Heavy-duty Hydrogen Fueling Station Corridors

Mark Chung
National Renewable Energy Laboratory

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Project Goal and Approach

Assess **ranges of levelized cost of dispensed hydrogen** to meet hydrogen fueling demand for transportation in the heavy-duty vehicle sector to support development of hydrogen fueling corridors in the United States.

(1) System boundary and pathways

- Define system boundary
- Define major assumptions and inputs
- Define pathways to assess

(2) Run HDSAM and estimate costs

- Run HDSAM given inputs and assumptions
- Calculate costs by pathway and at the station component level

(3) Assess results

- What is the levelized cost contribution of each component?
- What is the production component?
- Understand where there is room for improvement

Overview

Timeline and Budget

- Project Start Date: 10/22
- Project End Date: 3/24
- NREL's Project Budget: $300K
  - Total DOE Share: 60%
  - Total EPA Share: 30%
- FY 2024: $200K

Partners

- NREL's project lead: **Mark Chung**, NREL
- Co-PI(s): Bin Wang, LBNL

Barriers and Targets

- Project closes the information/knowledge gap barrier
  - for strategic heavy-duty vehicle infrastructure deployment with respect to location, volume, and station type (e.g., gaseous or liquid)
  - for most economic pathway for heavy-duty hydrogen vehicle dispensed costs
- Project supports DOE's freight vehicles infrastructure planning efforts and accelerate zero-emission vehicles adoption in the United States

Potential Impact

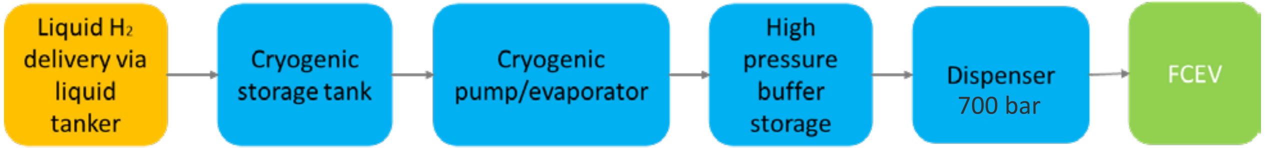
Photo credit: iStock

1. Facilitate **development** and **early adoption** of hydrogen fueling corridors
2. Calculate ***dispensed*** **levelized cost of dispensed hydrogen (LCOH)** under a few scenarios which could be used by industry in planning of station and/or fleet deployment
3. **Accelerate decarbonization** of the HDV hydrogen fleet
4. Use to **inform** other similar transportation decarbonization studies

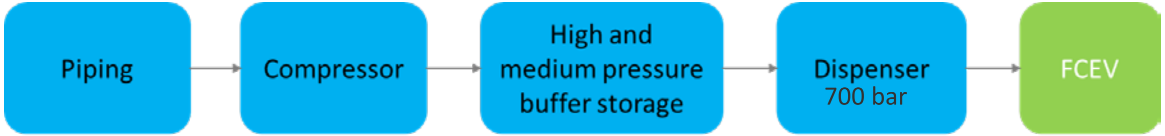
Accomplishments and Progress (1/6): Pathway Definitions

Consideration given to two types of hydrogen fueling station supply configurations*

(1) Liquid H2 delivery to hydrogen fueling station



(2) On-site gaseous H2 produced and piped short distance to fueling station



*Note: Pathways chosen due to higher level of commercial readiness

Accomplishments and Progress (2/6): Major Assumptions

Review of key parameters

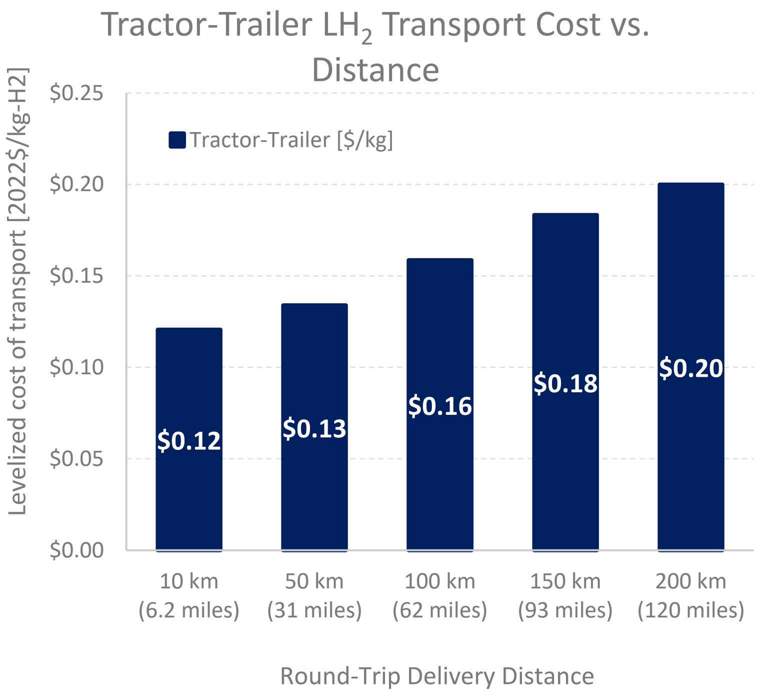
Refueling Parameters	Assumption
Fill rate [kg/min]	5
Dispensed hydrogen per truck [kg]	50
State of charge at refueling [%]	15-25
Hours of operation [hours]	18
Refueling demand profile	Back-to-Back
Vehicle linger time [mins]	5
Fleet size to station size ratio	20 vehicles per MTPD capacity

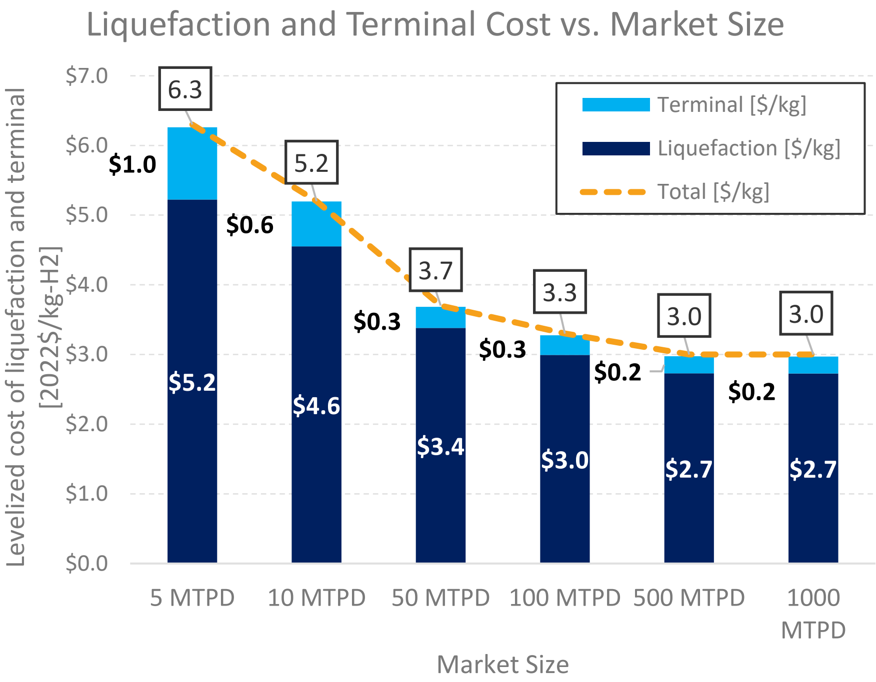
Delivery Parameters	Assumption
Production cost [USD/kg]	1.5*
Liquefier and terminal size [MTPD]	50
Baseline LH_2 delivery distance [km]	100
On-site production piping length [km]	0.1

*Note: Assumed cost used as a place holder. Based on median production cost for predominant form of production today: https://liftoff.energy.gov/clean-hydrogen/

Accomplishments and Progress (3/6): Liquid Pathway Delivery Costs

Liquefaction is a major cost contributor in the LH2-supplied station pathway





Source: HDSAM v4.5

Accomplishments and Progress (4/6): Heavy-Duty Fueling Station Characterization

HRS Costs Breakdown by Component at 4 MTPD, 700-bar dispensing

Components	On-Site GH2 Station	LH2 Station
Compressors and Pumps	8 total compressors Energy: 5.5 kWh/kg CAPEX: $6.96 MM	4 LH_2 pumps Energy: 0.54 kWh/kg CAPEX: $5.18 MM
Storage	401 kg cascade storage 3,100 kg low-pressure storage CAPEX: $8.36 MM	10,720 kg cryogenic tank 241 kg cascade storage CAPEX: $1.91 MM
Dispensers (2)	CAPEX: $0.37 MM	CAPEX: $0.37 MM
Refrigeration and Heat Exchanger	2 condensing/heat exchange units 16 ton capacity each CAPEX: $0.57 MM	2 heat exchangers 1 evaporator CAPEX: $1.14 MM
Electrical, Controls, and Other	BoP and electrical equipment CAPEX: $0.56 MM	BoP and electrical equipment CAPEX: $0.27 MM
Indirect Capital Costs	$3.9 MM	$2.04 MM
Capital Cost (Total, per kg-day)	$20.7 MM $5,170/kg-day	$10.9 MM $2,730/kg-day

Source: HDSAM v4.5

Key Considerations:

- Storage size may vary depending on station requirements, station operating profile, and access to reliable supply and delivery
- Requirement for heat exchangers may also differ per station developer requirements (e.g. pre-cooling needs).
- Safety code and standards must also be met when deciding station location and considering space requirements.

Accomplishments and Progress (5/6): Heavy-Duty Fueling Station Characterization

HRS Costs Breakdown by Component at 18 MTPD, 700-bar dispensing

Components	On-Site GH2 Station	LH2 Station
Compressors and Pumps	20 total compressors Energy: 4.1 kWh/kg CAPEX: $17.4 MM	9 LH_2 pumps Energy: 0.54 kWh/kg CAPEX: $11.7 MM
Storage	963 kg cascade storage 5,950 kg low-pressure storage CAPEX: $16.7 MM	10,720 kg cryogenic tank 803 kg cascade storage CAPEX: $3.75 MM
Dispensers (5)	CAPEX: $0.92 MM	CAPEX: $0.92 MM
Refrigeration and Heat Exchanger	5 condensing/heat exchange units 16 ton capacity each Energy: 0.09 kWh/kg CAPEX: $1.32 MM	5 heat exchangers 1 evaporator CAPEX: $2.59 MM
Electrical, Controls, and Other	BoP and electrical equipment CAPEX: $0.58 MM	BoP and electrical equipment CAPEX: $0.56 MM
Indirect Capital Costs	CAPEX: $8.49 MM	CAPEX: $4.48 MM
Capital Cost (Total, per kg-day)	$45.4 MM $2,520/kg-day	$24.0 MM $1,330/kg-day

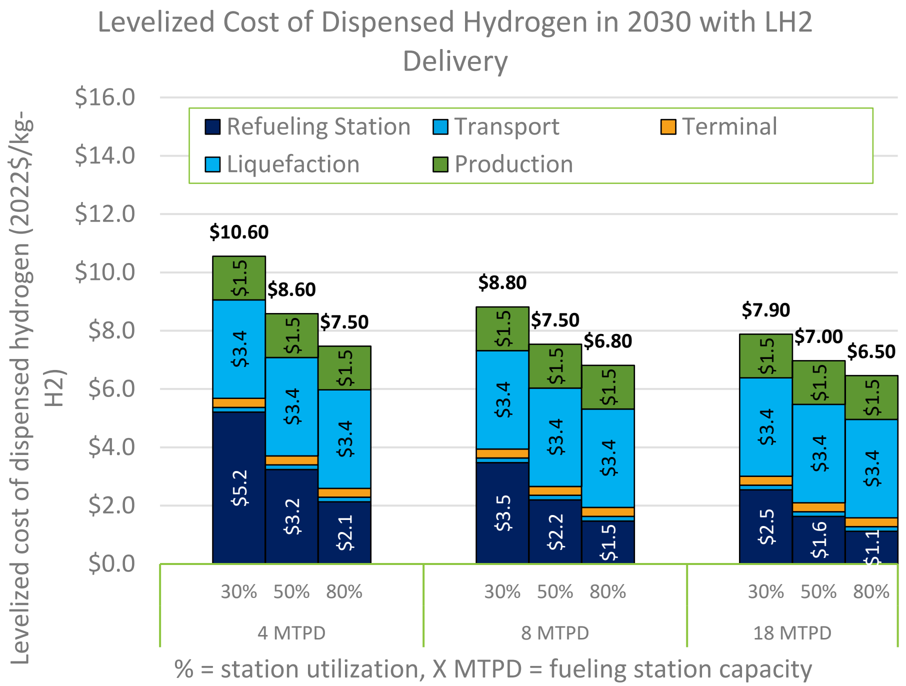
Source: HDSAM v4.5

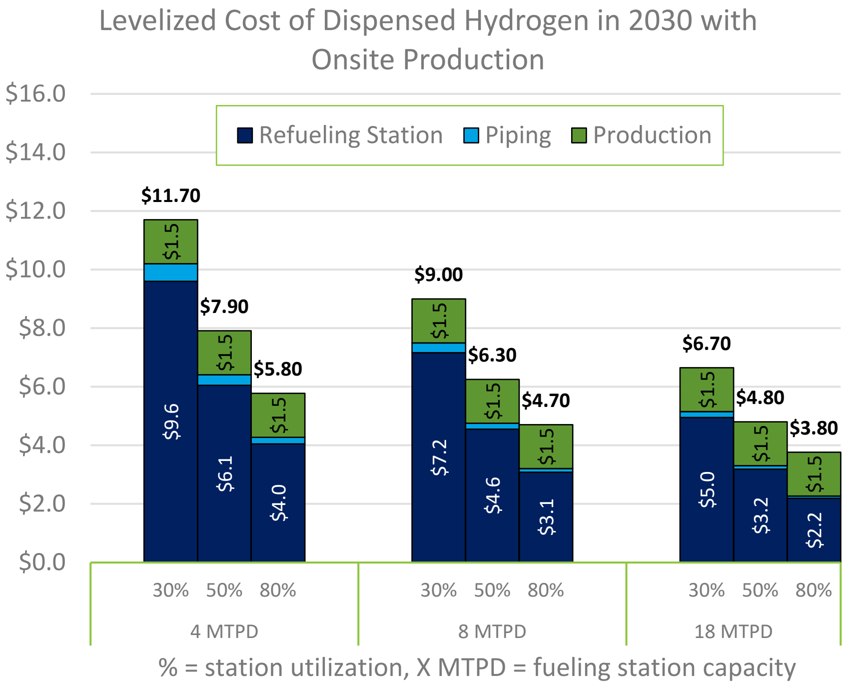
Key Considerations:

- Storage size may vary depending on station requirements and access to reliable supply and delivery.
- Requirement for heat exchangers may also differ per station developer requirements (e.g. pre-cooling needs).
- Long-distance pipeline delivery scenario not modeled here.

Accomplishments and Progress (6/6): Analysis

Potential *dispensed LCOH* can vary widely depending on many conditions (HRS utilization rate and up-time, fill rates, on-site storage, delivery method and distance)





Source: Bracci et. al 2024

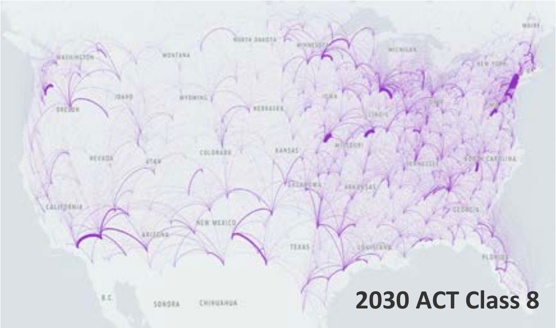
Note: Prices are not retail. Retail prices may include additional markup and subject to numerous dynamics not accounted for in this analysis.

Accomplishments and Progress:
Response to Previous Year Reviewers' Comments

- This project was not previously reviewed at an AMR

Collaboration and Coordination

- Support and input provided by EPA and HFTO
- Coordination with ANL on hydrogen fueling station cost parameters using HDSAM v4.5
- Collaboration with LBNL on the electric vehicle (EV) freight analysis using Medium- and Heavy-Duty Electric Vehicle Load, Operations, and Deployment (HEVI-LOAD) software tool



Remaining Challenges and Barriers

- Challenges are associated with obtaining data
  - high quality fueling station cost data to adequately model their deployment with station parameter changes
- Uncertainty of costs of hydrogen and electricity
- Uncertainty of reliability and up-time of fueling stations

Proposed Future Work: Considerations for HRS Parameters

There may be numerous HRS configurations depending on end-user requirements

- Incorporate latest learnings and cost data from newly built fueling stations to refine dispensed LCOH analysis. Parameters that may change could include direct capital costs, utilization rates, storage capacity, number of dispensers, refrigeration and cryogenic equipment, maintenance and operations costs, etc.
- Alignment on methodologies and assumptions with literature, academia, and industry.
- Coordinate with other national labs or incorporate latest from hydrogen hubs to assess potential national and/or regional adoption scenarios.

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

Summary

- Dispensed LCOH for heavy-duty fueling stations can ***vary widely*** with utilization rates, station sizing, production costs, access to storage, delivery pathways, and hours of operation, for example.

- Economies of scale contribute to ***lowering costs*** at larger fueling station capacities; however, liquefaction remains a ***large cost*** component of the LH_2 pathway.

- Current estimates for the 2030 timeframe range from as low as ***$3.80/kg to $11.70/kg*** [at 4 to 18 MTPD station capacities and 30%-80% utilization rates]

- This cost is ***not a retail price***. Additional markup may be added depending on the retailer and supply/demand dynamics.

- Tax incentives ***were excluded*** from this analysis and could lower LCOH

Thank You

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