Shell Hydrogen Refueling Station Cost Reduction Roadmap

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12 December, 2018
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Shell Light Duty and Heavy Duty cost progression

Cost Reduction from # of Retail Stations

Cost Reduction from # of Vehicles

Parity with gasoline (35 MPG @ 3.50 $/gal)

Parity with Heavy Duty Diesel (@ 3.20 $/gal)

H2 Retail Cost ($/kg)

Market Situation for Scaling

H2 Delivered  HRS Equipment and Tax  Construction & Commissioning  OPEX

Baseline 100+ stations Many vehicles HD

Total Vehicles >100,000 >10,000

KG H2/vehicle 4-10 35-100

Delivered H2

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 onsite SMR slightly increases cost

Construction

Cost learning & equipment efficiencies

Out-of-city construction saves costs

Construction Cost learning & equipment efficiencies

Out of city construction saves costs

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HD Cost Reduction Roadmap: Medium Duty and Heavy Duty

**Medium Duty**
- **Uses**: Buses, drayage from ports, vehicle fleets
- **Info**: - 350 bar - Cost effective for high duty-cycle vehicles

**Heavy Duty**
- **Uses**: Long haul transport
- **Info**: - 700 bar - Long-distance haul where BEV is too heavy

**Very Heavy Duty**
- **Uses**: Trains and Ships
- **Info**: - Cost-effective compared to electrolyzing lines

### Distribution Technology Progression

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

### Potential Future Cost Reduction Technologies

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<th>Use Case</th>
<th>Technical Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid Oxide Fuel Cells</td>
<td>- Potentially higher efficiencies - Ability to deal with lower quality fuel</td>
<td>- Technology is very far from deployment</td>
</tr>
<tr>
<td>Liquid Hydrogen Fuel Carriers</td>
<td>- Potential distribution cost reductions - Potential uses in HD refueling</td>
<td>- Efficient use requires on-board heating and H₂ extraction</td>
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First Generation Heavy Duty Cost Breakdown

Shell-Toyota Heavy Duty Station CAPEX

- SCTM (Two Modules): 30%
- Dispensers (Two H70, One H35): 14%
- Ground Storage (1600 kg): 20%
- Other Equipment (Utility upgrade, Canopy, Supply cabinet, POS etc.): 15%
- Equipment Installation: 7%
- Civil Works: 5%
- Engineering, Permitting, and EPCM: 9%

First-Gen HD Refueling: Major Cost Drivers

SCTM
- Storage, compression, and thermal management:
  - On-site H2 production requires compression from 30 bar to 700 bar requires several stages of compression.
  - 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.
- This is a first-build refueling station with requirements to support two upcoming stages of technology change.
- 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.

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Hydrogen Distribution Progression and LH₂ vs. GH₂

**Increasing demand raises numbers of stations and utilization rate**

*This yields increasing network efficiency*

### Distribution Cost Progression

<table>
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<tr>
<th>Unit Technical Cost ($/kg)</th>
<th>Past</th>
<th>Present</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractor CapEx</td>
<td></td>
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<tr>
<td>Tractor OpEx</td>
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<td>Trailer CapEx</td>
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</table>

**Trailer Capacity (kg)**

- Past: 600
- Present: 1200

**Trailer Pressure (Bar)**

- Past: 450
- Present: 517

### Liquid H₂ Transport and Refueling

**Capital and Risk Intensive**

- Economies of scale at massive size require build-out that is out-of-phase with demand
- Difficult to economically supply small-scale systems

**Station Tech and Protocol Issues**

- Current stand-off distance requirements create issues for liquid HRS (NFPA2)
- In the absence of on-board LH₂ use, current dispensers and compressors are cost prohibitive and have short uptime between required maintenance

**Opportunities as Technology Progresses**

- Distribution costs relative to GH₂ become attractive with larger volume stations (est. >1T per day) or longer distribution lines (est. >250m radius)
- Very likely to be the solution to future shipping opportunities, especially cruise liners

### Gaseous H₂ Transport

**Flexible Stations**

- Enables very low-cost 35MPa medium duty and heavy duty refueling
- 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 H₂ Production and Requirements for Success

Present Electrolyzer CapEx Cost Stack

- Electrolyzer: 22%
- BoP: 30%
- Civil & Utilities: 40%
- Engineering: 8%

Path to Diesel-Competitive Renewable Electrolyzer H₂

Cost Reduction:

- Current costs of over $1MM / MW capacity for electrolyzers need to be at least halved
- Electricity costs are the major driver of electrolyzer H₂ 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 H₂, 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 H₂

- SMR is a very mature technology, and is capital-efficient
  - New efficient SMR designs in sized from 100-20,000 kg/day are capable of producing H₂ from low-cost natural gas feedstock
  - SMR H₂ production on-site of biogas production locations will likely not yield production and distribution efficiencies of SMR from a natural gas pipeline.

Efficient Trading Structures:

- Efficient and traceable RIN trading is thus a likely pre-requisite of large-scale green SMR in the near term
# Shell Global Hydrogen – a Growing Presence in the US

## Shell Global Hydrogen Projects and Expansions

<table>
<thead>
<tr>
<th>Station Type</th>
<th>Description</th>
<th>Learnings and Challenges</th>
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</table>
| 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  
- Understanding of technology needs led to better current-gen stations |
| Northern California | Shell Hydrogen is building and branding seven current-generation stations in Northern 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  
- 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  
- The progressive stages will increase station refueling capacity, truck refueling speed, and number of heavy duty stations  
- 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  
- Partners can license our latest-generation technology and brand reliability to be leaders in their markets **while expanding consumer access to hydrogen** |