dispenser, low-cost heat exchanger, and full-scale DSRC system have been manufactured and installed at NREL's HITRF facility. Functional testing of the dispenser is complete, thus allowing for the future activities below.

- Validate prototype dispenser for compliance to SAE J2601/1 at NREL's HITRF.
  - Leverage test procedures in CSA HGV 4.3 (2019) and the vehicle simulator to test hardware over 27 fueling events with pressures up to 700 bar and average fueling rates of 30 grams per second.
  - Assess compliance using the MC Method Validation Tool.[4]
- Demonstrate 4% or better accuracy of flow measurement by comparing total mass dispensed per fueling event to a calibrated gravimetric device over a range of fueling conditions including flow rates up to 30 grams per second and 700-bar fueling.
- Demonstrate transmission of SAE J2601/1 refueling messages from a simulated vehicle to the dispenser control unit per the requirements of SAE J2799 using DSRC hardware.
- Validate back-to-back performance of hydrogen cooling hardware to simulated results.

FY 2019 PUBLICATIONS/PRESENTATIONS

1. Bryan Gordon, "Alternatives to IrDA using Dedicated Short Range Communication (DSRC)." Society of Automotive Engineers Interface Task Force Conference, Honda R&D Americas Inc, Torrance, CA, June 6, 2018.
2. Bryan Gordon, "Summary of Alternatives to IrDA using Dedicated Short Range Communication (DSRC)," Honda R&D Americas Inc., Torrance, CA, June 19, 2018.

[4] https://www.wenger-engineering.de/en/mc-formula-validation-calculator-login

3. Chris O'Brien, Bryan Gordon, and Darryl Pollica, "Advancing Hydrogen Dispenser Technology by Using Innovative Intelligent Networks," presented at the 2018 DOE Annual Merit Review and Peer Evaluation Meeting, Washington D.C., June 2018.
4. Bryan Gordon, Chris O'Brien, and Darryl Pollica, "Advancing Hydrogen Dispenser Technology by Using Innovative Intelligent Networks," presented at the 2019 DOE Annual Merit Review and Peer Evaluation meeting, Crystal City, VA., April 2019.