NREL
Transforming ENERGY

Assessment of Heavy-Duty Fueling Methods and Components

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National Renewable Energy Laboratory
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Project ID: SCS031

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Project Goal

Develop a comprehensive assessment of heavy-duty (HD) fuel cell electric vehicle fueling protocols and fueling hardware to understand the effects of fueling protocol architectures on station design, vehicle design, functional safety requirements, and the implications on the total cost of ownership (TCO).

Assessment of new HD fueling concepts and components at NREL's HD fast-flow facility.

Leverage existing models and tools to perform techno-economic assessments and total cost of ownership.

Provide industry stakeholders with key information and data along with publicly available modeling tools.

NREL Fast Flow Research Facility (April 2023)

Overview

Timeline and Budget

- Project start date: 2/2/2022
- Project end date: 2/1/2024
  – 2-year project
- Total project budget: $4.2M
  – Total recipient share: $835K
  – Total federal share: $3.3M
  – Total DOE funds spent*: $1.125M
  – Total Non-DOE Funds: $645K

  * As of 04/01/2023
- 2020 DOE HFTO H2@Scale CRADA Call AOI Topic 1: Fueling Components for HD Vehicles

Barriers

- Availability of heavy-duty hydrogen fueling infrastructure is limited (globally) to evaluate the performance of fueling protocol concepts and hardware.
- Lack of understating how heavy-duty fueling concepts will influence infrastructure and vehicle design, specification, and cost.
- Robust modeling tools for heavy-duty fueling concepts currently do not exist.

Partners

- PI: Shaun Onorato (NREL)
- Co-PI(s): Dr. Taichi Kuroki (NREL), Mark Chung (NREL), Amgad Elgowainy (ANL), Lauren Mattar (NextEnergy), & Emily Moreyra (Chevron)
- Partner organization(s)
  – **NextEnergy** - Industry Group and Component Liaison
  – **Chevron** – Energy Company
  – **Argonne National Laboratory** - Modeling Partner

Potential Impact

Project relevance to DOE and Administration goals

Goal	Impact
Provide pathways to private sector uptake	Evaluation of prototype HD hydrogen fueling components and protocols under real-world conditions providing a pathway to commercial market availability.
Build clean energy infrastructure	Provide support to industry, government, and codes and standards groups to build out new heavy-duty hydrogen infrastructure for hydrogen trucks and create jobs.
Lower greenhouse gas emissions and criteria pollutants	Enabling infrastructure R&D will accelerate the use of hydrogen powered heavy-duty vehicles, which will significantly reduce emissions and pollution.
Support and improve energy, environmental, and/or social justice	Adoption of hydrogen powered heavy-duty vehicles has the potential to reduce emissions and pollution in areas of disadvantaged communities.

Approach: Project Level

The project structure utilizes 3 subgroup teams that support execution of taskwork

Project Subgroups

Hardware

Real world component and fueling protocol evaluation at NREL's fast flow research station.

- Evaluation of industry supplied fueling components for performance, usability, and temperature/pressure data (nozzle, hose, receptacle, and breakaway devices).
- Implementation of new fueling protocol concepts and evaluation with a vehicle tank system to address performance, technology gaps, and new communication concepts.
- Generate data for modeling/analysis tasks and industry partners (dP, dT, $\dot{m}$, K_v, etc.).

Modeling

HD component and fueling protocol modeling with validation using experimental results

- Perform computational fluid dynamics (CFD) utilizing NREL's super-computer (HPC) on hydrogen vehicle tank systems and fueling hardware under various conditions.
- Upgrade the NREL H2FillS model for HD fueling and integrate HD fueling protocols and capability to run fueling tables using experimental data.
- Provide results to hardware/modeling/partner groups and release HD-H2FillS to public.

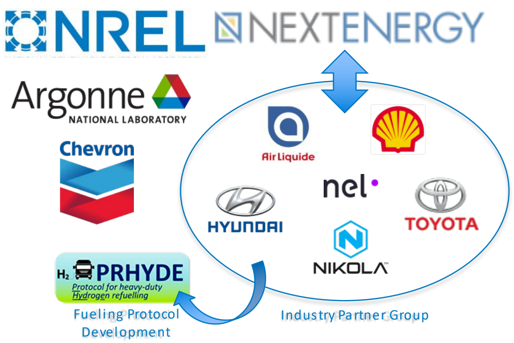
Analysis

Perform comprehensive techno-economic assessments (TEA) to determine total cost of ownership (TCO) of HD station concepts and vehicle architectures.

- Leverage existing modeling tools developed at NREL and ANL to perform TEA and TCO on data generated in hardware and modeling tasks as well as industry supplied metrics.
- Develop a publicly available TEA/TCO analysis tool for distribution at project conclusion.
- Provide supporting analysis information to hardware and modeling tasks.

Coordination with industry partners

Project Partner Structure



Primary Deliverables

- **HD component and fueling protocol performance test data under fast-flow conditions.**
- **CFD modeling results for hydrogen storage tanks and HD components.**
- **TEA/TCO results for industry supplied scenarios.**
- **Public version of upgraded HD-H2FillS model.**
- **Public model structure to run TEA/TCO with NREL/ANL legacy models.**
- **Final comprehensive report.**

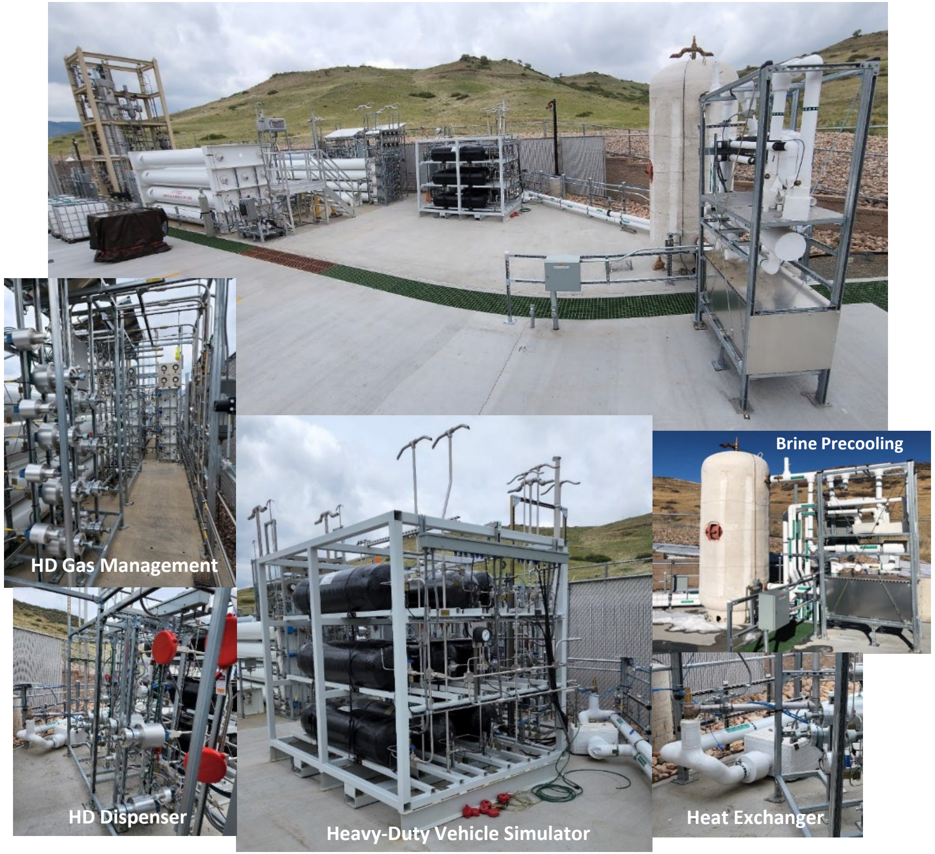
Approach: Hardware

First-of-its-kind, experimental research capability for medium and heavy-duty fast-flow fueling R&D

- Located: Energy Systems Integration Facility (ESIF)
  - Golden, Colorado, USA
- Leverages NREL's light-duty infrastructure research capability
- Fueling capability (gaseous): 70 MPa (nominal), -40°C precooling, 10 kg/min average (20 kg/min peak) mass flow
- Comprised of:
  - **Heavy-Duty Dispenser** (HDD)
  - **Heavy-Duty Vehicle Simulator** (HDVS)
    - +80 kg fill mass (equivalent to a Class 8 truck)
    - Type IV and Type III tanks
    - Configurable volume & heavily instrumented
  - **Bulk gas storage** ~650 kg (Low, Med, High Pressure)
    - Limited back-to-back fueling capability
  - **Brine based precooling system & micro-channel heat exchanger.**
  - **HD gas management panel**
    - Configurable for cascade fueling approach
    - Gas recirculation to save on cost

✓ **Enables HD fueling protocols, components, and hardware evaluations.**

NREL's Heavy-Duty Hydrogen Fast-Flow Research Station



Approach: Hardware

Phased Test Plan for Fueling Hardware and Protocol Evaluations

- Test plan broken into 4 phases and addresses various aspects of fueling hardware and fueling protocol performance, characterization, and feasibility.
- Leverages dual dispenser capabilities: NREL HDD and Bennett HD Commercial Dispenser
- Evaluate industry selected fueling protocols: MC H70 HF (SAE-5) and EU PRHYDE

NREL Phased Test Plan for Fueling Hardware and Protocol Evaluations

	Year	Year 1	Year 2												Year 3		
	Month	1-12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
Test Plan Phases	Preliminary Phase: NREL Station Benchmark/Commissioning	Complete															
	Phase I – Refueling Hardware Commissioning																
	Installation of nozzle assembly, receptacle, mass flow meter, and sensors.																
	Phased pressurization and commissioning tests of refueling hardware on NREL HDD.																
	Readiness Review for full pressure testing.																
	Phase II – Refueling Hardware Performance Evaluation																
	Flow tests at full nominal pressure (70 MPa) utilizing constant pressure ramp rate to assess component pressure drop, thermal mass, and overall usability.																
	MC H70 HF protocol flow tests (70 MPa, -40C, 18 kg/min max, and within APPR bounds) into various configurations of HDVS.																
	Nozzle freeze lock refueling tests with MC H70 HF refueling protocol.																
	Phase III – PRHYDE Protocol Evaluations																
	PRHYDE Static, Initial+, and Throttle fueling protocol fueling tests with industry hardware and fueling into HDVS.																
	Evaluate advanced vehicle to station.																
	Phase IV – Other Evaluations																
	Mass flow meters, other nozzle sets, other communications, and follow-up protocols evaluations.																

HD Protocols Development Status

Entity	Status	Application	Hardware	Comms
SAE J2601 Category D	Published	CHSS >10 kg (LD Station)	LD Based	IRdA
Japan MF	In Progress	MD, HD	LD Based	IRdA
Korean	In Progress	HD	New, HD	Advanced
MC H70 HF	In Progress	HD	New, HD	IRdA
EU PRHYDE	In Progress	HD	New, HD	Advanced

EU Protocol for Heavy-Duty Hydrogen Refuelling Project: https://lbst.de/prhyde/?lang=en

NREL and Bennett Dispensers with HDVS

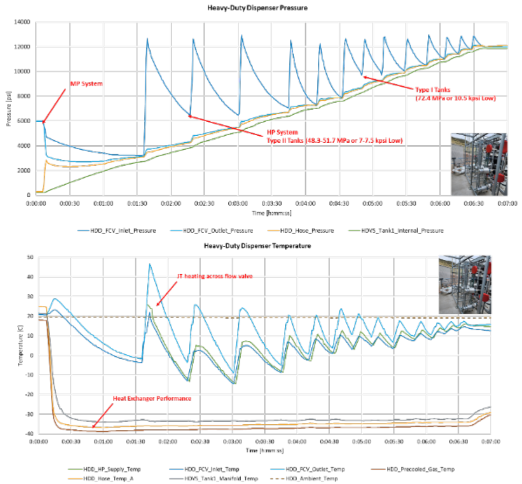
Bennett HD dispenser development falls under the Electricore DOE project titled: High Pressure, High Flow Rate Dispenser And Nozzle Assembly For Heavy Duty Vehicles: https://www.hydrogen.energy.gov/pdfs/review22/ta049_quong_2022_o.pdf

Accomplishments: Hardware

Heavy-Duty Fast Flow Testing - Major Achievements

- Multiple flow-tests completed over 2022 leading up to two major benchmarks tests.
- Two major fills into HDVS system using all tanks and only Type IV tanks (model validation).

Heavy-Duty Test Data for NREL HD Dispenser



Industry and DOE Target Metrics:

Mass
60-100kg

Time
<10 minutes

Mass Flow
Average: 10 kg/min
Peak: 20 kg/min

Vehicle
Within tank temp & pressure limits

Temperature
-40 C

Pressure
70 MPa

Major milestone fast flow tests completed:

Date (mo./yr.)	Fill Mass (kg)	Time (mins)	Average Mass Flow Rate (Kg/min)	Peak Mass Flow Rate (Kg/min)	SOC (%)	Notes
08/2022	61.5	4.7	13.2	18.7	94%	Type IV Only (60 kgs)
10/2022	**82.3**	6.6	12.6	23	100%	Complete HDVS (>80 kgs)

☑ **Met all industry and DOE target metrics for fast-fill tests into the HD vehicle simulator.**

Approach: Industry Hardware Development

Heavy-Duty Hydrogen Component Development

- Industry Group funded the development of 70 MPa hydrogen heavy-duty vehicle high-flow (H70HF) hardware components against proposed global standards and industry specific metrics.
- NextEnergy, on behalf of the Industry Group, facilitated conversations and information sharing between the component manufacturers and NREL in support of the CRADA work.
- Component Suppliers:
  - **Nozzle, Receptacle, and Breakaway:** Tatsuno Corporation (Japan)
  - **Hose:** Parker (Germany)

Fueling Components Specification Targets

Nominal Working Pressure	70 MPa (H70)
Maximum Operating Pressure	87.5 MPa - All Components 96.25 MPa - Nozzle & Receptacle
Maximum Allowable Working Pressure	96.25 MPa
Operating Temperature	-50^{O}C to 95^{O}C
Maximum Average Flow Rate	180 g/s (10.8 kg/min)
Maximum Peak Flow Rate	300 g/s (18 kg/min) Component Limitation

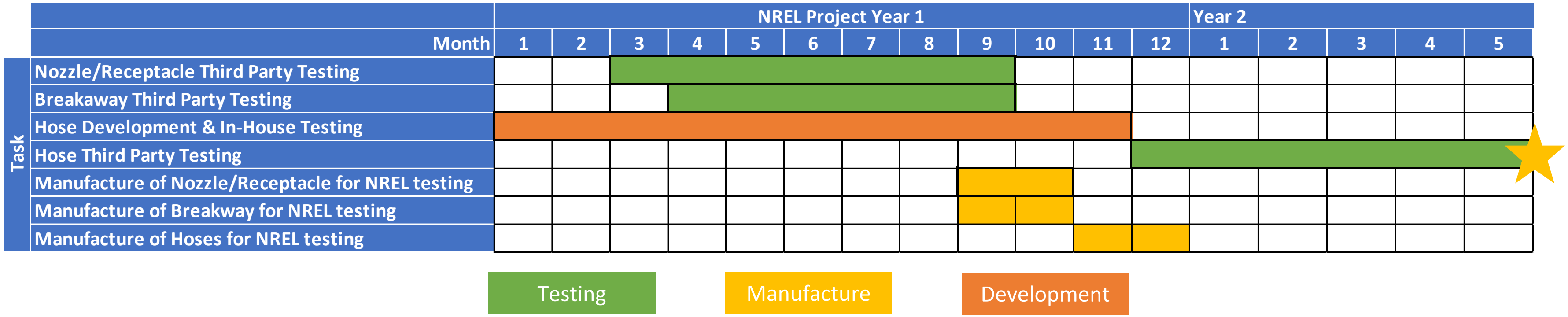
Heavy-Duty Hydrogen Fueling Components
Top: Nozzle with Protective Plastic Cover
Bottom: Breakaway, Nozzle without cover, Receptacle, and Hose

Accomplishment: Industry Hardware Development

Heavy-Duty Hydrogen Component Development

- Hardware manufactured at individual component suppliers and sent for 3rd party testing.
  - Hardware tested against specifications at pressure, temperature, flow rate, drop, freeze, etc.
  - Provided required specs, internal test results, and other critical information from hardware suppliers to NREL for safety assessments.
- Revised hardware designs (based on 3rd party testing results), manufactured new assemblies, and shipped to NREL for evaluation at fast flow facility.
  - Full sets delivered in January 2023 (two of each component).
- Facilitated conversations between hardware suppliers and NREL to support modeling tasks.

Industry Hardware Development Schedule

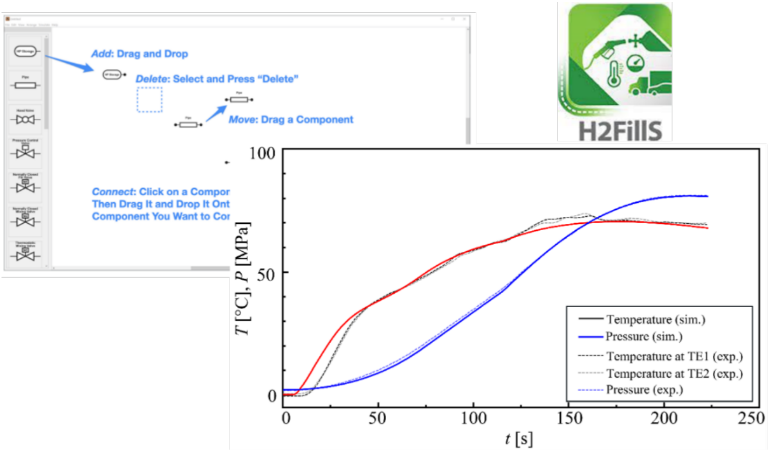


Approach: Modeling (H2FillS)

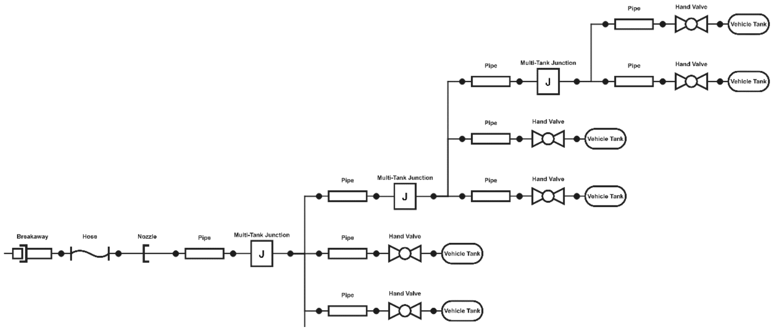
Upgrade NREL H2FillS legacy model to accommodate:

- High-flow HD fueling
  - Validated with CFD and experimental data
- Large & complicated onboard storage systems
- Defueling processes of storage tanks
- Fueling table derivation for advanced fueling protocols

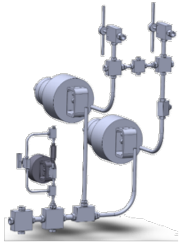
✓ **Provide public tool for hydrogen stakeholders**



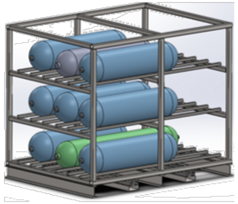
H2FillS Model User Interface and Sample Model Results



Accomplishment: Modeling (HD-H2FillS)



HD dispenser specifications



HD vehicle simulator specifications

Fill conditions

Name	Value
Ambient temp	23.0°C
HDVS size	86.8 kg
HDVS initial gas press	1.7 MPa
HDVS ending gas press	76.2 MPa
Fill time	360 s
Corresponding pressure ramp rate	12.4 MPa/min
Time-averaged mass flow	13.1 kg/min
Peak mass flow rate	23.2 kg/min

Reliability of Heavy-Duty Version of H2FillS (HD-H2FillS)

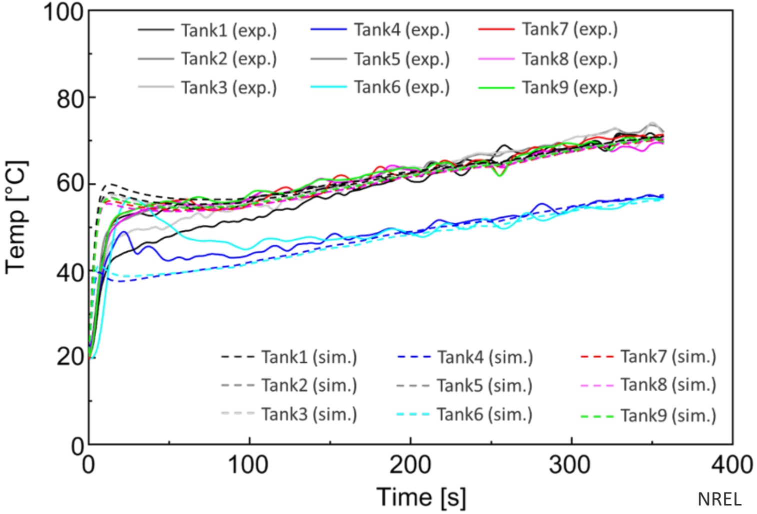
1. NREL's HD dispenser and vehicle simulator specifications and fill conditions were modeled in H2FillS and ran as a simulation.
2. The H2FillS' results were compared with the real-world testing data.
   - Some variations existed between the model and test data, but the differences decrease towards the end of the fill.
   - The model was refined with addition test data.

Feed

H2FillS

Result

H2FillS Model Results Compared to Fast-Flow Data



Accomplishment: Modeling (Fueling Protocols)

HD-H2FillS Modifications for use with new Heavy-Duty Fueling Protocols

- Modification of HD-H2FillS to run fueling protocol concepts (MC H70 HF [SAE-5] and EU PRHYDE)
- The integration allows HD-H2FillS to generate the required fueling tables for the associated protocols.
  - Tables can be installed in NREL's HD dispenser to perform fueling tests with a chosen fueling protocol.
  - Tables will be provided to codes and standards groups for publication.
- Fueling protocol programming will be translated to the NREL HD dispenser for fueling tests.

Integration of PRHYDE protocol using NREL's HPC system & H2FillS

H2FillS + Fueling Protocol PRHYDE *Protocol for heavy-duty Hydrogen refuelling* +

HPC system

NREL's High-Performance Computing (HPC) is a supercomputer featuring state-of-the-art computational modeling and predictive simulation capabilities: https://www.nrel.gov/computational-science/hpc-user-facility.html

Generated Fueling Table Examples

Table C.5: 750 ≤ V_{CHSS} ≤ 1250 L, and $V_{tank\text{-}large}$ ≤ 200 L

MATC / T_{amb}	-40	-38	-36	-34	-32	-30	-28	-26	-24	-22	-20	-18	-16	-14	-12	-10
50	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
45	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
40	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
35	xx.x	xx.x	x													
30	xx.x	xx.x	x													
25	xx.x	xx.x	x													
20	xx.x	xx.x	x													
15	xx.x	xx.x	x													
10	xx.x	xx.x	x													
5	xx.x	xx.x	x													
0	xx.x	xx.x	x													
-10	xx.x	xx.x	x													
-20	xx.x	xx.x	x													
-30	xx.x	xx.x	x													
-40	xx.x	xx.x	x													

Table C.3: 750 ≤ V_{CHSS} ≤ 1250 L, and 300 < $V_{tank\text{-}large}$ ≤ 400 L

MATC / T_{amb}	-40	-38	-36	-34	-32	-30	-28	-26	-24	-22	-20	-18	-16	-14	-12	-10
50	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
45	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
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-10	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
-20	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
-30	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
-40	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x

Approach/Accomplishment: Modeling (CFD)

Computational Fluid Dynamics Modeling:
Vehicle On Tank Valve Injector Shape Evaluation

- Leveraged NREL's high performance computing system (supercomputer) to run CFD with Ansys Fluent.
- Investigated the influence of injector geometry on internal tank temperatures and the development of hot spots and thermal stratification that would exceed tank specifications.
  - Results influence fueling protocol development.
- Primary simulations generated for tank injectors (2):

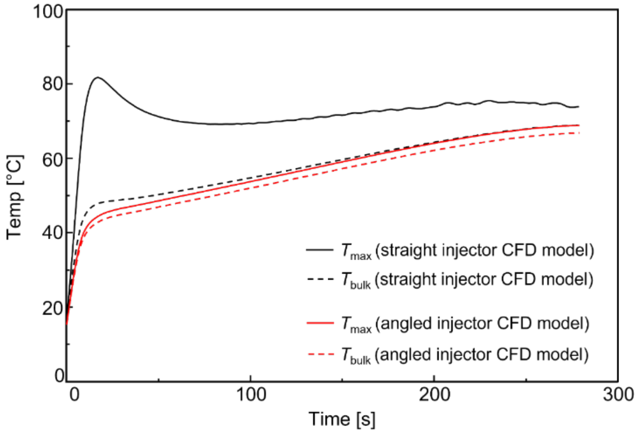
<u>1. Straight Injector Model</u>

- Result: Large temperature gradients (hot spots) found at the beginning of the fill, which causes a large difference in bulk-average and maximum gas temperatures.

<u>2. Angled Injector Model</u>

- Result: Determined angled injectors mix the gas well; resulting in a small difference in the maximum and bulk average gas temperatures.

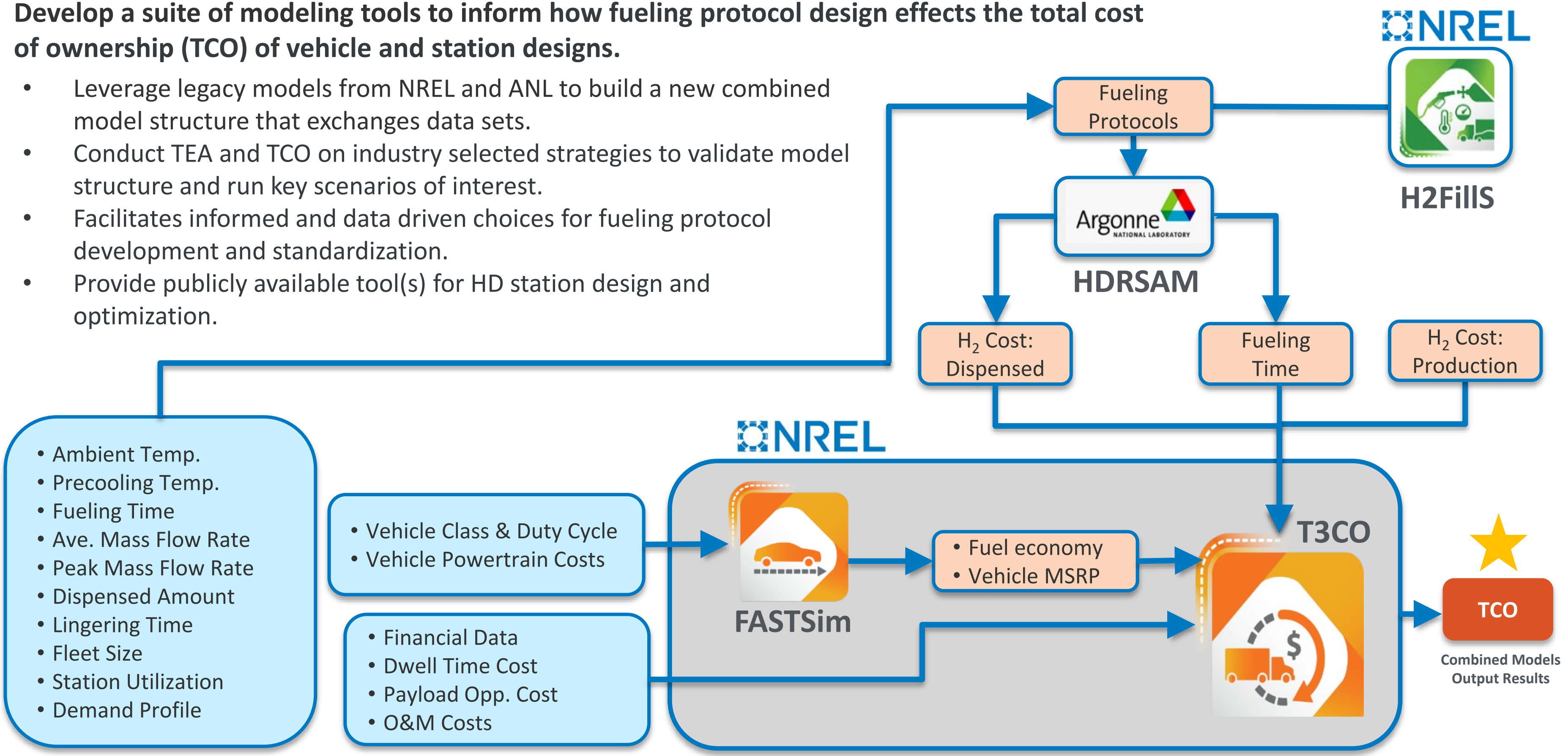
CFD Model Results for Straight and Angled Injectors



Approach: Analysis (TEA/TCO)

Develop a suite of modeling tools to inform how fueling protocol design effects the total cost of ownership (TCO) of vehicle and station designs.

- Leverage legacy models from NREL and ANL to build a new combined model structure that exchanges data sets.
- Conduct TEA and TCO on industry selected strategies to validate model structure and run key scenarios of interest.
- Facilitates informed and data driven choices for fueling protocol development and standardization.
- Provide publicly available tool(s) for HD station design and optimization.



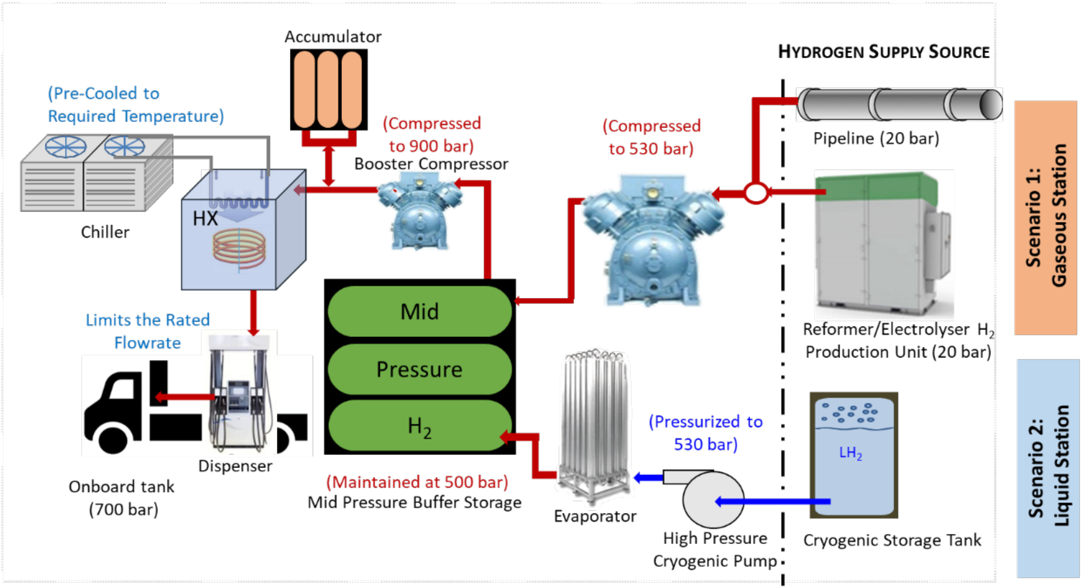
Approach: Analysis (TEA - HDRSAM)

HDRSAM model Assumptions - Station Parameters & Configuration

- HDRSAM is an Excel based techno-economic assessment model for fueling a fleet of heavy-duty hydrogen vehicles. https://hdsam.es.anl.gov/index.php?content=hdrsam
- The model evaluates the cost of hydrogen fueling for various fueling station configurations and demand profiles.
- Data generated in HD-H2FillS were provided from new fueling protocols and used as inputs (fueling time, mass flow rate, etc.).
- Industry partners identified key metrics for station configurations to perform analysis:
  - Liquid and gaseous supply
  - Metrics in table below

Industry-Provided Metrics for Station Configuration and Fueling Parameters

Station and Fueling Parameters	Value
Fueling Pressure [bar]	700
Dispensed Amount [kg]	60
Max. Dispensed Temperature [ºC]	-20, -40
Ambient Temperature [ºC]	10, 40
Lingering Time [minutes]	3
Fleet Size [trucks]	100, 40
Station Utilization [%]	100



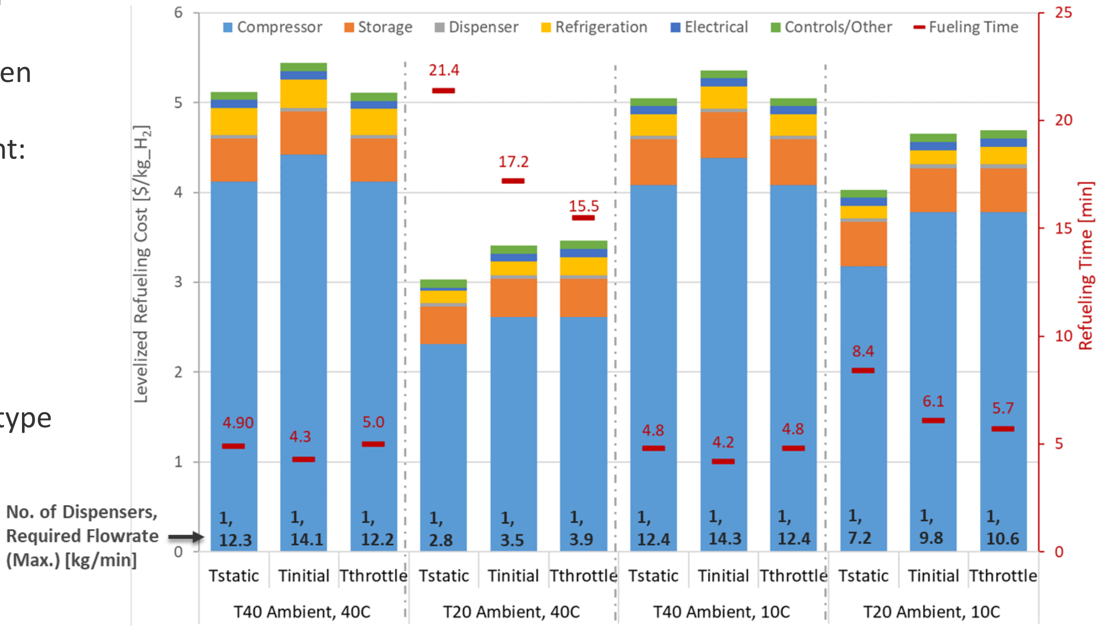
HDRSAM Station Configurations (Liquid and Gaseous Hydrogen Supply)

Accomplishment: Analysis (TEA - HDRSAM)

HDRSAM Model Assumptions - Station Parameters & Configuration

- Preliminary analysis were completed using HDRSAM on industry selected metrics and fueling protocol data from H2FillS.
- The cost of hydrogen fueling was estimated for various ambient and precooling temperatures (industry directed) over 3 fueling protocols taken from the EU PRHYDE project.
- Cost data is broken down by station component:
    - Compressor
    - Storage
    - Dispenser
    - Refrigeration
    - Electrical
    - Controls/Other
- Fueling time is broken out by fueling protocol type with associated flow rate.
- Number of dispensers required is broken out per each individual scenario.
- Cost are shown in levelized fueling cost:
    - $/Kilogram of hydrogen gas dispensed

Example Analysis Result:
Cost Contribution of Gaseous Station Components (40 Truck Fleet Size)



Accomplishment: Analysis (TCO)

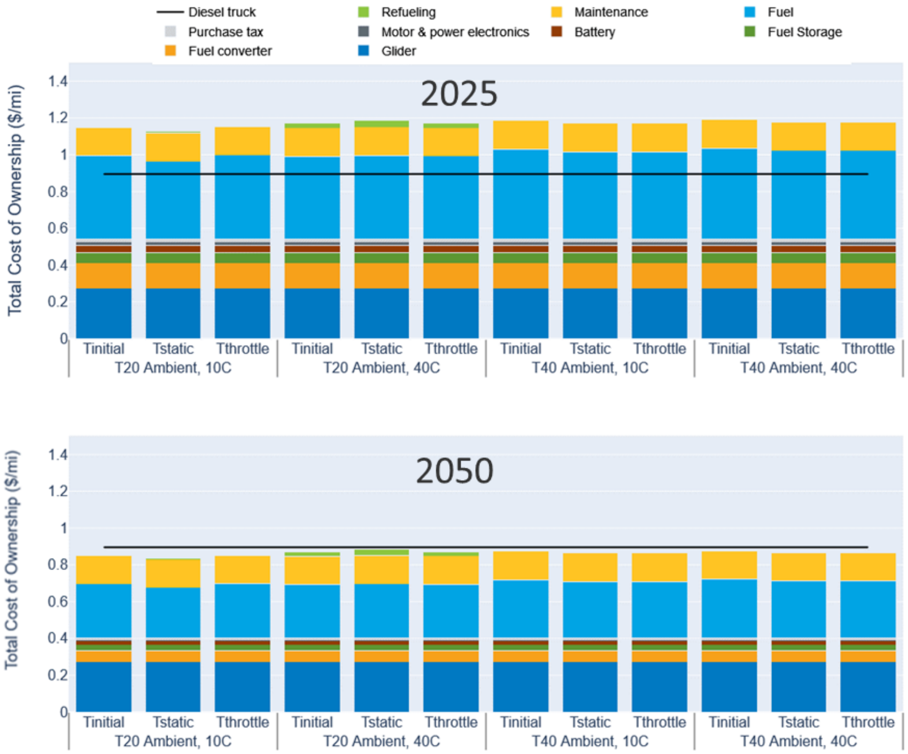
Total Cost of Ownership Methodology

- Calculate using NREL's FASTSim and T3CO tools utilizing inputs from H2FillS and HDRSAM.
- TCO breaks down truck components and ownerships costs and compares powertrains, protocols, and industry selected ambient/precooling temperatures.
- Incorporated HFTO/VTO technology goals 2025 to 2050:

Technology Year	2025	2050
Fuel cell power (kWh/kg)	0.7	1.0
Fuel cell cost ($/kW)	130	60
Fuel cell peak efficiency	0.65	0.70
H_2 storage cost ($/kWh)	10	8

- Class 8 trucks (sleeper, day cab, and box) are considered with fuel cell powertrains.
- TCO decreases as technology is assumed to improve.
  - Improvements in fuel cell performance and cost.
  - Reductions in storage costs.
- Fuel price incorporates dispensing and production.
- **Result:** Preliminary analysis shows scenarios with long fueling times incur larger fueling cost, but the overall affect on the TCO is minor.

Example Analysis Result:
Total Cost of Ownership of Class 8 Sleeper Trucks with PRHYDE Protocols and Industry Selected Criteria



Accomplishments and Progress: Response to Previous Year Reviewers' Comments

This project has no yet been reviewed. There are no current comments to address.

Collaboration and Coordination

- **Industry:** NextEnergy, Chevron, & Argonne National Lab
  - Weekly hardware/modeling meetings
  - Monthly progress updates
  - Provide feedback on technical approach
- **International:** EU and Japan
  - **EU PRHYDE** - NREL was admitted as a technical expert
  - **ISO TC 197 Working Groups 5 and 24** – Group Member
  - **SAE J2601-5 Working Groups -** NREL was admitted as a technical expert
  - **NEDO/JARI** - Coordination on CFD work
  - **Kyushu University** - Continued collaboration on H2FillS
- **Component Suppliers:** New HD fueling components for evaluation at NREL

EU Protocol for Heavy-Duty Hydrogen Refuelling Project:
https://lbst.de/prhyde/?lang=en

PRHYDE is a European based project, funded by the FCH2 JU under the Horizon 2020 program, looking at the current and future developments needed for fueling medium and heavy-duty hydrogen vehicles, predominantly road vehicles, but also other applications such as rail and maritime.

Remaining Challenges and Barriers

Challenge/Barrier	Solution
Delayed installation and commissioning of industry supplied fueling hardware could result from supply chain constraints (of peripheral components) or unexpected component failures.	The project team has worked to place orders for long lead time components and spare parts in-advance of test schedules. Two sets of each industry component were provided to mitigate the risk of failure and resulting delays.
Potential for current flow control technology to not meet performance requirements demanded by new fueling protocol concepts.	Modeling in H2FillS confirmed dispensers could meet baseline performance metrics and validated with benchmark flow tests. The NREL dispenser could be easily modified with new hardware. This issue remains and industry wide technology gap.
Lack of accurate cost data to provide as inputs to the TEA and TCO models for heavy-duty hydrogen station components that currently do not exist or are under development.	The analysis team is working closely with industry partners to obtain updated cost data for modeling efforts, as available. The team is leveraging DOE MYRD&D plans and cost data from parallel DOE projects and efforts (Strategic Analysis, ANL, etc.).
Public release schedule delays for full TEA/TCO model structure due to individual development schedules of models (maintained under their own unique projects/programs).	The analysis team is working on a stop-gap solution for offering model subsets or quarterly posted databases for model structures that partners/public could access until all models are publicly available.

Proposed Future Work

Hardware:

- Perform fast flow tests to generate data for model validation under various precooling and tank conditions.
- Evaluate advance fueling protocols with industry supplied HD fueling component sets using the developed hardware test plan.
- Inform Codes and Standards working groups, industry partners, and DOE on performance data and technology gaps to facilitate/expedite fueling protocol and component standardization.

Modeling:

- Validate HD-H2FillS against HD fueling data and release new versions of the beta test model to partners.
- Assist SAE and ISO in development of HD fueling protocols.
- Full public release on HD-H2FillS on NREL's website at project conclusion.

Analysis:

- Perform iterations of techno-economic assessments (TEA) and total cost of ownership (TCO) based on industry selected inputs and factors.
- Finalize the combined model structure and methodology for partner beta testing.
- Release a combined model structure for public use.

Summary

Hardware:

- Performed fast-flow fueling tests at NREL's research station and benchmarked the system performance to verify system exceeds industry and DOE targets.
- Met requirements to actively participate in codes and standards organizations as well as associated working groups (FCH-JU PRHYDE, ISO TC 197 Working Groups 24 and 5, and SAE J2601-5).
- Implemented necessary station improvements, controls, and conducted safety analysis in preparation to install industry supplied fueling components and evaluate those devices with new heavy-duty fueling protocols.

Modeling:

- Modified H2FillS for heavy-duty applications and verified model accuracy with fast flow fueling data from the NREL research station.
  - Modifications included defueling tanks, complex storage systems, fueling table derivation, larger component sizes, HD fueling components, etc.
- Released the beta test version of HD-H2FillS to partner for evaluations.
- Performed numerous CFD simulation runs for hydrogen tanks that informed research and fueling protocols.

Analysis:

- Constructed the combined model structure and methodology for how legacy models (NREL and ANL) will interact to perform TEA and TCO.
- Ran baseline analysis with PRHYDE fueling protocols and industry selected strategies to investigate the affects on station design, station cost, and vehicle cost.
- Established a baseline strategy for creating a public combined tool that leverages legacy analysis/modeling tools.

Thank You

www.nrel.gov

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