Hydrogen Refueling Analysis of Fuel Cell Heavy-Duty Vehicles Fleet

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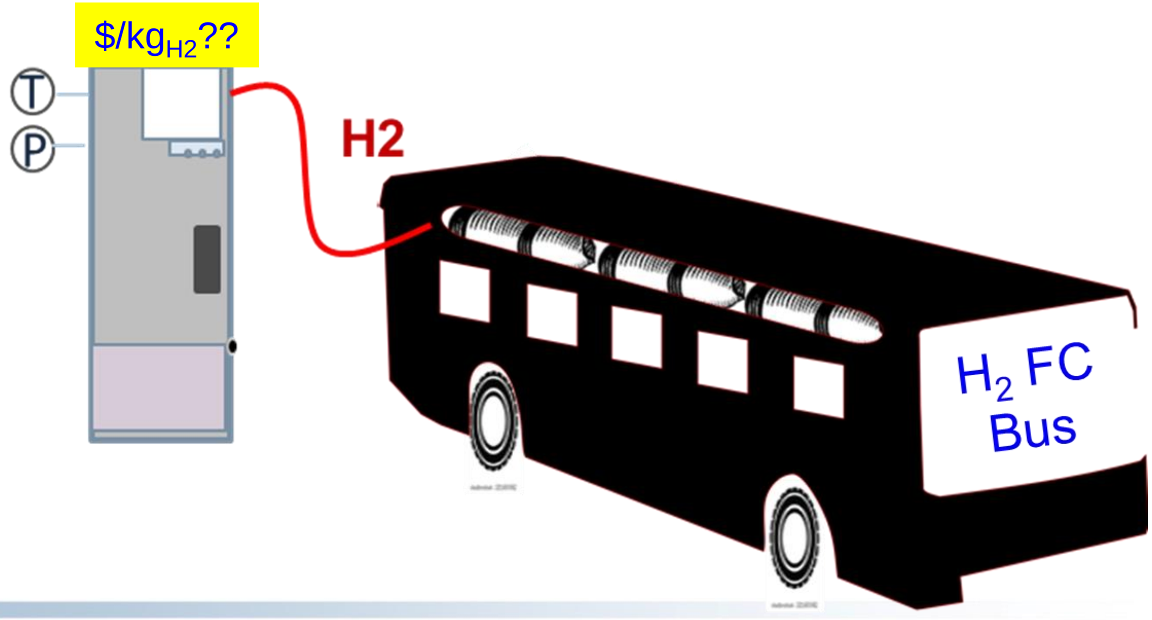
Motivation and Objective

- Hydrogen fueling cost for heavy duty vehicles is different from light duty vehicles
  - ➢ With respect to fueling pressure, fill amount, fill rate, fill strategy, precooling requirement, etc.

➢ Evaluate impacts of key market, technical, and economic parameters on refueling cost [$\$/kg_{H2}$] of heavy-duty fuel cell (FC) vehicles

- ✓ Evaluate fuel cell bus fleet as a surrogate for other M/HDVs



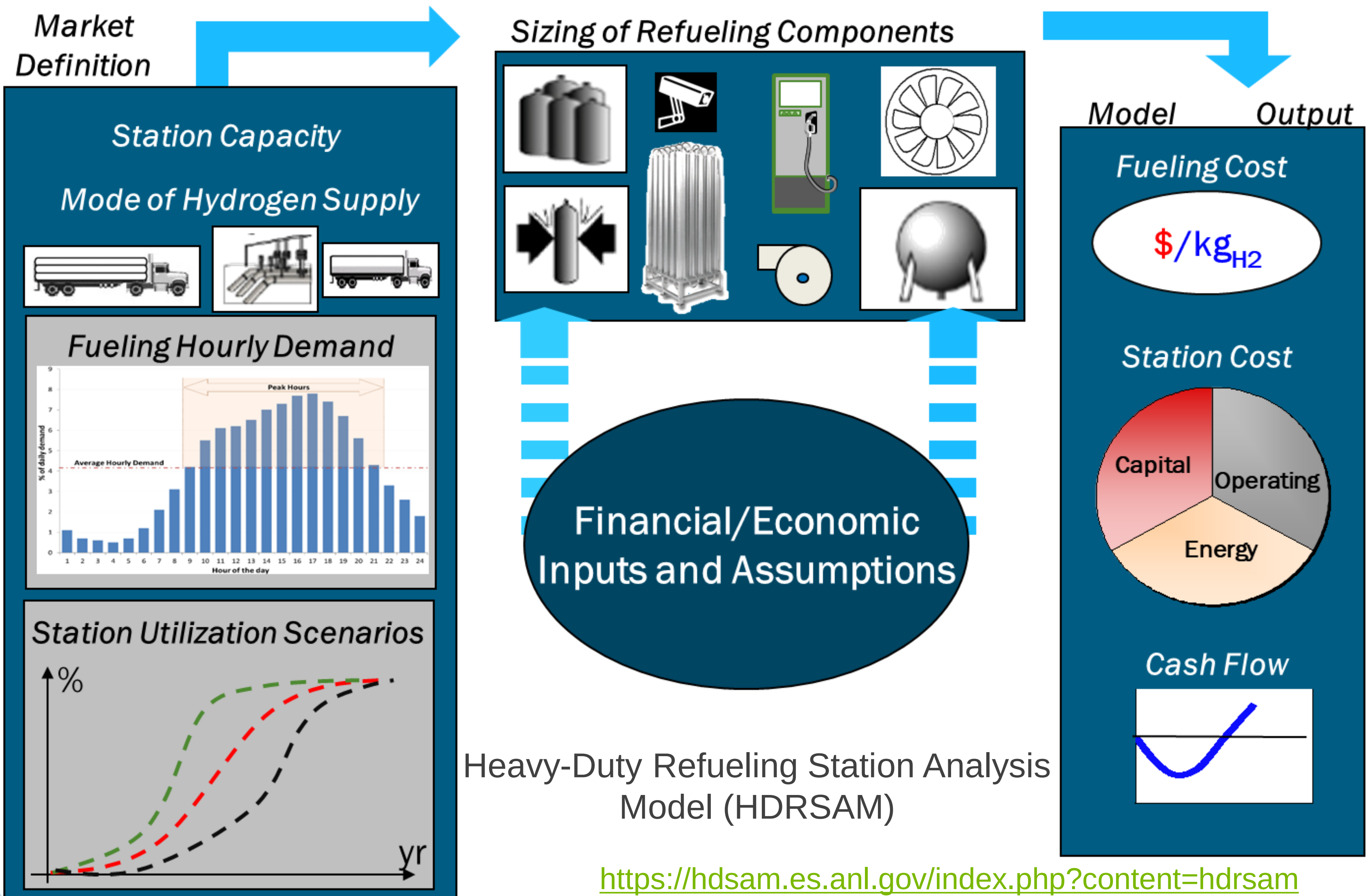
Parameters to evaluate

- Market parameters:
  - Fleet size (10, 30, 50, 100 buses)
  - Hydrogen supply (20 bar gaseous, liquid tanker, tube trailer)
  - Market penetration (production volume of refueling components, i.e., low, med, high)
- Technical parameters:
  - Refueling pressure (350 bar and 700 bar)
  - Tank type (III, IV)
  - Dispensed amount per vehicle (20 kg, 35 kg)
  - Fill rate (1.8, 3.6, 7.2 kg/min)
  - Fill strategy (back-to-back, staggered, number of dispensers)
  - SAE TIR specifies fueling process rates and limits (not a protocol)
- Financial parameters:
  - 10% IRR
  - 20-year project life

> Parameters in red color are defaults for parametric analysis

Approach: Develop a refueling model for FC HDV fleet

➢ Systematically examines impact of various parameters



Heavy-Duty Refueling Station Analysis Model (HDRSAM)

https://hdsam.es.anl.gov/index.php?content=hdrsam

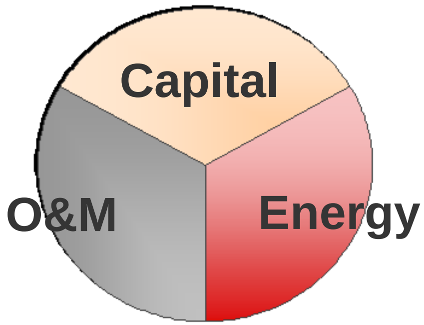
HDRSAM Model Outputs

HDRSAM characterizes the economics of a user-defined station

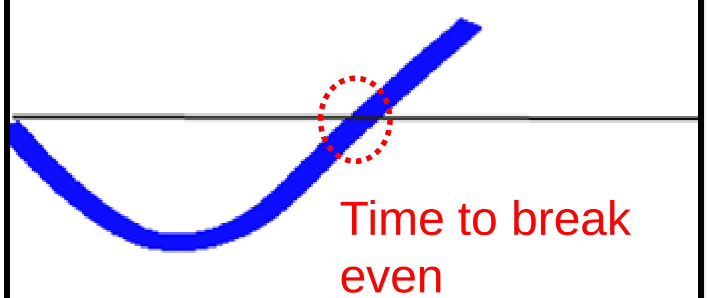
Station Levelized Cost

$\$/kg\_H_2$

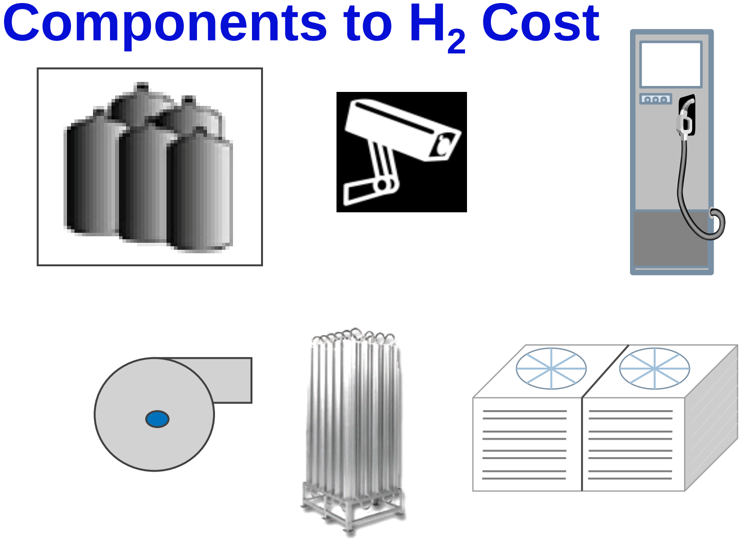
Contributions to Levelized Cost



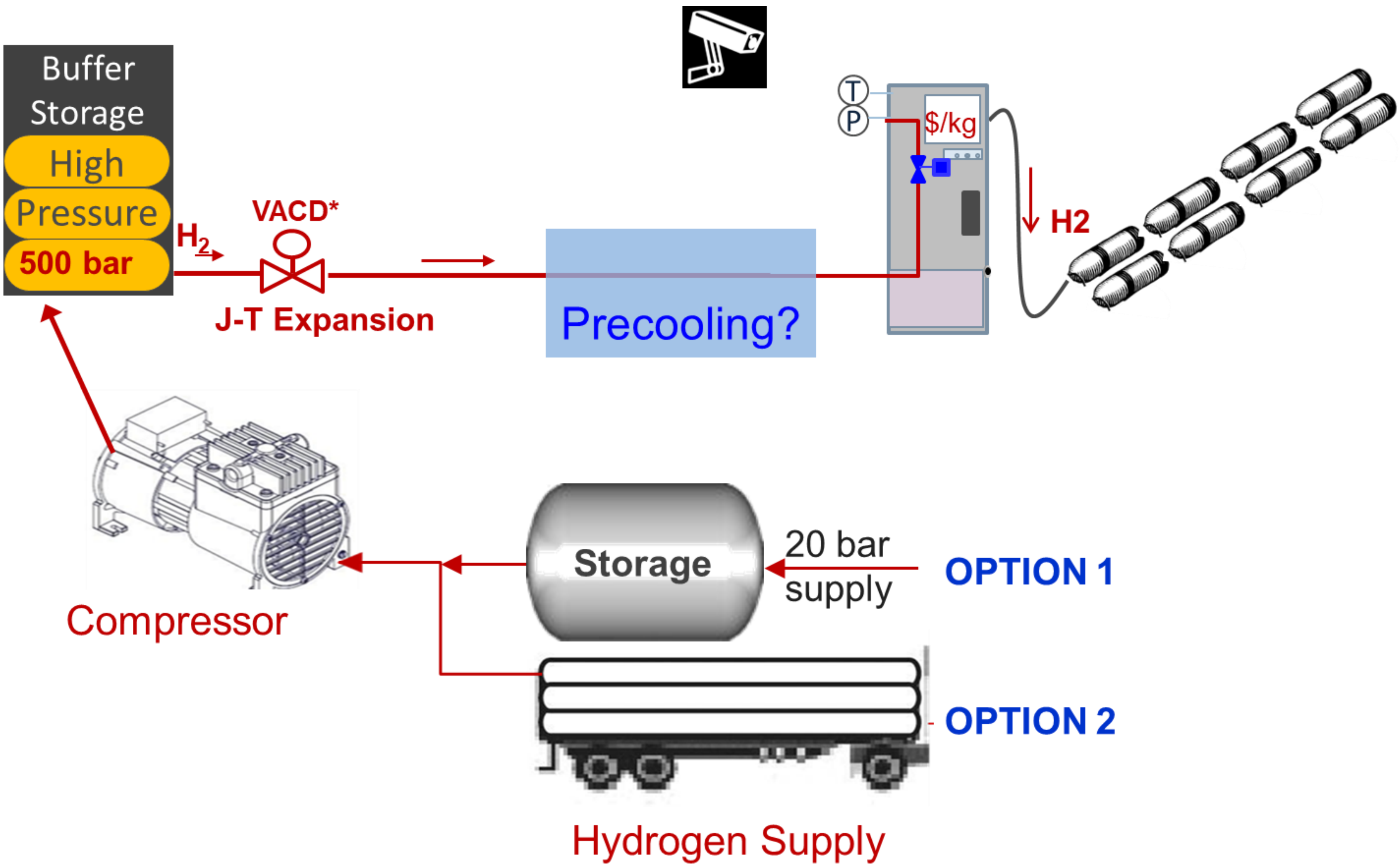
Cumulative Cash Flow



Contribution of Station Components to H_2 Cost

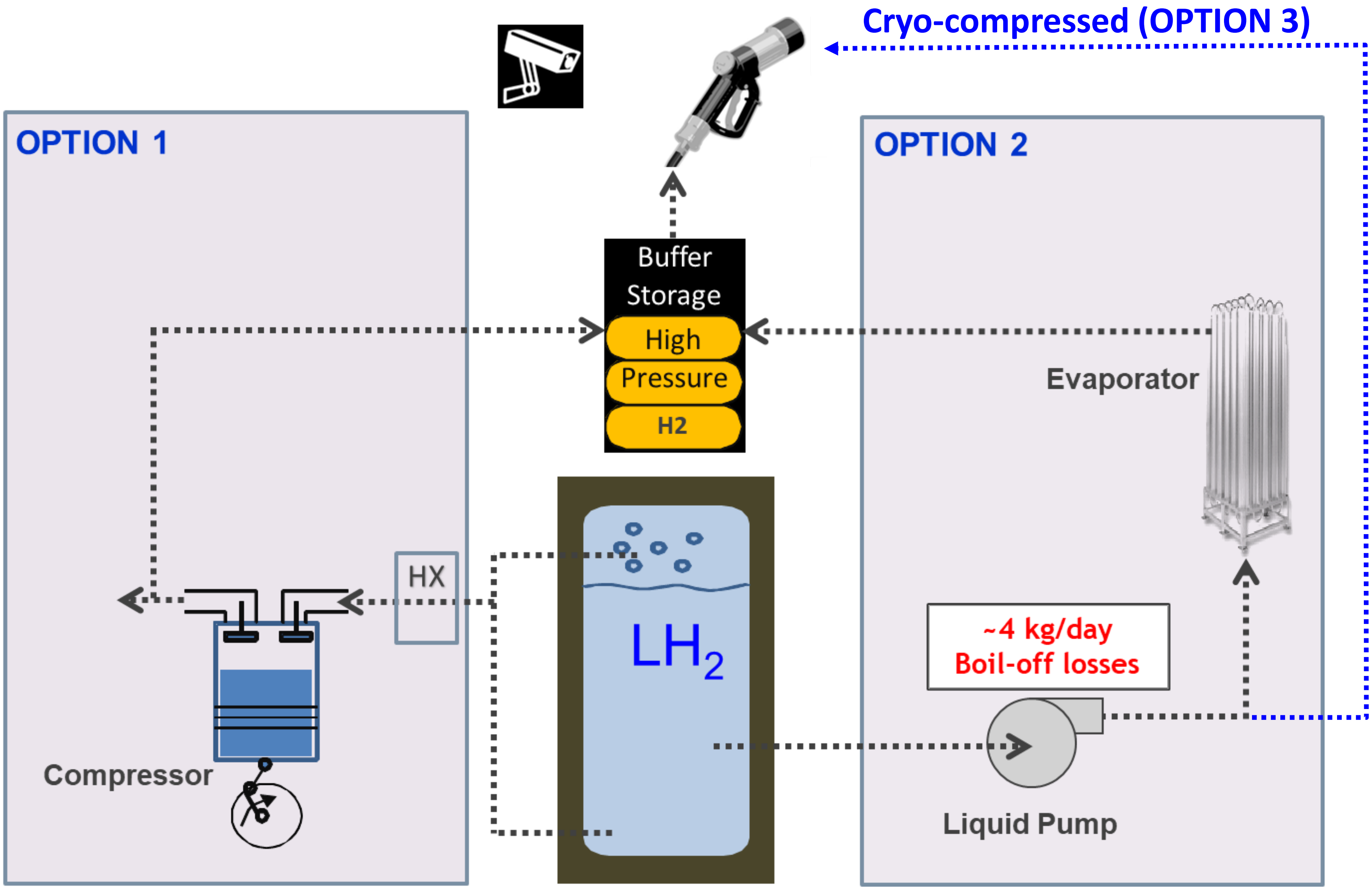


Refueling configuration options for gaseous H_2 supply

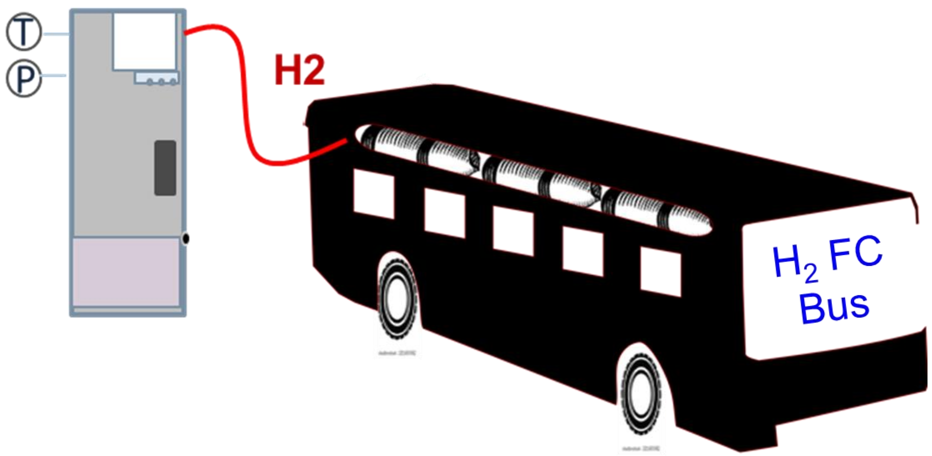


*variable area control device

Refueling configuration options with $\underline{LH_2}$ delivery



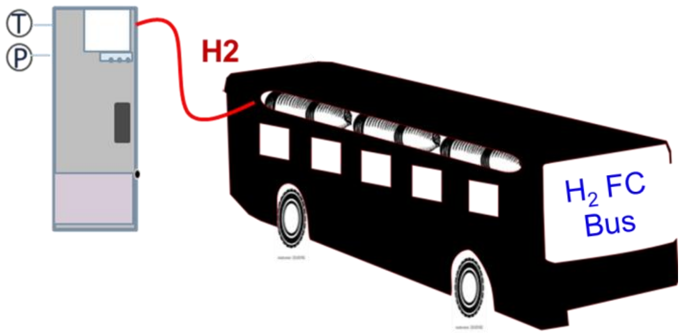
Evaluate precooling requirement for various vehicle tank types, fill pressures and refueling rates

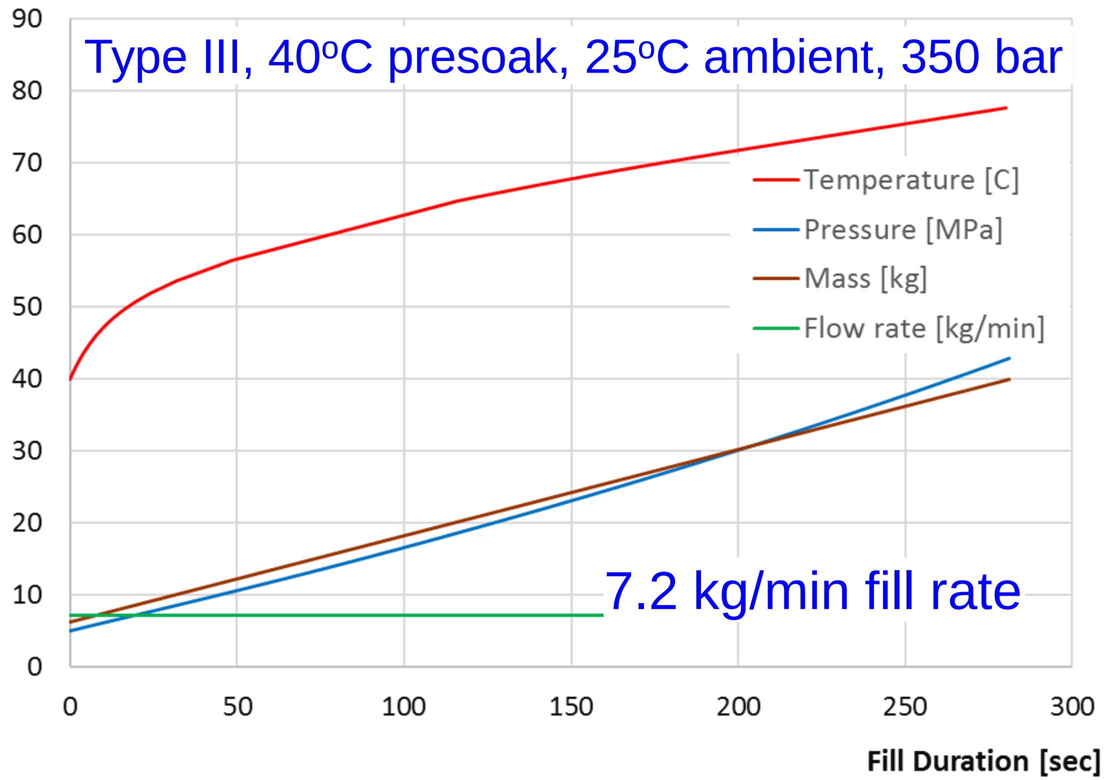


Bus Onboard Storage System (350 bar, Type III)	
Storage System Capacity [kg]	40
Number of Tanks	8
Tank Capacity [kg]	5
Initial tank pressure [MPa]	5
Geometry	
Outer Diameter [in]	17.74
Thickness [in]	1.78
Length [in]	88.7
Volume [L]	208

- Simulated tank fills with H2SCOPE Model
  - ✓ Type III and Type IV (350 bar and 700 bar)
- Simulated various refueling rates (1.8, 3.6, and 7.2 kg/min)
- Solved physical laws to track mass, temperature, and pressure
  - ✓ Determine precooling requirement

Type III tanks do not require precooling at all fill rates





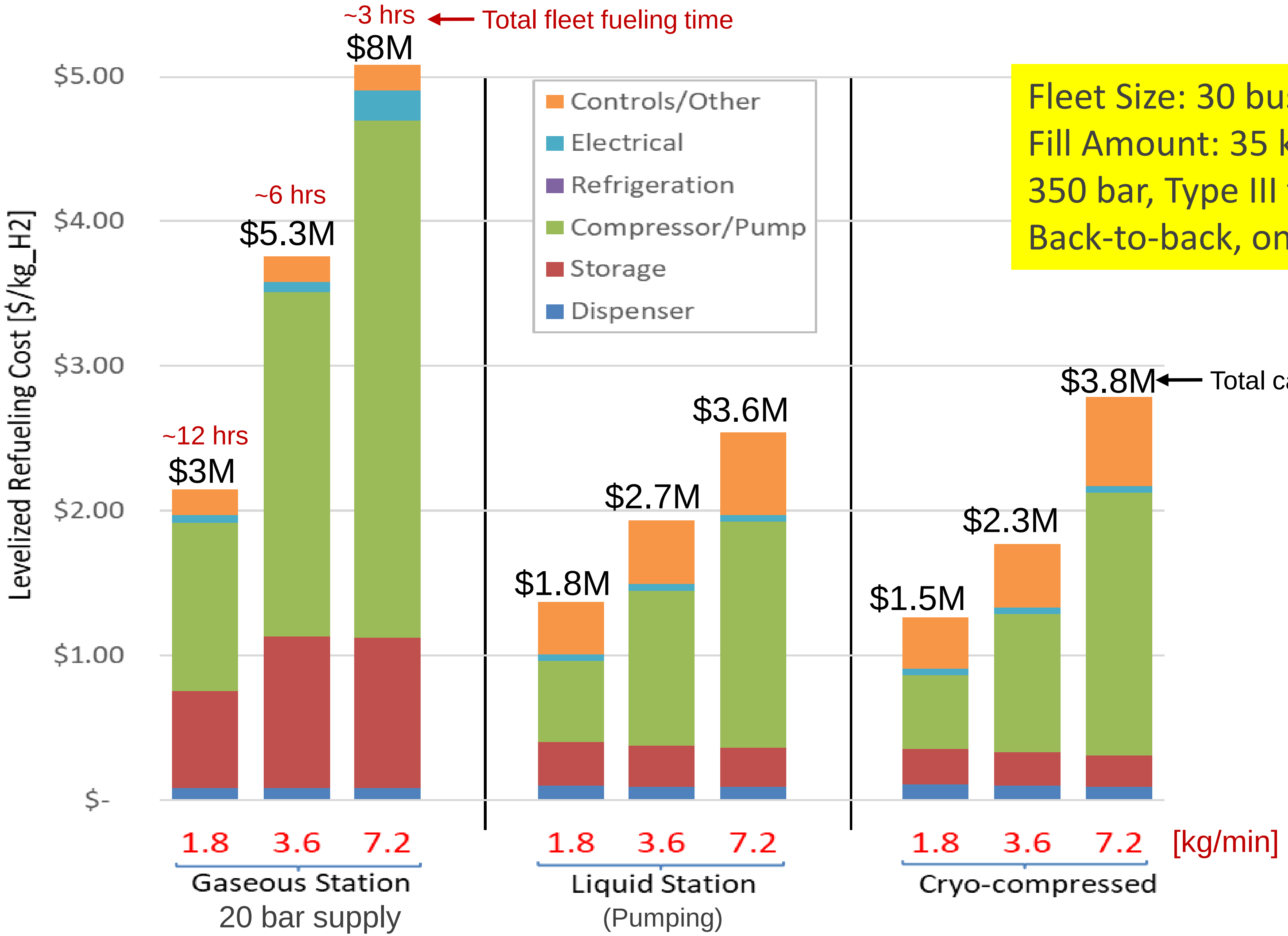
Tank Type	Fueling Rate [kg/min]	Required Temperature at Dispenser [°C]
III (350 bar)	1.8	No precooling required
	3.6	No precooling required
	7.2	No precooling required
IV (350 bar)	1.8	No precooling for 350 bar
	3.6	20°C for 350 bar
	7.2	5°C for 350 bar

Cost estimates for sourcing H_2 to refueling station (near-term)

- Cost of liquid H_2 delivered to refueling station (3.5-4 MT payload), 100-500 miles transportation distance:
  - $6-8/kg_$H_2$
- Cost of onsite water-electrolysis H_2 production (@ $1000/kW) + compression:
  - $7-10/kg_$H_2$
- Cost of onsite SMR H_2 production + compression:
  - $3-4/kg_$H_2$
  - Steady operation desirable
    - ✓ Additional storage cost may be required

H_2 production/transportation costs are additional to refueling cost

Compression and pumping dominate refueling cost



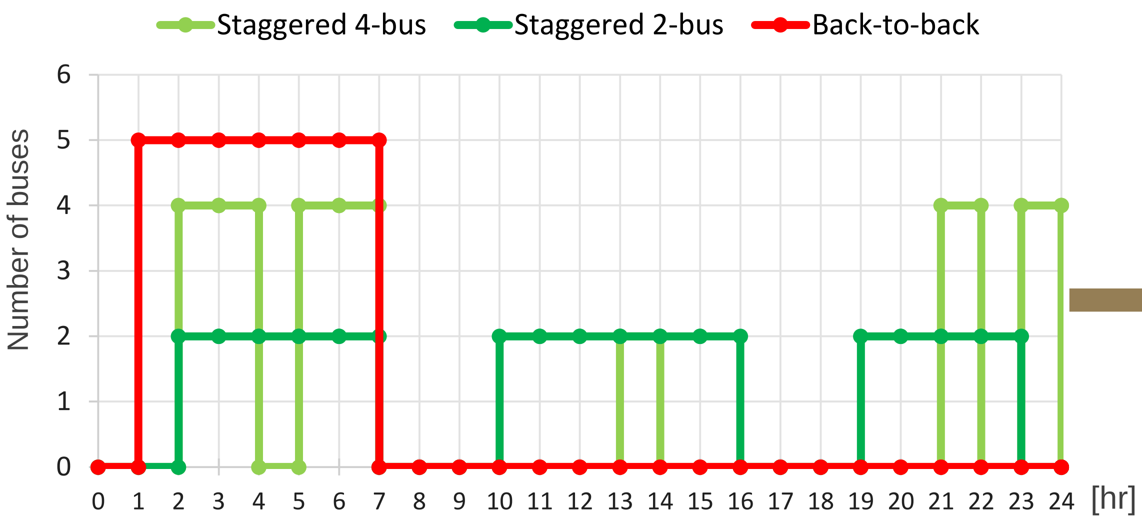
Fleet Size: 30 buses
Fill Amount: 35 kg
350 bar, Type III tanks
Back-to-back, one dispenser

- Faster fills require higher capacity equipment and result in higher cost
- Liquid stations can handle faster fills with less cost increase

Additional H_2 liquefaction capacity will be needed to serve a growing market

Region	Liquefaction Capacity (MT/day)
California	30
Louisiana	70
Indiana	30
New York	40
Alabama	30
Ontario	30
Quebec	27
Tennessee	6
Total	263

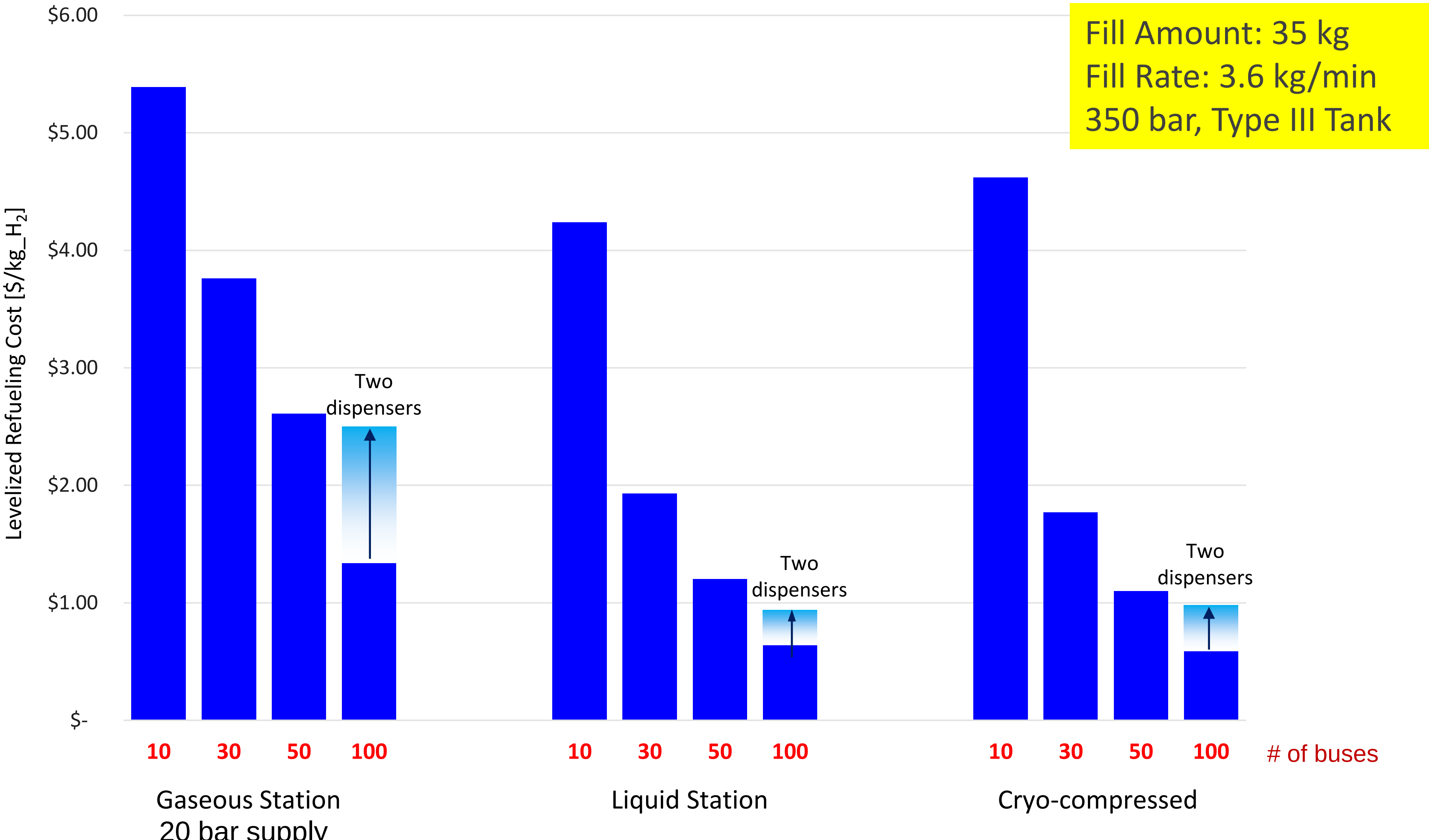
Staggered fueling can reduce fueling cost vs. back-to-back fills



Staggered refueling may be restricted by bus operation schedule

Fleet Size: 30 buses
Fill Amount: 35 kg

*Impact of **fleet size** (demand) on refueling*



- Strong economies of scale with fleet size (daily demand)
  - ✓ fueling cost can drop to ~$1/kg$_{H2}$ with large fleet size
- Liquid station, in general, provides a lower cost option

Summary

- Lower refueling cost of HDV fleet compared to refueling LDVs
- Faster fills require higher capacity equipment and result in higher fueling cost
- Back-to-back fills increase fueling cost with higher fill rates, while staggered fueling reduces fueling cost, even at higher fill rates
- Liquid station, in general, provides a lower cost option for HDV fleet refueling compared to gaseous stations (cost of H_2 source is additional and vary by source)
  - ✓ Additional liquefaction capacity needs to be built
- Strong economies of scale can be realized with fleet size and fill amount (impacting station demand/capacity)
  - ✓ ~$1/kg_$H_2$ station cost for 100 FC bus fleet with today equipment cost
- Type IV tanks do not appreciably increase fueling cost compared to type III tanks
- Future cryo-compressed tanks offer similar or lower refueling cost compared to gaseous refueling

Acknowledgments

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Thank You!!!

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- ✓ Free access to techno-economic models and publications is available at:

  https://hdsam.es.anl.gov/index.php?content=hdrsam

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