Fuel Cell Technologies Office Webinar

Manufacturing Competitiveness and Supply Chain Analyses for Hydrogen Refueling Stations

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Analyst - Clean Energy Systems
National Renewable Energy Laboratory

05/011/2017
Question and Answer

• Please type your questions into the question box
Manufacturing Competitiveness and Supply Chain Analyses for Hydrogen Refueling Stations

Ahmad Mayyas
National Renewable Energy Laboratory
Agenda

I. Introduction

II. International HRS Status

III. Analysis of HRS Capital Cost

IV. Manufacturing of HRS components

V. Concluding Remarks
Introduction
Relevance & Goals

• Provide a platform for manufacturing cost analysis for major hydrogen refueling station (HRS) systems
  – Identify cost drivers of major parts in the HRS
  – Investigate effect of learning experience and availability of part suppliers on the cost of some HRS systems

• Study supply chain and evaluate U.S. manufacturing competitiveness in the international market
Key Outputs

1) HRS system manufacturing costs and minimum sustainable prices
2) International trade flows and supply chain maps (U.S. supply chain)
3) Estimation of future HRS technologies cost and effects on H₂ price
Hydrogen Delivery to the HRS

A configuration of a hydrogen station with gaseous hydrogen delivery

A configuration of a hydrogen station with Liquid hydrogen delivery
Gaseous HRS Components

Hydrogen Refueling Station (HRS)

Compression System
- Bleed Valves
- Check Valves
- Air Operated Valves
- Position Switch

Storage System
- Compressor
- Check Valves
- Bleed Valves
- Pressure Safety Valve
- Hydrogen Receiving

Dispensing System
- Bulk Pressure Storage
- Air Operated Valves
- Cascade Storage
- Pressure Safety Valve
- Tubing and Fittings

Electrical System
- PLC (card reader, digital display, etc.)
- Nozzles (35MPa/70MPa)
- Valves
- Hoses
- Tubing
- Fittings
- Cooler
- Heat Exchanger

* Modeled
FCEV Sales 2015-2030

- 2020 sales/production estimate >30,000 FCEVs
- 2030 sales/production estimates >250,000 FCEVs on roads
- Is hydrogen infrastructure ready to support this number of FCEVs?

Pratt et al., 2015

UkH2Mobility

FCEV number between 2014-2028

(Source: Pike Research)
II International HRS Status
International HRS Rollouts

HRS: Hydrogen Refueling Station

Data Sources: PNNL, CEC, NEDO, HySUT, NOW, CEP
International Manufacturers

This map can be accessed from: https://maphub.net/mayas111/HRS
III Analysis of HRS Capital Cost
HRS Capital Cost

**HRS Cost - Europe - Air Liquide Analysis**

- Labor and other expenses
- Piping+ Control & safety
- Dispenser
- Storage tanks
- Electrical
- Chiller
- Compressor

**HRS Cost - Japan**

- Labor and other expenses
- Piping+ Control & safety
- Dispenser
- Storage tanks
- Electrical
- Chiller
- Compressor

**HRS Cost - USA - ANL Analysis**

- Labor and other expenses
- Piping+ Control & safety
- Dispenser
- Storage tanks
- Electrical
- Chiller
- Compressor

**HRS Cost - USA - H2FIRST Analysis**

- Labor and other expenses
- Piping+ Control & safety
- Dispenser
- Storage tanks
- Electrical
- Chiller
- Compressor

Other Expenses include site engineering, permitting, commissioning, and construction

**CEMAC – Clean Energy Manufacturing Analysis Center**

Mossa, 2013

Shinka, 2014

Pratt et al., 2015

Suzauki, 2014
IV Manufacturing of HRS components
Assumptions- Compressor Manufacturing

- 1 stage compressor
- Compression ratio < 6:1
- $P_{\text{in}} = 150\text{-}200\text{ bar, } P_{\text{out}} = 350\text{-}420\text{ bar (5,000\text{-}6,000 psi)}$
- Manufacturing cost model for compressor case and internal parts only
- Balance of system was added to the direct manufacturing cost of the compressor case & internal parts
- Profit margin was estimated using weighted average cost of capital (WACC) method
- 70 MPa HRS might need a hydrogen booster besides the compressor to increase the pressure from 350-420 bar (35-42 MPa) to about 700-900 bar for direct filling or storage in the cascade/buffer system
Process Flow Diagram- Piston Compressor
Manufacturing Cost Analysis

- Compressor frame and internal parts
- Not including balance of system
H₂ Compressor - Balance of System
Minimum Sustainable Price - Compressor

- Compressor capacity$= 92 \text{ Nm}^3/\text{hr}$ or $200 \text{ kg/day}$ (1 stage)
- $P_{\text{in}} = 150-200 \text{ bar}$, $P_{\text{out}} = 350-420 \text{ bar}$
- Shipping cost is assumed for shipping compressors from East Coast to West Coast in this example
- Margin was calculated using WACC
Input parameters were varied by +/- 10% (relative) from base values to identify the modeled price sensitivities to various input assumptions.
Minimum Sustainable Price - Compressor

- United States advantages are lower shipping and interest rates and longer experience in this field.
- China’s advantage relative to the U.S. is driven by lower labor (including assembly), low material cost, building and energy costs.
- Mexico’s advantage relative to the U.S. is driven by lower labor (including assembly), and building costs.
Dispenser Cost Analysis

H35 Dispenser Parts Cost = $35,048

- Valves and Meters: 57%
- Nozzle & Hose: 13%
- Sensors (Pressure, Temp., H2 leak): 12%
- Electrical & Control: 9%
- Hydrogen filter: 3%
- Enclosure: 3%
- Other: 1%
- Piping and Tubing: 3%

H35/H70 Dispenser Parts Cost = $67,595

- Valves and Meters: 60%
- Nozzle & Hose: 22%
- Enclosure: 5%
- Electrical & Control: 1%
- Hydrogen filter: 3%
- Sensors (Pressure, Temp., H2 leak): 7%
- Other: 0%
- Piping and Tubing: 2%

Parts & Assembly Cost (assuming 20% discount per 10X increase in purchased quantity)

H35 Dispenser Cost

- Cost ($/unit) vs. Annual Production Volume (unit/yr)

H35/H70 Dispenser Cost

- Cost ($/unit) vs. Annual Production Volume (unit/yr)
Minimum Sustainable Price - Dispenser

- United States advantages are lower shipping and interest rates and longer experience in this field
- Mexico’s advantage relative to the U.S. is driven by lower labor, and building costs
Advance Heat Exchanging Technology

DCHE: Diffusion Bonded Compact Heat Exchanger

Images for: NREL HRS and Kobelco DCHE

Example of integration with dispenser

Photo Credit: JX Nippon Oil & Energy Co.
**Microchannel Heat Exchanger - Process Flow**

- Plate cleaning
- Chemical etching
- Quality check (profilometer)

  *Mask (Ferric Chloride)*

- Cold & Hot plate stacking
- Vacuum diffusion bonding
- Welding nozzles to the stack

- Adding housing
- Pressure testing

- Chemical etching can be replaced by laser grooving.
- Laser grooving speed = 300mm/min

Image Source: Heatric.com
**Plate Design Parameters**

### Parabolic Channels

\[ y = h \left(1 - \frac{x^2}{a^2}\right) \]

- **Plate thickness (mm)**: 0.25
- **Arc length (mm)**: 0.897
- **Plate thickness (mm)**: 0.500
- **Transfer area of individual channel (mm²)**: 458.97
- **Individual plate size**: 400*300 mm² = 375,000 mm²
- **Distance between individual channels**: 750 μm

### Square Channels

- **Height (mm)**: 150
- **Width (mm)**: 300
- **Plate length**: 400 mm
- **Plate width**: 300 mm
- **Transfer area of individual channel (mm²)**: 400.00

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**Chosen Design**

<table>
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<tr>
<th>Parabolic Channel Design Channel Parameters</th>
<th>Square Channel Design Channel Parameters</th>
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</thead>
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<tr>
<td>a (mm)</td>
<td>h (mm)</td>
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<td>0.125</td>
<td>0.20</td>
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</table>
Minimum Sustainable Price - MCHE

- United States advantages are lower shipping and interest rates and longer experience in this field
- Mexico’s advantage relative to the U.S. is driven by lower labor, and building costs
- China’s advantage relative to the U.S. is driven by lower labor, low material cost, building and energy costs
V Concluding Remarks
HRS Capital Cost and Hydrogen Price

Ways of reducing hydrogen cost
- Economies of scale for HRS systems can reduce hydrogen cost more than 5-10% (~20 of CSD cost)
- Standardization can do similar thing (e.g. compressors, chillers, heat exchangers, etc.)
- Installing liquid hydrogen station. Depends on number of FCEV and utilizations of HRS

1 kg H₂ ≈ 1 gallon of gasoline equivalent (gge)
Conclusions

• Lack of standardization may result in higher manufacturing cost
• U.S.-based manufacturers have advantages of longer experience in the field and low energy cost
• Future technologies and economies of scale will have great impact on the HRS cost and H₂ prices
Thank you

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www.manufacturingcleanenergy.org
• Please type your questions into the question box
Thank you

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Ahmad Mayyas  
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hydrogenandfuelcells.energy.gov
References

- Amgad Elgowainy et al., 2015. Overview of Station Analysis Tools Developed in Support of H2USA http://energy.gov/sites/prod/files/2015/05/f22/Fcto_webinarslides_h2usa_station_analysis_tools_051215.pdf
- UKH2Mobility. http://www.theregister.co.uk/2013/02/04/hydrogen_could_be_mainstream_car_fuel_by_2030/
http://autogreenmag.com/tag/india/page/6/
- Bruce Hedman and Ken Darrow. CHP Technology Characterizations. July 2010
Backup Slides
### Single Hose Dispenser H35

<table>
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<th>Part No.</th>
<th>Part</th>
<th>Supplier 1</th>
<th>Required Units</th>
<th>Dispenser ($)</th>
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### Dual Hose Dispenser H35/H70

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<td><strong>Total</strong></td>
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</table>
Double Tube Heat Exchanger

HX Design

Counter Flow

Coolant in

1,000 mm

150 mm

Coolant in

H₂ out

H₂ out

Process Flow

Tube inspection → CNC bending → Quality checking → Adding spacer to internal tubes → Tube welding

Pressure testing → Housing/closure → Welding nozzle → Stacking and insulation