Reference Station Design

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Overview

Timeline
• Task Start Date: March 2014
• Task End Date: March 2015
• Percent Complete: 100%

Budget
• Total Task Budget: $280k
  – DOE Share: $280k
  – Funds Spent To-date: $280k
    • SNL: $140k
    • NREL: $140k

Barriers (Delivery area)
A. Lack of Hydrogen/Carrier and Infrastructure Options Analysis
K. Safety, Codes and Standards, Permitting

Partners
• National Labs: Sandia*, NREL*, Argonne
• H2USA Hydrogen Fueling Station Working Group
• California Air Resources Board
• DOE-EERE-FCTO
*Task Co-Leads
Objective and Relevance

• Goal: Speed acceptance of near-term hydrogen infrastructure build-out by exploring the advantages and disadvantages of various station designs and propose near-term optima.

• FY15 Impacts:
  – Provide a detailed view of how these stations fit in greenfield and existing sites in relation to the NFPA 2 standard
  – Help station developers quickly evaluate the suitability of their sites for a particular station type and capacity.
  – Provide station developers and local authorities a complete picture of the devices, components, and associated costs that make up a station
  – Provide a tool that the H2USA financing and market support and acceleration working groups can use to develop station rollout scenarios
  – Promote common component sizing and interchangeability
Approach

1. Define parameters and ranges
   - Compressor, land, O&M, 875 bar storage, ...

2. Specify cost data and metrics. Review.

ANL with input from H2FIRST Team and DOE*

3. Specify and simulate station concepts utilizing HRSAM's optimization method.

H2FIRST Team

4. Station concept selection based on comparative economics and technical feasibility

5. Match station concepts to market needs

6. Alignment of designs to actual equipment

7. Station designs

H2FIRST Team

H2FIRST Team with inputs from CARB & literature

H2FIRST Team with inputs from DOE

*Leverage of other DOE-EERE funded work
Approach

- **Uniqueness**
  - H2FIRST team updated economic modeling tools to give outputs relevant to “now-term” station development
  - The team incorporated current codified setback distances into station layout designs to present realistic usage implication and identify needs for improvement
  - The team looked at the whole picture, from macro-scale FCEV and station roll-out factors to component level station designs

- **Leveraging**
  - H2FIRST team leveraged other DOE-EERE work through the use of the HRSAM economic model
  - The team also leveraged market analysis and rollout strategy work done by the State of California (ARB) and the California Fuel Cell Partnership
Accomplishments: Summary

• Primary results
  – Selected four high-priority, near-term station concepts based on economics, technical feasibility, and market need
  – Produced spatial layouts, bills of materials, and piping & instrumentation diagrams

• Ancillary Results
  – Near-term, year-by-year FCEV rollout scenario compilation and assessment
  – Near-term hydrogen station rollout analysis year-by-year including number of stations, capacity, and overall utilization
  – Compilation of current costs for all station components and comparison of HRSAM- and BOM-predicted equipment and materials costs
  – Costs of 120 station permutations: capital cost and station contribution to cost of hydrogen, including effect of different utilization scenarios

Useful to: Station developers, municipalities, local authorities/code officials, finance and planning groups
Accomplishment: Determined station parameters with near-term ranges of interest

Average network utilization was estimated from station growth and vehicle roll-out scenarios and modeled to increase from 5% to 80% over the next 10 years.
Accomplishment: Determined station parameters with near-term ranges of interest

The values for the five performance parameters were chosen with industry input to reflect near-term station requirements and most common characteristics.

<table>
<thead>
<tr>
<th>Performance Parameter</th>
<th>Values Used for Screening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design capacity (kg/day)</td>
<td>50, 100, 200, 300</td>
</tr>
<tr>
<td>Peak performance</td>
<td>2, 3, 4, 5, 6 consecutive fills per hose</td>
</tr>
<tr>
<td>Number of hoses</td>
<td>1, 2</td>
</tr>
<tr>
<td>Fill configuration</td>
<td>Cascade, booster compressor</td>
</tr>
<tr>
<td>Hydrogen delivery method</td>
<td>Gas (tube trailer), liquid trailer</td>
</tr>
</tbody>
</table>
Three basic station designs were considered in the economic analysis:

1. **Tube trailer** (51 - 253 bar)
2. **Compressor** (994 bar discharge)
   - **Cascade Storage Low** (330 - 944 bar)
   - **Cascade Storage Medium** (613 - 944 bar)
   - **Cascade Storage High** (802 - 944 bar)
3. **Precooler** (to -40 C)
4. **Hose**
Common station designs

Three basic station designs were considered in the economic analysis:

1. Liquid Supply
2. Cascade Fill

- Cryogenic Storage (2 bar) → Liquid Pump → Vaporizer
  - Compressor (994 bar discharge)
    - Cascade Storage Low (330 - 944 bar)
    - Cascade Storage Medium (613 - 944 bar)
    - Cascade Storage High (802 - 944 bar)

- Precooler (to -40°C)
  - Hose
  - Hose
Three basic station designs were considered in the economic analysis.
Accomplishment: Station capital cost

HRSAM estimates of station capital costs typically vary from $1M to $2M.
Accomplishment: Station contribution to the cost of hydrogen

Cost of hydrogen typically varies from $40/kg to a low of $6/kg
Example: Market needs from ARB 2014 report

<table>
<thead>
<tr>
<th>Classification</th>
<th>Daily Throughput</th>
<th>Hourly Peak Throughput</th>
<th>Dispensers</th>
<th>Technical Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Use Commuter</td>
<td>High</td>
<td>High</td>
<td>More than 2</td>
<td>Back-to-back, simultaneous fills</td>
</tr>
<tr>
<td>Low Use Commuter</td>
<td>Low–intermediate</td>
<td>Low</td>
<td>2</td>
<td>Simultaneous fills</td>
</tr>
<tr>
<td>Intermittent</td>
<td>Low, intermittent</td>
<td>Low</td>
<td>1–2</td>
<td>Limited fuel capabilities</td>
</tr>
</tbody>
</table>

Three station classifications with corresponding near-term performance requirements were identified.
Accomplishments: Matched economically best-performing station design possibilities with market needs

<table>
<thead>
<tr>
<th>Profile</th>
<th>Site Type</th>
<th>Delivery</th>
<th>Capacity (kg/day)</th>
<th>Consecutive Fills</th>
<th>Hoses</th>
<th>Station Contribution to Hydrogen Cost ($/kg)</th>
<th>Capital Cost (2009$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Use Commuter</td>
<td>Gas station or greenfield</td>
<td>Gaseous</td>
<td>300</td>
<td>6</td>
<td>1</td>
<td>$6.03</td>
<td>$1,251,270</td>
</tr>
<tr>
<td>High Use Commuter</td>
<td>Greenfield</td>
<td>Liquid</td>
<td>300</td>
<td>5</td>
<td>2</td>
<td>$7.46</td>
<td>$1,486,557</td>
</tr>
<tr>
<td>Low Use Commuter</td>
<td>Gas station or greenfield</td>
<td>Gaseous</td>
<td>200</td>
<td>3</td>
<td>1</td>
<td>$5.83</td>
<td>$1,207,663</td>
</tr>
<tr>
<td>Intermittent</td>
<td>Gas station or greenfield</td>
<td>Gaseous</td>
<td>100</td>
<td>2</td>
<td>1</td>
<td>$13.28</td>
<td>$954,799</td>
</tr>
</tbody>
</table>

The top-performing station types that best-matched market needs were selected for detailed conceptual design.
Produced Piping and Instrumentation Diagrams (P&IDs)...

The P&IDs illustrate typical system designs for gaseous and liquid delivery stations.
...physical layouts considering NFPA-2 setback distance requirements, for greenfield...

The layouts show the amount of space required to install these stations to code.
...and at existing gasoline stations...

The layouts also show how a station can be sited at an existing gasoline station.
...and Bills of Materials (BOMs) with off-the-shelf components and costs.

The BOMs list typical components needed for stations along with present-day costs.

<table>
<thead>
<tr>
<th>Description</th>
<th>Tag Number</th>
<th>Quantity</th>
<th>Approx Cost</th>
<th>Ext Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen tank 401</td>
<td>PBNH-401</td>
<td>1</td>
<td>$40,000</td>
<td>$40,000</td>
</tr>
<tr>
<td>Hydrogen tank 402</td>
<td>PBNH-402</td>
<td>1</td>
<td>$40,000</td>
<td>$40,000</td>
</tr>
<tr>
<td>Hydrogen tank 403</td>
<td>PBNH-403</td>
<td>1</td>
<td>$40,000</td>
<td>$40,000</td>
</tr>
<tr>
<td>Pressure transmitter w/ indicator</td>
<td>PT-101</td>
<td>1</td>
<td>$1,000</td>
<td>$1,000</td>
</tr>
<tr>
<td>Pressure transmitter w/ indicator</td>
<td>PT-202</td>
<td>1</td>
<td>$1,000</td>
<td>$1,000</td>
</tr>
<tr>
<td>Pressure transmitter w/ indicator</td>
<td>PT-300</td>
<td>1</td>
<td>$1,000</td>
<td>$1,000</td>
</tr>
<tr>
<td>Pressure transmitter w/ indicator</td>
<td>PT-401</td>
<td>1</td>
<td>$1,000</td>
<td>$1,000</td>
</tr>
<tr>
<td>Pressure transmitter w/ indicator</td>
<td>PT-402</td>
<td>1</td>
<td>$1,000</td>
<td>$1,000</td>
</tr>
<tr>
<td>Pressure transmitter w/ indicator</td>
<td>PT-403</td>
<td>1</td>
<td>$1,000</td>
<td>$1,000</td>
</tr>
<tr>
<td>Block and bleed valve</td>
<td>HV-101</td>
<td>1</td>
<td>$500</td>
<td>$500</td>
</tr>
<tr>
<td>Block and bleed valve</td>
<td>HV-202</td>
<td>1</td>
<td>$500</td>
<td>$500</td>
</tr>
<tr>
<td>Block and bleed valve</td>
<td>HV-300</td>
<td>1</td>
<td>$500</td>
<td>$500</td>
</tr>
<tr>
<td>Block and bleed valve</td>
<td>HV-401</td>
<td>1</td>
<td>$500</td>
<td>$500</td>
</tr>
<tr>
<td>Block and bleed valve</td>
<td>HV-402</td>
<td>1</td>
<td>$500</td>
<td>$500</td>
</tr>
<tr>
<td>Block and bleed valve</td>
<td>HV-403</td>
<td>1</td>
<td>$500</td>
<td>$500</td>
</tr>
</tbody>
</table>
Accomplishments: Supported HRSAM-predicted equipment costs through comparison to costs estimated from BOMs

<table>
<thead>
<tr>
<th>Profile</th>
<th>Delivery</th>
<th>Capacity (kg/day)</th>
<th>Consec. Fills</th>
<th>Hoses</th>
<th>HRSAM Equip. Costs</th>
<th>BOM Equip. Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Use Commuter</td>
<td>Gaseous</td>
<td>300</td>
<td>6</td>
<td>1</td>
<td>$753,491</td>
<td>$767,000</td>
</tr>
<tr>
<td></td>
<td>Liquid</td>
<td>300</td>
<td>5</td>
<td>2</td>
<td>$933,350</td>
<td>$998,000</td>
</tr>
<tr>
<td>Low Use Commuter</td>
<td>Gaseous</td>
<td>200</td>
<td>3</td>
<td>1</td>
<td>$660,486</td>
<td>$742,000</td>
</tr>
<tr>
<td>Intermittent</td>
<td>Gaseous</td>
<td>100</td>
<td>2</td>
<td>1</td>
<td>$573,605</td>
<td>$717,000</td>
</tr>
</tbody>
</table>

HRSAM uses major equipment costs as representative of all material and equipment costs. In the range studied, these were close to the BOM estimates which consider all station equipment and materials individually.
H2FIRST itself is a **SNL-NREL** co-led, collaborative project.

**Other collaborators:**

- **ANL** modified HDSAM to HRSAM
- **H2USA** (primarily HFSWG)
  - HRSAM development
  - Reviewed final report
  - Reviewed parameters and ranges of interest
- **FCTO** team assisted with:
  - HRSAM development
  - Parameter definition
  - Vehicle and station roll-out and utilization scenarios
- **California ARB** participated in informal discussions on vehicle and station roll-out scenarios
Remaining Barriers and Challenges for Near-Term Infrastructure Rollout

- **Component level R&D** for chillers, cryogenic pumps and evaporators, high-capacity delivery trailers, and underground storage tanks

- **System innovation** to reduce chilling needs, address liquid boil-off issues with low-utilization stations, and optimize storage-compressor interactions

- **Revision of liquid hydrogen setback distances** by providing the scientific basis needed to assess and potentially reduce these current codified setback distances

- **Modeling and/or demonstration of business practice methods** such as fleets, consumer driven economics, big stations vs. many stations, and integration of mobile fueling trucks.
Potential Future Reference Station Work

• Assess technological and economic changes
• Re-evaluate parameter ranges of interest to near-term stations
• Re-assess economic potential of new station concepts, for example:
  – On-site generation
  – Light/heavy duty mixed stations
• Assist with assessing economic impact of different business practices
• Produce new station designs that reflect these changes
Technology Transfer Activities

- HRSAM is intended to be publically released.
- No other technologies were developed through this project.
Summary

• The Reference Station Design Task has produced results that include:
  – Vehicle roll-out scenario compilation and assessment
  – Detailed engineering and design of near-term station concepts
  – Economic and market assessments
  – Identification of areas for future efforts

• Stakeholders that benefit from this work are varied and include:
  – Planning groups including H2USA and state/local agencies
  – Technology developers and R&D organizations/agencies
  – Local municipalities and the general public
  – Station developers
  – Code authorities
Characterized FCEV rollout scenarios (for California)
## Estimated number of stations and network capacity

<table>
<thead>
<tr>
<th>Year</th>
<th>CaFCP (2014)</th>
<th>ARB (2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>51</td>
<td>51</td>
</tr>
<tr>
<td>2016</td>
<td>59</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>67</td>
<td>73</td>
</tr>
<tr>
<td>2018</td>
<td>77</td>
<td></td>
</tr>
<tr>
<td>2019</td>
<td>87</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>99</td>
<td>100</td>
</tr>
<tr>
<td>2021</td>
<td>111</td>
<td></td>
</tr>
<tr>
<td>2022</td>
<td>123</td>
<td></td>
</tr>
</tbody>
</table>

*180 kg/day average capacity*
Full cost comparison of station types

Percent increase from Minimum Cost

Delivered Gas – Single Compressor

Delivered Gas – Boost Compressor

Delivered Liquid – Single Compressor

Number of Consecutive Fills

Station Capacity [50 100 200 300]

Relative Fuel Price from Minimum

Relative Capital Cost from Minimum