Integrated Systems Modeling of the Interactions between Stationary Hydrogen, Vehicles, and Grid Resources

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Project End Date: September 30, 2019

Overall Objectives

- Provide an integrated modeling capability—the Hydrogen Vehicle to Grid Integration (H2VGI) Model—to quantify the interactions between stationary hydrogen generation, fuel cell vehicles, and grid support resources.
- Quantify potential grid support and balancing resources from flexible hydrogen systems (e.g., dispatchable production of hydrogen by electrolysis).
- Develop methods to optimize the systems configuration and operating strategy for grid-integrated hydrogen systems.

Fiscal Year (FY) 2018 Objectives

- Realistic integration of hydrogen resources into grid models to capture potential benefits and impacts for hydrogen technologies.
- Refine input values into economic models for hydrogen resources from available data and literature (e.g., fuel cell vehicle, electrolyzer, and fueling station costs).
- Garner industry feedback for project modeling strategy and results.
- Submit economic case study quantifying the scale of the opportunity from hydrogen-vehicle-grid integration for several utility regions in the Western Interconnect for both central and distributed electrolyzer operation and station configuration/storage sizing.
- Quantify the value of hydrogen production for fuel cell electric vehicles (FCEVs) in the Western Electricity Coordinating Council (WECC) area to support renewable supply integration.
- Draft a short report on testing and validation of an H2VGI economic modeling case study with key graphs and figures summarizing findings.

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[1]:

(A) Lack of Fuel Cell Electric Vehicle and Fuel Cell Bus Performance and Durability Data

(D) Insufficient Suite of Models and Tools.

Contribution to Achievement of DOE Systems Analysis Milestones

This project will contribute to the 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 1.5: 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)

[1] https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

FY 2018 Accomplishments

- Submitted a paper to explore the opportunity for providing balancing support to the grid. This shows the potential impact that hydrogen systems can have on a large grid system.
- Refined the refilling behavior according to realistic data.
- Established a concept model in PLEXOS to perform the economic analysis.
- Assessed several utility regions in the Western Interconnect with all assumptions and methods vetted
- Forecasted FCEVs, which were used to estimate the hydrogen consumption.
- Compared the economic cost for the central and distributed hydrogen generating scenarios.
- Created the PLEXOS model to compare the economic cost for different electrolyzer sizes.

INTRODUCTION

The goal of this multiyear project is to establish the available capacity, value, and impacts of interconnecting hydrogen infrastructure and FCEVs to the electric grid. The first objective is to quantify the opportunity of utilizing flexibility from hydrogen systems to support the grid. This includes provisions for vehicle and station controllable loads. The second objective is to develop and implement methods to assess the optimal system configuration and operating strategy for grid-integrated hydrogen systems. This involves developing a modeling framework that can analyze the value of optimally dispatching resources based on grid needs while respecting hydrogen production and vehicle travel requirements. The third objective is to develop the economic model to evaluate the cost in different hydrogen production scenarios. For example, both the centralized and the distributed hydrogen stations are analyzed to evaluate the cost difference. By exploring different electrolyzer sizes, variations in system cost are investigated using PLEXOS in the WECC area. These results can form the basis for future hydrogen station installations and provide a reference for future electricity grid planning.

APPROACH

There are two key topics to be investigated: (1) explore the cost difference between the centralized and distributed hydrogen stations, considering the delivering process; and (2) explore the cost difference as a function of electrolyzer size in the whole WECC area by using PLEXOS. First, vehicle and station rollout scenarios will be developed using the Scenario Evaluation and Regionalization Analysis (SERA) model [1]. Individual vehicle models, energy demands from large numbers of FCEVs, and backup power capacity for grid services will be developed using the Lawrence Berkeley National Laboratory V2G-Sim modeling framework [2, 3]. The National Renewable Energy Laboratory will lead the development of individual hydrogen generation/station models and aggregate hydrogen generation capacity allocation for grid services [4]. Finally, vehicle and hydrogen generation data will be integrated into external grid models (e.g., vehicle operating characteristics and historical market prices) to quantify the economic impacts of flexible hydrogen resources on grid operation. After estimating hydrogen consumption volume, central and distributed hydrogen production options will be analyzed. For both the United States and California scenarios, the hydrogen station operation cost will be analyzed. In the PLEXOS model [5], the hydrogen consumption rate will be used to calculate the volume of electricity needed to generate the hydrogen. Then, the pumped hydroelectric storage capability of PLEXOS will be used to simulate the hydrogen generation and utilization process. Finally, the electrolyzers will be connected to nodes and interact with the whole grid system to supply the hydrogen generation.

RESULTS

Fuel cell vehicle models have been formulated and calibrated for use using V2G-Sim, which has been extended to include FCEVs. The FCEV models allow hydrogen consumption to be predicted for any trip, given speed and terrain versus time profiles for the trip and the prediction of hydrogen demand from large collections of vehicles based on travel itinerary data using National Household Travel Survey data [6]. The coupled sub-models include calibrated fuel cell vehicle models and a preliminary refueling sub-model, which governs when individual vehicles are refueled within their travel itineraries.

Using the hydrogen FCEV demand sub-models, preliminary results have been found for the hydrogen demand, electrolyzer cycling profiles, and grid power demand at the hydrogen fueling station for nearly 3,000 vehicles driving and refueling over 40 days. This capability to predict and aggregate FCEV hydrogen demand is a key building block for determining temporally and spatially resolved hydrogen fueling demand as a function of adoption scenario.

We plotted the refueling probability as the red line in Figure 1 to show a clear comparison with our previous assumption. There is a probability that refueling will occur when the tank level is lower than 100% and that probability grows as the tank level reduces.

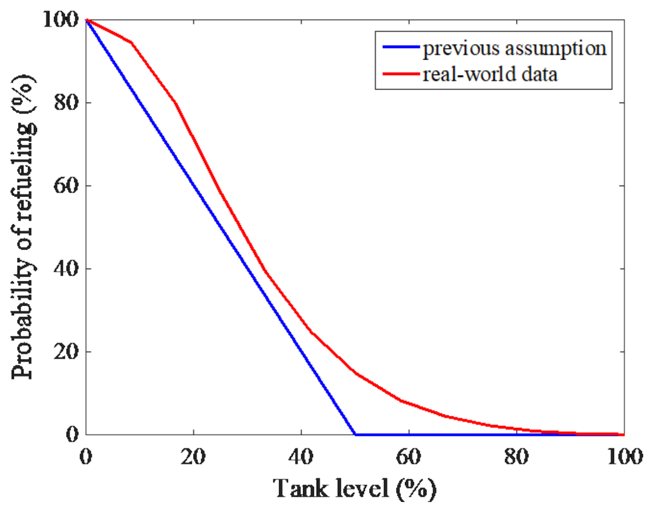

Figure 1. FCEV refueling behavior assumption in our previous work

Using the H2VGI toolkit, the value of central versus distributed production was explored for the entire hydrogen production-distribution-dispensing network, largely with the SERA model, and also for individual stations within the network using V2G-Sim. For individual hydrogen stations, the electricity consumption is highly dependent on the type of station (e.g., gaseous delivered, liquid delivered, gaseous on-site production). An on-site electrolysis station's electricity consumption is dominated by the electrolyzer. The consumption for the other components is an order of magnitude less than for the electrolyzer. Without considering electrolyzer consumption, a liquid delivered hydrogen station has the highest consumption, followed by the on-site electrolysis station, and, last, the gaseous delivered hydrogen station. This is because both the liquid and on-site electrolysis stations require additional electricity to compress the hydrogen into medium-pressure tanks, while the gaseous delivered station gets pressurized hydrogen into the medium-pressure tanks.

Figure 2 shows the total cost to operate the entire hydrogen network. The cost increases for each successive year as more hydrogen infrastructure is installed and more hydrogen is delivered to customers. Regarding electrolysis, for the entire United States, the cost for central electrolysis is lower than for distributed electrolysis due to large economies of scale; however, in California the cost for central electrolysis is higher than distributed electrolysis for all years considered due to the limited market size. This is attributed to the market conditions in California (e.g., fuel prices for trucks and large travel distances due to cities being spread out).

Figure 3 shows the annual total generation cost and average price of the WECC load. Three points can be made:

- The flexible hydrogen generation scenarios can optimize the hydrogen production process, which appears to reduce the total generation cost.
- The total generation cost can be reduced as the electrolyzer size becomes larger in flexible scenarios.
- The average price has a similar trend as the total generation cost.

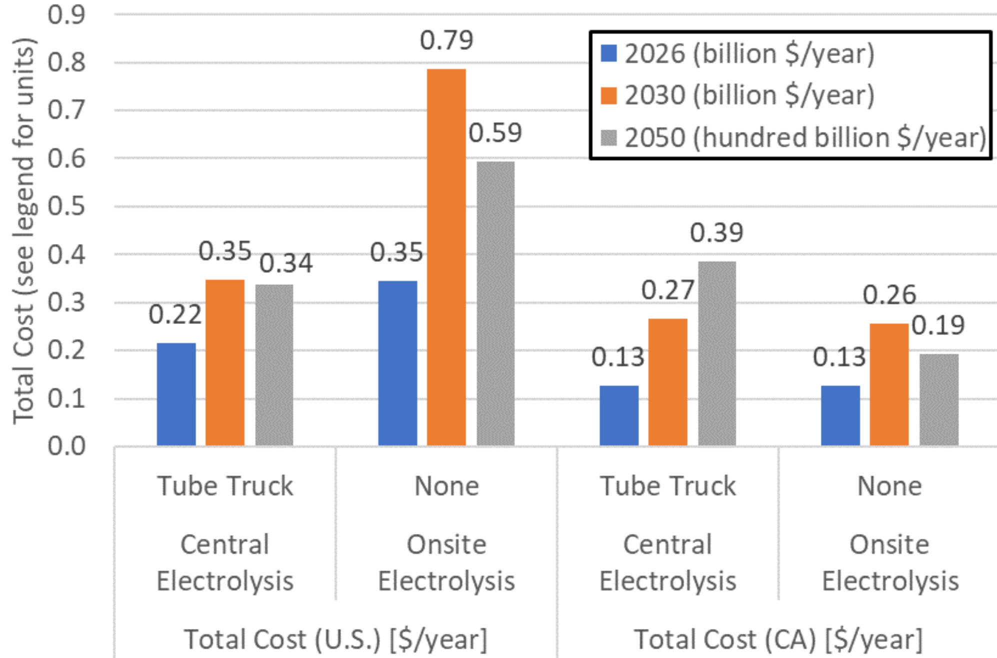

Figure 2. Total cost of operating hydrogen network

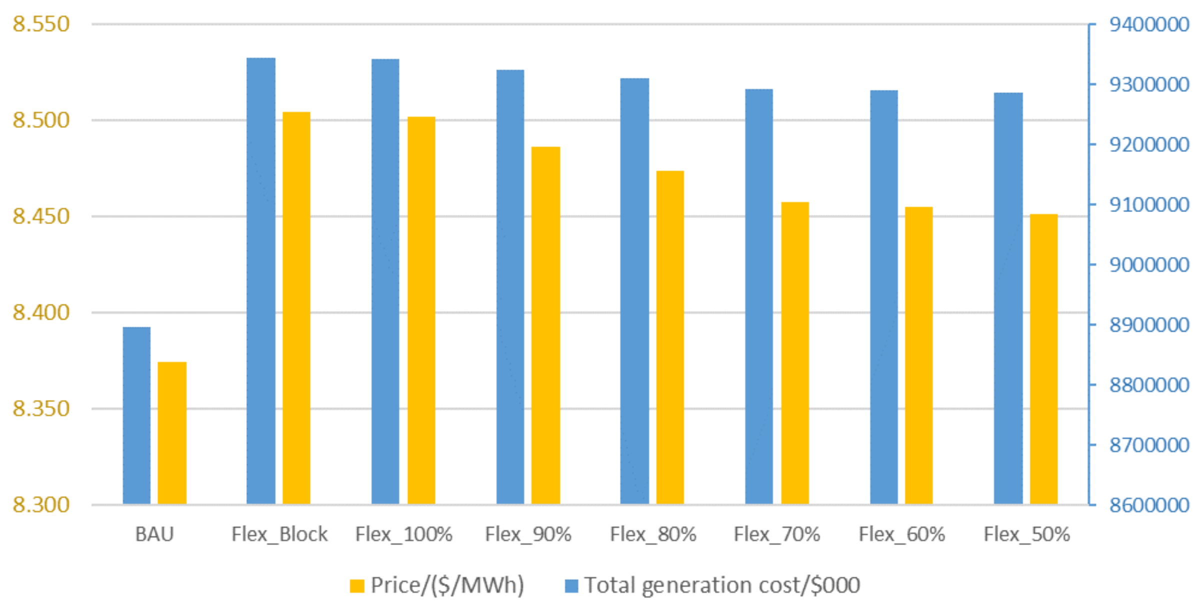

Figure 3. The annual total generation cost and average price of the WECC grid

As is shown in Figure 4, CO_2 emissions are also a significant parameter to evaluate to determine whether the electricity generators are environmentally friendly. Although CO_2 emissions increase after including the flexible hydrogen generating load, the CO_2 emissions decrease again as the electrolyzer size increases. It means that the larger flexible load can be more helpful in decreasing CO_2 emissions.

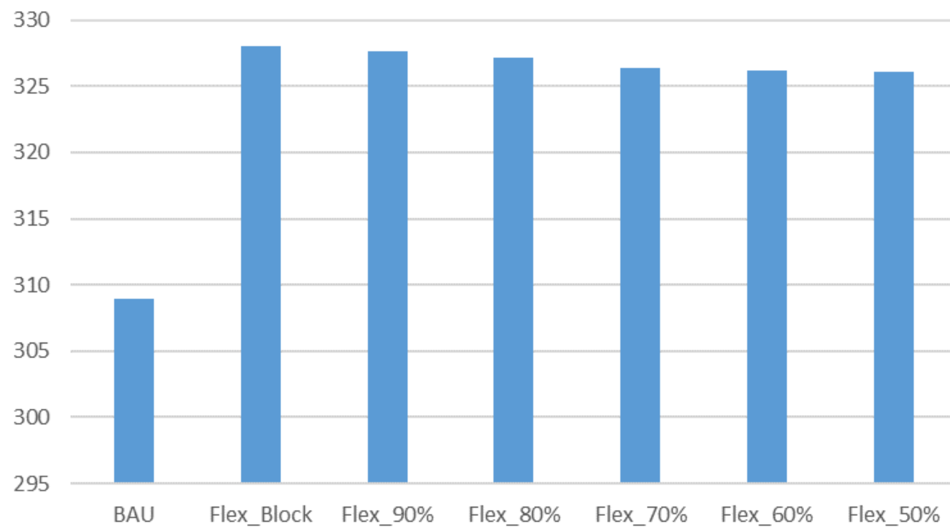

Figure 4. The CO_2 emissions of the WECC grid

CONCLUSIONS AND UPCOMING ACTIVITIES

The team has made progress on developing several sub-models for the H2VGI toolkit that include vehicle deployment scenarios, FCEV drivetrain models, fueling demand from large vehicle populations, modeling of fuel station electricity demand components, and an initial case study of the potential economic influence on the grid electricity price. In addition, for the centralized and distributed hydrogen stations, a cost comparison is also given for different scenarios.

Upcoming activities include publishing initial results on the PLEXOS case study to quantify the economic opportunity of FCEVs and developing more comprehensive scenarios to quantify the economic opportunity for FCEVs (e.g., light, medium, and heavy duty) to provide grid services within the larger alternative fuel vehicle opportunity space. A key output will be a simulation matrix defining the number of scenarios and parametric variations to be explored in each scenario. We will also estimate the hydrogen demand for FCEVs (light, medium, and heavy duty) and calculate the time-dependent hydrogen production load profiles, by implementing scenarios in PLEXOS to quantify the economic opportunity for FCEVs (light, medium, and heavy duty) to provide grid services within the larger alternative fuel vehicle opportunity space. Key outputs of this activity will be a set of H2VGI+PLEXOS models to simulate each of the defined scenarios. We will generate comprehensive results from H2VGI+PLEXOS for each of the chosen scenarios, and scenarios will include high fractions of intermittent renewable generation (e.g., 30%, 40%) and increasing adoption of hydrogen-powered vehicles (e.g., 10%, 20%, 30% of the light-duty vehicle fleet and up to 30% of the heavy-duty vehicle fleet). For this activity, we will compare the relative economic benefits and renewables integration opportunities across the different scenarios of light, medium, and heavy-duty FCEV adoption.

FY 2018 PUBLICATIONS/PRESENTATIONS

Publications:

1. Dai Wang, Matteo Muratori, Joshua Eichman, Max Wei, Samveg Saxena, Cong Zhang, “Quantifying the Flexibility of Hydrogen Production Systems To Support Large-Scale Renewable Energy Integration,” *Journal of Power Sources* 399 (2018): 383-391.

Presentations:

1. Sam Saxena (Primary Contact), Max Wei, Cong Zhang, Josh Eichmana, Matteo Muratoria, Fernando Dias, Stevic Svetomir, “Integrated Systems Modeling of the Interactions between Stationary Hydrogen, Vehicles, and Grid Resources,” presented at the 2017 DOE Annual Merit Review and Peer Evaluation Meeting, Washington, DC, June 13, 2018.

2. Sam Saxena (Primary Contact), Dai Wang, Jeff Greenblatt, Max Wei, Cong Zhang, Josh Eichmana, Matteo Muratoria, Fernando Dias, Stevic Svetomir, "Integrated Systems Modeling of the Interactions between Stationary Hydrogen, Vehicles, and Grid Resources," Online webinar for the industry, March 28–30, 2018.

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2. D. Wang, M. Muratori, J. Eichman, M. Wei, S. Saxena, and C. Zhang, "Quantifying the flexibility of hydrogen production systems to support large-scale renewable energy integration," *Journal of Power Sources* 399 (2018): 383–391.
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4. J. Eichman and F. Flores-Espino, *California Power-to-Gas and Power-to-Hydrogen Near-Term Business Case Evaluation*, Technical Report NREL/TP-5400-67384 (Golden, CO: National Renewable Energy Laboratory, December 2016).
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6. National Household Travel Survey, "National Household Travel Survey" (2009).