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

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Overall Objectives

- Provide an integrated modeling capability (hydrogen-vehicle-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) 2019 Objectives

- Develop more comprehensive scenarios to quantify the economic opportunity for fuel cell electric vehicles (FCEVs) (e.g., light, medium, and heavy duty) to provide grid services within the larger alternative fuel vehicle (AFV) opportunity space. Key output is a simulation matrix defining the number of scenarios and parametric variations to be explored in each scenario.
- Estimate the hydrogen demand for FCEVs (light, medium, and heavy duty) and calculate the time-dependent hydrogen production load profiles. Implement scenarios in PLEXOS to quantify the economic opportunity for FCEVs (light, medium, and heavy duty) to provide grid services within the larger AFV opportunity space. Key output is a set of H2VGI+PLEXOS models to simulate each of the defined scenarios.
- Generate comprehensive results from H2VGI+PLEXOS for each of the chosen scenarios. 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 light-duty vehicle [LDV] fleet and up to 30% of heavy-duty vehicle [HDV] fleet).
- Compare the relative economic benefits and renewables integration opportunities across the different scenarios of light-, medium-, and heavy-duty FCEV adoption.
- Synthesize and disseminate results on economic opportunity for FCEVs (light-, medium-, and heavy-duty) to provide grid services within the larger AFV opportunity space.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation and Systems Analysis sections 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.

Technical Targets

This project will contribute to achievement of the following DOE milestones from the Systems Analysis section of the Fuel Cell Technologies

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

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
- Milestone 1.9: Complete analysis and studies of resource/feedstock, production/delivery, and existing infrastructure for technology readiness.

FY 2019 Accomplishments

- Generated the hydrogen consumption profiles for HDVs.
- Generated the hydrogen refilling profiles for HDVs (station level).
- Established a detailed model in PLEXOS to perform the economic analysis.
- Assessed several utility regions in the Western Interconnect with all assumptions and methods vetted.
- Forecasted heavy-duty FCEVs in addition to earlier light-duty FCEVs, which were used to estimate the hydrogen consumption.
- Created the PLEXOS model to compare the economic cost for different electrolyzer size.

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. Additionally, the methodology and results of this project can support understanding of available grid services and their optimal implementation as it relates to hydrogen systems. 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. There are a number of emerging use cases for hydrogen systems that this work will expand upon. Delineating these use cases is of particular importance, since hydrogen production spans a variety of energy sectors. Success of this project after three years is measured by the development and integration of a set of models to assess the opportunity for grid integration of hydrogen production. This includes development of new models and controllers and leveraging existing models to understand the capacity of available hydrogen infrastructure to provide grid support and to understand the value stemming from that support. 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 Western Electricity Coordinating Council (WECC) area. These results can form the basis for future hydrogen station installations and provide a reference for future electricity grid planning.

APPROACH

This project will develop an H2VGI toolset to quantify and optimize the complex interactions between these energy systems. The toolset will consider the needs, technical capabilities, value streams, and costs for drivers, vehicles, hydrogen stations, utilities, system operators, and other stakeholders. The H2VGI toolset will be applied in several case studies to both quantify the opportunity for hydrogen to simultaneously support mobility and the grid and develop implementation approaches that provide the best value proposition. There are two key questions that need to be investigated: (1) based on the fuel consumption and vehicle, explore the hydrogen refilling profiles at hydrogen stations; and (2) explore the cost difference as a function of electrolyzer size in the whole WECC area by using PLEXOS [1].

First, the number of heavy-duty FCEVs is forecasted based on Energy Information Administration data, including the individual vehicle categories. Second, based on the emission factor (EMFAC) fuel consumption and the forecasted vehicle number, the aggregated hydrogen consumption of HDVs is calculated [2]. Finally, vehicle and hydrogen generation data will be integrated into external grid models to quantify the economic impacts of flexible hydrogen resources on grid operation. In the PLEXOS production cost model, the hydrogen consumption rate will be used to calculate the volume of electricity energy 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 electrolyzer will be connected to regional nodes near the vehicle demand locations and interact with the whole grid system to supply the hydrogen generation. The output of the PLEXOS can show the operational cost under different electrolyzer scenarios

RESULTS

We examined five scenarios provided in four studies of zero-emission medium- and heavy-duty vehicles in California (as shown in Table 1). All were presented in some fashion at the California Climate Policy Modeling (CCPM3) Workshop at the University of California (UC) Davis in May 2018 [3]:

- Energy and Environmental Economics (E3) contributed their PATHWAYS model results for California Air Resources Board (CARB)'s Scoping Plan scenario in November 2017 [4].
- Energy Innovation's Energy Policy Simulator was used to develop a California policy scenario [5].
- Marshall Miller at UC Davis developed a scenario using a model that was presented at [6]. An earlier version of the model was published in November 2017 [7].
- Southern California Edison (SCE) published "The Clean Power and Electrification Pathway: Realizing California's Environmental Goals" in November 2017. We utilized two scenarios from this study: high electrification and high hydrogen [8].

Table 1. The Heavy-Duty FCEV Matrix for 2030

#	Description	Electrolyzer Size	Number of Vehicles (Fraction of Stock)
1	Baseline	0	
2	FCEVs—averaged hydrogen generation	Average hydrogen generation power	5.0 million LDVs 180,000 MDVs 22,000 HDVs 12,750 buses[a]
3	FCEVs—90% electrolyzer capacity factor	Average hydrogen generation power/90%	5.0 million LDVs 180,000 MDVs 22,000 HDVs 12,750 buses
4	FCEVs—80% electrolyzer capacity factor	Average hydrogen generation power/80%	5.0 million LDVs 180,000 MDVs 22,000 HDVs 12,750 buses
5	FCEVs—70% electrolyzer capacity factor	Average hydrogen generation power/70%	5.0 million LDVs 180,000 MDVs 22,000 HDVs 12,750 buses
6	FCEVs—60% electrolyzer capacity factor	Average hydrogen generation power/60%	5.0 million LDVs 180,000 MDVs 22,000 HDVs 12,750 buses
7	FCEVs—50% electrolyzer capacity factor	Average hydrogen generation power/50%	5.0 million LDVs 180,000 MDVs 22,000 HDVs 12,750 buses

[a] Buses include transit, school, and other buses
MDV – medium-duty vehicle

Figure 1 shows the average hourly hydrogen production rate for two electrolyzer capacities (corresponding to capacity factor [CF] = 50% and 100%) across a year. We see that in the CF = 100% case, hydrogen production is by necessity constant, whereas for the CF = 50% case it is quite variable. With hydrogen demand highest in morning and evening periods and lowest at night, in both cases there is a depletion of hydrogen storage through the evening hours, reaching a minimum close to midnight. Hydrogen storage is then gradually built up again in early morning hours.

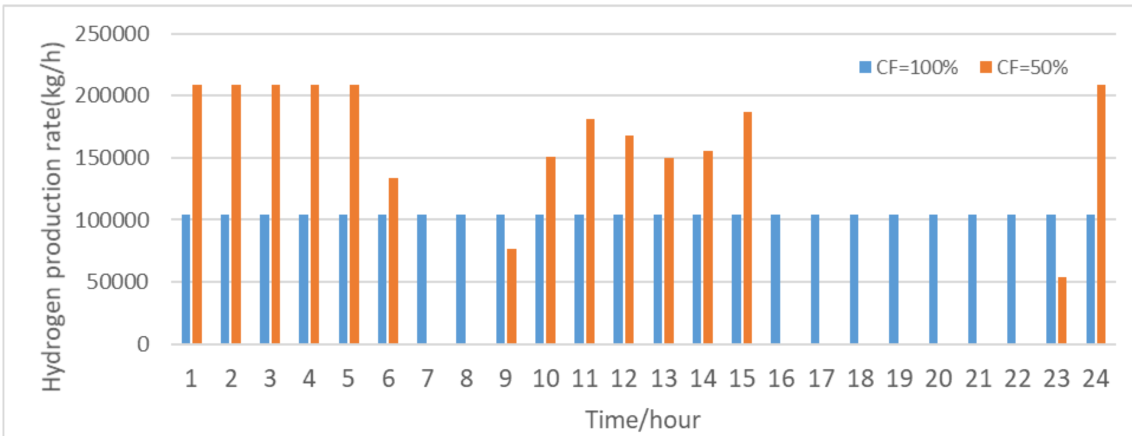
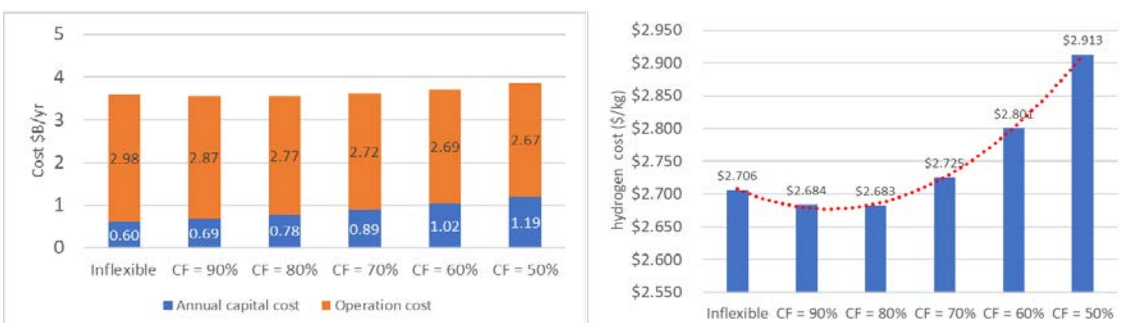


Figure 1. Hydrogen production rate in two scenarios

To determine the optimal amount of electrolyzer flexibility, we have included estimates of the capital cost of electrolyzers and associated hydrogen storage infrastructure and removed the business as usual costs. This results in the total marginal cost to install and operate the electrolyzers for each scenario (Figure 2). Assuming a future electrolyzer cost of $300/kW, we see that the total cost has a minimum point of $3.55 billion/yr at CF = 80%, indicating an optimal point between decreasing operational costs and increasing capital costs. The results are sensitive to the assumed equipment cost. In the present day, the electrolyzer cost is higher (>$1,000/kW), which results in the lowest cost scenario being the inflexible case, with no advantage to oversizing.



(a) (b)

Figure 2. (a) The total system cost (including the capital cost and operating expenses); (b) the composite cost of hydrogen production ($/kg)

CONCLUSIONS AND UPCOMING ACTIVITIES

The team has made progress on developing several sub-models for the H2VGI tool set—vehicle deployment scenarios, FCEV drivetrain models and fueling demand from large vehicle populations, and modeling of fuel station electricity demand components—and has demonstrated an initial case study of the potential economic influence on the grid electricity price.

The hydrogen electrolyzing process can be regarded as a flexible load in the grid system. This flexible load can provide grid service to smooth the demand profiles. In the current assumption, the hydrogen producing load occupies around 3% of the overall grid load. As a comparison, the average cost per megawatt-hour increases 1.55% and 0.9% for the Inflexible and CF = 50% cases, respectively. Analyzing the hourly hydrogen production rate profiles, the period of high hydrogen production is found in the load valley period, which is a consequence of the flexible load profiles in the simulation. For future work, there are two main parts. First, this flexible load from hydrogen production can facilitate higher levels of renewable energy penetration. With policy targets for higher renewable energy penetration in the future, the benefits of incorporating varying levels of flexible hydrogen generation and storage is an area for further quantification. Second, with more zero-emission vehicles anticipated in the future, the benefits of flexible load from both battery-electric vehicles and hydrogen generation for FCEVs will be important to model under various assumptions of vehicle adoption, vehicle technologies, and grid supply sources.

FY 2019 PUBLICATIONS/PRESENTATIONS

1. Cong Zhang, Samveg Saxena, Jeffery Greenblatt, Max Wei, Joshua Eichman, Matteo Muratori, and Omar Guerra, "Integration of Flexible Hydrogen Production from Electrolysis onto the Grid Could Lower Electricity Costs and Reduce Renewables Curtailment." *Journal of Power Sources* (in draft).
2. Sam Saxena, Jeffrey Greenblatt, Max Wei, Cong Zhang, Josh Eichmana, Matteo Muratoria, Fernando Dias, and Stevic Svetomir, "Integrated Systems Modeling of the Interactions Between Stationary Hydrogen, Vehicles, and Grid Resources," presented at the 2019 DOE Annual Merit Review and Peer Evaluation Meeting, Washington, D.C., April 30, 2019.

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