XI.3 Hydrogen Refueling Infrastructure Cost Analysis

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Fiscal Year (FY) 2012 Objectives

- Identify the capacity (kg/day) and capital costs associated with "Early Commercial" hydrogen stations (defined below)
- Identify cost metrics for larger numbers of stations and larger capacities

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Future Market Behavior
(C) Inconsistent Data, Assumptions and Guidelines
(E) Unplanned Studies and Analysis

Contribution to Achievement of DOE Systems Analysis Milestones

This project will contribute to achievement of the following DOE milestone from the Systems Analysis section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

- Milestone 1.4 (Systems Analysis Task 1: Perform Studies and Analysis): Complete evaluation of fueling station costs for early vehicle penetration to determine the cost of fueling pathways for low and moderate fueling demand rates. (4Q, 2012)

FY 2012 Accomplishments

- Responses from the Hydrogen Station Cost Calculator (HSCC) were weighted and aggregated to develop a generic representation of hydrogen station costs and rollout timeframes.
- Received HSCC responses from 11 stakeholders, representing a variety of stakeholder groups.
- HSCC responses where collected by IDC Energy Insights and were conveyed in a weighted, aggregated form to NREL staff, with the highest detail possible while still maintaining respondent anonymity.
- Identified priorities for research, development, demonstration and deployment across an array of component options.
- Quantification of station sizes (kg/day), capital costs, lifetime average utilization rates, and deployment time periods for 4 distinct station types: State-of-the-Art (SOTA), Early Commercial (EC), More Stations (MS), and Larger Stations (LS).

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Introduction

The early introduction of fuel cell electric vehicles (FCEVs) will prove to be dependent upon the successful deployment of hydrogen refueling stations (HRS). Deployment of HRS will depend, in part, upon cost reductions over time due to learning, mass production, and economies of scale achieved with increasing station capacities (measured in kg/day). This project builds upon many past HRS cost studies and data sources [1-4] by conveying quantitative, near-term HRS cost estimates provided by multiple key stakeholders through the HSCC. This work builds upon the qualitative feedback received from the Market Readiness workshop held in February 2011 [5]. The quantitative results from the HSCC provide insight into how the qualitative cost reductions opportunities discussed at the Market Readiness workshop might be realized within the 2014-2016 timeframe. These results are relevant to a wide range of stakeholders, including public-private partnerships developing plans for the early introduction of FCEVs.

Approach

Based upon feedback from Market Readiness workshop participants, four station types were defined within the HSCC. These definitions are provided in Table 1 as they were presented within the HSCC. The most relevant station type is EC, which provides a baseline from which additional cost reductions might be attained through deployment of multiple stations, MS, and production of similar stations at larger capacities, LS. Stations being installed today are defined as SOTA stations. The HSCC was distributed to a select list of organizations with direct experience with hydrogen station projects. Responses were received from 11 stakeholders, shown by type in Figure 1. IDC Energy Insights administered collection of feedback from these stakeholders, and conveyed aggregated, weighted, anonymous results to NREL staff. IDC Energy Insights weighted responses based upon the historical experience of each respondent with the installation of hydrogen stations, thereby giving greater weight to respondents with more extensive experience. These results underwent several reviews, including reviews by HSCC respondents, and were revised as a result to best articulate costs associated with each station type defined in Table 1.

The HSCC was designed to allow respondents to provide a significant amount of detail, or to provide relatively sparse detail, and to place multiple types of responses on a consistent basis. Within the HSCC respondents could calculate the cost of hydrogen ($/kg), based upon discounted cash flow calculations used in the Hydrogen Analysis (H2A) models [1], and then revise inputs in response to the resulting $/kg cost. However, due to the variety of approaches in which the HSCC was completed, and the limited number of respondents, costs could only be reported for a limited number of cost factors while maintaining the anonymity of respondents. In additional, station costs could not be

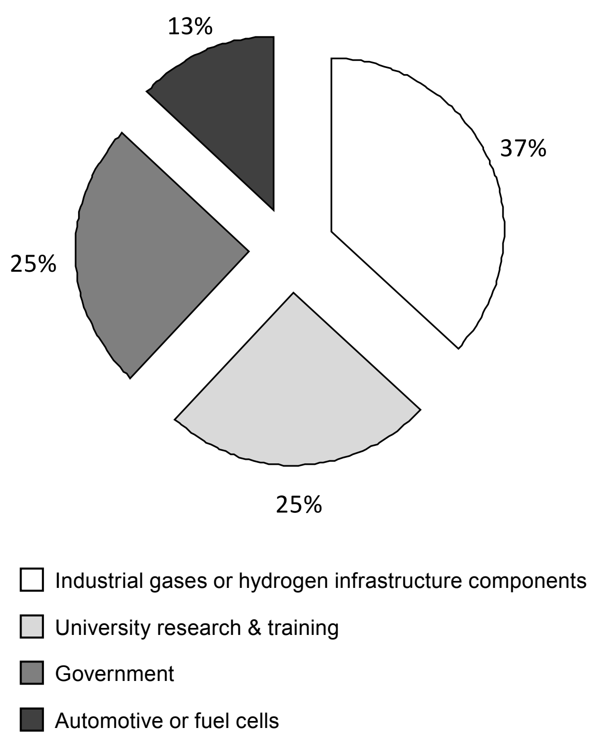

FIGURE 1. HSCC respondents by stakeholder type

associated with specific station configurations, such as onsite production vs. truck delivery. The estimates are therefore general representations of HRS costs as stations are deployed in certain volumes and over a specified timeframe. Additional information on the HSCC is provided in [5].

Results

The cost, size, and timeframe results by station type are summarized in Table 2. Given that SOTA stations are being installed today, these results suggest that significant cost reductions will be achieved before the 2014-2016 timeframe when EC stations with an estimated average capacity of

TABLE 1. Definitions of station types, as presented within the HSCC

1. State-of-the-Art Stations (SOTA). Newly installed hydrogen stations with the following attributes: • The stations would be installed and operational within the 2011-2012 timeframe. • The stations would include the most recent generations of major components, but would not necessarily include novel or "demonstration" components that have not been previously tested in the field. • The stations would be sized to meet hydrogen demands in a geographic region with promising future market demand.
2. Early Commercial Stations (EC). Based upon your organization's understanding of the growth in demand for hydrogen in the near future (next 5-20 years from the fuel cell electric vehicle, transit bus and material handling equipment markets), consider hydrogen stations to be "Early Commercial" stations if they have the following attributes: • The stations are financially viable with little government support. Based on financial criteria, such as return on investment, and requiring far less financial support or subsidy than the average support offered to all previous hydrogen stations in the same area or region (70-90% less). Disregard ongoing support offered to all types of alternative or low carbon fuels, such as low carbon fuel standard fuels, alternative fuel credits or carbon credits. The stations are sized to support growing demand in a promising market region, and to ensure adequate return on investment. This size could vary from station to station and neighborhood to neighborhood, but consider what might be a typical size for new EC stations. • The station design enables cost reductions because it is replicable. The same station design may be used for other stations, reducing the cost of subsequent stations through standardization and economies of production.
3. More Stations (MS). Identical to EC stations, but deployed in larger numbers. Default value is 10 times more stations being deployed than anticipated in the time period identified for EC stations. Additional cost reductions are achieved through standardization, mass production, streamlining of installation processes and learning by doing.
4. Larger Stations (LS). Identical to EC stations, but designed for higher volume output. The number deployed is assumed to be similar to EC stations, but growth in market demand warrants larger station sizes. Default value is a 1.5 increase in size over the EC stations, with 2,000 kg/day as an upper limit.

TABLE 2. Early station sizes, timeframes and capital costs

Station Attribute	Units	Station Type			
		State-of-the-Art	Early Commercial	More Stations	Larger Stations
Introduction timeframe	years	2011-2012	2014-2016	after 2016	after 2016
Capacity	kg/day	160	450	600	1,500
Utilization	%	57%	74%	76%	80%
Average output	kg/day	91	333	456	1,200
Total Capital	**$M**	**$2.65**	**$2.80**	**$3.09**	**$5.05**
Capital Cost per capacity	$1,000 per kg/d	$16.57	$6.22	$5.15	$3.37
Reduction from SOTA	%	na	62%	69%	80%

450 kg/day are expected to be installed at a capital cost of $2.8 million per station. On a capacity basis, EC capital costs represent a 62% reduction from the capital intensity of SOTA stations. Additional capital cost reductions are achieved with MS and LS station types, with LS stations reaching a capacity of 1,500 kg/day after 2016 and an 80% reduction in capital per capacity. Examples of opportunities that would likely contribute to these cost reductions include the following [5]:

- Develop "Standard" station designs
- Harmonize/Standardize dispensing equipment specifications
- Develop "Type Approvals" for use in permitting
- Encourage station buyers to design request for proposals that incentivize standard, scalable designs or networks of stations (rather than one-off, custom-built projects)

These weighted, aggregate results were re-entered into the HSCC to calculate costs per kg of hydrogen delivered from each station type. Unfortunately, a consistent view of variable costs (feedstock costs and variable operating costs such as compression) could not be included in these general $/kg estimates. The resulting costs are therefore only part of the total costs that must be recovered at the pump (e.g., from consumers or fuel subsidies). For example, in the case of a truck delivery station, these costs would not include the cost of the hydrogen delivered to the station—though they do include some upstream capital cost components directly associated with truck delivery stations. The $/kg costs associated with fixed operating and capital costs are indicated in Figure 2, along with the approximate number of FCEVs that would be served when each station type becomes viable. As indicated, significant reductions are anticipated between SOTA and EC stations, and then an additional 19%

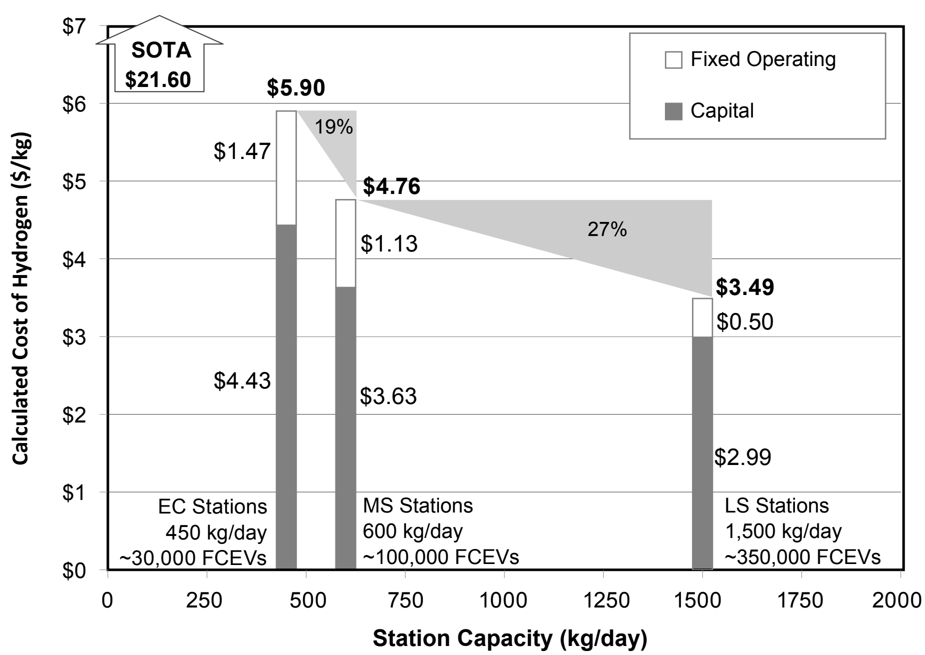

FIGURE 2. Capital and fixed operating costs by station type and capacity. Station capacities and total FCEVs supported at the time of introduction are indicated for each station type.

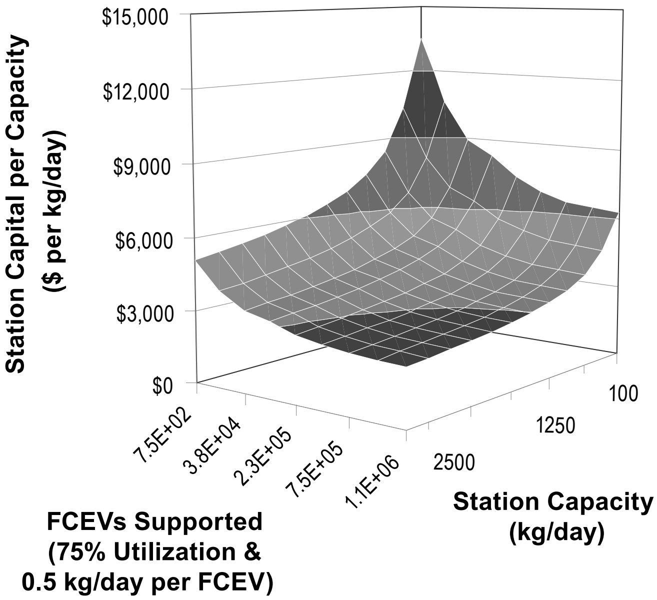

FIGURE 3. Surface plot of general function for capital cost per capacity

reduction moving from EC to MS stations, and an additional 27% reduction moving from MS to LS stations. Research, development, demonstration and deployment priorities from the HSCC are reviewed in [5].

Capital cost results from the HSCC can be articulated as a function of station size and the total capacity of stations installed over time, which itself can be expressed as the total number of FCEVs supported. This capital cost function, shown in Figure 3, is the following:

$$C' = C^o \left(\frac{Q'}{Q^o} \right)^{\alpha} \left(\frac{V'}{V^o} \right)^{\beta}$$

Where,

C' = Station Capital Cost ($/station)

C^o = Base Station Capital Cost ($/station) ($C^o_{EC}$ = $2.65M)

Q' = Station Capacity (kg/d)

Q^o = Base Station Capacity (kg/day) (Q^o_{HSCC} = 450 kg/day)

V' = Cumulative Capacity (kg/day)

V^o = Cumulative Capacity at Cost Status of Base Station (kg/day) (V^o_{HSCC} = 25,000 kg/d)

α = Scaling Factor (α_{HSCC} = 0.707)

β = Learning Factor (β_{HSCC} = -0.106)

The numerical values for base station capital cost, scaling factor, and learning factor result from a functional fit to the data shown in Table 1.

Conclusions and Future Directions

Additional information on HRS costs in the near term (2012 to 2016+) has been quantified on a consistent basis for general hydrogen stations, as expected by a select group of expert stakeholders for four types of hydrogen stations. Each station type represents a distinct level of technology development: SOTA stations represent HRS being deployed today, EC stations have a unique market-based definition (Table 1), MS stations reflect EC stations deployed in larger numbers, and LS stations represent EC stations deployed with higher capacities. Cost reductions associated with each station type have been quantified on a weighted, aggregated basis, reflecting input provided from 11 stakeholders by way of the HSCC. Significant reductions in HRS capital costs are anticipated in the 2014-2016 timeframe; capital cost per capacity ($ per kg/day) is expected to be reduced by 62% between SOTA and EC stations, and by 80% between SOTA and LS stations (Table 2). Additional items that must be taken into consideration to develop more realistic analytic representations of future HRS network rollout costs are:

- Improving the representation of station size distributions, especially with respect to infrastructure rollout requirements for station coverage (stations per area) and capacity (with larger stations having more favorable return on investment).
- More realistic business case metrics to inform investment decisions and rollout strategies. The dynamic interaction between station rollout over time and vehicle adoption rates will determine station utilization rates across a given network of stations. Moreover, multi-party agreements will likely include different sources of capital with different risk tolerance levels, and subsidies may be applied selectively to best leverage public funds.

References

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