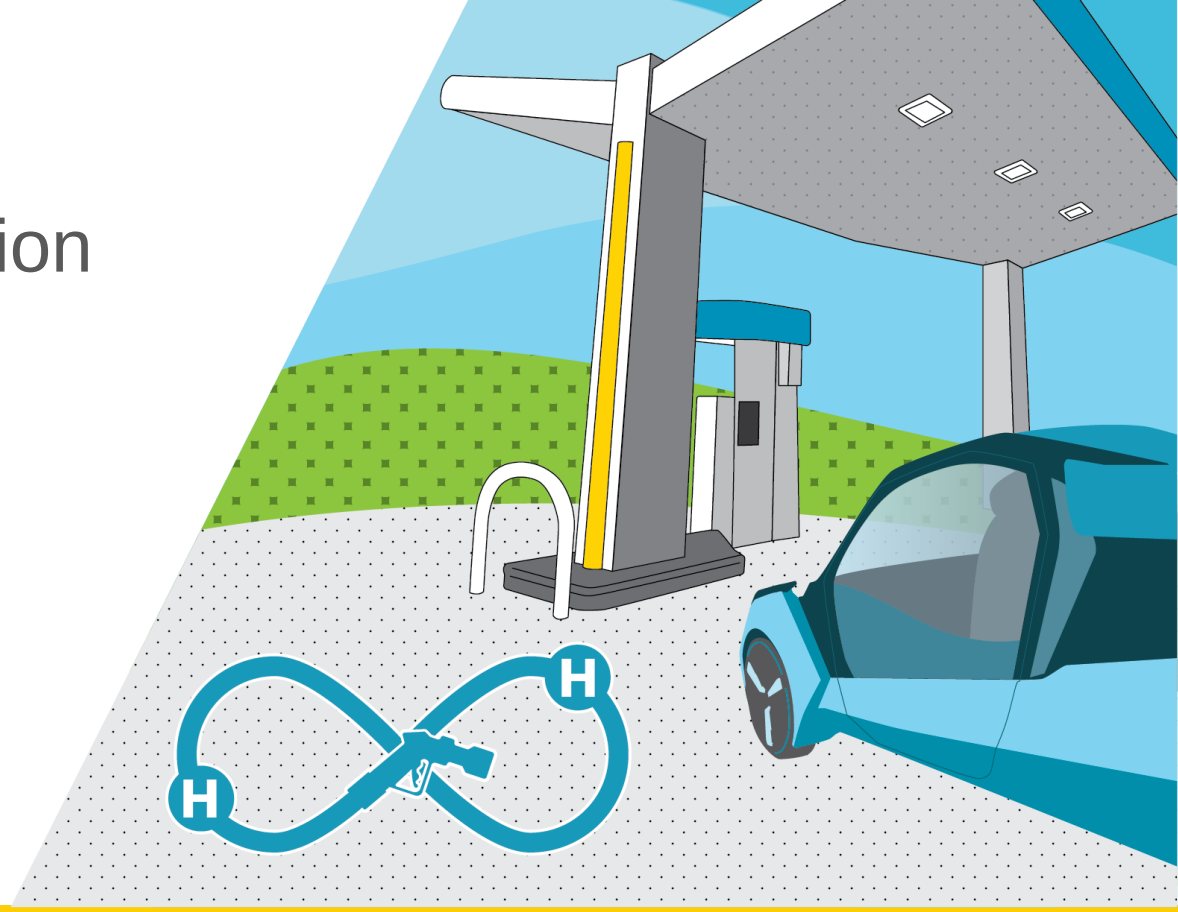
# Shell Hydrogen Refueling Station Cost Reduction Roadmap

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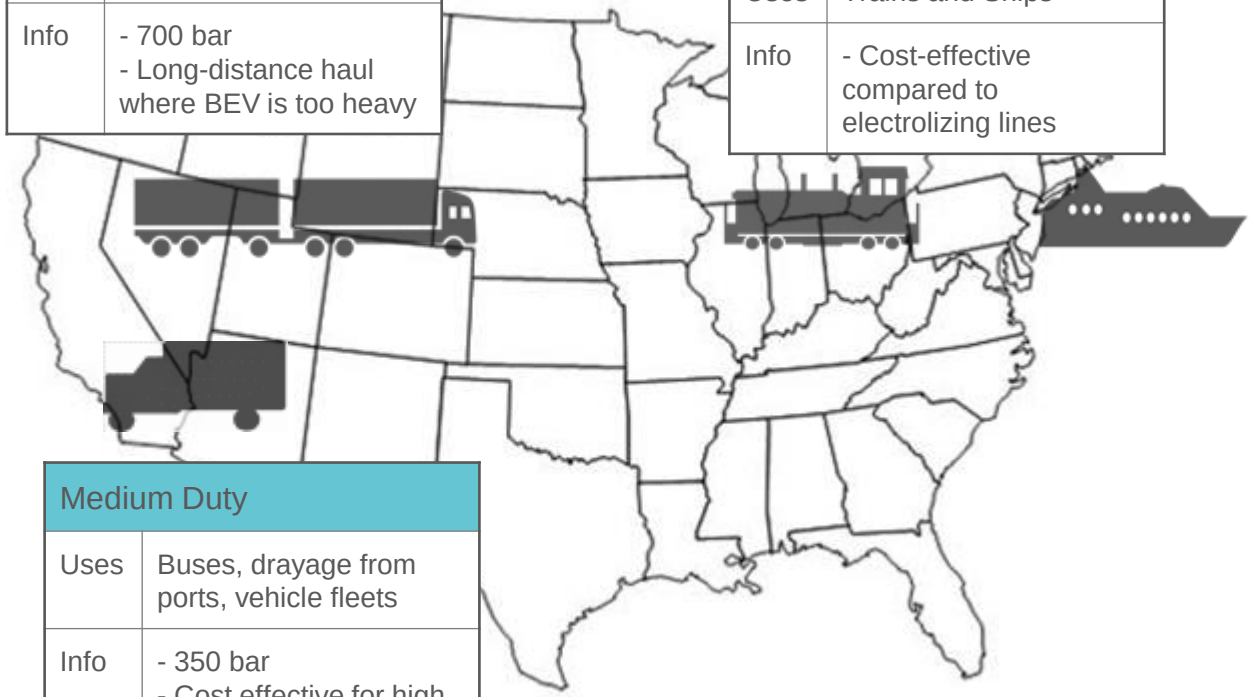
# Shell Light Duty and Heavy Duty cost progression


| Extracted Cost Savings | | |
|---|---|---|
| | **LD Station** | **HD Station** |
| Total Vehicles | >100,000 | >10,000 |
| KG $H_2$/vehicle | 4-10 | 35-100 |
| <u>Delivered H2</u> | Higher volume of daily use yields **production savings** and **distribution efficiencies** | |
| KG/day | 400 | 2000-4000 |
| Tech Deployed | | Liquifaction and Onsite SMR ***decreases delivery cost*** |
| HRS Equipment and Tax | At-scale production of heavy equipment and cost learning | |
| | | Liquifaction or on-site SMR ***slightly increases cost*** |
| Construction | Cost learning & equipment efficiencies | |
| | | Out-of-city construction **saves costs** |

# HD Cost Reduction Roadmap: Medium Duty and Heavy Duty

| Heavy Duty | |
|---|---|
| Uses | Long haul transport |
| Info | - 700 bar<br>- Long-distance haul where BEV is too heavy |

| Very Heavy Duty | |
|---|---|
| Uses | Trains and Ships |
| Info | - Cost-effective compared to electrolizing lines |

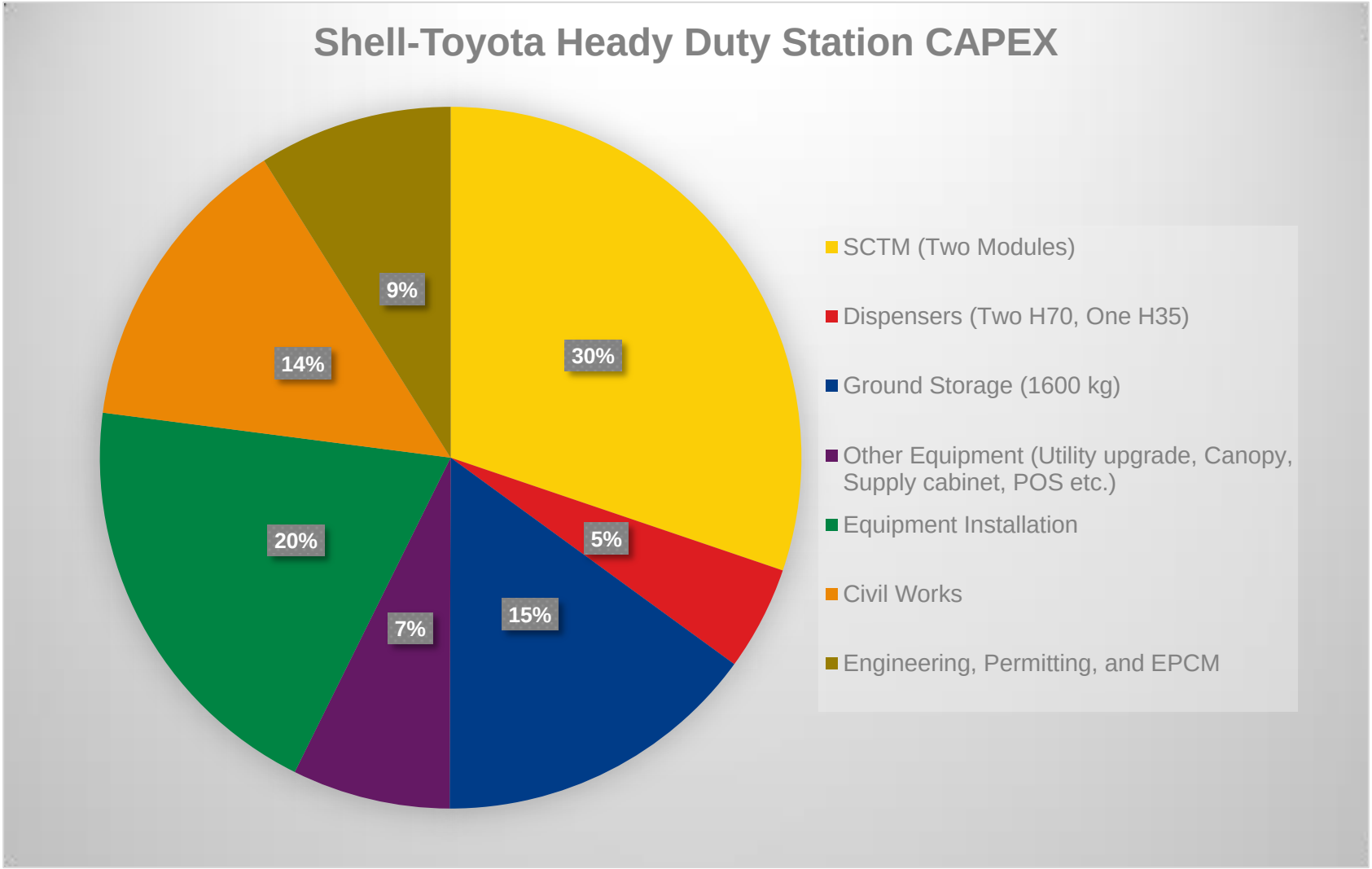


| Medium Duty | |
|---|---|
| Uses | Buses, drayage from ports, vehicle fleets |
| Info | - 350 bar<br>- Cost effective for high duty-cycle vehicles |

| Distribution Technology Progression | | |
|---|---|---|
| **Tech** | **Use Case** | **Technical Requirement** |
| Efficient On-Site SMR | - 5 tons daily Steam Methane Reformation on or near site<br>- Extremely low distribution costs | - High volume of purchase at heavy-duty stations |
| $H_2$ Liquifaction | - Transporting and distributing hydrogen over long distances<br>- **Cost reductions** in distribution, but **cost increases** in production | - Cryogenic pumps at refueling stations to pressurize and gasify H2<br>- Robotic refueling and onboard LH2 use for heavy duty |
| $H_2$ Pipeline transport system | - Large scale transport of hydrogen 2+ decades from now<br>- Distribution costs go from dollars per kg to cents per kg | - Kilotons per day usage in cities across the country required for effective capital efficiency |

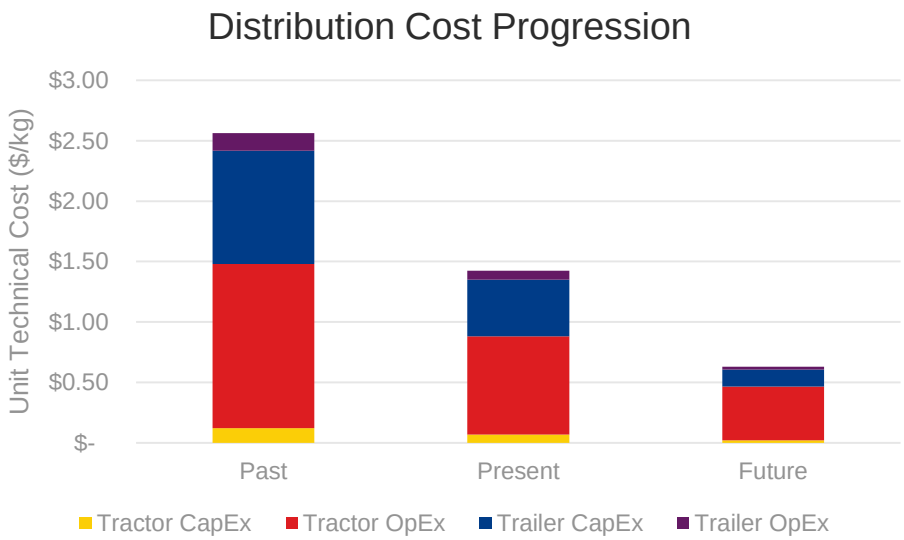
| Potential Future Cost Reduction Technologies | | |
|---|---|---|
| **Tech** | **Use Case** | **Technical Requirement** |
| Solid Oxide Fuel Cells | - Potentially higher efficiencies<br>- Ability to deal with lower quality fuel | - Technology is very far from deployment |
| Liquid Hydrogen Fuel Carriers | - Potential distribution cost reductions<br>- Potential uses in HD refueling | - Efficient use requires on-board heating and $H_2$ extraction |

# First Generation Heavy Duty Cost Breakdown




| First-Gen HD Refueling: Major Cost Drivers | |
|---|---|
| SCTM | *Storage, compression, and thermal management*<br><br>On-site H2 production requires compression from 30 bar to 700 bar requires several stages of compression<br><br>700 bar compressor technology is still young, the markets for these compressors is still small, and the products are thus not mass-produced and are expensive |
| Construction, Permitting, Installation | California is more expensive to permit and construct in than most states or countries<br><br>This is a first-build refueling station with requirements to support two upcoming stages of technology change<br><br>Cost-learning, standardized protocols and construction, and building in other parts of the country will drastically reduce cost by shrinking line items representing ~70% of current costs |

# Hydrogen Distribution Progression and $LH_2$ vs. $GH_2$




| | | | |
|---|---|---|---|
| Trailer Capacity (kg) | 600 | → | 1200 |
| Trailer Pressure (Bar) | 450 | → | 517 |

Increasing demand raises numbers of stations and utilization rate

*This yields increasing network efficiency*

## Liquid $H_2$ Transport and Refueling

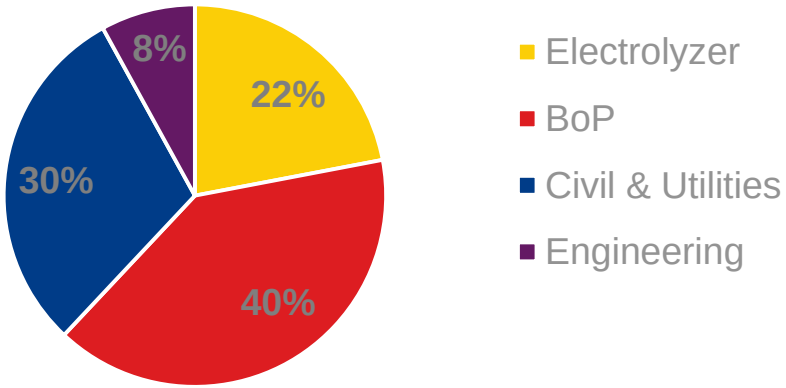
| | | |
|---|---|---|
| Capital and Risk Intensive | : | Economies of scale at massive size require build-out that is out-of-phase with demand<br>Difficult to economically supply small-scale systems |
| Station Tech and Protocol Issues | : | Current stand-off distance requirements create issues for liquid HRS (NFPA2)<br>In the absense of on-board $LH_2$ use, current dispensers and compressors are *cost prohibilitive* and have *short uptime between required maintenance* |
| Opportunities as Technology Progresses | : | Distribution costs relative to $GH_2$ become attractive with larger volume stations (est. >1T per day) or longer distribution lines (est. >250m radius)<br>Very likely to be the solution to future shipping opportunities, especially cruise liners |

## Gaseous $H_2$ Transport

| | | |
|---|---|---|
| Flexible Stations | : | Enables very low-cost 35MPa medium duty and heavy duty refueling<br>Allows for use of both small and large distribution options as demand shifts and grows |
| Technology Requirements | : | Requires high capacity (1000kg+) and low cost (<$1000/kg) transportation and storage |

# Renewable $H_2$ Production and Requirements for Success

Present Electrolyzer CapEx Cost Stack




## Path to Diesel-Competitive Renewable Electrolyzer $H_2$

| | | |
|---|---|---|
| Cost Reduction | : | Current costs of over $1MM / MW capacity for electrolyzers need to be at least halved<br>Electricity costs are the major driver of electrolyzer $H_2$ costs, requiring $0.04 per kwh at half the current CapEx to break-even with On-Highway diesel prices in the Midwest |
| Utilization Rate | : | CapEx efficiencies can only be realized at near-full utilization rates, requiring high-capacity factor renewables or massive over-sizing of variable renewable resources |

Steam Methane Reformation (SMR) is the current workhorse of hydrogen production

While SMR provides the easiest path to cost-competitive $H_2$, the energy intensity of the process and leaks in the natural gas production and transport can result in greenhouse gas emissions on par with diesel vehicles.

## Path to Green SMR-produced $H_2$

| | | |
|---|---|---|
| Capital Efficiency | : | SMR is a very mature technology, and is capital-efficient<br>New efficient SMR designs in sized from 100-20,000 kg/day are capable of producing $H_2$ from low-cost natural gas feedstock |
| Efficient Trading Structures | : | SMR $H_2$ production on-site of biogas production locations will likely not yield production and distribution efficiencies of SMR from a natural gas pipeline.<br>*→ Efficient and traceable RIN trading is thus a likely pre-prequisite of large-scale green SMR in the near term* |

# Shell Global Hydrogen – a Growing Presence in the US

| Shell Global Hydrogen Projects and Expansions | | |
|---|---|---|
| **Station Type** | **Description** | **Learnings and Challenges** |
| Torrance | Our first-generation hydrogen refueling stations is one of the longest operating Hydrogen Refueling Stations in California | - High maintenance costs and early-stage technology decrease reliability<br>- Understanding of technology needs led to better current-gen stations |
| Northern California | Shell Hydrogen is building and branding seven current-generation stations in Northen California with major reliability improvements | Current generation of technology, better use of reliable and low-cost distribution systems, and efficient use of redundancy will result in ***reduced costs*** and ***increased reliability*** |
| Next Generation California Expansion | Shell Hydrogen has leveraged large-scale opportunities to improve performance across the entire value chain | - We have worked with partners to procure and engineer the next-generation systems and components to reduce cost and increase reliability<br>- Our next generation refueling stations have a contractual pathway to ***decrease CapEx***, ***increase uptime*** and ***decrease maintenance costs*** |
| Heavy Duty Refueling Stations | We are working with Toyota and California to develop three heavy-duty refueling stations | - Shell and others are developing demonstration heavy-duty refueling stations in stages<br>- The progressive stages will increase station refueling capacity, truck refueling speed, and number of heavy duty stations<br>- These stations will help inform heavy duty refueling protocols |
| Dealer Value Proposition | Shell Global Hydrogen is using our learnings from our stations to strategically license our technology | - Shell has created an offering to work with partners to strategically expand consumer access to hydrogen in markets outside of our core strengths<br>- Partners can license our latest-generation technology and brand reliability to be leaders in their markets ***while expanding consumer access to hydrogen*** |