II.I.6 Fuel Choice for Fuel Cell Vehicles: Hydrogen Infrastructure Costs

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Objectives

- Analyze transition scenarios that are associated with developing a hydrogen infrastructure for fuel cell vehicles (FCVs)
  - Determine investment risk and economic viability
  - Consider additional important fuel chain/vehicle combinations as appropriate
- Identify key economic barriers to development of a hydrogen infrastructure and possible development paths
  - Assess impact on various stakeholders and how risks could be shared and minimized
  - Evaluate scenarios that could bring down the initial costs of hydrogen (added scope)

Technical Barriers

This project addresses the following technical barriers from the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- Hydrogen Production: AD. Market and Delivery
- Hydrogen Delivery: A. Lack of Hydrogen/Carrier and Infrastructure Options Analysis
- Hydrogen Storage: V. Life Cycle and Efficiency Analysis

Approach

- Obtain stakeholder feedback on preliminary assumptions and "straw-person" results, and modify hydrogen infrastructure model accordingly
  - Incorporate regional-based transition scenarios
  - Consider impacts of mobile fuelers and hydrogen internal combustion engine vehicles (ICEVs)
- Calculate capital investments and net present value (NPV) for various transition scenarios using the model
  - Compare results for investment, cash flow, and NPV to identify key barriers, possible development paths, and risks to various stakeholders
  - Incorporate scenarios that could bring down the initial costs of hydrogen (added scope)

Accomplishments

We modified last year's hydrogen infrastructure model based on stakeholder input and evaluated transition scenarios.

- Presented the straw-person results to a limited number of stakeholders including ExxonMobil and Shell
- Based on stakeholder input, the model has been modified for distinct regional introduction of hydrogen vehicles

- Large- and small-capacity stations were changed to 1,500 and 100 kg H_2/day, respectively, to be consistent with other DOE analysis activities (i.e., H_2A Working Group[2])
- Transition scenarios have been developed to determine the least-cost or lowest-risk approaches to building the required hydrogen infrastructure
  - Utilizing existing excess hydrogen capacity and mobile fuelers to reduce early capital investments
  - Considering the effects of fuel cell vehicle demos and fleets, and hydrogen ICEVs, to improve capacity factors

Future Directions

For the final report, we will develop additional transition scenarios and compare their impacts on stakeholders.

- Validate and modify model inputs if necessary based on other DOE analysis activities (i.e., H_2A Working Group)
- Identify key economic barriers and possible development paths (continued)
  - Evaluate additional scenarios that could bring down the initial costs of hydrogen
  - Evaluate potential impacts on the existing infrastructure
  - Determine what may trigger the introduction of hydrogen-fueled FCVs (e.g., oil price increase, carbon taxes, aggressive FCV introduction)
- Determine energy and environmental impacts of scenarios
- Arrive at a joint DOE/industry understanding of the situation and complete draft and final reports

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Introduction

In the previous phase of work, TIAX assessed the well-to-wheel energy use, greenhouse gas emissions and ownership costs of various fuel choices for FCVs at a future point in time assuming high capacity factors and high manufacturing production volumes for equipment (Lasher, et al 2001). However, alternative fuels require significant up-front investment during a transition period, representing a risk to both vehicle manufacturer and fuel provider. The financial risks involved in each of the fuel options vary, and the risk may shift from one player in the value chain to another. Dealing with this risk represents a formidable barrier to the use of alternative fuels, especially hydrogen, for FCVs. In the current phase of work, the DOE has commissioned TIAX to assess the relative risks of various hydrogen pathways for use in FCVs.

Approach

In order to evaluate financial risks and the effect that potential triggers may have on the various hydrogen infrastructure stakeholders, we have developed a net present value (NPV) analysis. The NPV analysis takes into account the time value of money so that early investments are weighted more heavily than future profits. The NPV analysis is incorporated into a hydrogen infrastructure model that is used to project the buildup of the hydrogen infrastructure over time based on a number of user-supplied inputs, including an assumed hydrogen vehicle market penetration curve. Other model inputs include capital costs as a function of production volume, operating costs, fuel prices (e.g., gasoline), and vehicle fuel economies.

We have generated a "straw-person" scenario of the hydrogen infrastructure introduction based on results from previous work, literature sources, and additional analysis. We have presented the straw-person scenario assumptions and results to a limited number of energy company representatives. We will expand this outreach element to include hydrogen vehicle developers and additional stakeholders to verify and refine the assumptions and discuss the risk aspects for each stakeholder. Based on the feedback from these presentations, we will refine our analysis and rank the hydrogen fuel chains with respect to a set of performance criteria, in particular to overall financial risk.

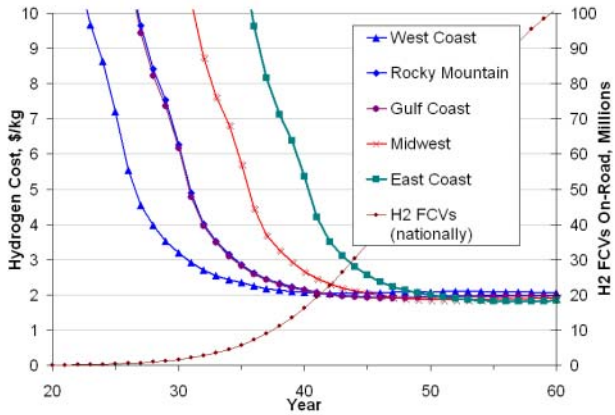

Figure 1. Regional Hydrogen Costs – Large (1500 kg/day) On-site Natural Gas Steam Reforming Station

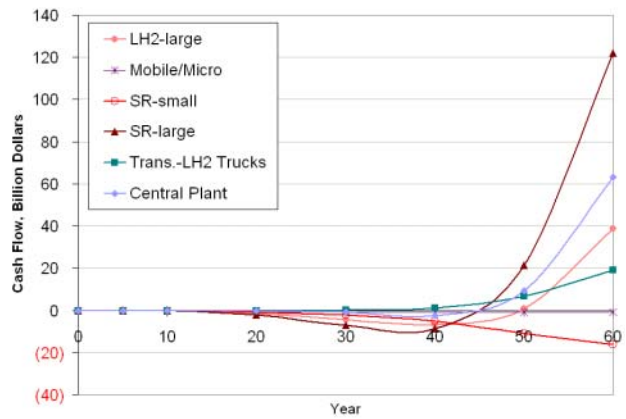

Figure 2. Cumulative Cash Flow – Various Stakeholders and Pathways

Results

We have met with stakeholders and others outside of DOE to present our results/perspectives and solicit feedback on our progress. Based on stakeholder input, the hydrogen infrastructure model has been modified for distinct regional introduction of hydrogen vehicles based on the U.S. PADD (Petroleum Administration for Defense Districts) regions. Hydrogen vehicle introduction is assumed to start in one region and move gradually to others so that regional fueling station coverage[3] can be met with reduced economic risk versus achieving immediate national coverage. Fueling station capacity factors are no longer user inputs, but model outputs based on the assumed coverage requirements and mix of station types. Assumptions can also be made about urban versus rural station coverage and market shares.

The NPV model can be used to evaluate the cost of hydrogen from various pathways in each region over time. As seen in Figure 1, hydrogen production costs[4] would ultimately reach $2/kg, but initial costs are high in all regions. Hydrogen costs are high for later regions despite assumed reduced capital costs due to "economies of scale," reflecting the fact that hydrogen costs depend strongly on station capacity factors. Although more optimistic scenarios can be envisioned, early hydrogen sales will likely require some form of subsidies to be competitive with conventional fuels.

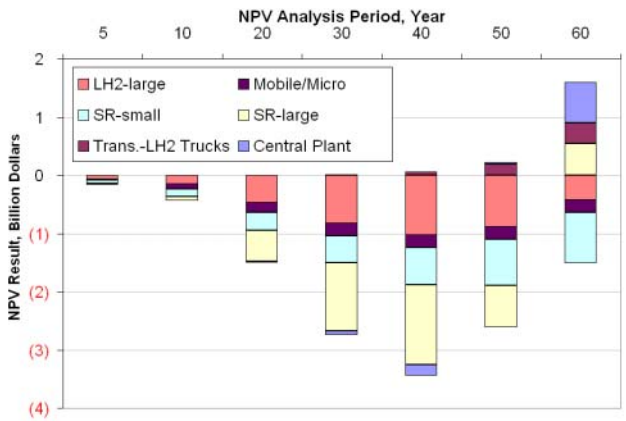

Figure 3. Net Present Value – Various Stakeholders and Pathways

We can use the analysis to evaluate stakeholder risks and the economic viability of various pathways. As can been seen in Figures 2 and 3, it is a very long time before the stakeholders of any pathway are able to turn a profit (Figure 2) and even longer before they recover their investments (Figure 3). Note that the scenario shown in these figures assumes a mix of pathways with end-user hydrogen selling prices varying with time. Central plant and truck delivery stakeholders are assumed to achieve fixed internal rates of return on their investment. Forecourt fueling station stakeholders (i.e., LH2-small, LH2-large, Mobile/Micro, steam reformer [SR]-small, and SR-large) achieve rates of return based on end-user hydrogen selling prices that are assumed to be equivalent to fuel for conventional vehicles on a

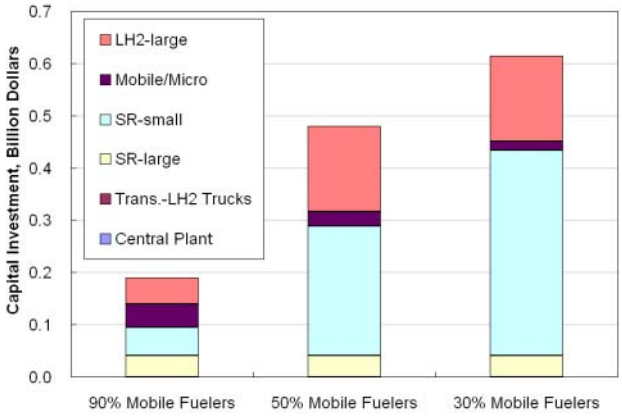

Figure 4. Mobile Fuelers Impact – California Capital Investment through 2013

$/mile basis. The end-user hydrogen selling prices are a function of the assumed conventional vehicle fuel economy, hydrogen vehicle fuel economy, gasoline price, and assumed fuel taxes over time.

Additional scenarios have been developed to determine the least-cost or lowest-risk approaches. In a California scenario shown in Figure 4, mobile fuelers significantly reduce the initial capital investment required to meet fueling station coverage requirements. Note that existing liquid hydrogen (LH_2) capacity in California can meet the 2013 demand from vehicles in this scenario. If new central plant capacity is required, mobile fuelers are not as attractive.

It should be noted that the results presented here are based on projections of the future cost of a high-efficiency hydrogen infrastructure. We did not use DOE targets, and there is on-going work at DOE and in various industries to improve costs and performance beyond those projected here. In addition, these results were based on the DOE Office of Transportation Technologies (OTT) "Case I: 3% by 2030" fuel cell vehicle introduction scenario. Faster vehicle introduction scenarios result in more positive economic outcomes.

Conclusions

Based on the results of a limited number of scenarios, a few general conclusions can be drawn:

- Hydrogen production costs could ultimately be low (<$2/kg), but initial costs are high due primarily to low capacity factors in the early years.
- If hydrogen were priced to provide cost parity with conventional vehicles, most hydrogen infrastructure stakeholders could turn a profit in the long run, but break-even would not be achieved for many years.
- Unconventional pathways are needed to improve capacity factors and reduce capital cost of the hydrogen infrastructure, especially in the early years of infrastructure development.
- Utilizing existing regional hydrogen capacity can result in significant capital investment reductions in the early years.
- Early hydrogen sales and/or infrastructure capital investments will likely require some form of subsidies to be competitive with conventional fuels.

References/ Footnotes

1. Lasher, S., J. Thijssen, S. Unnasch, "Guidance for Transportation Technologies: Fuel Choice for Fuel Cell Vehicles", *2001 Annual Progress Report – Fuels for Advanced CIDI Engines and Fuel Cells,* EERE OTT, November 2001

2. The H_2A effort was organized to develop the building blocks and frameworks needed to conduct rigorous analysis of a wide range of hydrogen technologies. In February 2003, a group of analysts who are focused on addressing economic, energy and environmental aspects of hydrogen (the "H_2A Working Group") came together for the first time to discuss potential merits and objectives that the working group might bring to the DOE Hydrogen, Fuel Cells and Infrastructure Technologies (HFCIT) Program. Analysts from national laboratories, research organizations, and contractors, including TIAX, have participated in the group.

3. Coverage refers to the number of fueling stations with hydrogen capacity divided by the total number of fueling stations.

4. Includes capital, feedstock, and operating and maintenance costs.

FY 2004 Publications/Presentations

1. Lasher, S., "Candidate Fuels for Vehicle Fuel Cell Power Systems: Stakeholder Risk Analysis", presented at the 2003 Hydrogen and Fuel Cells Merit Review Meeting, Berkeley, CA, May 19-22, 2003

2. Lasher, S., P. Teagan, and S. Unnasch, "Fuel Choice for Fuel Cell Vehicles: Near-Term and Long-Term Perspectives", presented at the 2003 SAE Powertrain and Fluid Systems Conference and Exhibition, Pittsburgh, PA, October 27-30, 2003

3. Lasher, S., P. Teagan, and S. Unnasch, "Near-Term and Long-Term Perspectives of Fuel Choices for Fuel Cell Vehicles", presented at the 2003 Fuel Cell Seminar, Miami Beach, FL, November 7, 2003

4. Lasher, S. and S. Unnasch, "Hydrogen Infrastructure Costs", presented by E. Carlson at the First International Conference on Fuel Cell Development and Deployment, Storrs, CT, March 10, 2004

5. TIAX LLC, "Technology and Market Assessments of Hydrogen as a Transportation Fuel", presented by B. Weber at the Council for Chemical Research 25th Annual Meeting, Tampa, FL, April 17-20, 2004

6. Unnasch, S., B. Blackburn (CEC), and E. Ebeles (U.C. Davis), "Hydrogen Supply and Demand for Future Fuel Use", presented at the National Hydrogen Association Meeting, Los Angeles, CA, April 26-29, 2004