H2@Scale CRADA: CA Research Consort. (Ref. Station, Fueling Perf. Test Device, Station Cap Model)

PI: Sam Sprik (National Renewable Energy Laboratory)
Presenters: Ethan Hecht (Sandia National Laboratories, Reference Stations), and Taichi Kuroki (NREL, Station Capacity Model)
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DOE Hydrogen Program
2023 Annual Merit Review and Peer Evaluation Meeting

Project ID: H2041

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Project Goals

The goal of this project is to continue the research partnership between national laboratories, DOE, and California public agencies for the advancement of hydrogen fueling infrastructure for heavy-duty vehicles.

Two subproject goals are to:

- Provide design considerations and risk analysis for heavy-duty hydrogen fueling stations
- Develop a model to evaluate the dispensing capacity of heavy-duty hydrogen stations

This cooperative work reflects directly to California's transition to Zero Emission Trucks as spelled out in the California Air Resource Board's 2020 Advanced Clean Truck Regulation and Governor Gavin Newsom's zero-emission vehicle Executive Order N-79-20.

This project will provide tools and information that lead to more efficient design, acceptance, and commissioning of these larger capacity, higher flow rate stations serving heavy-duty applications.

Overview

Timeline and Budget

- Project start date: 10/01/21
- Project end date: 12/31/23
- Total project budget: $1,171k ($65k In-Kind)
  - DOE share: $1,056k
  - Cost share: $50k
  - DOE funds spent*: $356k
  - Cost share funds spent*: $10k

  * As of ~03/31/2023

Partners

- National Renewable Energy Laboratory (**NREL**): Sam Sprik (PI), Taichi Kuroki, Kazunori Nagasawa, Jacob Thorson
- Sandia National Laboratories (**SNL**): Ethan Hecht (Co-PI), Steven Wirydinata, Qi Guo
- Argonne National Laboratory (**ANL**): Amgad Elgowainy
- California Governor’s Office of Business and Economic Development (**GO-Biz**): Gia Vacin
- California Air Resources Board (**CARB**): Andrew Martinez
- California Energy Commission (**CEC**): Esther Odufuwa
- South Coast Air Quality Management District (**South Coast AQMD**): Maryam Hajbabaei

Relevance/Potential Impact

- Tasks will enable the build-out of heavy-duty (HD) hydrogen fueling stations with large dispensing capacity and high flow rates servicing HD hydrogen trucks such as class 8 trucks in long haul applications
  - leverages national lab capabilities including staff and equipment at SNL, NREL, and ANL with collaboration and funding cost share from California agencies (CEC, South Coast AQMD, and GO-Biz)
  - provides tools and information that lead to more efficient design, acceptance, and commissioning of large capacity, high flow rate stations serving HD applications
- Helps increase demand for hydrogen substantially; scale-up will aid in achieving the Hydrogen Shot goal of $1 for 1 kg hydrogen in 1 decade
- Replacing diesel with hydrogen at HD fueling stations will lower greenhouse gas emissions and criteria pollutants from the trucking industry
- Build out of HD stations will create good-paying jobs in the United States
- HD hydrogen stations are part of building a clean energy infrastructure
- Clean fuel at HD stations supports energy, environmental, and social justice by preventing pollution near the stations and on truck routes while strengthening U.S. manufacturing and providing pathways to private sector uptake


https://pressroom.toyota.com/first-heavy-duty-fuel-cell-electric-trucks-set-for-delivery-to-pilot-program-customers-at-ports-of-l-a-and-long-beach/


https://trucknbus.hyundai.com/global/en/products/truck/xcient-fuel-cell


https://nikolamotor.com/press_releases/nikola-motor-company-announces-u-s-and-canadian-class-8-trucks-will-be-hydrogen-fuel-cell-powered-and-100-emission-free-30/

Approach: Tasks/Meetings

SNL led tasks (with guidance and review from ANL and NREL)

- Year 1: Report on reference station designs for HD vehicles
- Year 2: Report on risk analysis of an HD vehicle fueling station

NREL led tasks (with guidance and review from ANL and SNL)

- Year 1: Beta version of model to evaluate HD hydrogen fueling station for high pressure onboard (70 MPa) and on-site production
- Year 2: Publicly available, executable model that can be used by H2@Scale community to evaluate HD hydrogen fueling station dispensing capacity based on the specified station equipment and the expected vehicle storage and demand profile
- Year 2: Report on design concepts for HD fueling performance test device

All:

- Year 2: CRADA final report – Project summary
- Regular monthly meetings with partners are used for task updates and project review

Approach: HD Reference Station Development

1. **Survey industry to ascertain station parameters, e.g.:**
   - Onboard vehicle storage conditions (e.g., 700 bar, 350 bar, cryo-compressed)
   - Station capacity needed (kg/day)
   - Fueling protocols (rate, temperature, etc.)
   - Whether there are multiple fueling connections to vehicle
   - Fueling profiles (back-to-back fill needs, etc.)
   - Storage/generation (LH2 storage, electrolyzer on-site, etc.)
2. **Report on components needed for multiple system designs**
   - 700 bar, 10 kg/min
     - Electrolyzer supplied
     - Liquid hydrogen supplied
       - » Using low-pressure vaporizer and compressor
       - » Using liquid pump and high-pressure vaporizer
3. **Determine broad cost considerations for stations**
4. **Develop footprint of different station concepts, based on codes and standards**
5. **Year 2: perform risk assessment on HD reference station and assess any gaps in codes and standards for HD stations**

- ➢ **Ensure that designs are relevant for industry**
- ➢ **Provide several reference station concepts so that results are widely applicable**
- ➢ **Provide technical and cost information**
- ➢ **Help stakeholders identify and interpret the latest applicable regulations, codes and standards**

Accomplishments and Progress: HD Reference Station Development

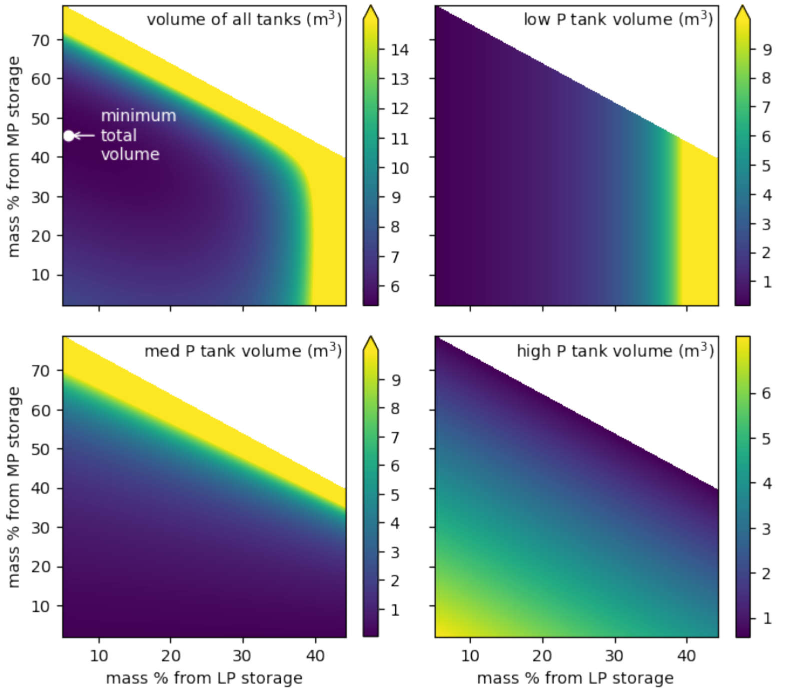
5 variations in station designs were considered:

Design name	Low pressure storage (kg)	Pump/compressor flowrate (per dispenser, kg/min)	High pressure (cascade) storage (kg)
LH2 – cryopump	4,200	10	0
LH2 – large compressor	4,200	10	0
LH2 – small compressor	4,200	5	600
Electrolyzer – off peak	4,200	5	600
Electrolyzer – on demand	1,200	5	600

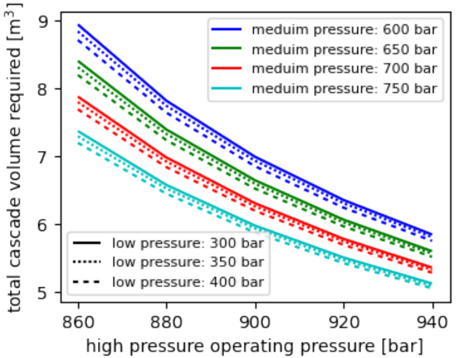
Accomplishments and Progress: HD Reference Station Development

Specific components were considered and sized for each station

Example: Cascade buffer tanks



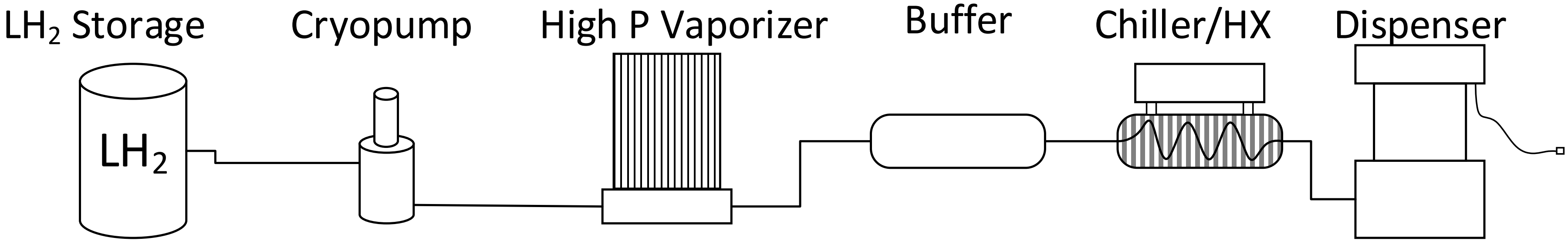
- Cascade pressure and mass from each tier affects sizing of system
- Additional mass from higher pressure tiers tends to reduce size
- Higher pressures require more compression energy



Accomplishments and Progress: HD Reference Station Development

For each station, components were assessed for generic size and cost

Example: LH2 Cryopump



LH_2 Storage
- 4,200 kg
- 2x 11,000 gal tanks
- Each tank: 2.9 m (D) x 10.4 m (H)
- $400k capex

Cryopump
- 16x 55 kW (1.8 kg/min)
- Each pump in container: 5 m x 3 m x 3 m
- $7.2M capex

High P Vaporizer
- 4 x 490 kW_t
- Each vaporizer: 2.5 m x 2.9 m x 7.2 m
- $300k capex

Buffer
- 4 cylinders (0.7 m^3)
- Mounted in rack: 1 m x 1 m x 3 m
- $150k capex

Chiller/HX
- 4 x 87 kW_t
- Each containerized: 5.5 m x 2.4 m x 3 m
- $400k capex

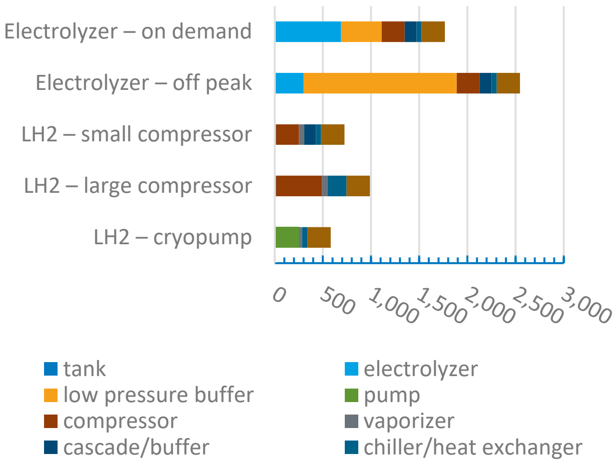
Dispenser
- 4 dispensers
- 240 m^2 (includes area for dispensing with trailer)
- $600k capex

Accomplishments and Progress: HD Reference Station Development

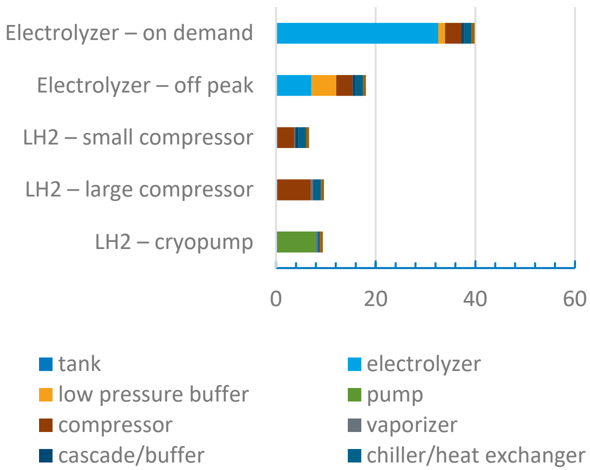
Comparisons of the various station designs have been made

- LH2 with a cryopump minimizes equipment footprint
- LH2 with a small compressor minimizes capital expenditures
- All LH2 designs have smaller equipment footprint and capital cost than electrolyzer stations, but higher operating costs
  - Electrolyzers have high capital cost
  - Electrolyzer stations have lower operating costs due to high cost of liquid hydrogen

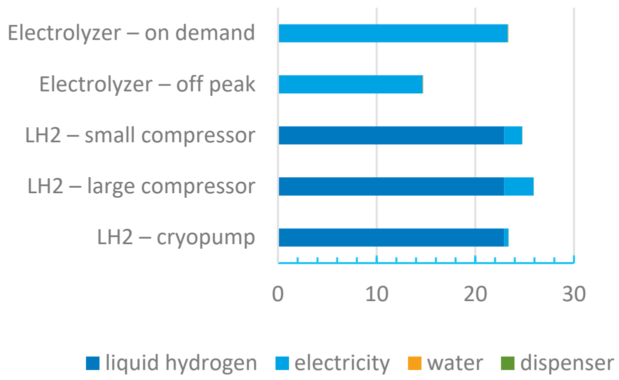
Equipment footprint (m^2)



Equipment Capital Costs ($M)



Operating costs ($M/yr)



Approach: Hydrogen Fueling Capacity (HyCap) Model Configurations

Electrolyzer (implemented)

http://www.hydrogenbatteries.org/Electrolyzers_Electrolysis_Hydrogen_Production.htm

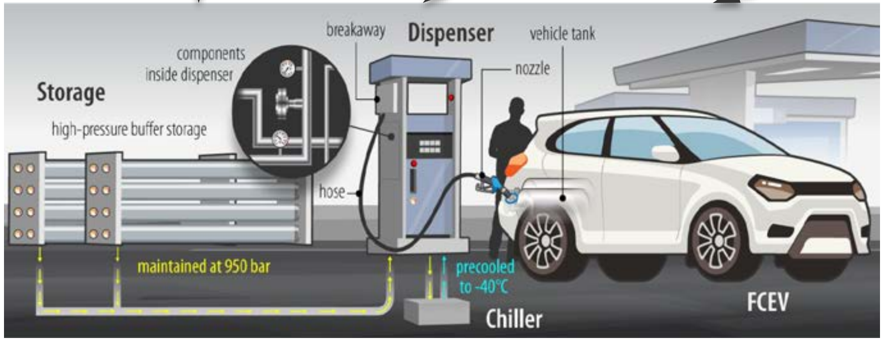
Delivery truck (implemented)

https://www.energy.gov/eere/fuelcells/gaseous-hydrogen-delivery

Liquid (in progress)

https://www.greencarcongress.com/2018/12/20181206-mancryo.html

These three capabilities can be added to the core configuration



Core configuration

- Fueling system from ground storage through vehicle that is capable of:
  - Light- & heavy-duty (LD&HD) fueling
  - Compression

Approach: Fueling Capacity Model
Comparing Model with NREL LD& HD Dispensing Hardware

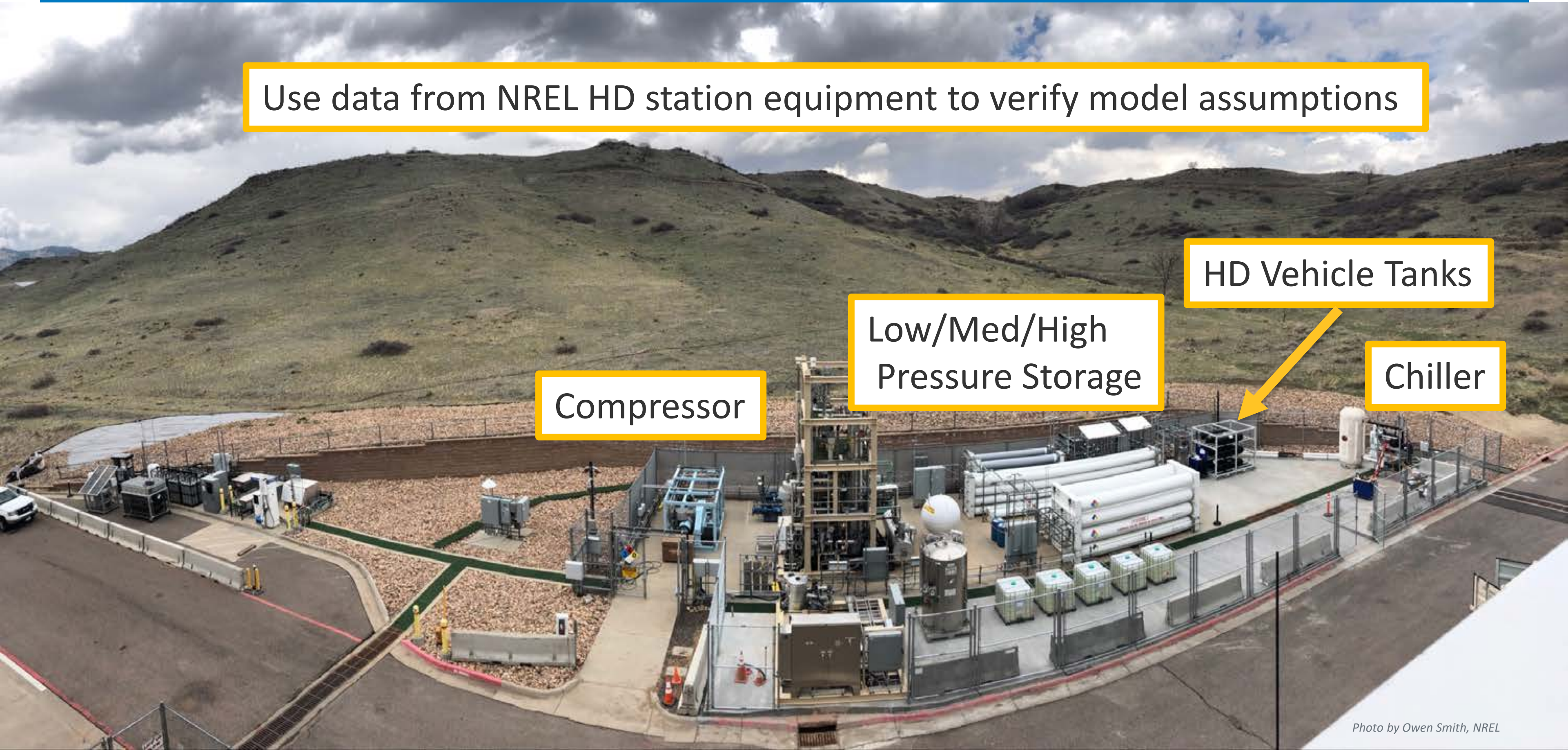
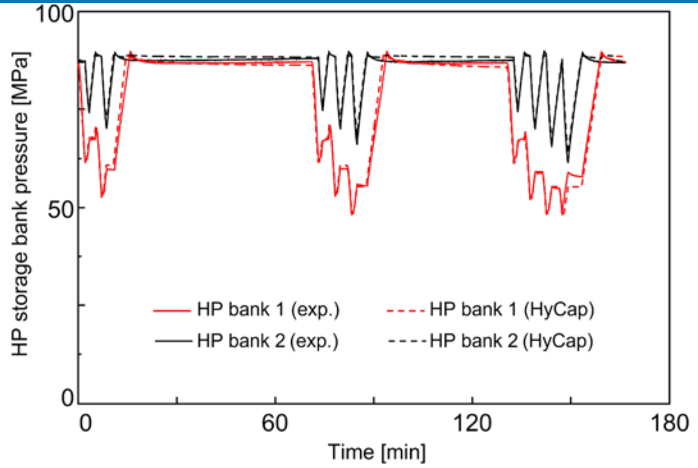
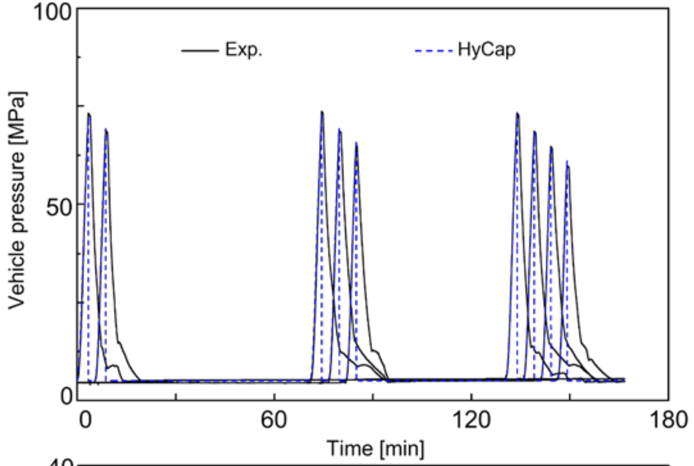
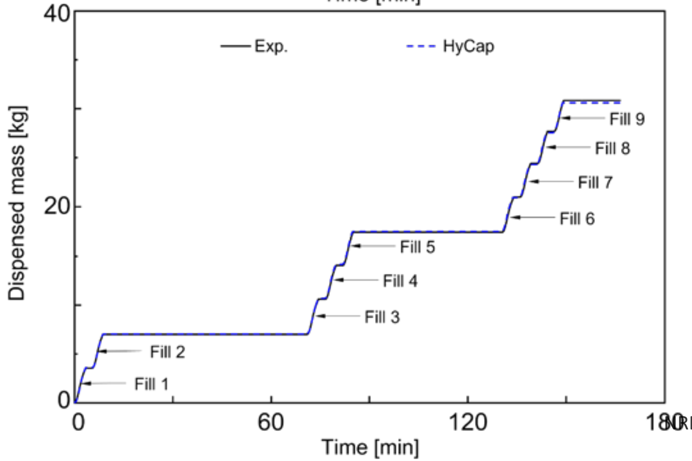


Photo by Owen Smith, NREL

Accomplishments and Progress:
Validation of Model's Reliability with LD Fueling Data



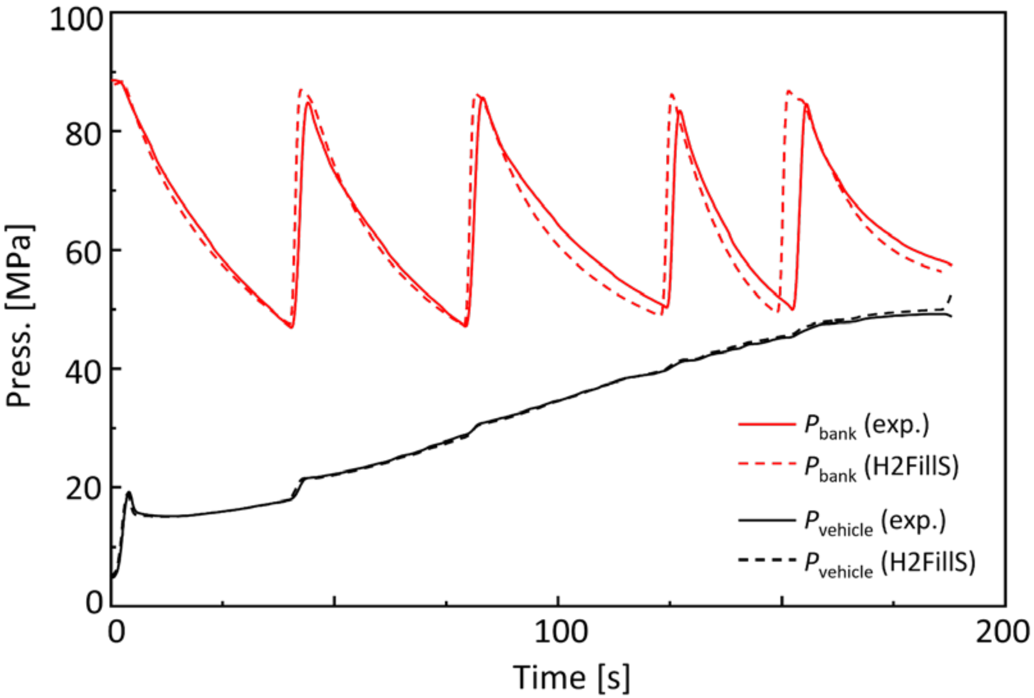




<u>Test conditions used for model validation</u>

- 9 LD vehicles with a 4.3 kg storage system were filled back-to-back.
- High-pressure (HP) banks were used only to dispense hydrogen into the LD vehicles.
- Low-pressure (LP) banks were used only to replenish the HP banks through a compressor.

Accomplishments and Progress: Validation of Model's Reliability with HD Fueling Data



Fill conditions

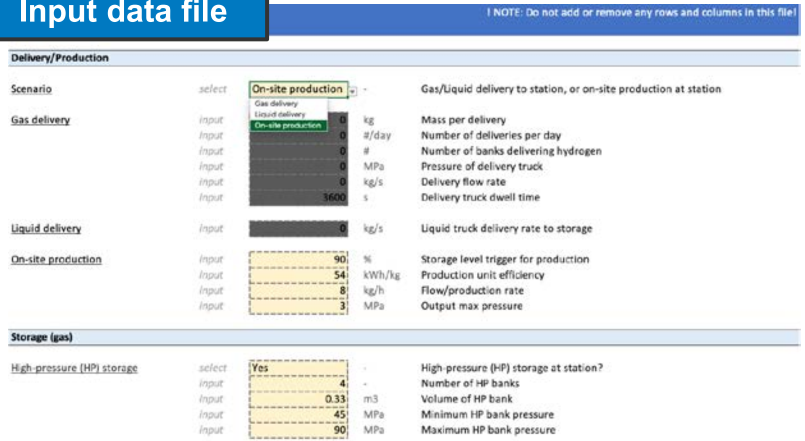
Name	Value
Ambient temp	4.0°C
Onboards storage system	58.8 kg (6*9.8 kg)
Vehicle initial gas press	4.7 MPa
Vehicle ending gas press	49.2 MPa
Fill time	190 s
Time-averaged mass flow rate	10.7 kg/min
Pre-cooling temp	-40.0°C

- HyCap was compared with a high-flow HD fueling data
  - The model was able to predict the change in the HP bank and vehicle tank gas pressures.

Accomplishments and Progress: Web Interface Development

- Built the draft version of simulation codes for heavy-duty
- Started designing the web interface
  - The web interface loads user-defined input (Excel) file and simulates the dispensing capacity on the host server

Input data file



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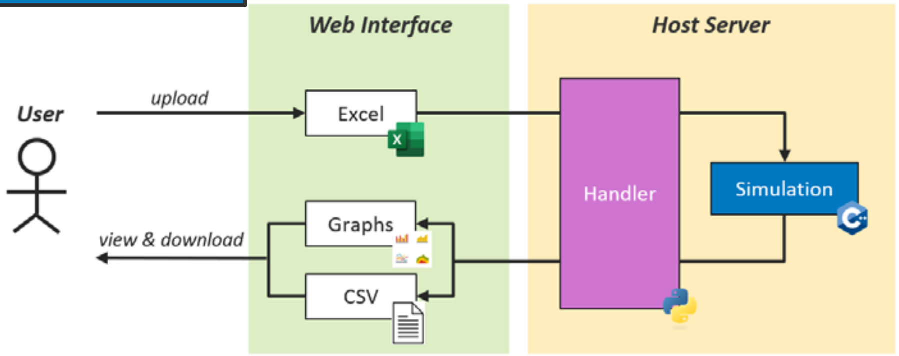
Delivery/Production				
Scenario	select	On-site production (Gas delivery / Liquid delivery / On-site production)	-	Gas/Liquid delivery to station, or on-site production at station
Gas delivery	input	0	kg	Mass per delivery
	input	0	#/day	Number of deliveries per day
	input	0	#	Number of banks delivering hydrogen
	input	0	MPa	Pressure of delivery truck
	input	0	kg/s	Delivery flow rate
	input	3600	s	Delivery truck dwell time
Liquid delivery	input	0	kg/s	Liquid truck delivery rate to storage
On-site production	input	90	%	Storage level trigger for production
	input	54	kWh/kg	Production unit efficiency
	input	8	kg/h	Flow/production rate
	input	3	MPa	Output max pressure
Storage (gas)				
High-pressure (HP) storage	select	Yes	-	High-pressure (HP) storage at station?
	input	4	-	Number of HP banks
	input	0.33	m3	Volume of HP bank
	input	45	MPa	Minimum HP bank pressure
	input	90	MPa	Maximum HP bank pressure

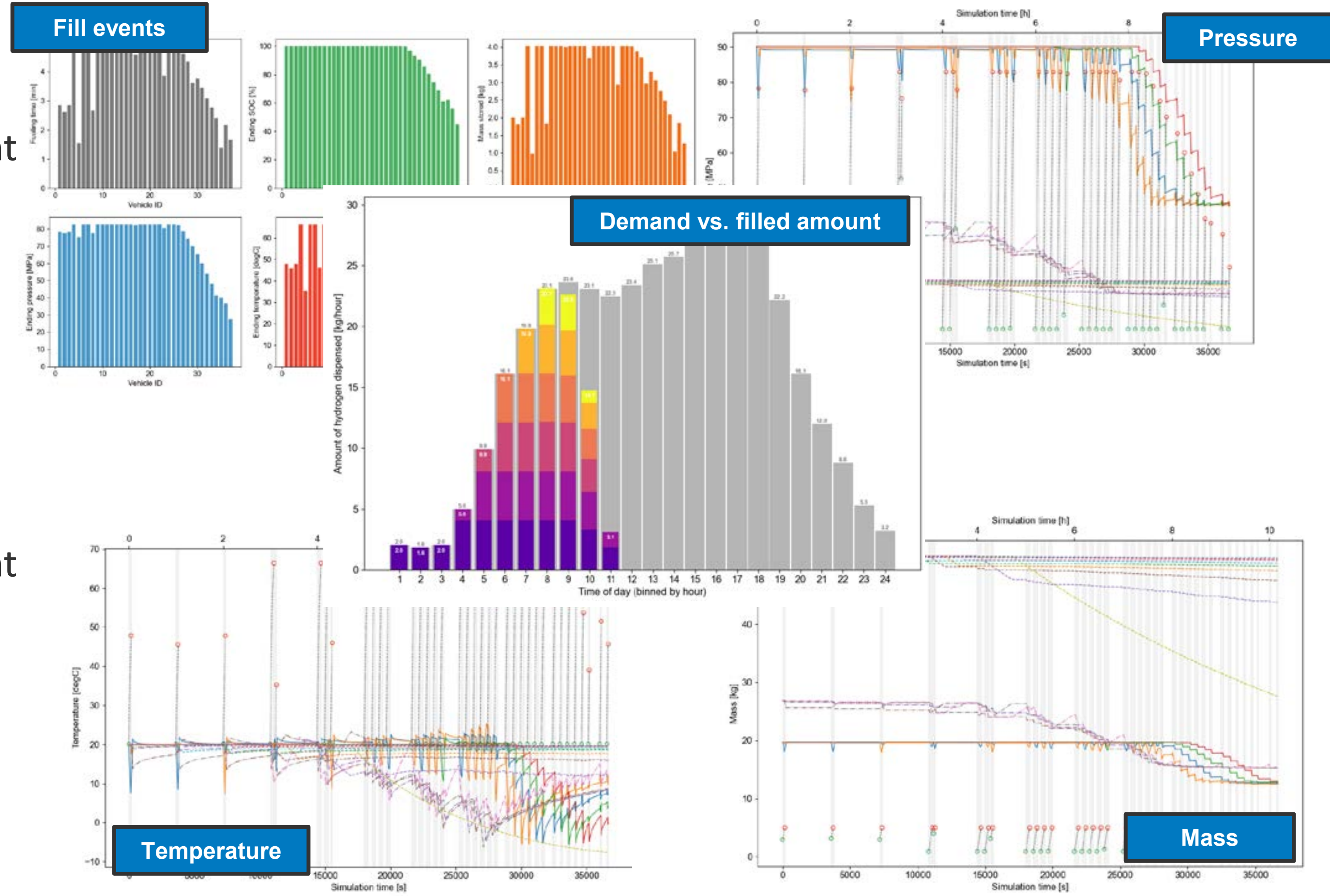
Data flows



Accomplishments and Progress: Outputs from Model

- HyCap generates 5 plots
  - Demand vs. filled amount
  - Mass
  - Pressure
  - Temperature
  - Fill events

- HySCapE generates 3 plots
  - Demand vs. filled amount
  - Mass
  - Pressure



Accomplishments and Progress:
Response to Previous Year Reviewers' Comments

- This project has not been previously reviewed

Collaboration and Coordination

NREL	Lead the development of the HD station fueling capacity model and the design concepts for station performance test device
SNL	Lead the HD reference station designs and risk analysis
ANL	Provide guidance and review of station design concepts

GO-Biz – California Governor's Office of Business and Economic Development **CARB – California Air Resources Board** **CEC – California Energy Commission** **South Coast AQMD – South Coast Air Quality Management District**
Provide guidance, review, feedback and stakeholder engagement

Remaining Challenges and Barriers

- Finish 3D renderings of station designs
- Finalize report on HD reference station contents
- Implement an algorithm for liquid hydrogen storage system
- Completing and testing code with web interface for heavy-duty station fueling capacity
- Selecting fueling profiles that make sense for heavy-duty industry
- Determining specifications for a fueling performance test device

Proposed Future Work

Task Name	Future Deliverables
HD Reference Station Design	• FY23 – Develop and report on reference station designs for HD hydrogen vehicles • FY24 – Develop and report on quantitative risk assessments and how codes and standards apply to HD stations
HD Station Test Device Design	• FY23 – Establish design requirements and report results for a HD hydrogen station test device to analyze hydrogen fueling performance
HD Station Capacity Tool	• FY23 – Finalize station capacity model with additions of liquid and pipeline delivery options
Overall Project	• FY24 – Summarize project outcomes in a final CRADA Report

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

Summary

Relevance:

- Enables the build-out of heavy-duty (HD) hydrogen fueling stations with large dispensing capacity and high flow rates servicing HD hydrogen trucks such as class 8 trucks in long haul applications

Approach:

- Develop reports on reference station designs for HD vehicles and risk analysis of HD vehicle fueling stations
- Build a hydrogen station capacity (HyCap) model for HD hydrogen stations that works for LD also.
- Station performance test device concept development for other projects to use in building of test device.

Accomplishments and Progress:

- Developed 6 variations in HD station designs
- Sized and developed cost estimates for components for each of the designs
- Draft HyCap model ready for partner testing based on onsite production and 70MPa fills. Web interface draft complete.

Future Work:

- Finalize report on reference station designs for HD vehicles
- Report on risk analysis of HD vehicle fueling stations
- Develop HyCap model for liquid and gaseous pipeline delivery to station and make available to public.
- Develop and publish test device designs that would measure HD station fueling performance.

Thank You

www.nrel.gov

NREL/PR-5700-86022

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Technical Backup and Additional Information

Technology Transfer Activities

This project plans to provide:

- Report on reference station designs for HD vehicles
- Report on risks and applicability of codes and standards to HD stations
- Model to evaluate HD fueling station capacity
- Report on design concepts for HD fueling performance test device.