# Hydrogen for Transport

Infrastructure Pathway to Parity and Below

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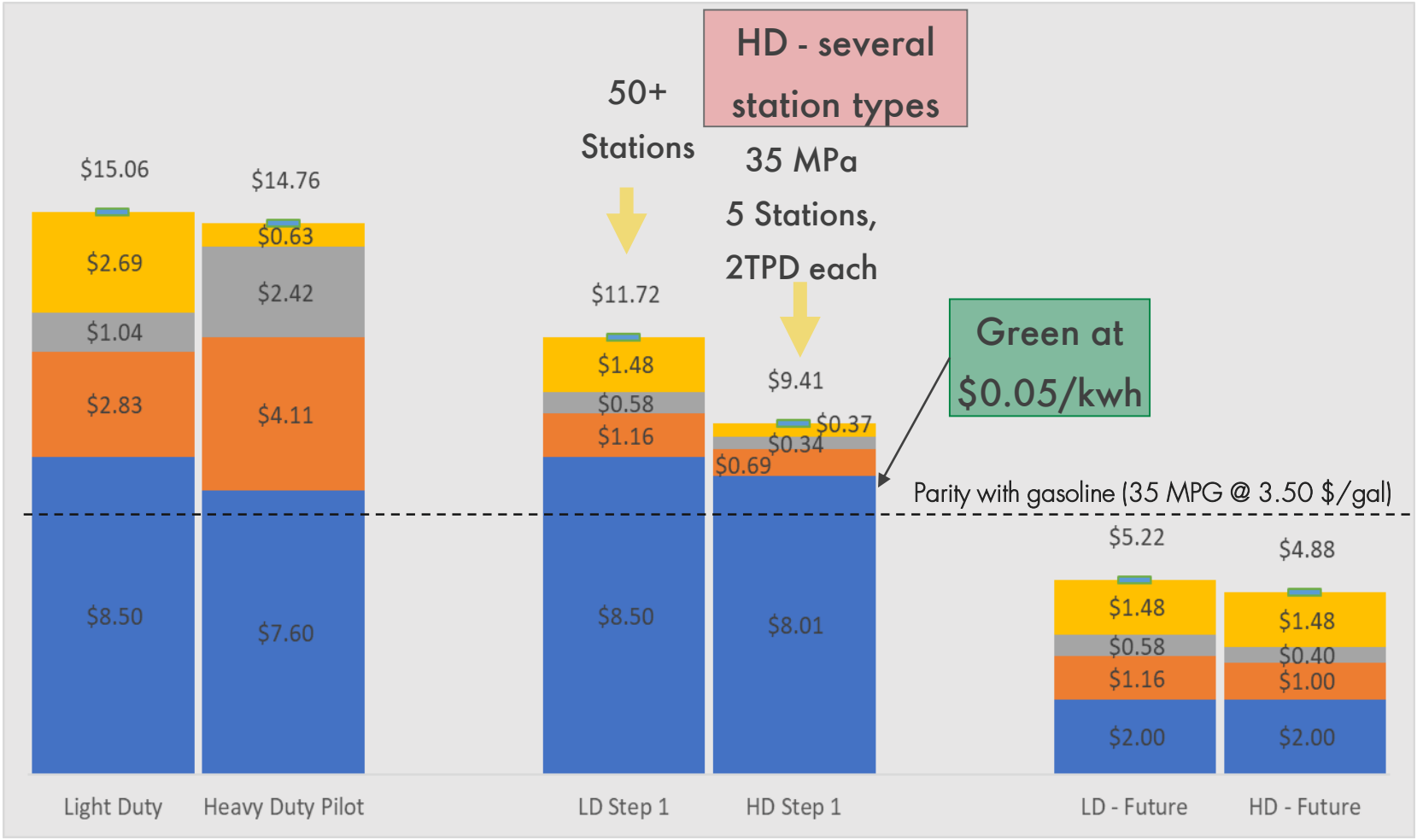
# Infrastructure Pathway to Parity - Overview

- Light-Duty (LDV) and Heavy Duty (HD) Vehicle Cost Reduction Roadmap, what has changed, key differences
- Vehicle Types: Parity Progression with Volume and Size
- Technology Advances, Liquid Hydrogen, and Gaseous Hydrogen use cases
- Heavy Duty as an Early Driver for Cost Reduction

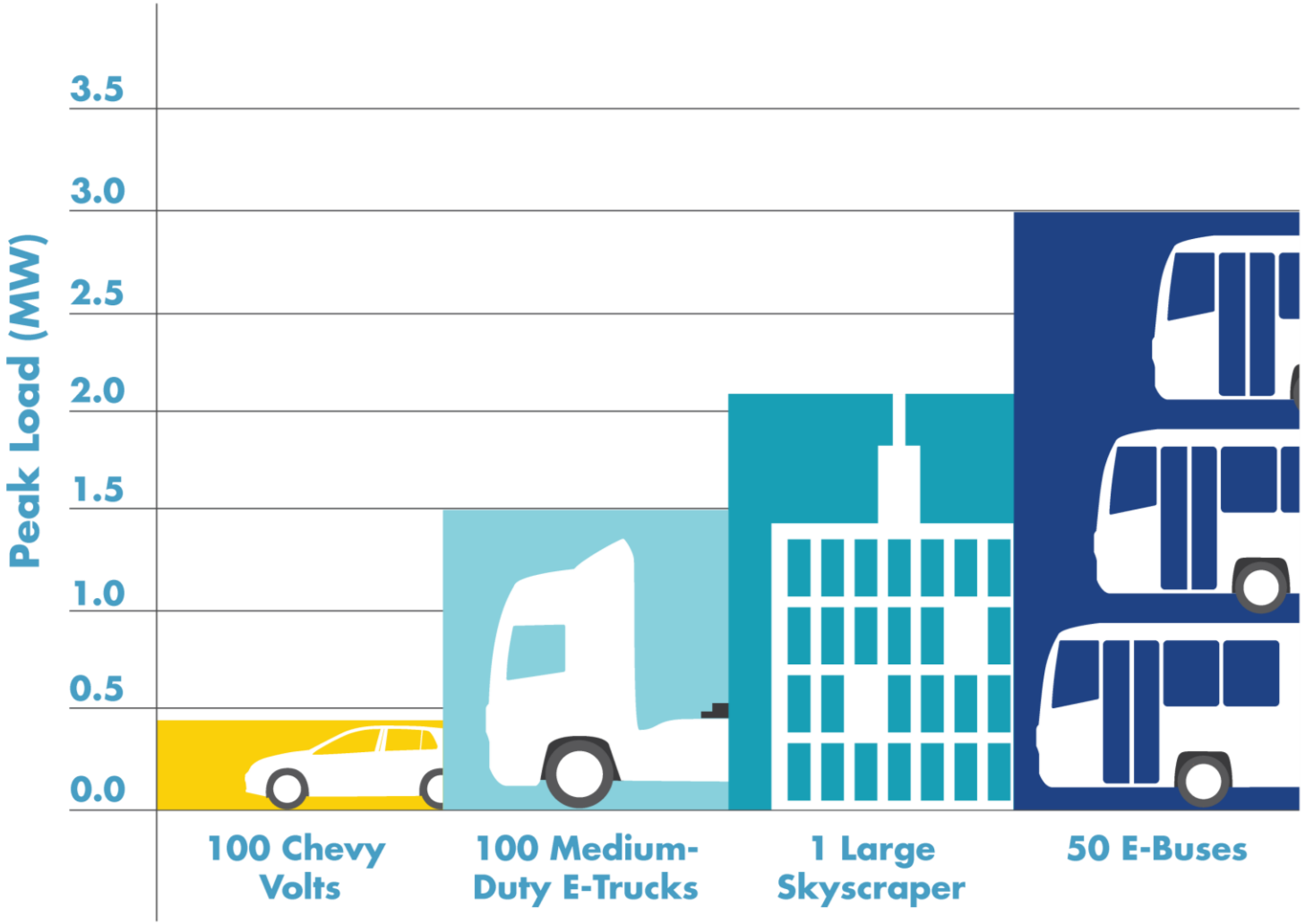
# Heavy Duty and Light Duty: Divergent Cost Reduction Triggers




| Pathways to Parity | | |
|---|---|---|
| | **LDV** | **HD** |
| **Step 1 (1-5 years)** | **50+ stations in a large region (California)** | **35 MPa Fleets**<br>**Low-cost renewables**<br>**County-scale density**<br>**Large stations (75+ buses or 100+ delivery vehicles each)** |
| **5-15 years** | **Equipment Improvements – compressors, tube trailers, construction, liquefiers**<br>**Greater density of HRS, 70MPa, etc.** | |
| **Future** | **Pipelines from low-cost renewables, better $H_2$ production tech, 60-65+% efficient fuel cells** | |

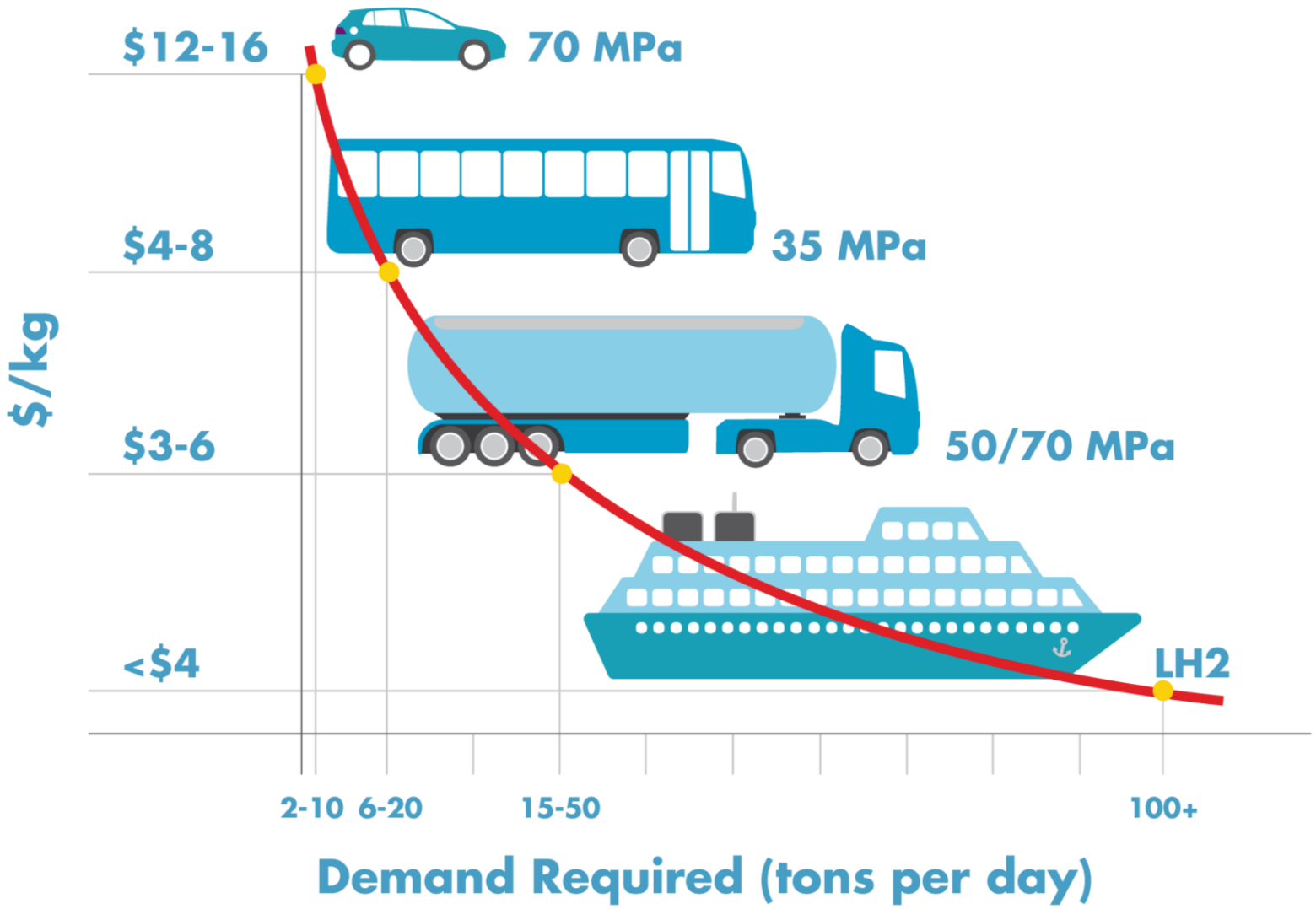
**H2 Delivered** **HRS Equipment and Taxes** **Construction & Commissioning** **OPEX**

# Why FCEV for HD? Infrastructure, Scaling, and Power Demand of EVs



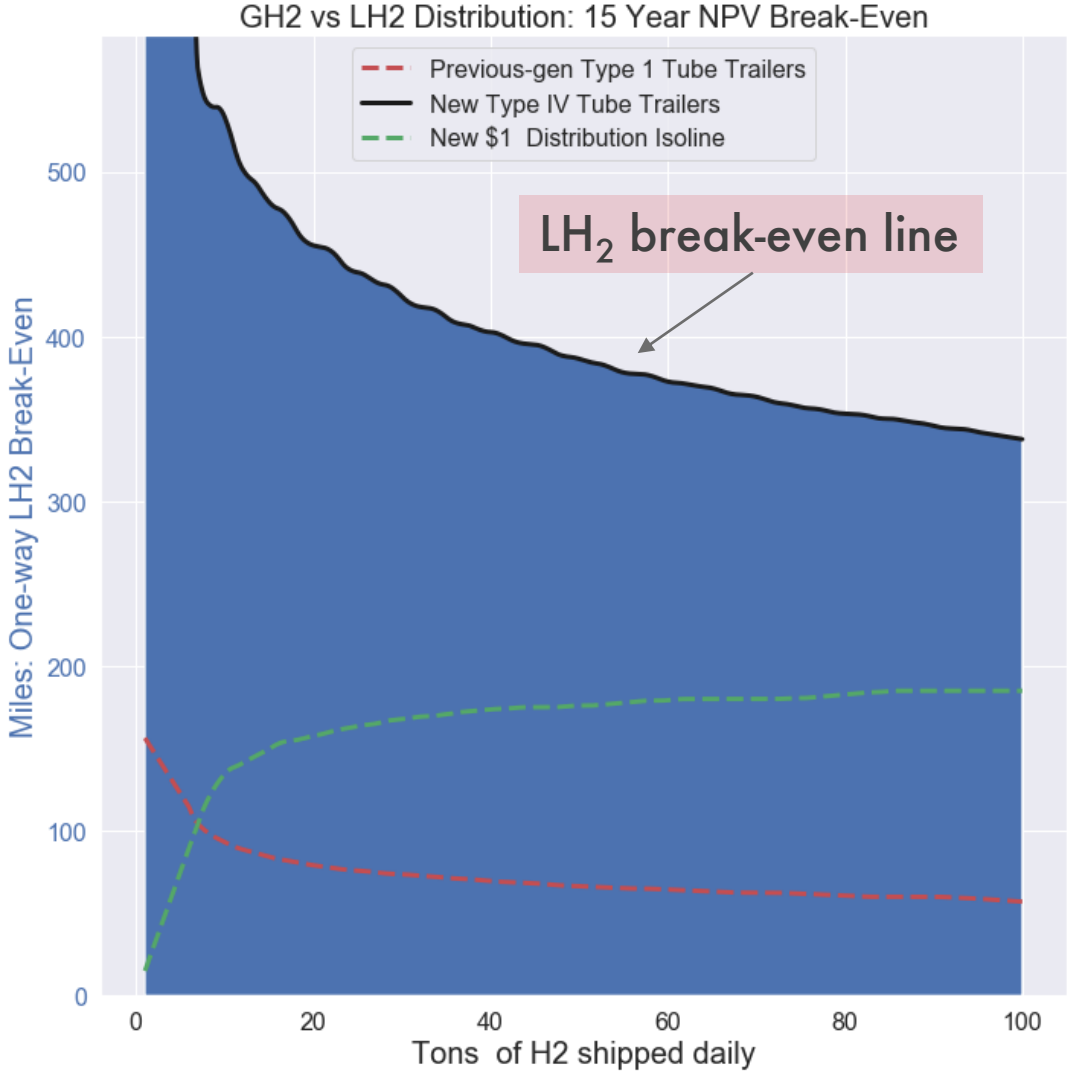

- The peak load at the substation level is challenged by a B-EV fleet
- Larger scale means FC is better able to handle fueling with a lower TCO
- Volt charge rate 3.3 kw, truck 15 kw, bus 60kw (4-6 hours to full charge for bus)

# Demand Will Drive Infrastructure Changes




- Increasing volumes of sales will drive cost-reducing infrastructure changes
- Progressively lower cost levels will open the market for larger volume and scale opportunities, further reducing costs
- Many Standards and fueling for heavy duty systems still need to be define
- The heaviest duty and longest haul vehicles will very likely need $LH_2$

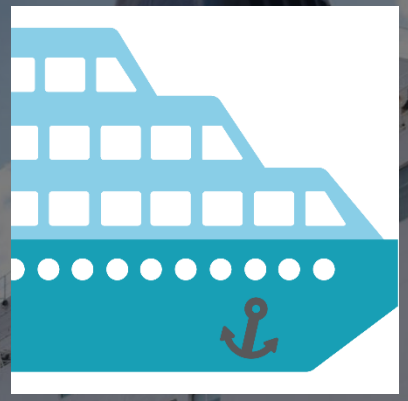
# $LH_2$ for Heaviest Use Cases, $GH_2$ for LDV and Distribution




## $LH_2$ vs. $GH_2$ – Key Differences in 15 Year NPV Costs

| | | |
|---|---|---|
| Economic Limits | : | **There are limits to economic overland shipment of $H_2$ with either $GH_2$ or $LH_2$** |
| $LH_2$ - More Capital Intensive | : | **Liquefaction is capital intensive, and the process does not get great returns to scale** |
| $GH_2$ for Regional Production and Distribution | : | **Low-cost $H_2$ will require <$1/kg distribution costs.**<br>**With current technology, the $1/kg isoline for delivery distance is always underneath the break-even cost for considering $LH_2$ vs $GH_2$**<br>**$LH_2$ is necessary for several large use cases** |
| Next Steps for Technologies | : | **$LH_2$: Lower cost liquefaction facilities (50%+ reduction); more efficient liquefaction (kwh/kg)**<br>**$GH_2$: Lower cost carbon fiber for tube trailers; compressors that are less expensive, more reliable, and more efficient (kwh/kg)** |

# Major Liquid Use Cases



## Marine

Ferries & Cruise Ships

Electrically driven, space limited, massive power requirements (50 tons per day)

## Mining

Very Large Mining Equipment

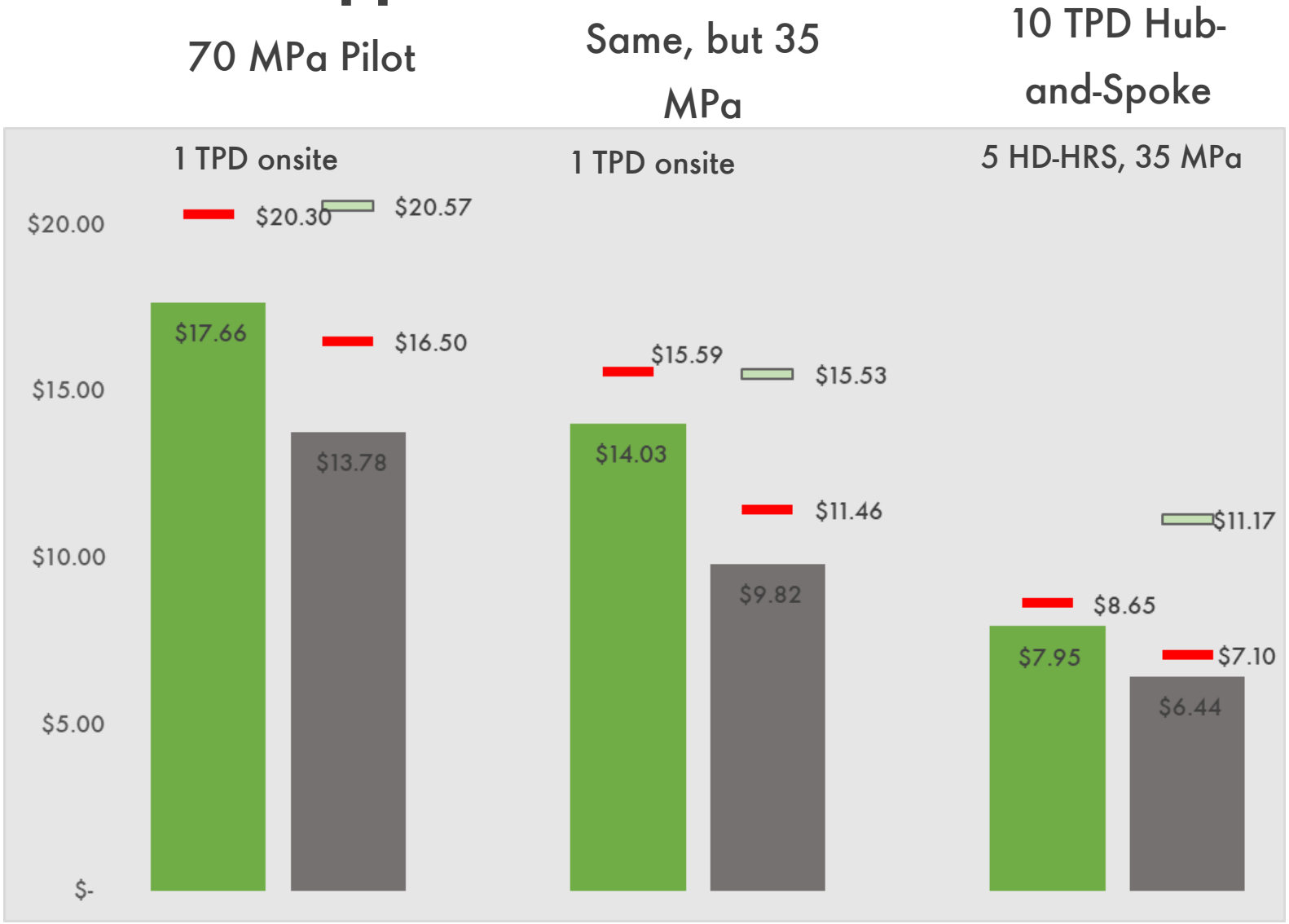
Tons of use per day per rig, often remote and off-grid

## Intercontinental Market Arbitrage

All Use Cases

Low-cost energy availability in other countries, LH2 to export energy

# Current Opportunities: Scale and Demand Drive Cost Reduction




Renewable Electrolysis | SMR Grey

With Contingency | SMR w/ RNG

## 35 MPa Use Case

| | | |
|---|---|---|
| **Pressure to Reduce Cost** | : | 35 MPa in use cases with <250 miles per day range allows for down-sizing of expensive and less reliable Hydrogen Refueling Station equipment |
| **Centralize Production** | : | Returns to scale with construction and locating near low-cost inputs reduce cost |
| **Increase Station Size** | : | Returns to scale on construction and distribution reduce cost |

# Cost Reduction and Technology with Scaling

## DEMAND AND SCALE UNLOCK COST REDUCTIONS

Demand drives costs lower through each fueling paradigm – 70 MPa car, 35 MPa truck, 50-70 MPa truck, $LH_2$ vessels

Larger vehicles drive exponentially increasing demand, driving costs down further

## MEDIUM TERM COST REDUCTIONS WITH FIT-TO-CASE SOLUTIONS

Tailoring heavy-duty refueling systems to specific use cases can provide low-cost $H_2$ *now* for specific segments

Cost reductions in HRS and distribution allow for lower-cost refueling paradigms for these segments

Industry consortiums contribute to system cost reductions

## LONG TERM EFFICIENCY GAINS

Increasing numbers of stations will reduce costs for components, driving down overall costs

Regional $H_2$ use rates will dictate emplacement of pipelines to drastically lower future transport costs

# Summary

- Refueling station scale and density of refuelling are both necessary to achieve lower costs
- Centralized production and next-gen gaseous distribution are both pathways to reduce cost in the next decade
- High volumes of $H_2$ production from heavy duty applications, particularly return-to-base applications like buses, drayage trucks, and fleet vehicles, will drive down hydrogen production costs, reducing the entire cost stack
- Liquid $H_2$ will be necessary for specific use cases and for some the largest $H_2$ use cases

# Questions and Answers