TECHNOECONOMIC ANALYSIS OF H_2 FUELING INFRASTRUCTURE FOR VARIOUS APPLICATIONS

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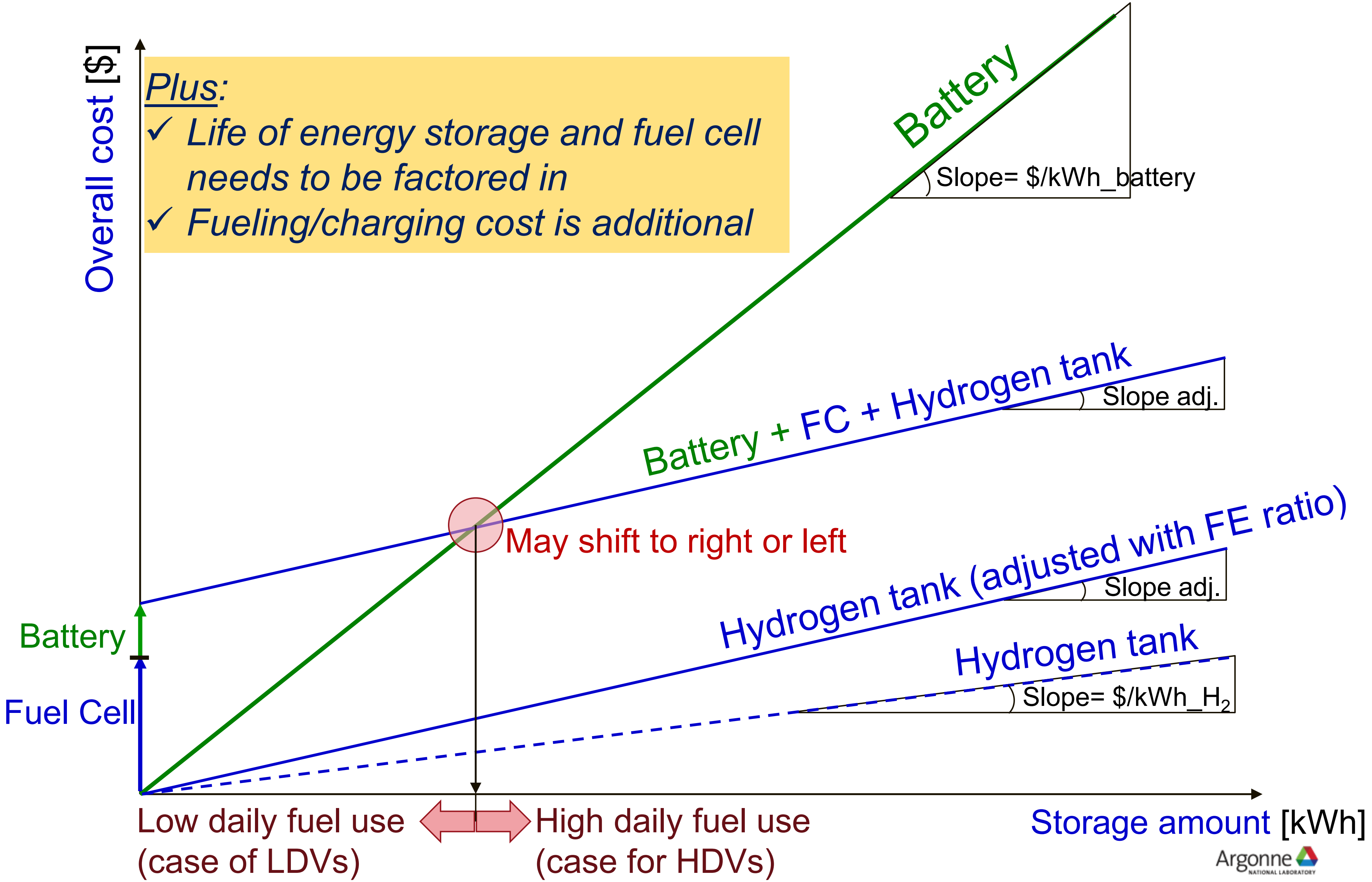
H_2 fuel cell electric vehicles are attractive zero-emission options when daily energy use is high *(vehicle cost perspective)*



✓FC: Fuel Cell
✓FE: Fuel Economy
✓LDV: Light-Duty Vehicle
✓HDV: Medium- and Heavy-Duty Vehicle

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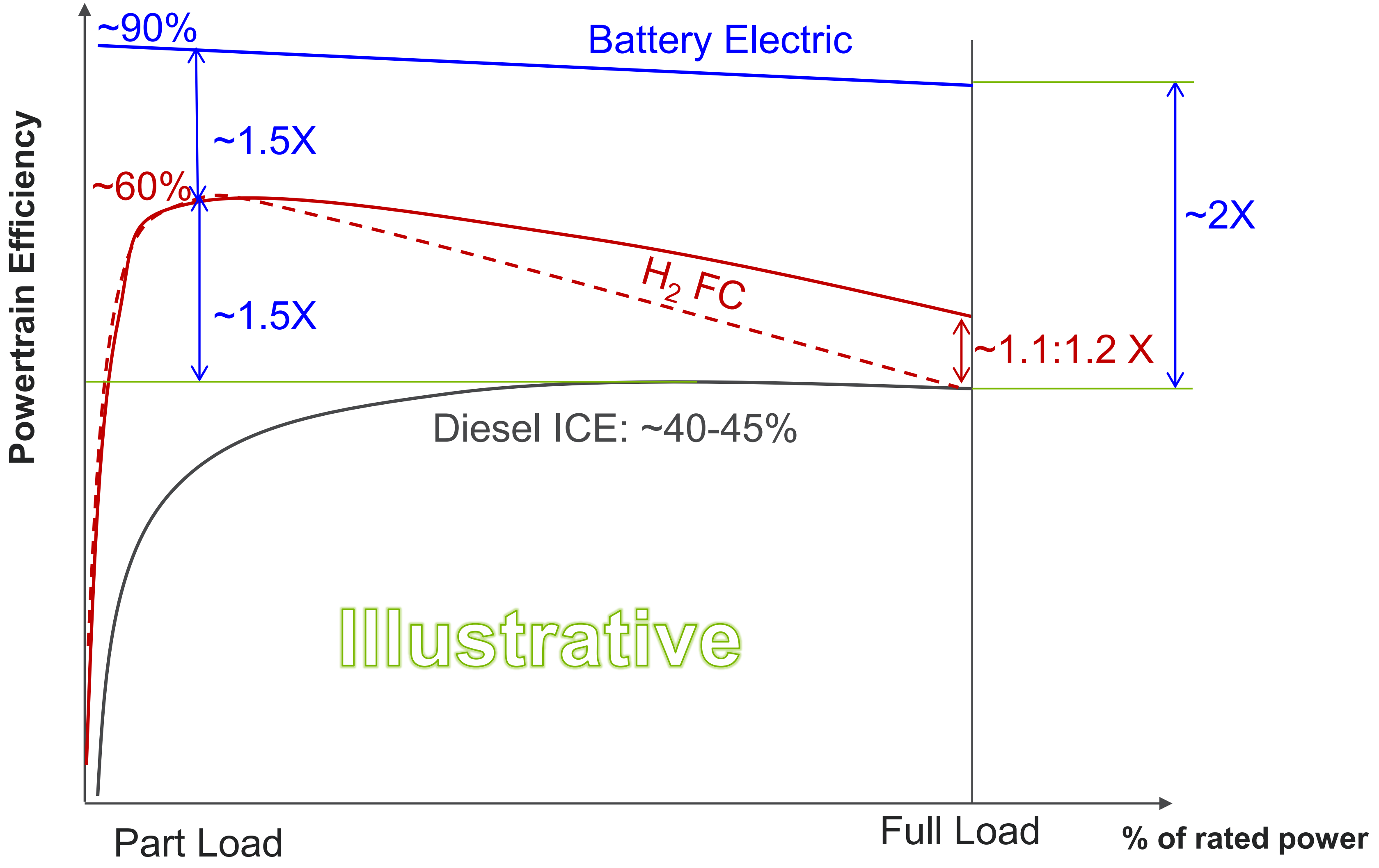
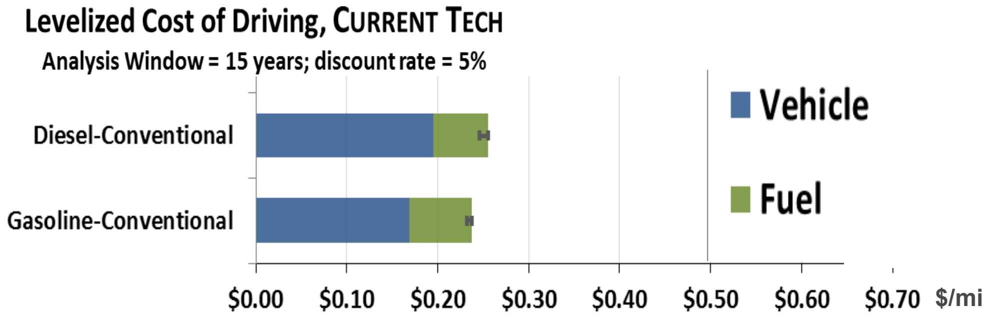
Fuel economy (or powertrain efficiency) is key to enabling a low carbon alternative to diesel ICEV



Low H_2 fueling cost is critical for enabling fuel cell vehicles in the M/HDV applications *(fuel cost perspective)*

✓*Mainly due to high daily VMT and low fuel economy of M/HDVs*
✓*Breakeven H_2 cost depends strongly on fuel economy ratio with diesel ICEV*



LDVs, https://greet.es.anl.gov/publication-c2g-2016-report

Average Marginal Costs in 2018	[$/mi]
Fuel Costs [$3.18/gal in 2018]	$0.433
Truck/Trailer Lease or Purchase Payments	$0.265

https://truckingresearch.org/atri-research/operational-costs-of-trucking/

	Class 6 PnD Box Truck		Class 8 Line Haul Truck	
	Diesel ICEV	H_2 FCEV	Diesel ICEV	H_2 FCEV
Fuel Economy	6.2 mpgd	16 mi/kg (~15 mpgde)	7.2 mpgd	9 mi/kg (8 mpgde)
Fuel Economy Ratio	~2.5		~1.1	
Equivalent Fuel Cost	**$2/gal**	**$5/kg**	**$2/gal**	**$2/kg**
	$3/gal	**$7.5/kg**	**$3/gal**	**$3/kg**
	$4/gal	**$10/kg**	**$4/gal**	**$4/kg**

✓LCOD: Levelized Cost of Driving
✓M/HDV: Medium- and Heavy-Duty Vehicle
✓VMT: Vehicle Miles Travelled
✓LDV: Light-Duty Vehicle
✓PnD: Pickup and Delivery
✓FCEV: Fuel Cell Electric Vehicle

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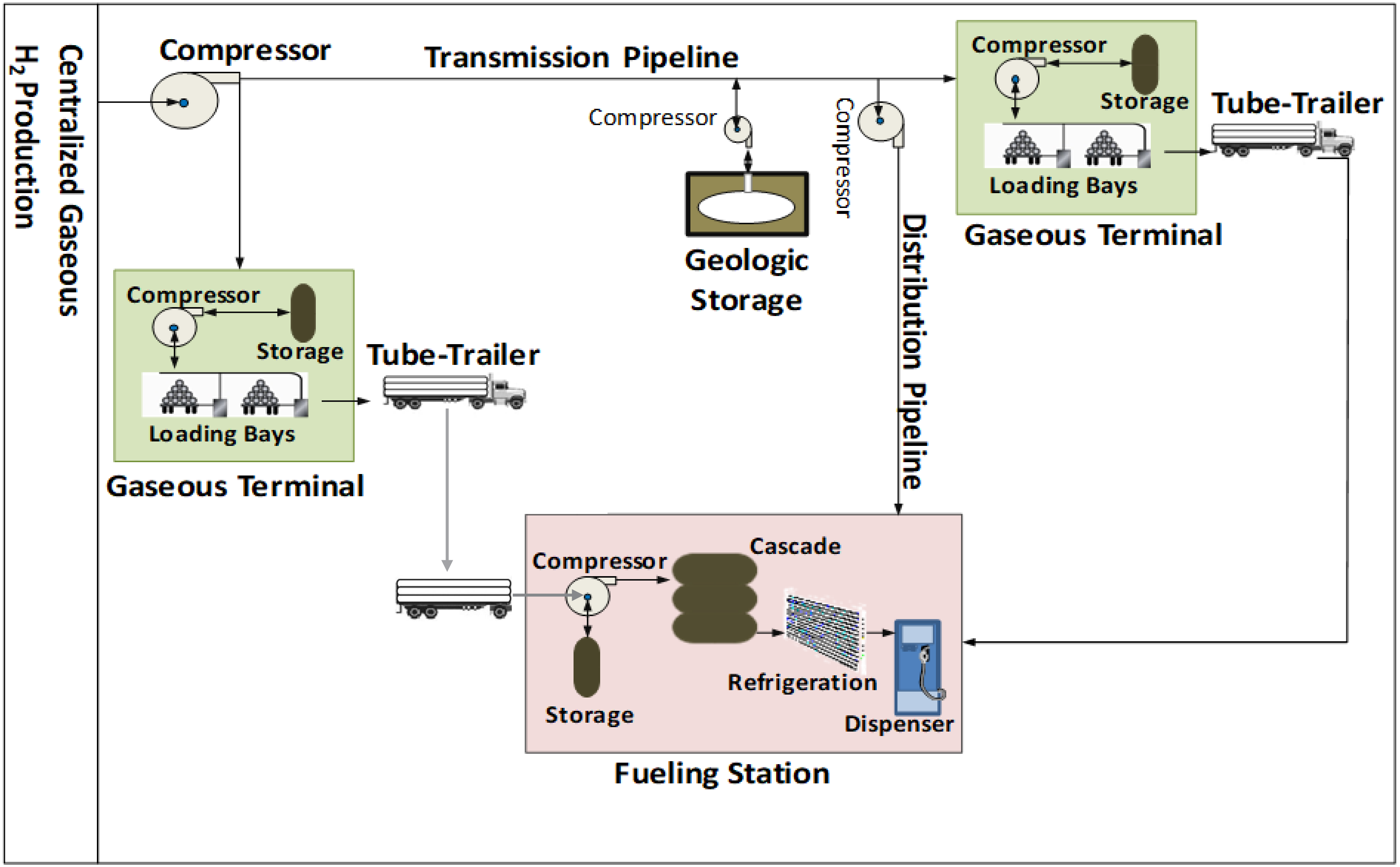
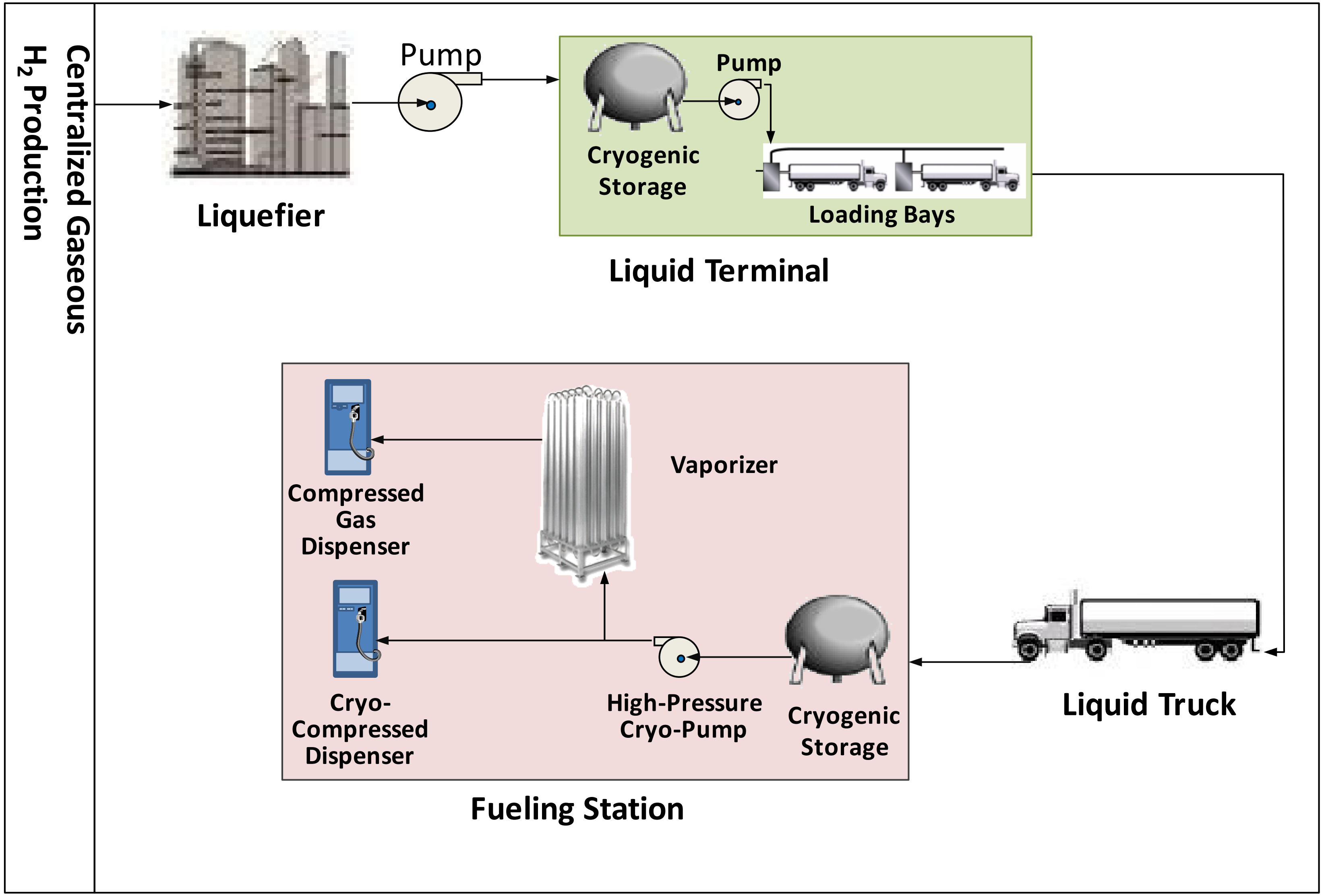
Infrastructure of gaseous hydrogen delivery



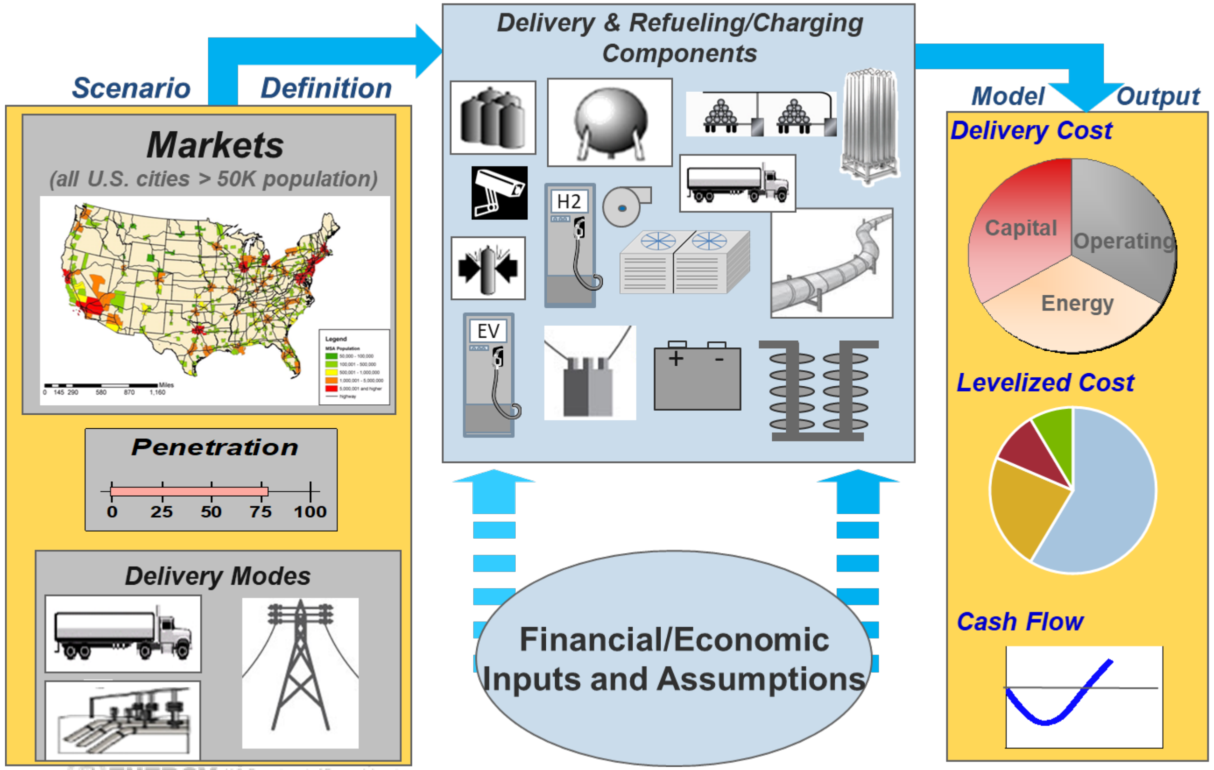
Infrastructure of <u>liquid</u> hydrogen delivery



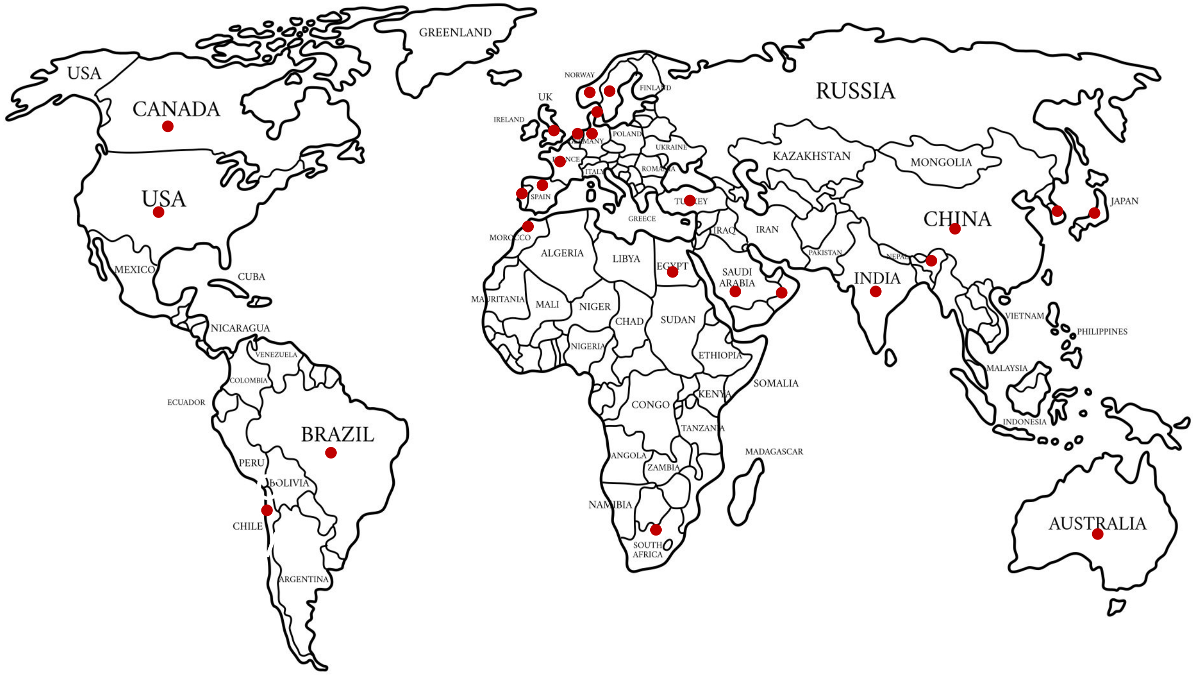
Hydrogen Delivery Scenario Analysis suite of Models (HDSAM)

Argonne's HDSAM and its derivatives evaluate the economic performance and market acceptance of hydrogen delivery technologies and fueling infrastructure for FCEVs

- Publicly available with >3000 users, including major gas and energy companies, in more than 25 countries
- Supported by U.S. Department of Energy's Hydrogen and Fuel Cell Technologies Office (HFTO) since 2004



https://hdsam.es.anl.gov/



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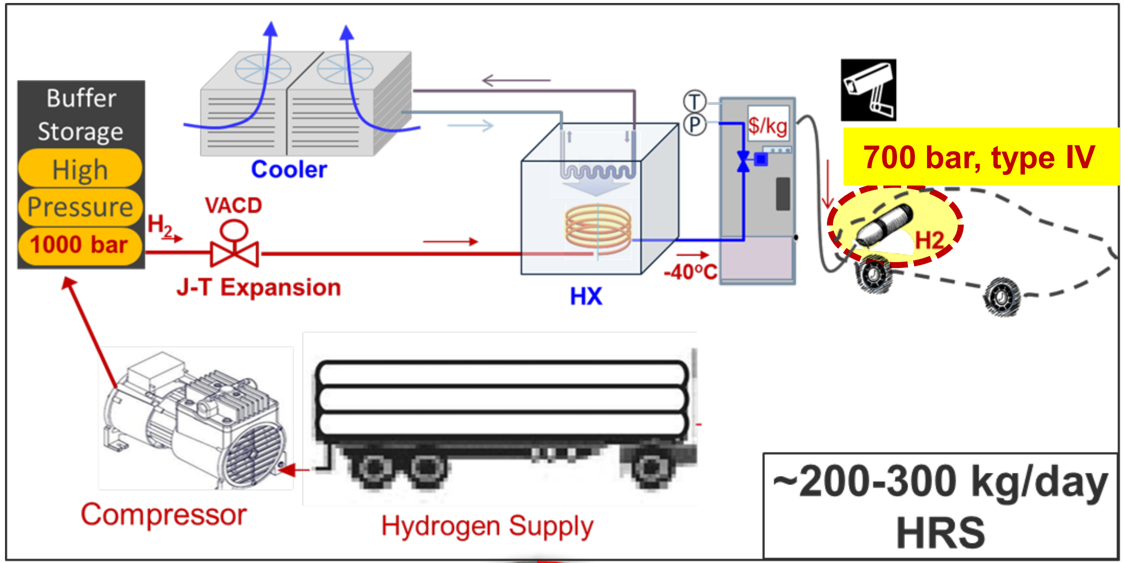
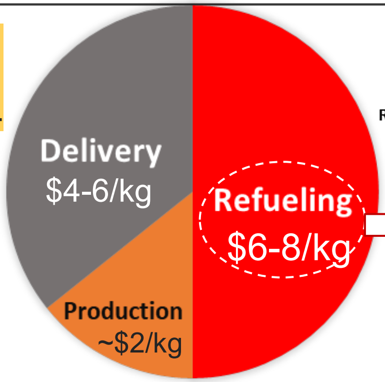
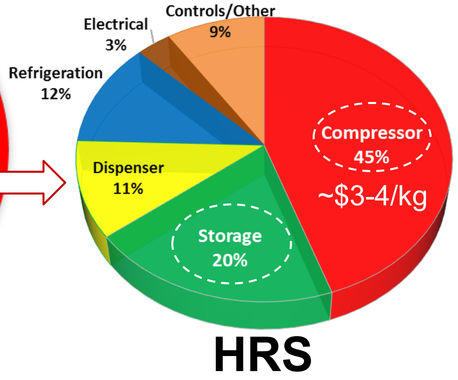
Cost of Hydrogen Delivery and Refueling for LD FCEVs is strongly driven by onboard storage requirement



Today, hydrogen cost at the dispenser in CA is $15-$16/kg

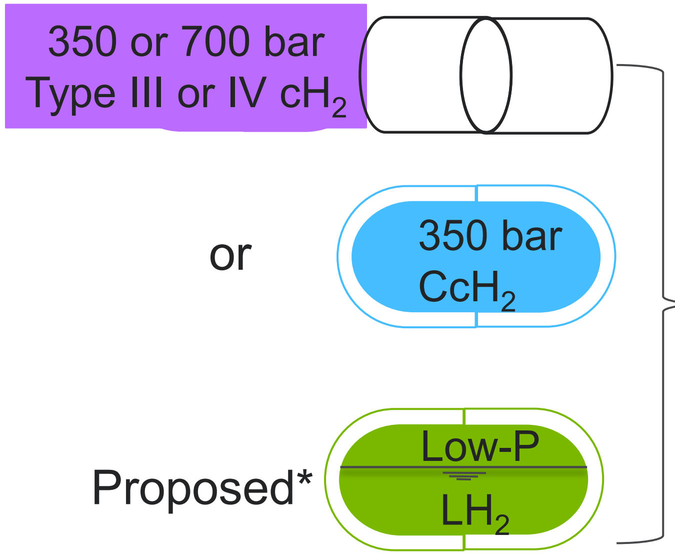
Bulk of H_2 cost is in delivery and refueling

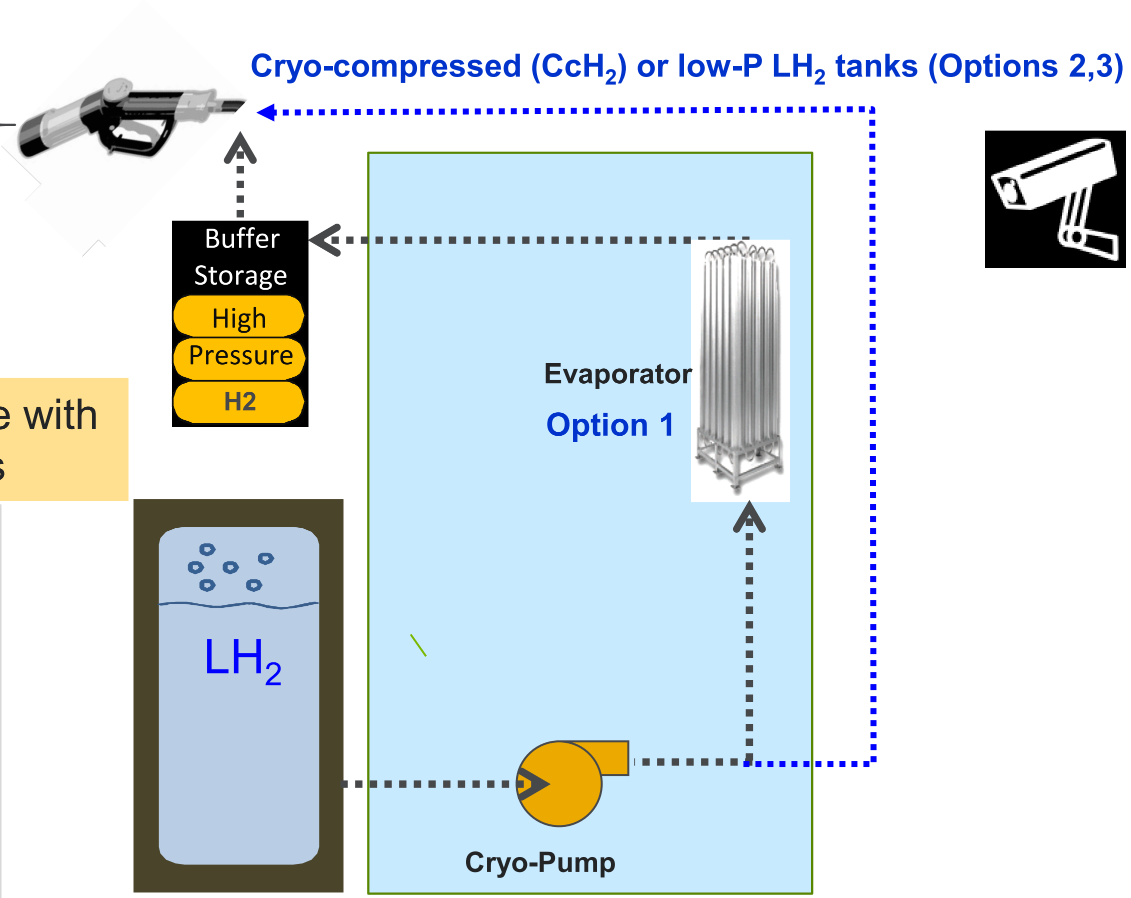




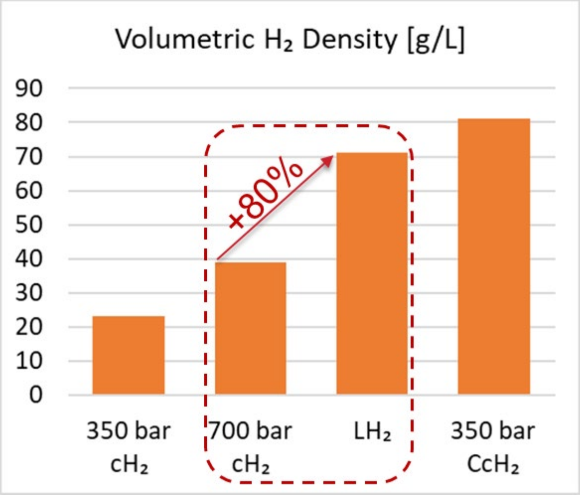
✓ HX: Heat Exchange	✓ VACD: Variable Area Control Device
✓ J-T: Joule-Thomson	✓ CA: California

Versatile refueling configuration options with LH_2 delivery



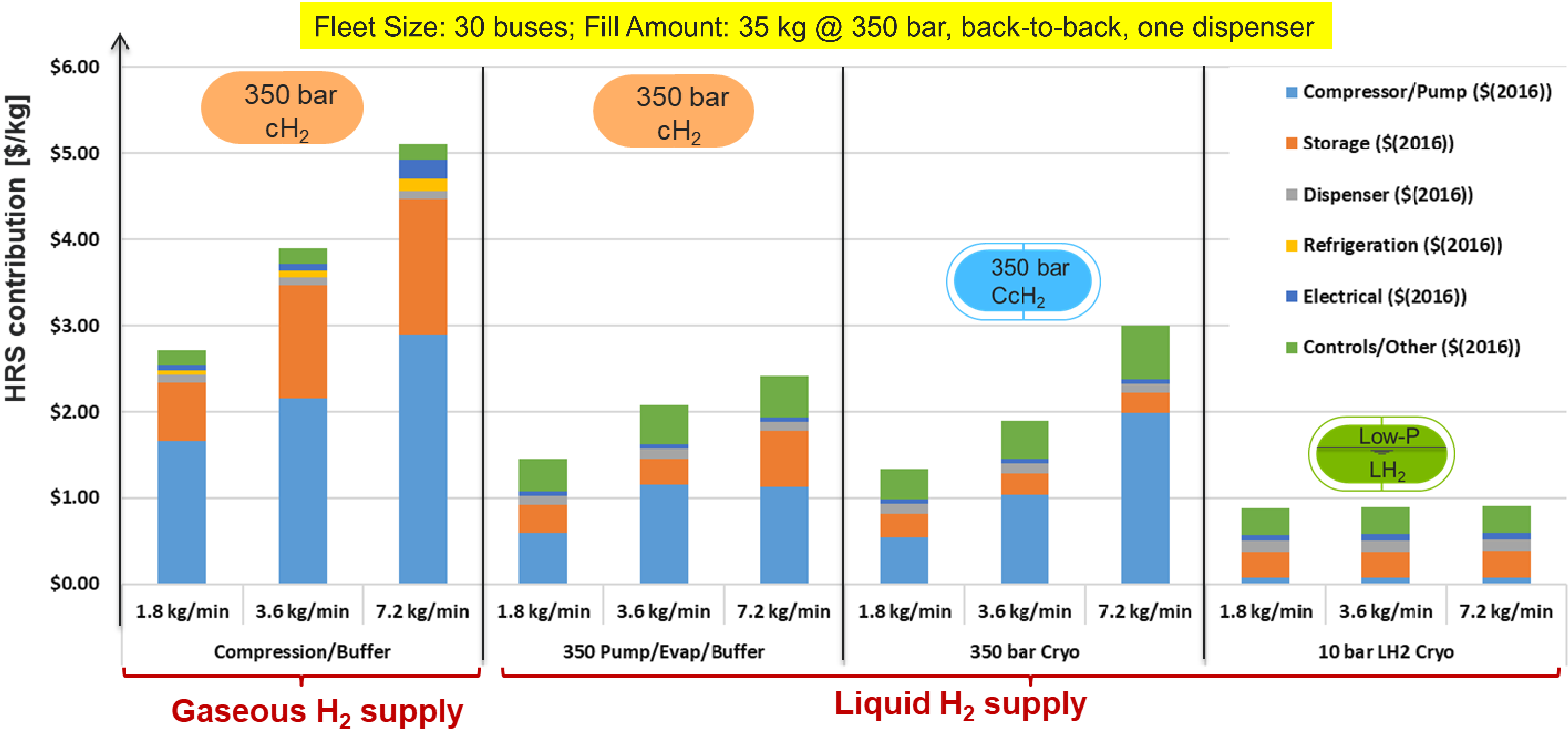


*Dormancy may be less of an issue with a predictable duty cycle of M/HDVs



- ✓ LH_2: Liquid Hydrogen
- ✓ CcH_2: Cryo-compressed hydrogen
- ✓ cH_2: compressed hydrogen
- ✓ Low-P: Low Pressure (<10 bar)

Compression and pumping dominate refueling cost for high-pressure tanks



- Liquid supplied stations can handle faster fills with less cost increase compared to gaseous supply
- Cost of H_2 delivered to the station is additional

Energy use and CO_2 emissions are critical for environmental sustainability of H_2 liquefaction*

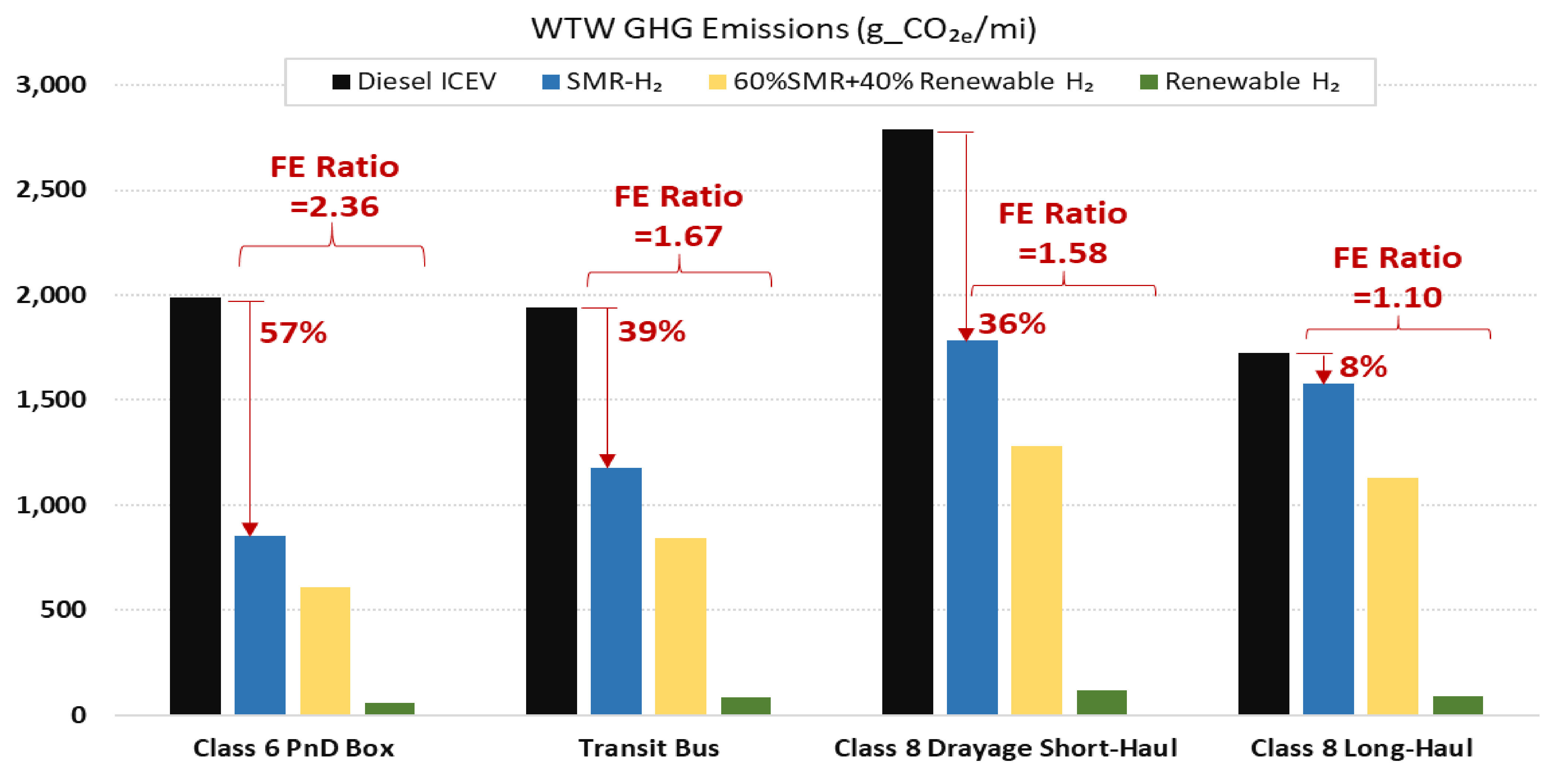
Region	Liquefaction Capacity (MT/day)
California	30
Louisiana	70 (2x35)
Indiana	30
New York	40
Alabama	30
Ontario	30
Quebec	27
Tennessee	6
Total	263

→ Liquefaction CO_2 emissions*= 0-10 $kg_{CO_{2e}}/kg_{H_2}$ (~5 with US mix in 2020)

- Additional H_2 liquefaction plants have been recently announced to serve the growing H_2 market
- Low-carbon electricity is critical for sustainability of LH_2 supply

* At 10 $kWhe/kg_{H2}$

Fuel economy ratio strongly impacts WTW GHG emissions of SMR-H_2 relative to diesel



* Gaseous H_2 supply

✓WTW: Well-To-Wheels ✓GHG: Greenhouse Gas ✓FE: Fuel Economy ✓SMR: Steam Methane Reforming

https://www.sciencedirect.com/science/article/pii/S0378775318304737

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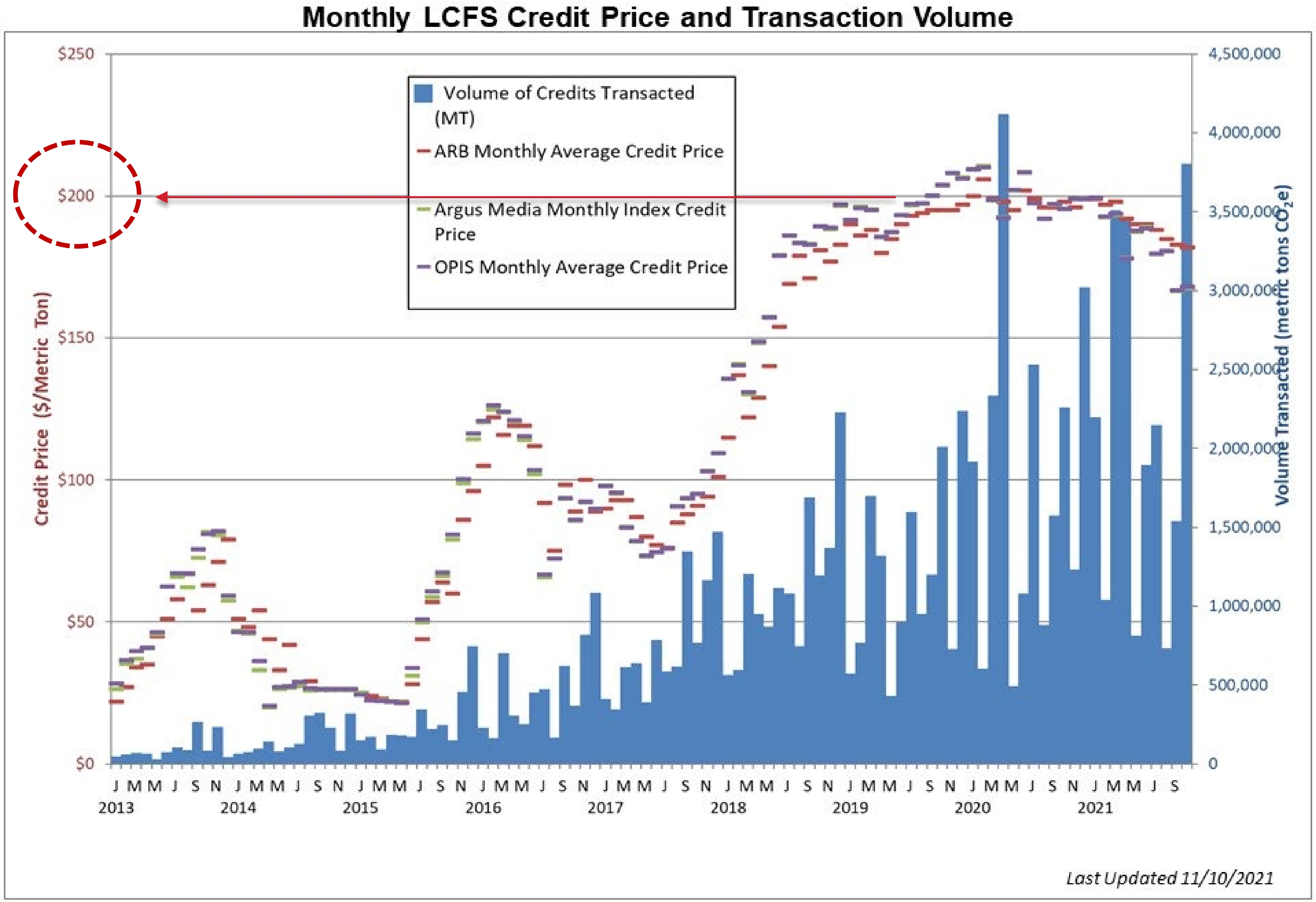
California LCFS generate credits for low-carbon fuels



source: http://www.arb.ca.gov/fuels/lcfs/dashboard/dashboard.htm

Thank You!

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Our models and publications are available at:

https://hdsam.es.anl.gov/

https://greet.es.anl.gov/publications