X.9 Electricity Market Valuation for Hydrogen Technologies

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Project Start Date: January 7, 2013
Project End Date: January 7, 2015

Overall Objectives

- Evaluate the ability of electrolyzers to bid into electricity markets
- Assess the value proposition for grid integration of hydrogen technologies
- Include hydrogen technologies into large-scale grid operation models

Fiscal Year (FY) 2014 Objectives

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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

(B) Stove-Piped/Siloed Analytical Capability

(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 System Analysis section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

- Milestone 1.5: Complete evaluation of hydrogen for energy storage and as an energy carrier to supplement energy and electrical infrastructure. (4Q, 2012)
- Milestone 1.9: Complete analysis and studies of resource/feedstock, production/delivery, and existing infrastructure for technology readiness. (4Q, 2014)

FY 2014 Accomplishments

- Determined, using operational data, that small (~40-kW) electrolyzers acting as demand response devices can respond sufficiently fast and for a long enough duration to participate in energy, capacity and ancillary service electricity markets.
- Created an optimization tool for analyzing the operation and economic competitiveness of hydrogen energy storage and demand response technologies.
- Performed an extensive review of methodology, inputs parameters and findings from industry and government stakeholders.
- Integrated the use of hydrogen storage and demand response technologies into a production cost model to determine grid system impacts.

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INTRODUCTION

Hydrogen is a versatile element that can be used in a variety of applications including chemical and industrial processes, transportation and heating fuel as well as for electricity generation. Traditionally, hydrogen technologies focus on providing services to one sector; however, engaging multiple sectors has the potential to provide benefits to each sector and increase revenue potential. Additionally, electrolyzers are amenable to operation on renewable electricity so there is also the potential to reduce greenhouse gas and criteria pollutant emissions, while providing grid services.

Fuel cells and electrolyzers do not currently bid into the electricity market; however, dispatchable generation and loads are allowed to participate. There is potential to increase revenue by participating in electricity markets. The additional revenue received from dispatching the hydrogen technologies to support the grid can serve to increase the economic competitiveness of those technologies and accelerate the timetable for achieving the DOE hydrogen production cost targets.

APPROACH

This work involved three sequential activities: 1) Determine the requirements for participation in electricity markets and test electrolyzers to see if they are technically able to participate. Electrolyzers from the National Wind Technology Center were tested for response time, ramp-rate, turndown, startup time and shutdown time. 2) Develop an optimization tool capable of maximizing revenue from participation in electricity markets and the sale of hydrogen. This was done by modifying a price-taker model developed for analyzing energy storage to accommodate demand response devices and the sale of hydrogen. This tool was developed for the GAMS modeling environment and uses CPLEX as the solver. Historical prices from California in 2012 are used for energy, regulation, spinning and non-spinning reserve markets. With knowledge from the two previous steps for the most economic hydrogen system architectures, the final step is to 3) implement hydrogen technologies into a production cost model, PLEXOS. While the price-taker model presents the ideal operation to maximize profits the production cost model complements those results by calculating the optimal operation to support the larger grid system.

RESULTS

First, the operating flexibility of electrolyzers was tested using small (~40-kW) proton exchange membrane and alkaline electrolyzers. Electrolyzers acting as demand response devices can respond sufficiently fast and for long enough duration to participate in energy, capacity and ancillary service electricity markets. Furthermore, electrolyzers can be operated to support a variety of applications while also providing hydrogen for industrial processes, transportation fuel, or heating fuel. This opens new markets for electrolyzers and can aid in reaching the DOE hydrogen production cost targets by providing supplemental revenue streams. The results from the tests are summarized in the following and more details can be found in reference [1].

- Small electrolyzer systems begin changing their electricity demand within milliseconds of a set-point change
- The settling time after a set-point change is on the order of seconds
- Electrolyzers can reduce their electrical consumption for an unlimited amount of time
- Electrolyzers exhibit low part-load operation capabilities
- Electrolyzers can startup and shutdown in several minutes

Favorable operating properties and a variety of potential system architectures showcase the flexibility of hydrogen technologies. Figure 1 shows configurations for hydrogen equipment that we explore for economic competitiveness. Notice that multiple opportunities exist for each piece of

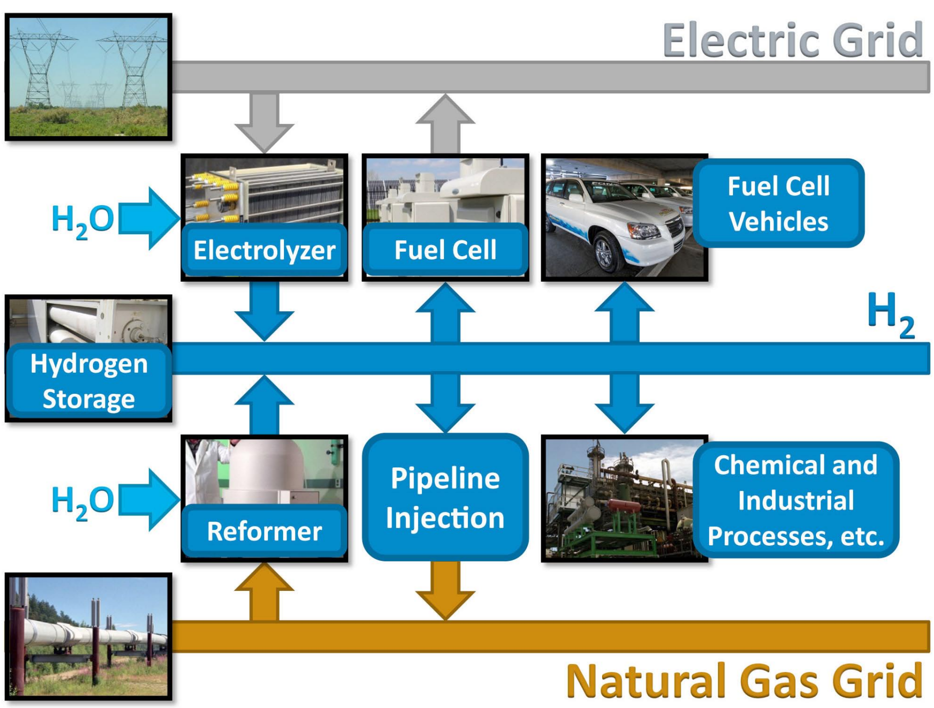

FIGURE 1. Hydrogen Technology Configurations[1]

[1] Picture sources (from top left by row), Path 26 Wikipedia GNU license; Matt Stiveson, NREL 12508; Keith Wipke, NREL 17319; Dennis Schroeder, NREL 22794; NextEnergy Center, NREL 16129; Warren Gretz, NREL 09830; David Parsons, NREL 05050; and Bruce Green, NREL 09408

equipment and depending on the configuration, multiple sectors become interconnected.

The maximum revenue achievable for each configuration was compared to the annualized cost to determine which systems are economically competitive (Figure 2). Hydrogen technologies (i.e., electrolyzer [EY], fuel cell [FC], and steam methane reformer [SMR]) are compared to conventional technologies (i.e., pumped hydro [HYPS] and lead acid batteries [batt]) and the competitiveness of not selling hydrogen (i.e., "no sale of H_2" means electricity-in, electricity-out devices) is compared to selling hydrogen at 80% capacity factor for the production equipment. List of assumptions can be found in Eichman, 2014 [Presentation 7]. Additionally, we compare different operation profiles including typical flat profile operation ("baseload"), providing only energy services ("Eonly") and providing both energy and ancillary services ("All")

It is clear that selling hydrogen can provide significantly more revenue than not selling hydrogen and strict electricity storage devices (e.g., electricity in, electricity out) using hydrogen are not competitive. In all cases, greater participation in electricity markets increased revenue. Devices providing both energy and ancillary services generate more revenue than devices only participating in energy markets. The demand response (i.e., last four on right) cases are particularly promising for hydrogen technologies. SMR is currently the widest used technology for hydrogen production and shows the greatest revenue margin but does not allow for integration with electricity markets. Electrolyzers are currently operated in baseload mode; however, there is significant value to capture from participating in electricity markets.

A sensitivity analysis is performed on the additional achievable value for increasing the energy capacity from 3 hours to 168 hours. Results for a fuel cell and electrolyzer storage device capable of providing both energy and ancillary services are presented in Figure 3. The revenue only slightly increases with additional capacity (i.e., 3.8% for \$3/kg hydrogen and 1.2% for \$10/kg hydrogen). This shows that more storage capacity is not necessarily more valuable in current energy and ancillary service markets. Aboveground steel tanks are used for storage so the cost increases linearly as the required storage capacity increases. Underground hydrogen storage could potentially reduce the cost for high volume storage; however, the revenue would not increase more on account of the storage technology used.

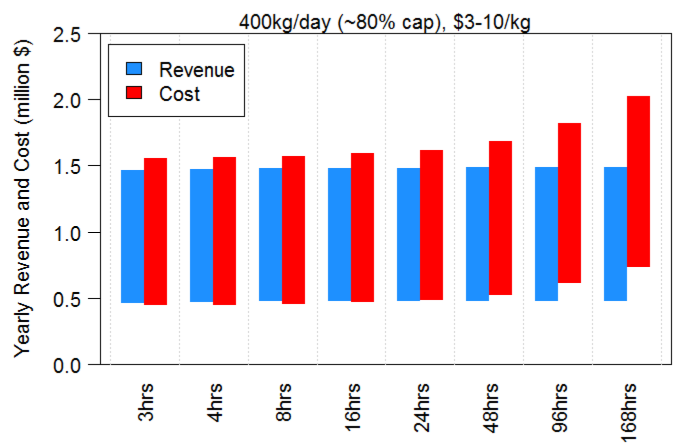

FIGURE 3. Storage Capacity Sensitivity Analysis

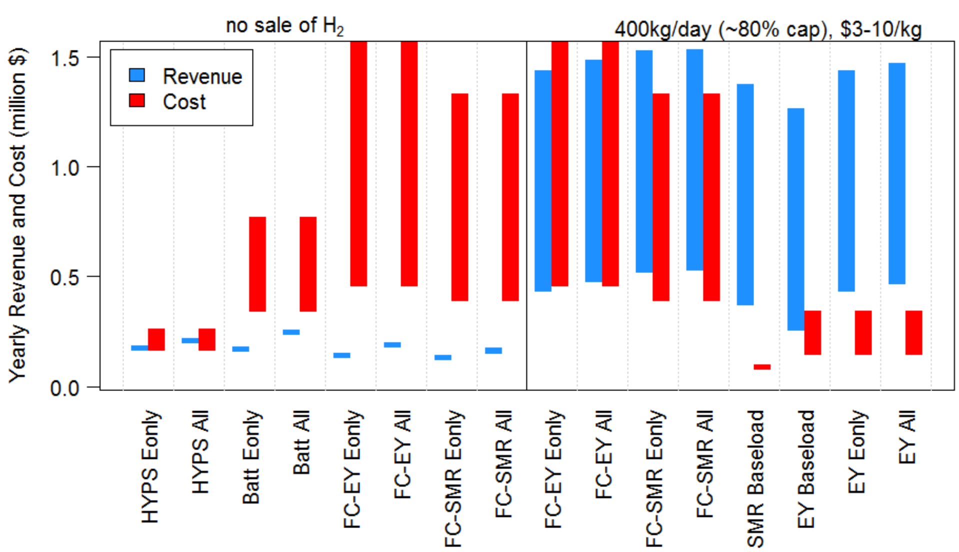

FIGURE 2. Comparison of Cost versus Electricity Market Revenue

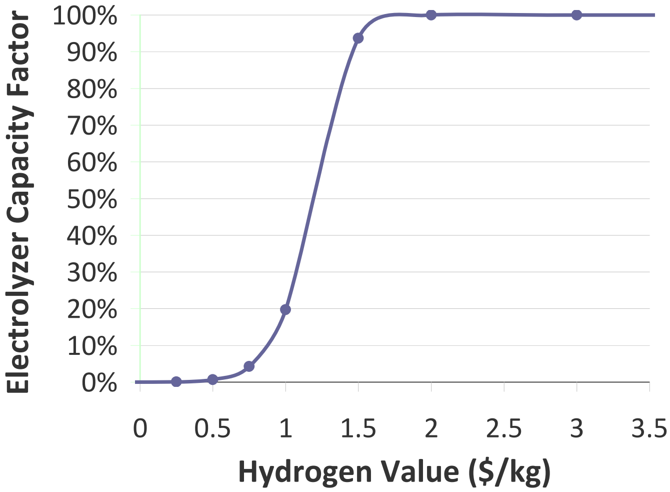

FIGURE 4. Electrolyzer Yearly Capacity Factor for Different Hydrogen Values from PLEXOS

We successfully integrated both hydrogen energy storage and demand response technologies into a production cost model. Figure 4 presents the electrolyzer yearly capacity factor with respect to hydrogen price. This shows how an electrolyzer operating as a demand response device changes operation with varying hydrogen sale price within California in 2022. With very low hydrogen prices, the grid receives the most value from participating in grid services but once the value of hydrogen is high enough, sale of hydrogen is more valuable than electricity (including arbitrage and ancillary services) and the capacity factor goes to 100%.

To the author's knowledge, this is the first time that hydrogen storage and demand response technologies have been integrated into a production cost model. The results offer great insight into the value of hydrogen from a utility or grid operator's point of view.

CONCLUSIONS AND FUTURE DIRECTIONS

This work bridges previously disconnected areas; that of hydrogen, and grid modeling and integration. From experimentally testing the operation parameters for electrolyzers it was found that they can respond sufficiently fast and for a long enough duration to participate in energy, capacity and ancillary service electricity markets. Knowing the flexibility of electrolyzers, we then explored the economic competitiveness of hydrogen technologies that participate in multiple sectors. We found 1) using hydrogen equipment to provide grid services has the potential to increase revenues beyond conventional operation, 2) the sale of hydrogen is important to achieve competitiveness; a strict electric storage device (electricity-in, electricity-out) is less competitive than technologies that sell hydrogen, and 3) additional energy storage capacity is not necessarily more competitive in current energy and ancillary service markets. Recognizing which configuration has the greatest potential can help to guide both industry and the DOE's decision making processes to maximize investments and to understand future market behavior.

One of the important factors that will impact the economics of having electrolyzers provide grid services is the impacts of variable operation on the operation and maintenance costs and lifetime of the equipment. This work did not consider the impacts of degradation on the stack or system; however, other NREL activities are exploring the impacts of variable electrolyzer operation on lifetime and stack performance. Economic comparisons were performed using California values for 2012, but looking at different years and different locations would improve the integrity of the results.

FY 2014 PUBLICATIONS/PRESENTATIONS

1. Eichman J., K. Harrison and M. Peters. (2014). "Novel Electrolyzer Applications: Providing more than just hydrogen," National Renewable Energy Laboratory. Golden, CO, NREL/TP-5400-61758 (In Review).

2. Eichman J., "Electricity Market Value for Fuel Cells and Electrolyzers," Presentation to FuelCell Energy on January 24, 2014.

3. Josh Eichman, "Electrolyzer Flexibility Study," Presentation to DOE FCTO on February 18, 2014.

4. Eichman J., "Electricity Market Value for Fuel Cells and Electrolyzers," Presentation to Xcel Energy on February 25, 2014.

5. Eichman J., "Electricity Market Valuation for Fuel Cells and Electrolyzers," Conference Presentation at ICEPAG in Irvine, California on April 2, 2014.

6. Eichman J., "H_2 Grid Integration: Tools and Analyses," Presentation at DOE/Industry Canada Hydrogen Energy Workshop in Sacramento, California on May 14, 2014.

7. Eichman J., "Electricity Market Valuation for Hydrogen Technologies," Presentation at the 2014 DOE Hydrogen and Fuel Cell Technologies Program Annual Merit Review on June 17, 2014.

REFERENCES

1. Eichman, J., K. Harrison and M. Peters. (2014). "Novel Electrolyzer Applications: Providing more than just hydrogen," National Renewable Energy Laboratory. Golden, CO, NREL/TP-5400-61758 (In Review).