High Pressure, High Flow Rate Dispenser and Nozzle Assembly For Heavy Duty Vehicles

PROJECT
ID# TA049

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ELECTRICORE, INC.
DOE AGREEMENT #DE-EE0008817
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Project Goals

- Develop a dispenser and nozzle assembly (nozzle, receptacle, hose, and breakaway) capable of fueling heavy-duty (HD) vehicles
- Test and demonstrate the system at the National Renewable Energy Laboratory (NREL) and under real-world conditions
- Based upon industry feedback, the team will target 100 kg fueling in 10 minutes at a nominal pressure of 70 MPa and will meet key industry standards
- The heavy-duty dispenser and nozzle assembly (HDND) will accelerate the development and adoption of sustainable transportation technologies.

Overview

Timeline

- Project Start Date: 10/01/2019
- Project End Date: 07/31/2023
  - Phase 1 – Specification and Design (Complete)
  - Phase 2 - Manufacturing, Testing and Demonstration (Ongoing)

Barriers and Targets

- **Barriers**
  - A robust, domestic manufacturing and component supplier base for hydrogen and fuel cell technologies needs to be developed
  - Lack of Hydrogen Refueling Infrastructure Performance and Availability Data to revise standards
- **Targets**
  - Support efforts to reduce the cost of manufacturing components and systems to produce and deliver hydrogen at <$4/gge (2007 dollars)

Budget

- Total Project Budget: $3,329,225
  - Total Recipient Share: $750,188
  - Total Federal Share: $2,579,037
  - Total DOE Funds Spent*: $2,108,390
  - Total Recipient Share Spent*: $616,650

* As of 02/28/2023

Partners

- Electricore Inc. – Federal Project Manager / PI
- WEH Technologies Inc. – Nozzle Technology Provider
- Bennett Pump Company – Dispenser Technology Provider
- Quong & Associates Inc. – Technical Lead
- NREL – Testing Facility

Relevance to DOE Goals

Build clean energy infrastructure	At the start of the project, there were no HD dispensers or H70 nozzle assemblies in the market
Validate and demonstrate hydrogen and fuel cells in real-world conditions.	System will be installed and tested at NREL's HD station
Lower greenhouse gas emissions	Acceleration of the development of H70 high flow components will reduce roadblocks for the entry of HD hydrogen vehicles
Create good-paying jobs in the U.S.	The project will increase domestic jobs at the project partners (Bennett, WEH) and expand the entire industry
Support environmental justice	Expansion of hydrogen trucks will reduce emissions in communities unfairly impacted by pollution

Barriers and Impacts

The HDND project address the need for and enables wide-scale hydrogen production, delivery, storage, and use across HD vehicle sector.

Barriers

- No commercial-ready HD H70 dispensers or nozzle assemblies were limiting expansion of HD hydrogen vehicles
- No clear specifications for diverse market with varying vehicle and station size and capabilities
- No data or real-world experience with new market and components

Project Goals

- Develop commercial ready HD dispenser (one) and three nozzle assemblies to lower fueling costs
- Survey HD vehicle, station, user, and supplier industry to develop specifications for the HD market
- Test HDND at NREL's Hydrogen Infrastructure Testing and Research Facility and then demonstrated under real-world conditions

Project incorporates a new high flow rate nozzle with a specialized dispenser for a complete, integrated, high throughput fueling solution.

Approach

- Industry stakeholder survey and Specifications (Complete)
- Develop specification and design of heavy-duty dispenser and nozzle assembly (Complete)
- Go/No-Go Decision: Design Review (Complete)
- Manufacture and testing of components (Complete)
- Demonstration at NREL HD station (In Progress as of mid-April)
- Publish results of the testing and demonstration

Deliverables

- Specifications report
- Design report
- 3 HD nozzle assemblies
- 1 HD dispenser
- Component and system testing
- Real-world demonstration
- Final report

Approach: Dispenser

- Dispenser completed HGV 4.1 factory tests including but not limited to:
  - Pneumatic Strength / Leak check
  - Dielectric Voltage
  - Calibration
  - Functional tests
  - PLC I/O Tests
  - IDRI Extended OD (optional data field)
- Nozzle boot mounted on the side of the dispenser to prevent interference with vehicles
- Bennett dispenser was installed on the NREL HD Pad at HITRF in December 2022

Bennett
simply better

Approach: Dispenser Testing

Factory Acceptance Testing:

Name	Parameters	Status/Actual Test Date
Leak check	Leak test with Nitrogen; 11600psi for 10 minutes high pressure line with PRV	Passed 7/22/2022
Leak check	Leak test with Nitrogen; 15000psi for 30 minutes high pressure line with no PRV	Passed 7/22/2022
Leak check	Leak test with Nitrogen; 2000psi for 30 minutes low pressure components	Passed 7/22/2022
Dielectric Voltage	1500VAC for 1 min	Passed7/22/2022
Electrical Functional Tests	Check circuit boards, wiring connections, displays, and communication.	Passed 7/26/2022
Calibration	Gas Detector	Passed 7/26/2022
Functional Tests	Gas Detector	Passed 7/26/2022
Functional Tests	Payment system	Passed 7/26/2022
PLC I/O Tests	Check functionality of fill and vent valves, flow control valve, meter, temperature sensors, pressure sensors, IR communication, ESTOP, Vibration Switch	Passed 7/27/2022
Dispenser Shutdown	Dispenser shall shutdown within 3 seconds	Passed 7/27/2022
Dispenser Ground Continuity		Passed 7/26/2022
Access to energized parts		Passed 7/27/2022

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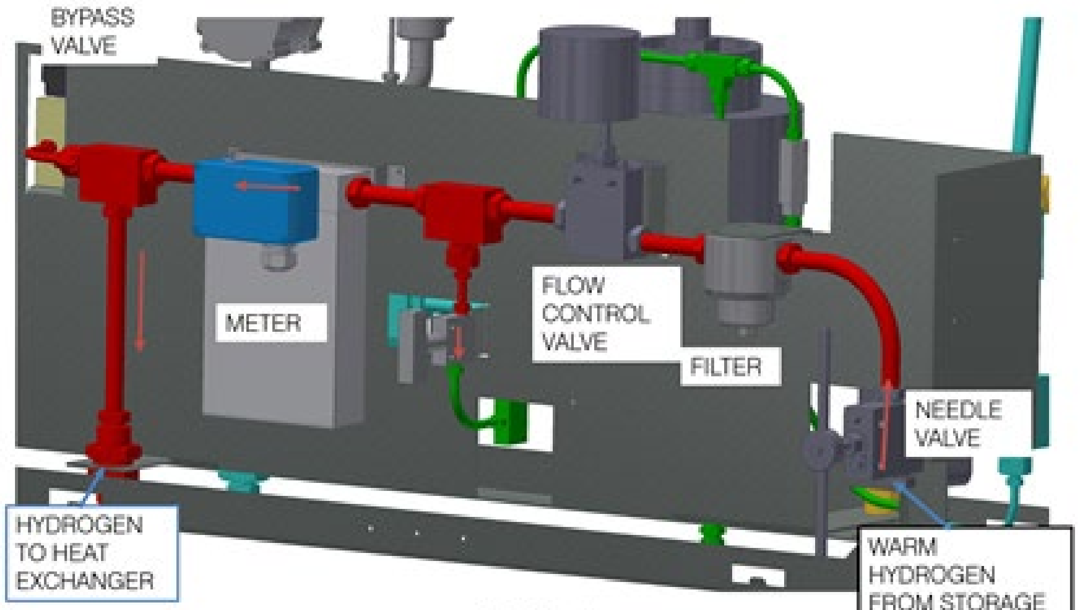
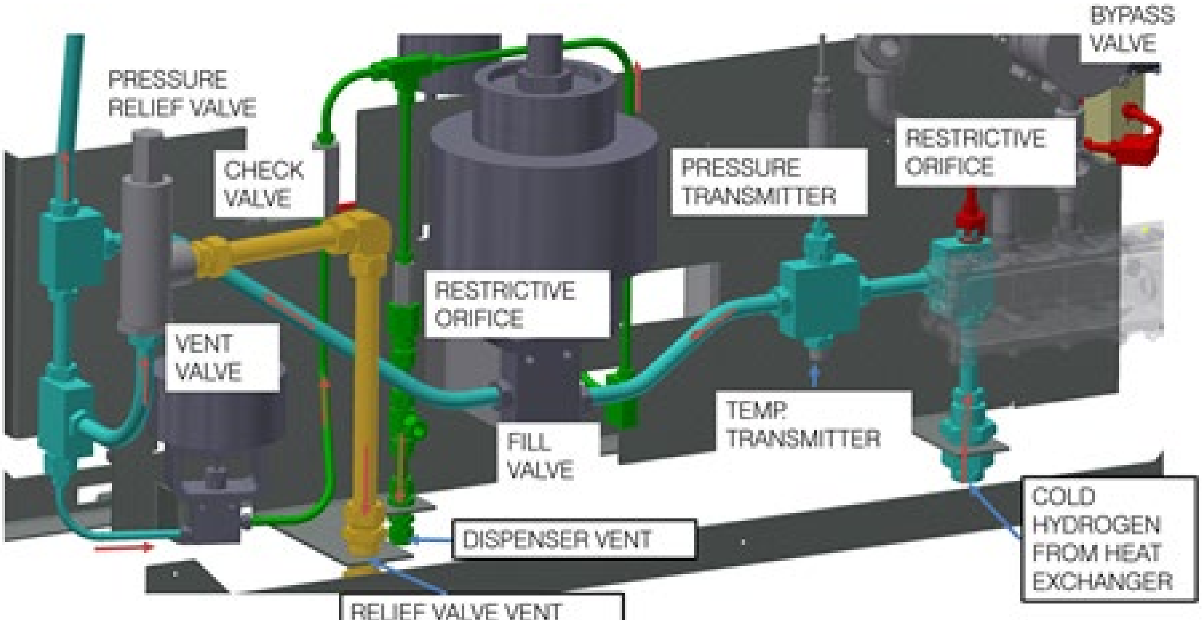
Approach: Dispenser Design



Front Angle

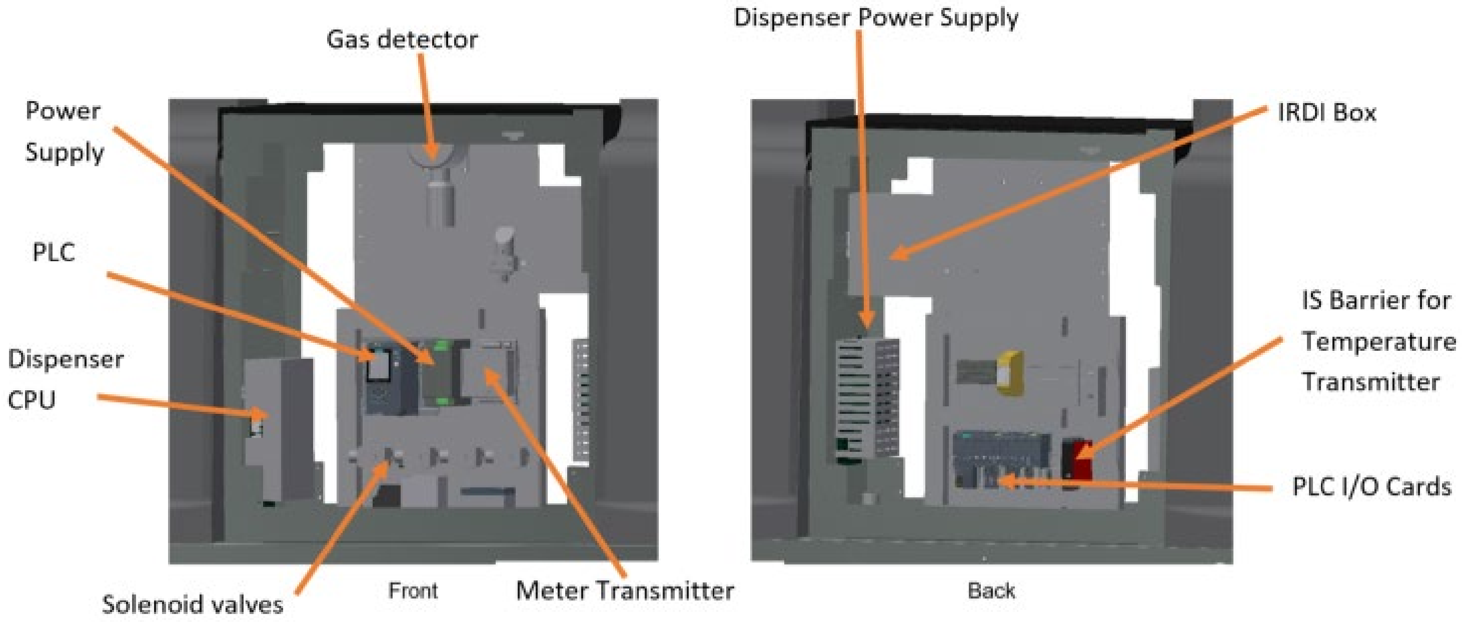


Back Angle

Approach: Dispenser Design

Bennett Dispenser Controls:

- Filling algorithm protocol
- IRDI interface to vehicle
- Valve control interface
- Meter pulse input
- Modbus communication to dispenser, meter and external PLC (station)
- Modbus communication to the nozzle
- ESTOP interface
- Ambient temperature
- Thermocouples
- Pressure Sensors
- Gas Detectors
- Payment CPU Interface



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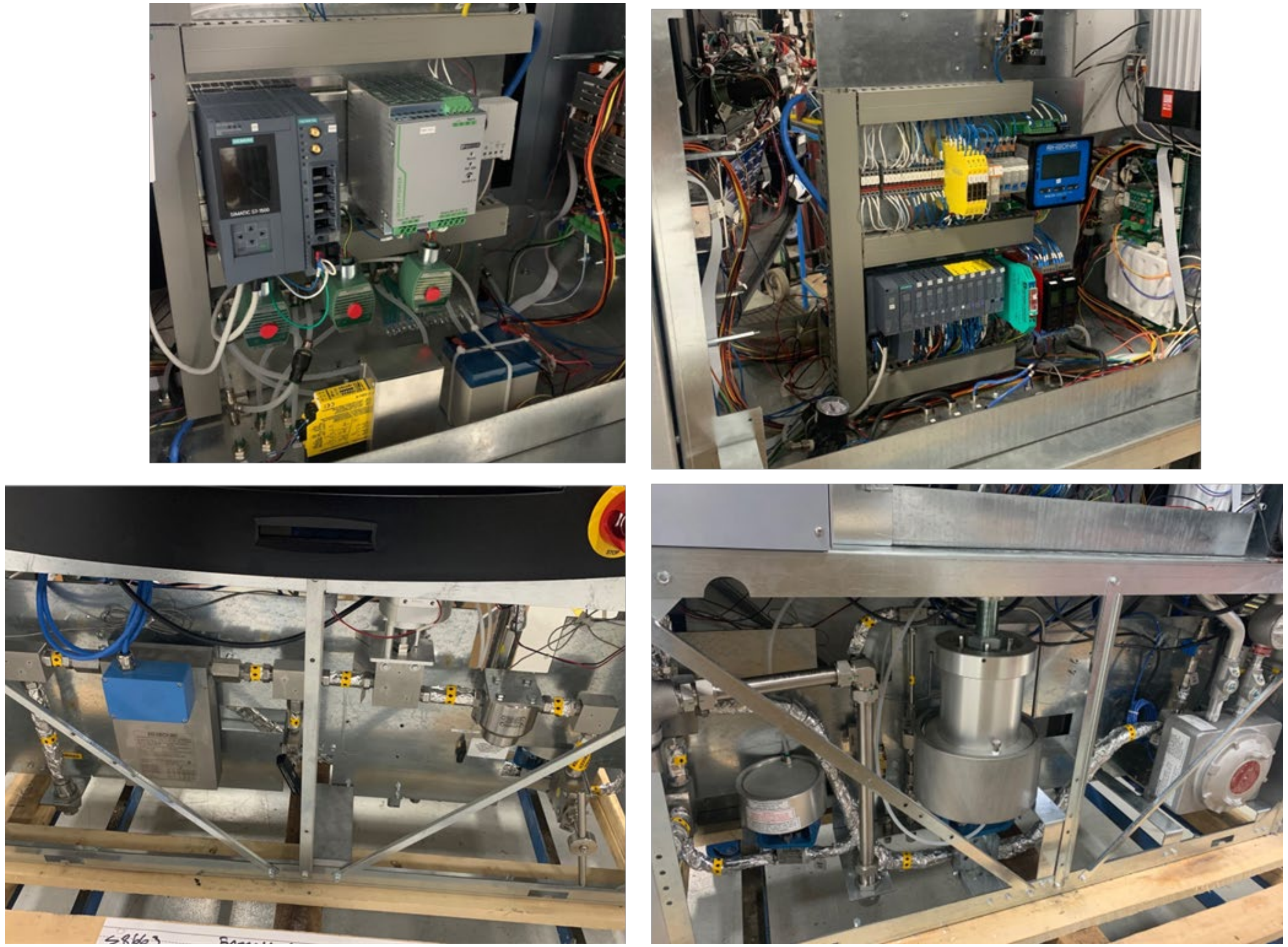
Approach: Dispenser Design

Standards dispenser is designed to:

- CSA HGV 4.1*, 4.3*, 4.9*
- SAE J2601*+, 2799
- NFPA 2
- ASME B31.2
- ISA 12.13.03
- CSA C22.1



Dispenser Build at Bennett

* Modified for heavy duty
\+ Team engaging with standards group

Bennett simply better

Approach: Nozzle

- Type C nozzle with purging line
  - Bore ID of Nozzle-to-receptacle interface = 12 mm
  - Bore ID of Nozzle-to-hose interface 7.5mm
- Component testing completed (to ISO 17268 modified for HD), including
  - Pneumatic durability (limited)
  - Precooling tests
- Pressure drop testing shows < 1 MPa pressure loss at approx. 165 g/s flow rate.
- Hydrogen exposure test passed
- Includes IrDA communication (SAE J2799) and electrically activated interlock and display
- Mounted on dispenser, but testing waiting until preliminary dispenser testing complete

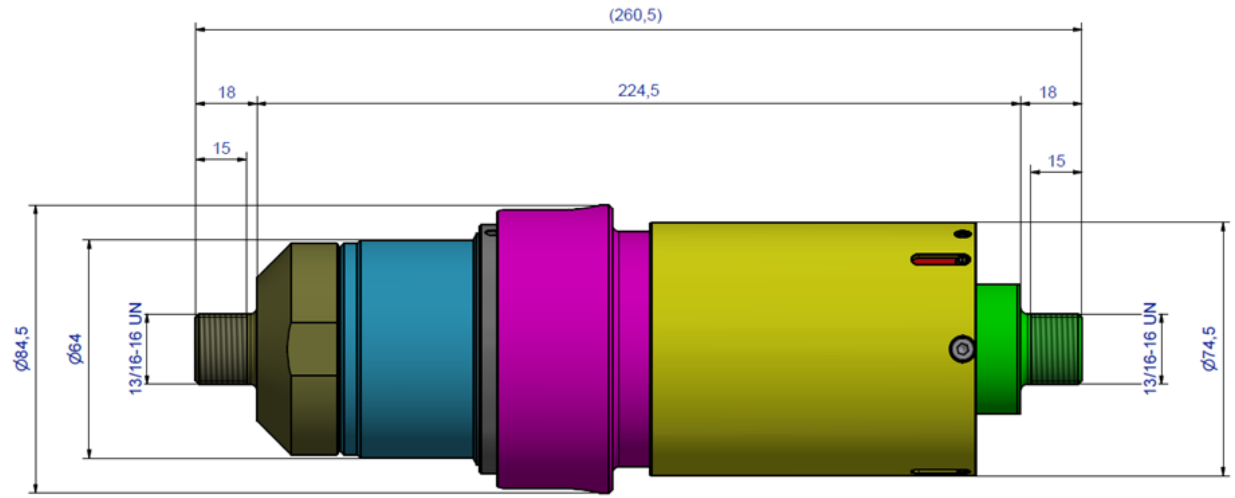
Light Duty WEH nozzle/receptacle (top) compared to Heavy Duty nozzle/receptacle (bottom)

Nozzle Display

WEH

Approach: Breakaway

- Single hose, single breakaway design
- Component testing completed (based on ISO 19880-3, and CSA standards with limited durability testing)



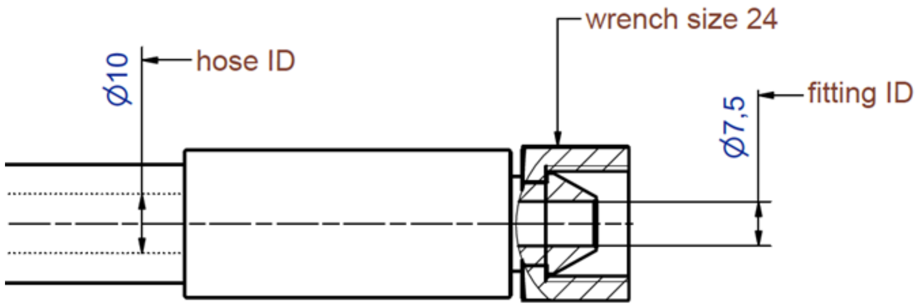
HD breakaway (left) compared to LD breakaway (right)

Approach: Hose

- Single hose with optimum compromise between flow/pressure drop and flexibility
  - Hose ID = 10 mm
  - Fitting ID = 7.5 mm
- Prototype built (with limited durability) and undergoing initial safety tests (several tests of ISO 19880-5)
- Hose assembly is designed to fulfill the following standards:
  - ISO 19880-5*+
  - ISO 19885-3*+

  * Modified for heavy-duty

  \+ Team engaging with standards group

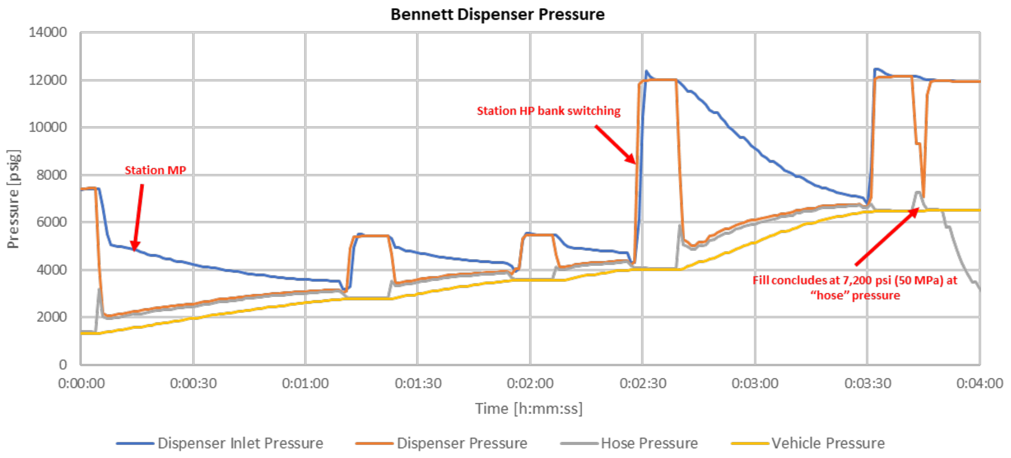


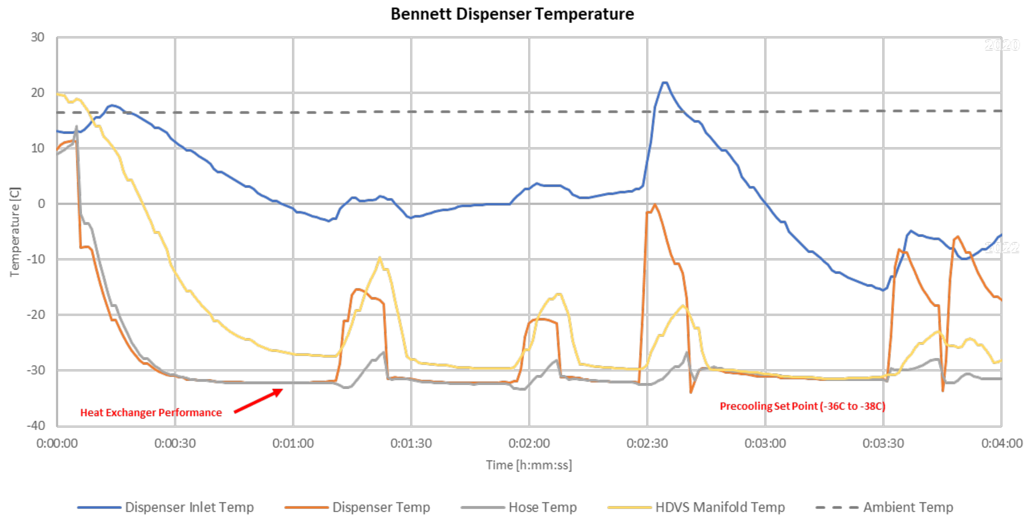
Heavy Duty Hose


Light Duty hose (left) compared to Heavy Duty hose (right)

Approach: NREL Testing & Demonstration

- As of mid-April 2023
  - Commissioning test at reduced pressures complete
  - Passed most of HGV 4.3 tests and SAE J2601 Category D fills up to 50 MPa nominal.
  - NREL internal review passed to proceed with high pressure testing (early April 2023).
  - Testing at full pressure (70 MPa nominal) underway.





Flow Tests Completed up to 50 MPa:

Test	Mass Transfer [kg]	Average Flow Rate [kg/min]	Peak Flow Rate [kg/min]	Fueling Event Time [mm:ss]	HDVS APRR [MPa/min]
1	15.7	4.7	10.8	03:20	9.9
2	20.5	4.9	16.1	04:11	12.8
3	18.3	4.8	12.4	03:49	10.8
4	18.4	5.0	13.8	03:43	12.0

NREL Transforming ENERGY

Accomplishments

- As of mid-April 2023 the team has accomplished the following:
  - Completed manufacturing and testing of HD Dispenser
  - Completed manufacturing and testing of nozzle assembly
  - Delivered dispenser and nozzle assemblies to NREL for installation and commissioning.
  - Completed commissioning tests at the NREL Station at reduced pressure (50 MPa)
  - Approval to proceed with all tests at full pressure (70 MPa nominal)

Reviewer Comments

Comment	Response
The extent to which new standards and/or standards revisions will be necessary to drive compatibility and interoperability is unclear. Changes in driving standards do not appear to be part of the scope of this project, but an understanding is needed of whether the solution is completely bound by existing standards and what needs to change, and this should be appropriately identified. The widespread adoption of technological developments will be dependent on interoperability. Also, there was no mention of communication specifications.	All of the components will be designed and tested to existing SAE, CSA, and ISO component standards modified for heavy duty, including SAE J2799 standard (with limited durability testing). The team is working directly with standard groups to inform them of any changes needed. One example is possible changes in NFPA 2 to the leak check procedure which may not be effective for heavy duty stations with larger capacity.
The weaknesses include addressing supply chain robustness and manufacturing challenges for mass commercialization, considering technology compatibility with other hydrogen pressures or cryogenic hydrogen, addressing cost impacts of technology, and challenges with different station integration approaches.	After a survey of the industry, the team decided to focus on 70 MPa gaseous hydrogen components, especially since 35 MPa high flow components are already in the market. Cryogenic hydrogen was outside the original DOE FOA and project scope.
Building a mechanical design for the dispenser is likely not the highest-risk or most challenging portion of a commercially viable dispenser. External interface standardization and the integration of components into a single package to support quality, testing, manufacturing, and constructability will be commercial roadblocks that need attention as well.	The team is working with CSR groups, industry consortiums, and other projects to ensure that the system will overcome some of the future roadblocks. For example, Bennett Pumps became a member of the EU PRHYDE team and may integrate some of the new HD protocols being developed.
Possible weaknesses include not having an explicit station customer who will pilot the first hardware and not having a clear high-flow 700 bar tank integrator ready to use the nozzle.	The team decided to integrate the HDND at NREL because it will be the first heavy duty stations in the US that will be able to deliver the high flow rates that the system is designed to. NREL also has a heavy-duty vehicle simulator with several different tank designs to be fueled.
This is new territory. H70 may not be the ultimate/optimal solution for HD hydrogen fast fueling.	The original DOE FOA focused on 35 and 70 MPa. The HDND team decided to propose H70 because H35 high flow components are already in the market.

Reviewer Comments

Comment	Response
The project might consider exploring whether there is any need for inclusion of HD nozzle design characteristics that allow for receptacle design that facilitates cryo-compressed hydrogen fueling or other forms of hydrogen (i.e., not only 700 bar gaseous hydrogen).	Cryogenic hydrogen was outside the original DOE FOA and project scope.
The robustness of the nozzle must be higher than that for LD vehicles, considering the higher weight of vehicles that could drive over it. Thus, the project might possibly need to consider abandoning the idea of IrDA altogether for when commercializing the nozzle.	Vehicle to dispenser communications is outside the scope of this project. However, the team is identifying areas where components need reliability improvements for use on heavy duty vehicles/dispensers.
Additional time could be devoted to nozzle design and scenario planning if the first choice fails at validation. The four options look radically different, and simulation may not capture the optimum nozzle to-hose configuration options.	Based upon feedback from the heavy-duty hydrogen industry, the team is focusing on a Type C nozzle with a single hose/single breakaway approach.
The project should identify necessary standards modifications and communicate those changes with standards committees.	The team is working directly with standard groups to inform them of any changes needed.

Collaboration and Coordination

	Team Members	Role
WEH	WEH Technologies, Inc.	Design and Fabrication of Nozzle Assembly
Bennett simply better	Bennett Pump Company	Design and Fabrication of Dispenser
Quong	Quong & Associates, Inc.	Technical Lead
NREL Transforming ENERGY	National Renewable Energy Laboratory	Field Testing and Analysis

Collaboration	Role
Multiple station manufacturers and OEMs	Advisor on component specifications
US Department of Energy - Hydrogen and Safety Panel	Safety Analysis
Industry stakeholders (27)	Provided feedback to develop specifications

Team providing direct feedback to hydrogen industry and SAE, CSA, and ISO standards

Remaining Challenges & Barriers

Challenge/Barrier	Solution
HDND cannot integrate into NREL HD station properly	Dispenser installed with minimal issues. Nozzle assembly tests should minimize any nozzle installation issues
HDND cannot handle high flow rates or has other design flaw	Dispenser and nozzle testing shows no issues with flow rates. Initial pressure, flow and functionality testing is assisting team in determining any modifications necessary to improve the design.
Control valve cannot react fast enough	Initial testing shows that control valve takes too long to react to leak checks or bank switches. Industry may need to modify valve or dispenser design
Advanced protocol testing may not be completed	Team is looking into options for addition testing after project is complete

Proposed Future Work for FY 2023

- Remaining tasks include:
  - Commissioning of nozzle assembly
  - Initial full pressure tests (70 MPa nominal)
  - SAE J2601 CHSS D tests to full pressure
  - Advanced protocol testing (depending on timing and funding)

Any proposed future work is subject to change based on funding levels

Summary

- The HDND project has been successful in building and testing a HD dispenser and nozzle assembly.
- The system has been installed at NREL ESIF and will be used for other projects and testing.
- Preliminary results show that equipment can achieve HFTO target of parity with conventional fuels, in terms of flow rates and SOC
- Results and lessons learned from the project will be used to improve components, codes and standards, and will lead to products available to the HD industry.

Contribution to Achievement of DOE Targets or Milestones

- Because there are very few HDND systems, there are no specific cost predictions for HDND

- Once the system is finalized, the team plans to compare their results to LDV dispenser cost estimates in the FCTO MYRDD

	FY 2015 Status	FY 2020 Target	Ultimate Target
Light duty vehicle Uninstalled cost/dispenser (1 hose per dispenser) (USD 2007)	\$65000	\$60000	\$40000
% Reduction from 2015		8%	38%
HDND cost		TBD	TBD
FCTO MYRDD Plan Section 3.2 Hydrogen Delivery Table 3.2.4			

Technical Backup Slides

Overall Specifications

Overall	Units	Min	Max	Requirement
Maximum H2 dispensed	kg		100	
Target fueling time for max H2 dispensed	min		10	
Time between fuelings	min		3	
Maximum operating pressure	MPa		87.5	
Average flow rate	g/s		180	
Peak flow rate	g/s		300	
Ambient temperature	C	-40	65	
Relative humidity	%	0	100	
Outdoor operations				Operates under rain, snow, wind, sun
Materials compatibility				All materials exposed to hydrogen shall be compatible and not introduce impurities at the designed pressures and temperatures

Dispenser Specifications

Dispenser	Units	Min	Max	Requirement
Gas operating temperature	C	-40	65	
Dimensions				Designed to fit on typical truck fueling island
Fueling protocol				Based upon industry standard or SAE J2601 2020 CHSS D
Retail system				EMV point of sale system
Display				Point of sale; Optional - information material
Vehicle communications				IRdA Communication fueling designed to SAE J2799 with backup non-communication fill
Station & POS communications				Bennett Open Protocol - Modbus
Design standards				NFPA2 and ANSI/CSA HGV 4.1^{+}, DMS, NFPA 496, CTEP, MET Labs Certification for purged and non-purged.
Products/Hoses				Up to 2 per side
Test requirements				ISO 19880-1 Section 12.5 Fueling safety and performance functional testing. CSA HGV 4.3 2021 for protocol

*To be determined as part of the project. $^{+}$Modified for heavy duty

Nozzle Specifications

Nozzle Assembly	Units	Min	Max	Requirement
Kv*			15	SAE J2601 2020 Section 7.2

Nozzle	Units	Min	Max	Requirement
Weight	kg		4.5	
Gas operating temperature	C	-40	85	
Communications				Field replaceable IRdA system designed to SAE J2799 which is electrically classified
Disconnection time	s		30	Designed to prevent freeze lock that prevents disconnection within 30 seconds
User protection				Designed to dissipate static electricity and protect user from frostbite
Receptacle inter-compatibility				Designed to prevent connection to nozzles designed for other vehicles or other higher-pressure heavy-duty nozzles
Nozzle inter-compatibility				Designed to prevent connection to receptacles designed for other vehicles or other lower pressure heavy duty receptacles
Hose protection				Designed with strain relief and twisting protection for the hose
Hose connection*				13/16"-16 UNF medium pressure female for 9/16" hose
Design standard				ISO 17268 2020^{+}
Testing standard				ISO 17268 2020^{+} except durability
*To be determined as part of the project. +Modified for heavy duty				

Breakaway Specifications

Breakaway	Units	Min	Max	Requirement
Weight	kg		5	
Separation force	N	222	1000	
Gas operating temperature	C	-40	65	
Connection*				9/16" - 16 UNF medium pressure female
Design standard				ISO 19880-3 2020+, CSA HGV 4.4 2013+
Testing standard				ISO 19880-3 2020+, CSA HGV 4.4 2013+

*To be determined as part of the project. +Modified for heavy duty

Hose Specifications

Hose	Units	Min	Max	Requirement
Length	m	0.5	4	
Bending radius	mm		250	
Design				Will consider approach to reduce hose whip
Gas operating temperature	C	-40	65	
Connection*				Type M 3/4 " x 16 UNF
Hose assembly protection				Bend restrictor at nozzle side Protection hose provided by nozzle manufacturer
User protection				Designed to dissipate static electricity and protect user from frostbite (protection hose)
Design standard				ISO 19880-5 2019+
Testing standard				ISO 19880-5 2019+ (except durability)
*To be determined as part of the project. +Modified for heavy duty				

Technology Transfer Activities

- Bennett Pump Company: Plans to offer the HD dispenser as a product

- WEH: Based upon test results, the results will be used to develop HD connector standards. After standardization is completed, WEH plans to develop the HD nozzle assembly further until series production

- NREL: Will use the HDND system for protocol and component testing in the future

Special Recognition or Awards

There are no awards to report.

Publication and Presentations

- The following publications and presentations were made:
  - Presentations to the DOE 21st Century Truck Meeting Group
  - Presentations to the EU PRHYDE project
  - Presentations to the ISO Working Group 24 on project progress
  - Presented modeling results in International Conference on Hydrogen Safety in 2021
  - Presented on aspects of this project during the DOE HFTO H2IQ Webinar series in 2022