

## VI.7 Manufacturing Competitiveness Analysis for Hydrogen Refueling Stations

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- (A) Lack of Hydrogen/Carrier and Infrastructure Options Analysis
- (B) Reliability and Costs of Gaseous Hydrogen Compression
- (E) Gaseous Hydrogen Storage and Tube Trailer Delivery Costs

### Contribution to Achievement of DOE Hydrogen Delivery Milestones

This project will contribute to achievement of the following DOE milestones from the Hydrogen Delivery section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

- Milestone 6.3: By 2020, reduce the cost of hydrogen delivery from the point of production to the point of use in consumer vehicles to <\$2/gge of hydrogen for the gaseous delivery pathway. (4Q, 2020)

### Overall Objectives

- Develop manufacturing cost models for major components in the hydrogen refueling stations such as the compressors, storage system, dispenser, chiller, and heat exchanger.
- Identify cost drivers associated with manufacturing of the hydrogen station parts and systems and highlight potential cost reduction through economies of scale and standardization.

### Fiscal Year (FY) 2017 Objectives

- Provide a platform for manufacturing cost analysis for major hydrogen refueling station (HRS) systems and components.
- Identify potential cost reductions in the manufacturing of dispensers, pressure vessels, chillers, and heat exchangers.
- Study international markets and global trade flows to examine potential competitiveness using number of installed HRSs in each country and number of HRSs shipped from/to certain countries.

### Technical Barriers

This project addresses the following technical barriers from the Hydrogen Delivery section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

### FY 2017 Accomplishments

- Manufacturing cost models were developed for hydrogen dispensers, pressure vessels, chillers, and heat exchangers.
- New set of updated maps were developed to assess global HRS supply chain and international trade flows for the period (2005–2017).
- Manufacturing cost model was developed for proton exchange membrane electrolyzers using different hydrogen production capacities (kilogram H<sub>2</sub> per day) and different annual production rates (electrolyzers/yr).



## INTRODUCTION

This study is one of a few studies that discuss cost of hydrogen infrastructure. While other studies focus on the big picture by assessing the effect of capital cost reductions on the hydrogen prices, this study provides a complete bottom-up manufacturing cost analysis for major systems in the hydrogen refueling stations (compressors, pressure vessels, chillers, heat exchangers, and dispensers). Manufacturing competitiveness analysis was performed to study the effect of cost components (e.g., labor, facilities and energy costs) in different countries on the final product cost. Besides the manufacturing competitiveness analysis, this study also aims at developing detailed supply chain and international trade

flow maps, which may help decision makers in visualizing main trade flows in the international markets and spot main markets for hydrogen station components from manufacturing countries to final installation locations.

**APPROACH**

This study is centered around three main analyses: manufacturing competitiveness analysis, supply chain analysis, and effect of qualitative factors on the selection of the manufacturing facility locations for manufacturing of the systems and parts used in the hydrogen refueling stations.

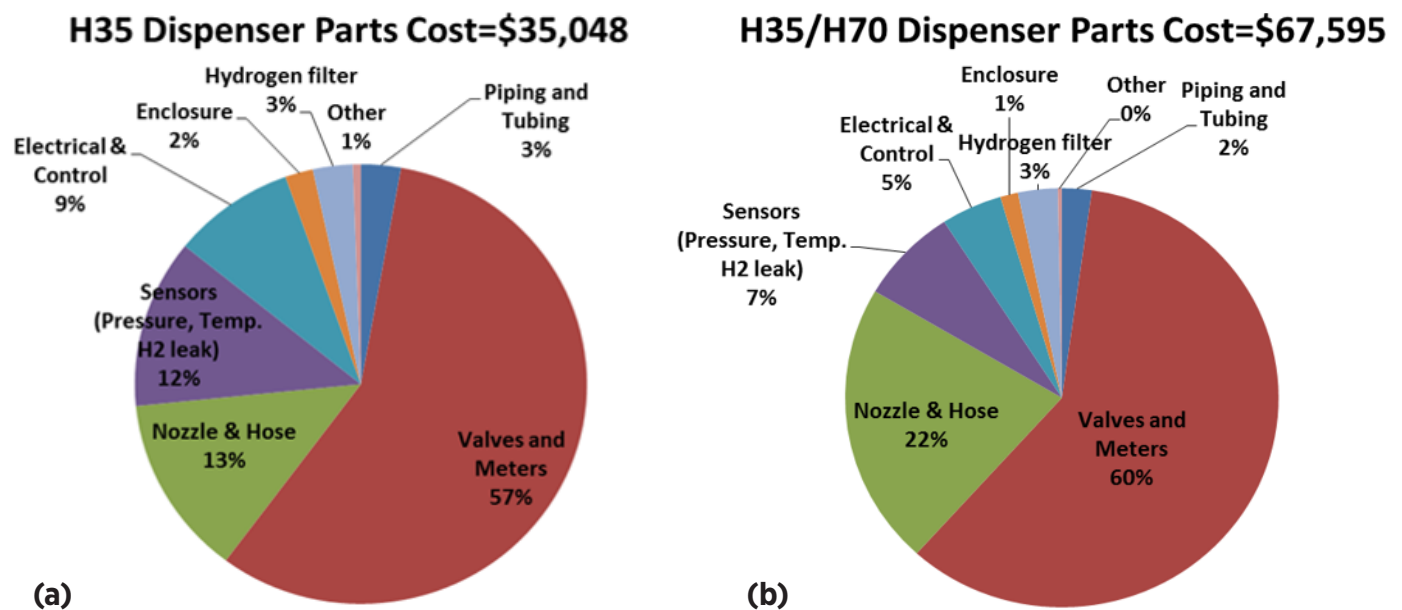
Manufacturing competitiveness analysis is used to evaluate relative manufacturing cost in selected countries in North America, Europe, and Asia, on manufacturing of main components in the hydrogen stations such as compressors, storage vessels, chillers, heat exchangers, and dispensers. Supply chain analysis was conducted with the aid of trade flow maps which show main trade flows between international markets from country of production to the final installation locations. Besides these two mentioned analyses, this study is also trying to address major factors that play a role in selecting manufacturing locations in the United States and other countries and the method of translating these factors into competitiveness metrics. Examples of these qualitative factors include manufacturing experience, product quality, skilled labor requirements and availability, tax policy, currency fluctuations, etc.

**RESULTS**

**Manufacturing Competitiveness Analysis**

The goal of this analysis is to dive deeper to study cost drivers associated with the manufacturing of some systems and major parts in the hydrogen refueling stations such as hydrogen compressors, Type I storage tanks, dispensers, chillers, and heat exchangers. The following example discusses the manufacturing cost model for two types of dispensers: H35 (35 MPa) single-hose dispenser and dual-hose dispenser H35/H70 (35 MPa and 70 MPa). Generally speaking, most of the dispenser manufacturers acquire major parts in the dispensers from reliable part vendors and then assemble these parts in-house. The main manufacturing processes involved in the production of the hydrogen dispenser include a sequence of manual and semi-automatic assembly processes followed by a pressure testing. If it passes the final pressure testing, then the end product can be shipped to the installation location.

After collecting the parts cost (Figures 1a and 1b), we plugged these numbers in the standard CEMAC cost model to estimate the final manufacturing cost with six cost components (parts, labor, capital, variable, energy, and building costs). Another cost component was estimated using the weighted average cost of capital method to account for the profit margin. Compiling these cost components in one chart gives the final manufacturing cost curve represented by the minimum sustainable price (MSP) curve. MSP can be defined as the minimum price that sustains a manufacturer’s



**FIGURE 1.** Part cost breakdown for (a) H35 single-hose dispenser and (b) H35/H70 dual-hose dispenser

business in a good financial state with no losses and no gains other than the manufacturing cost and internal rate of return required to cover the loan principal and interest (if presented) (see Figures 2a and 2b for H35 and H35/H70 dispensers, respectively). The MSP curve indicates significant cost reductions upon producing more units in the manufacturing

facility as a direct result of better resource utilization, i.e., lower capital and building cost per unit produced.

A comparative cost analysis using minimum sustainable prices was performed for hydrogen dispensers in selected countries (Figure 3). It can be seen clearly that Chinese- and Mexican-based manufacturers have advantages of lower labor

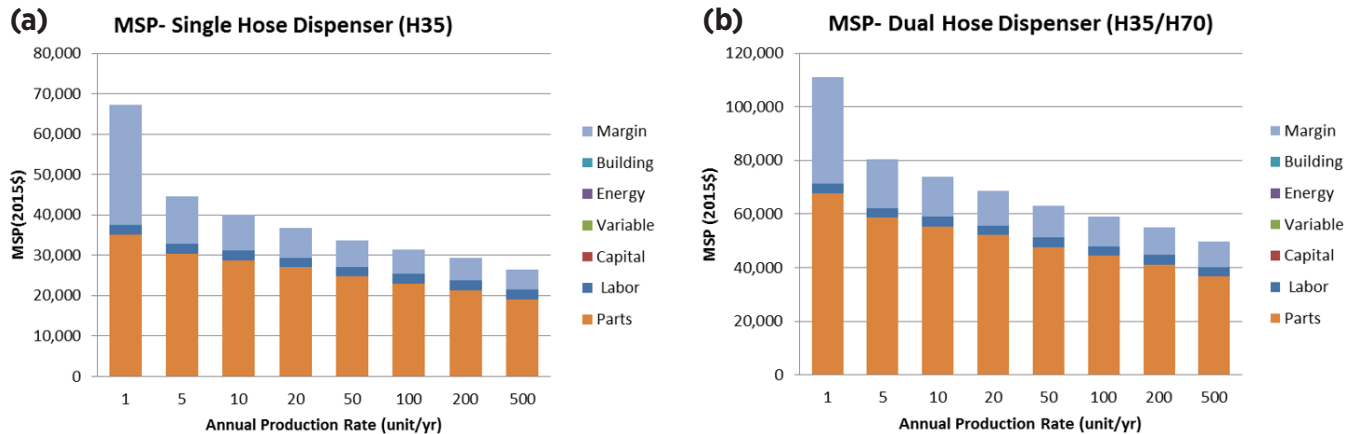


FIGURE 2. MSP curve for hydrogen dispensers manufactured in the United States for (a) H35 single-hose dispenser and (b) H35/H70 dual hose dispenser

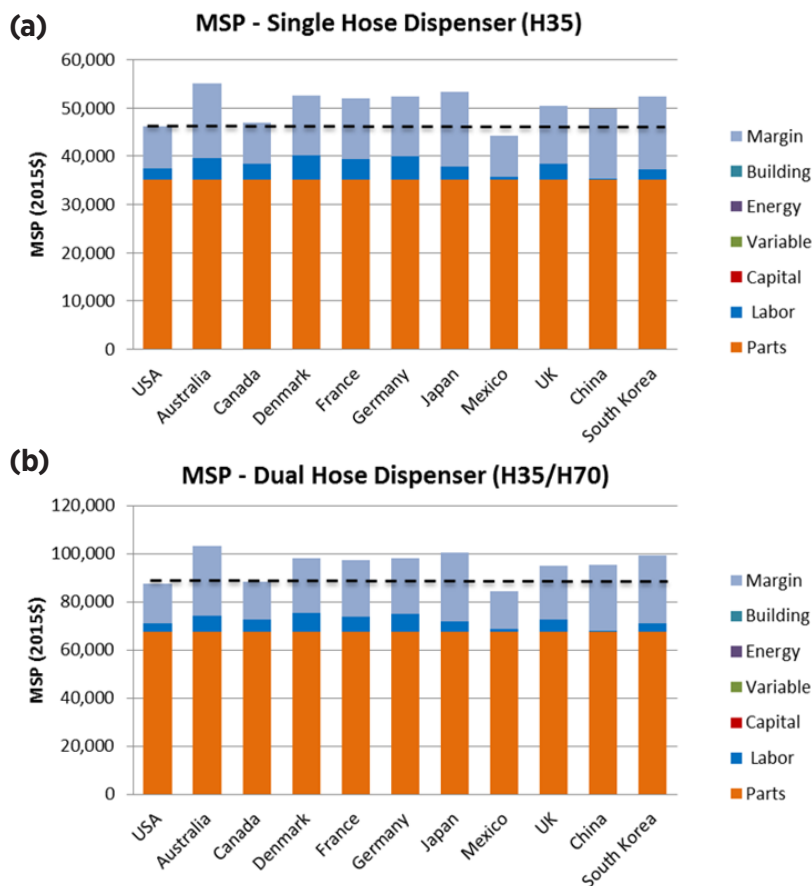


FIGURE 3. Comparative manufacturing cost analysis using MSP for hydrogen dispensers manufactured in selected countries: (a) H35 single-hose dispenser and (b) H35/H70 dual-hose dispenser

cost, lower building cost, lower materials cost, and lower energy cost (China only).

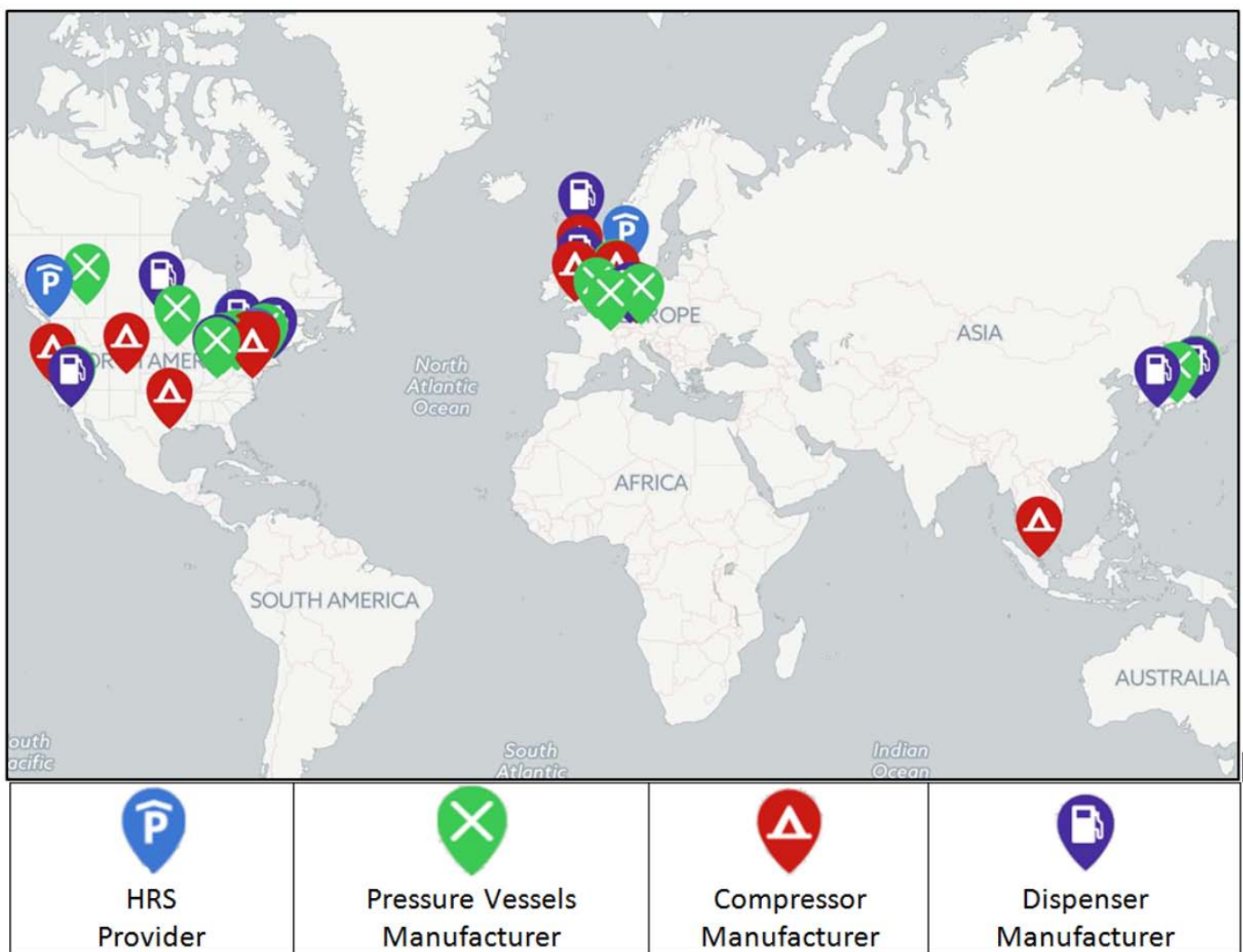
**Supply Chain and Trade Flow Maps**

This analysis is used as a qualitative measure to assess manufacturing competitiveness in selected countries and investigate level of specialization in manufacturing certain components used in hydrogen refueling stations. Figure 4 shows the location of major international manufacturers of hydrogen refueling station systems and HRS developers. Two main clusters can be seen in North America and Western Europe. Unsurprisingly, these two regions also see the highest level HRS activities represented by the number of HRS installations in the past few years (Figure 5). We

can say that the United States and Germany are the leading countries in number of manufactured HRSs and number of installations followed by Canada and Japan.

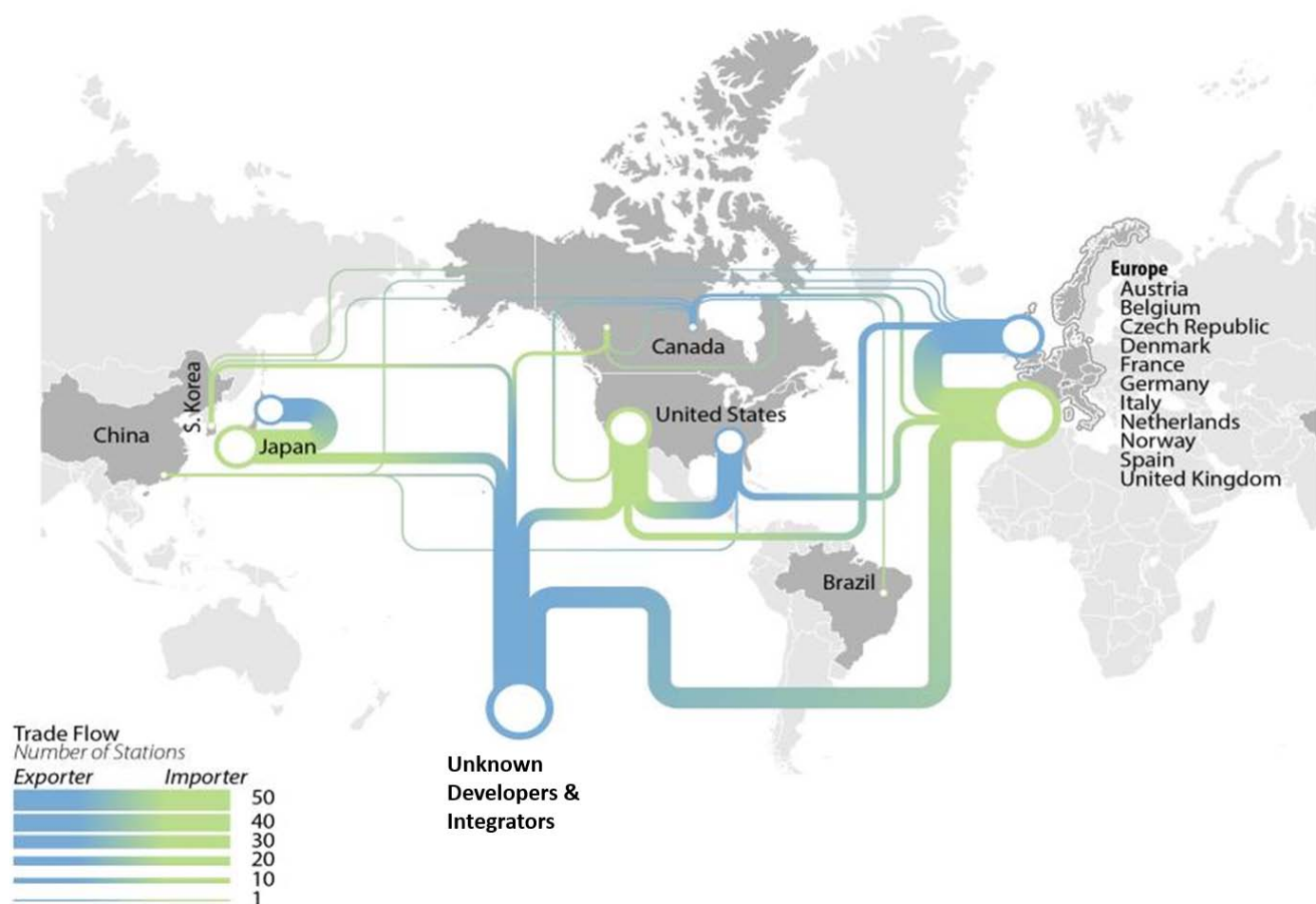
**CONCLUSIONS AND UPCOMING ACTIVITIES**

This project discusses manufacturing competitiveness and supply chain analyses for the hydrogen refueling stations and can help in understanding cost associated with manufacturing major components and systems in HRSs. Bottom-up cost analysis was used to develop manufacturing cost models for major systems in the HRS. Minimum sustainable price curves for hydrogen dispensers suggest that significant cost reductions (up to 40% or more) can be



**FIGURE 4.** Major international manufacturers of hydrogen refueling station systems





**FIGURE 5.** International trade flow map showing number of HRS shipped globally between 2005-2017 [1-4]

achieved if 100 units/yr are manufactured relative to the dispenser cost at 5 units/yr. International trade flow maps showed that the United States and Germany are leading countries in terms of number of produced units and number of installed hydrogen stations.

For FY 2018, manufacturing cost models and minimum sustainable price curves will be developed for onsite hydrogen production systems (proton exchange membrane and alkaline electrolyzers and small size steam methane reformers). After that the estimated MSP values will be summed up to estimate the capital cost of HRSs in different regions. These estimates will be then used to study the effect of capital cost reductions on the hydrogen prices.

**FY 2017 PUBLICATIONS/PRESENTATIONS**

1. Ahmad Mayyas, “Manufacturing Competitiveness and Supply Chain Analyses for Hydrogen Refueling Stations.” FCTO monthly webinar. May 11, 2017.
2. Ahmad Mayyas, “Manufacturing Competitiveness Analysis for Hydrogen Refueling Stations.” Presentation at the Annual Merit Review, June 6, 2017. Washington, D.C.

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2. PNNL (Pacific Northwest National Laboratory). Hydrogen Analysis Resource Center. International Hydrogen fueling stations. <http://hydrogen.pnl.gov/hydrogen-data/international-hydrogen-fueling-stations>
3. A. Iborra, E. Gupta, L. Seissler. 4th International Workshop on Hydrogen Infrastructure and Transportation. 24-25 May 2016, Egmond aan Zee, The Netherlands. <http://publications.jrc.ec.europa.eu/repository/bitstream/JRC103586/4%20int%20workshop%20on%20h2%20infra%20final%20pdfonline.pdf>. Last accessed 08/09/2017.
4. [www.H2Stations.org](http://www.H2Stations.org)