XI.3 Design and Economics of an Early Hydrogen Refueling Network for California

Joan Ogden
Institute of Transportation Studies
University of California
1715 Tilia Street
Davis, CA 95616
Phone: (530) 752-2768
Email: jmogden@ucdavis.edu

DOE Manager
Fred Joseck
Phone: (202) 586-7932
Email: Fred.Joseck@ee.doe.gov

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Overall Objectives

Provide system-level technical and economic analysis to support initial rollout of hydrogen and fuel cell technologies.

Fiscal Year (FY) 2013 Objectives

- Analyze strategies for early hydrogen fueling station placement, numbers and network development, to enable fuel accessibility for initial rollout of hydrogen fuel cell passenger cars.
- Develop robust data on costs and performance for early stations and scenarios and strategies for deployment.
- Conduct case studies for H2 fuel cell vehicle (FCV) rollout California, utilizing GIS-based analysis for station siting and consumer convenience and economics from perspective of the network, individual station owners and consumers (fuel cost).

Technical Barriers

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

(A) Future Market Behavior

(C) Inconsistent Data Assumptions and Guidelines

(D) Insufficient Suite of Models and Tools

Contribution to Achievement of DOE Systems Analysis Milestones

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

- Milestone 1.20: Complete review of fuel cell and hydrogen markets. (4Q, 2011 through 4Q, 2020)
- Milestone 1.4: 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 2013 Accomplishments

- Assessed alternative strategies for introducing FCVs and H2 infrastructure in Southern California over the next decade to satisfy the California Zero Emission Vehicle regulation. Considered station placement, number, size, and type of stations.
- Analyzed infrastructure economics from multiple perspectives: network, station owner, consumer. A spreadsheet model was developed to analyze different rollout scenarios.
- Presented results in reports and talks at meetings.
- Collaborated with California Fuel Cell Partnership and other stakeholder and analysts.

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INTRODUCTION

The cost and logistics of building early hydrogen refueling infrastructure are key barriers to the commercialization of hydrogen FCVs. Finding attractive infrastructure strategies is important to enable the initial introduction of hydrogen vehicles, when demand is small, and infrastructure must be closely coordinated with vehicle deployment. In this research, we explore the economics of a ‘‘cluster strategy’’ for introducing hydrogen vehicles and refueling infrastructure. Clustering refers to coordinated introduction of hydrogen vehicles and refueling infrastructure in a few focused geographic areas such as smaller cities (e.g. Santa Monica, Irvine) within a larger region (e.g. Los Angeles Basin) [1]. We analyze the design and economics of early hydrogen infrastructure networks over the next 10 years focusing on California, a likely site for introduction of hydrogen FCVs in support of the state's Zero Emission Vehicle regulation. Several DOE Systems Analysis goals are addressed in this work. It contributes to understanding future markets by illuminating how hydrogen might be supplied to early adopters of FCVs. Further, it helps fill gaps in station cost data and modeling.

APPROACH

To analyze alternative scenarios for building up hydrogen infrastructure over time, we developed an EXCEL-based hydrogen infrastructure rollout spreadsheet model (called HIR). Current and future hydrogen station capital and operation and maintenance (O&M) costs were estimated based on input from industry, the California Fuel Cell Partnership, the California Energy Commission and DOE analysts at the National Renewable Energy Laboratory, Oak Ridge National Laboratory and Argonne National Laboratory. We consider a range of station sizes (100 kg/d to 1000 kg/d), station types (compressed gas truck delivery, liquefied H2 truck delivery, onsite reformer, onsite electrolyzer), and technical maturity (current, 2014-5, 2015+). Our model is flexible and allows the user to run cases rapidly, to analyze a variety of hydrogen supply options, station sizes and types, and conduct sensitivity studies.

We analyzed infrastructure economics from several perspectives: the whole network, the individual station owner and the consumer (delivered hydrogen cost at the pump). Our modeling estimates how many stations would be needed and how much it will cost to develop cost competitive hydrogen supply. Outputs from the model include numbers and types of stations built, capital costs and O&M costs, hydrogen sales and cash flow over at each year. From the cash flow analysis we estimate a break-even year (the year when the station produces H2 competitively with gasoline on a cents per mile basis) and the subsidies required for various stakeholders.

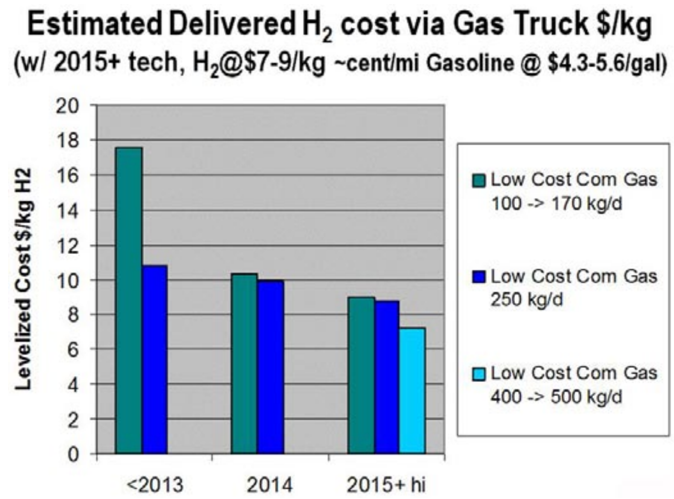

FIGURE 1. Estimated Delivered H2 Cost via Gas Truck $/kg

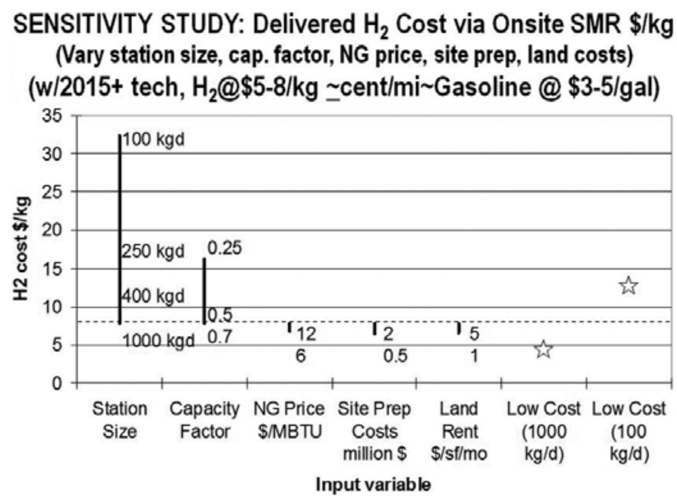

FIGURE 2. Sensitivity Study: Delivered H2 Cost via Onsite SMR $/kg

RESULTS

First we used our model to compare the cost of hydrogen from different types and sizes of hydrogen stations under steady-state conditions when stations are fully utilized.

- Results are shown in Figure 1 for stations based on compressed gas truck delivery. The levelized hydrogen cost ($/kg) is plotted for three time periods corresponding to present, 2014, and 2015+ technology and three different station sizes, from 100-500 kg/d. The cost of hydrogen decreases over time with technology improvement and with increased station size. For large stations beyond 2015, we find hydrogen costs of $7-9/kg equivalent on a cents per mile basis to gasoline at $4.3-5.6/gallon.
- Figure 2 illustrates a hydrogen cost sensitivity study for onsite reformer stations for changes in station size, utilization, natural gas cost, and other factors. For 1,000 kg/d onsite steam methane reformer (SMR) stations, we estimate costs of $5-8/kg depending on the input assumptions.

Alternative rollout scenarios were analyzed for introducing tens of thousands of FCVs and 60 to 80 stations in Southern California over the next 5-10 years, varying numbers and types of stations over time (an example station build-out schedule is shown in Figure 3: we analyzed many variations on this). The rollout analysis yielded the following key results:

- We estimate that 60-80 hydrogen stations would be needed to support 34,000 FCVs in Southern California c. 2018. (This fuel cell vehicle population was estimated by the California Fuel Cell Partnership based on a 2010 survey of automakers.) In the first few years relatively small stations are built, in later years larger stations are added (Figure 3).

- Capital investments of \$113-160 million would be needed to build a station network depending on the sizes and types of stations assumed (based on 700 bar stations ranging in size from 100 to 1,000 kg/d). This is about \$3,000-5,000 per car served for the first 60-80 stations. As more vehicles are deployed, the network expands, larger stations are built and the cost of hydrogen becomes competitive on a cents per mile basis with gasoline.
- Cash flow calculations were carried out for the whole network (Figure 4) and for an individual 500 kg/d station (Figure 5). Annual costs for station capital and operating costs and the annual revenue from hydrogen sales are shown (assuming that the station demand ramps up to 100% over four years as more FCVs arrive).
  - For the first few years, the network cash flow is negative, but it becomes positive after about 2017 as stations are better utilized (more hydrogen sales) and larger stations are added. The network breaks even in 5-7 years (Figure 4).
  - An early strategy using gas truck delivery yields H2 costs of <\$10/kg. If (H2 selling price) – (truck delivered H2 cost) ≥\$4/kg, the network breaks even in less than eight years.
  - The individual 500 kg/d station costing \$1.5 million has cash flow >0 within a few years (assuming rapid market growth). Support to compensate for early negative cash flow ~\$400-700K per station.
- We estimated a subsidy of \$50-70 million would be sufficient to support early network development to launch a competitive supply network. This accounts for capital + O&M for 18 small stations (100-250 kg/d) and support for sixty 500 kg/d stations until the cash flow becomes positive. Beyond this point, new 500 kg/d stations would make money selling H2 at competitive prices, assuming continued rapid market growth.

FIGURE 3. Scenario for Introducing 78 Stations in Southern California by Station Size and Type

#New Sta	2011	2012	2013	2014	2015	2016	2017
Mobile Refueler	4	0	0	0	0	0	0
Compressed Gas Truck Delivery							
170 kg/d	0	0	4	0	0	0	0
250 kg/d	0	0	0	10	0	0	0
400 kg/d	0	0	0	0	20	20	20
Total sta. capacity (kg/y)	400	400	1080	3580	11580	21580	31580
# FCVs in fleet	197	240	347	1161	12106	23213	34320
H2 demand (kg/y)	137	168	250	800	8500	16000	24000

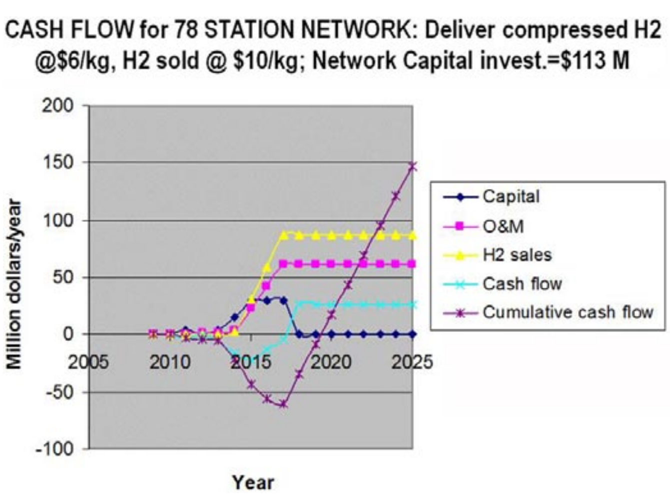

FIGURE 4. Cash Flow for 78 Station Network

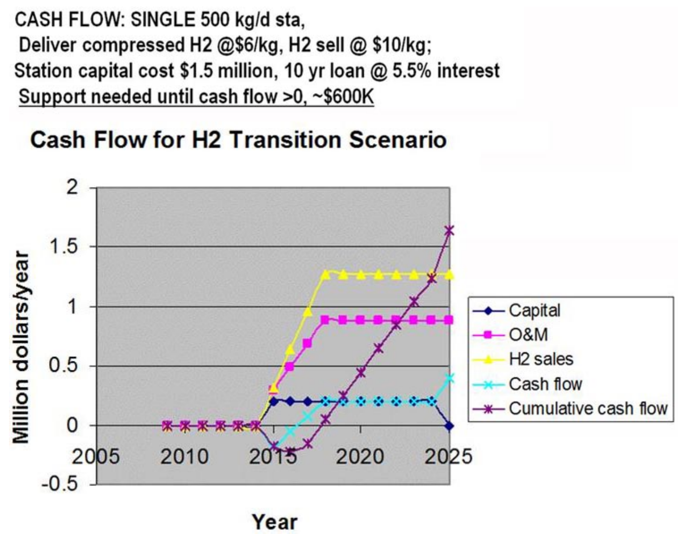

FIGURE 5. Cash Flow for Single 500 kg/d station

This research helps illustrate viable scenarios for H2 infrastructure rollout and highlight sensitivities. It contributes to understanding future markets by illuminating how hydrogen might be supplied to early adopters of FCVs. Further, it helps fill gaps in station cost data and modeling tools.

CONCLUSIONS AND FUTURE DIRECTIONS

Overall, we find that a cluster strategy provides good refueling convenience and reliability with a relatively small number of strategically placed stations, reducing infrastructure costs. There appear to be viable paths toward a cost competitive hydrogen supply network beyond 2017, assuming that markets for FCVs grow rapidly.

Future work

- Extend California rollout analysis to analyze H2 Infrastructure build out in other U.S. regions.
- Look at the potential role of tri-generation systems that co-produce electricity and heat for buildings and hydrogen for vehicles in early H2 infrastructure development (residential and commercial buildings).
- Examine longer term transition from early hydrogen supply based on natural gas derived hydrogen to “green” H2 from low net carbon pathways such as renewables and fossil with carbon capture and storage. Conduct case studies for California, U.S.

FY 2013 PUBLICATIONS/PRESENTATIONS

1. Tyson Eckerle, Remy Garderet, Ken Gunn ,Catherine Dunwoody, Jackie Birdsall, Bill Elrick, Joan Ogden, Tim Brown, “Incentivizing Hydrogen Infrastructure Investment, Phase 1: An Analysis of Cash Flow Support To Incentivize Early Stage Hydrogen Station Investment,” Report to the California Fuel Cell Partnership, June 18, 2012.

2. Michael Nicholas and Joan Ogden, “Analysis of Rollout Strategies for Fuel Cell Vehicles and Hydrogen Infrastructure in California,” presented at the UCDOE Hydrogen Technical Advisory Committee Meeting, November 15, 2012, Alexandria, VA.

3. Joan Ogden and Michael Nicholas, “Tools for Modeling Rollout Strategies for Fuel Cell Vehicles and H2 Infrastructure,” presented at NREL Hydrogen System Analysis meeting, March 12, 2013.

4. Joan Ogden, “Design and Economics of an Early Hydrogen Refueling Network for California, “USDOE, project an032, Hydrogen and Fuel Cells Annual Merit Review, Arlington, VA, May 14, 2013.

5. Michael Nicholas, “Siting Strategies for Early H2 Refueling Infrastructure in California: Learning from the Gasoline Experience”, project an031. USDOE, Hydrogen and Fuel Cells Annual Merit Review, Arlington, VA, May 14, 2013.

REFERENCES

1. Joan Ogden and Michael Nicholas, “Analysis of a ‘Cluster’ Strategy for Introducing Hydrogen Vehicles in Southern California”, *Energy Policy*, 39 (2011) 1923–1938.