VII.C.2 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) 2017 Objectives

- Survey prior studies on hydrogen–vehicle–grid integration and existing simulation tools.
- Develop H2VGI model structure and code development, including sub-model data exchange formats.
- Demonstrate sub-models for vehicle activity initializer, and individual vehicle models ready for integration into overall H2VGI model.
- Integrate fuel cell electric vehicle (FCEV) hydrogen consumption sub-models with hydrogen station models developed by NREL.
- Define case studies for hydrogen vehicle–station–grid integration.
- Quantify the value of hydrogen production for FCEVs in California to support renewable supply integration.
- Show input–output validation of fully integrated hydrogen sub-models within H2VGI model to confirm that the directions of model results change as expected with inputs that have well understood sensitivities.
- Demonstrate that the H2VGI model produces results that are directionally correct based on input–output validation.

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/Silod Analytical Capability

(D) Insufficient Suite of Models and Tools

Contribution to Achievement of DOE Systems Analysis Milestones

This project contributes 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 1.16: Complete analysis of program performance, cost status, and potential use of fuel cells for a portfolio of commercial applications (4Q, 2018).
- Milestone 1.19: Complete analysis of the potential for hydrogen, stationary fuel cells, fuel cell vehicles, and other fuel cell applications such as material handling equipment including resources, infrastructure, and system effects resulting from the growth in hydrogen market shares in various economic sectors (4Q, 2020).
- Milestone 3.3: Complete review of status and outlook of non-automotive fuel cell industry (biennially from 4Q, 2011 through 4Q, 2019).

FY 2017 Accomplishments

- Formulated and calibrated fuel cell vehicle models for use within the H2VGI framework, allowing FCEV hydrogen consumption to be predicted for any trip when given speed and terrain versus time profiles for the trip.
- Developed preliminary hydrogen demand sub-models for H2VGI to predict fueling station hydrogen demand from large collections of vehicles.
- Generated self-consistent FCEV adoption and hydrogen demand scenarios relevant to early market transition, considering geospatially- and temporally-resolved vehicle adoption in each urban area in California using the Scenario, Evaluation, Regionalization, and Analysis model [1].
- Integrated several vehicle deployment scenarios from NREL into hydrogen consumption sub-models from LBNL to estimate net load peak shaving and ramp mitigation from flexible hydrogen generation for the California net load "duck curve" [2] for 2016 and 2025.
- Produced preliminary results from the hydrogen station model developed at NREL (e.g., electricity consumption by component and component pressures).
- Incorporated national Utility Rate Database information into the RODeO (Revenue Operation and Device Optimization Model) model previously developed at NREL for the optimization of various equipment [3].

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INTRODUCTION

The goal of this multi-year project is to establish the available capacity, value, and impacts of interconnecting hydrogen infrastructure and fuel cell electric vehicles to the electric grid. The first objective is to quantify the opportunity of utilizing flexibility from hydrogen systems to support the grid. This includes provision 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 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 hydrogen grid integration. 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.

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 to develop implementation approaches that provide the best value proposition. One key question to be explored is to what extent can grid support from hydrogen generation provide sufficient value to justify near-term investment in fueling infrastructure prior to widespread deployment of FCEVs?

Figure 1 shows the model components and interactions. First, vehicle and station rollout scenarios will be developed using the Scenario, Evaluation, Regionalization, and Analysis model. Individual vehicle models, energy demands from large numbers of FCEVs, and backup power capacity for grid services will be developed using the LBNL V2G-Sim modeling framework [4]. NREL will lead the development of individual hydrogen generation and station models and aggregate hydrogen generation capacity allocation for grid services. 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 impacts of flexible hydrogen resources on grid operation. Case studies will focus on specific regions and balancing authorities in the United States such as California Independent System Operator (CAISO) and New England ISO and will explore outcomes as a function of deployment scenarios, performance assumptions, and timescales.

RESULTS

Fuel cell vehicle models have been formulated and calibrated for use with V2G-Sim [4], 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 from national household travel surveys [5]. 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.

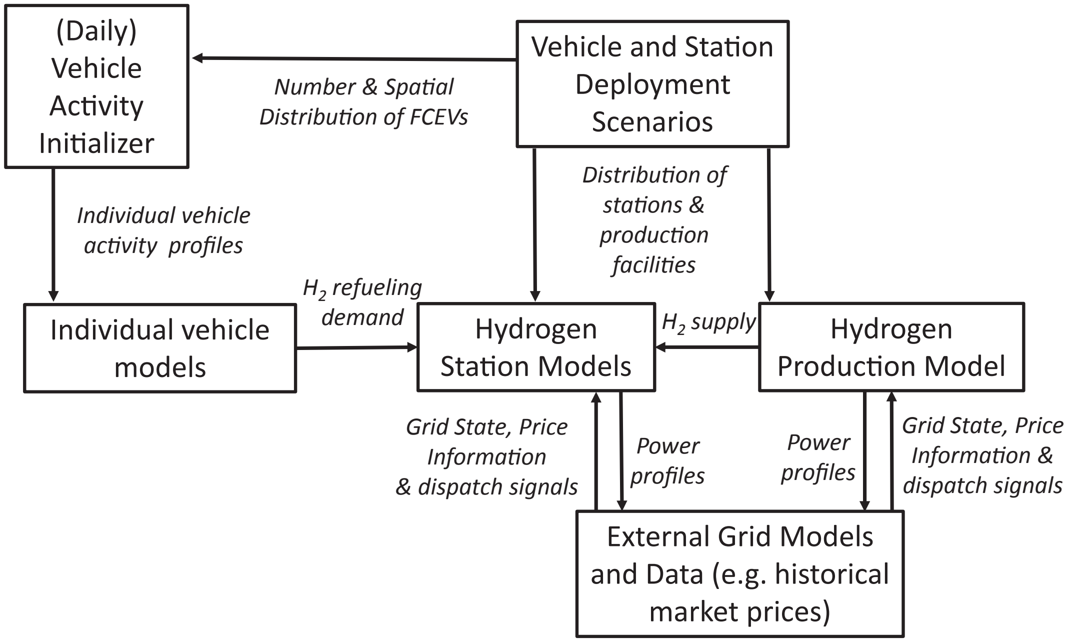

FIGURE 1. Modeling approach – H2VGI model structure

Using the hydrogen FCEV demand sub-models, preliminary results have been found for 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.

The potential benefit to California's net load shaping from a large population of FCEVs fueled by electrolytic production of hydrogen has been modeled for the first time. Increasing overall electrolyzer capacity in megawatts (or equivalently, successively lower capacity factors) is seen to provide some valley-filling of the net load shape (Figure 2a). Figure 2b shows the potential that electrolytic hydrogen production can provide to net load ramping mitigation. Key results are that ramp rates can be significantly reduced when the electrolyzer is slightly oversized (capacity factor reduced from 1 to 0.9) with a ramping rate reduction of about 2.85 GW/h or about 26% from the maximum ramp rate without hydrogen production. The direction of these results are as expected when viewing the electrolyzer generation as a controllable load.

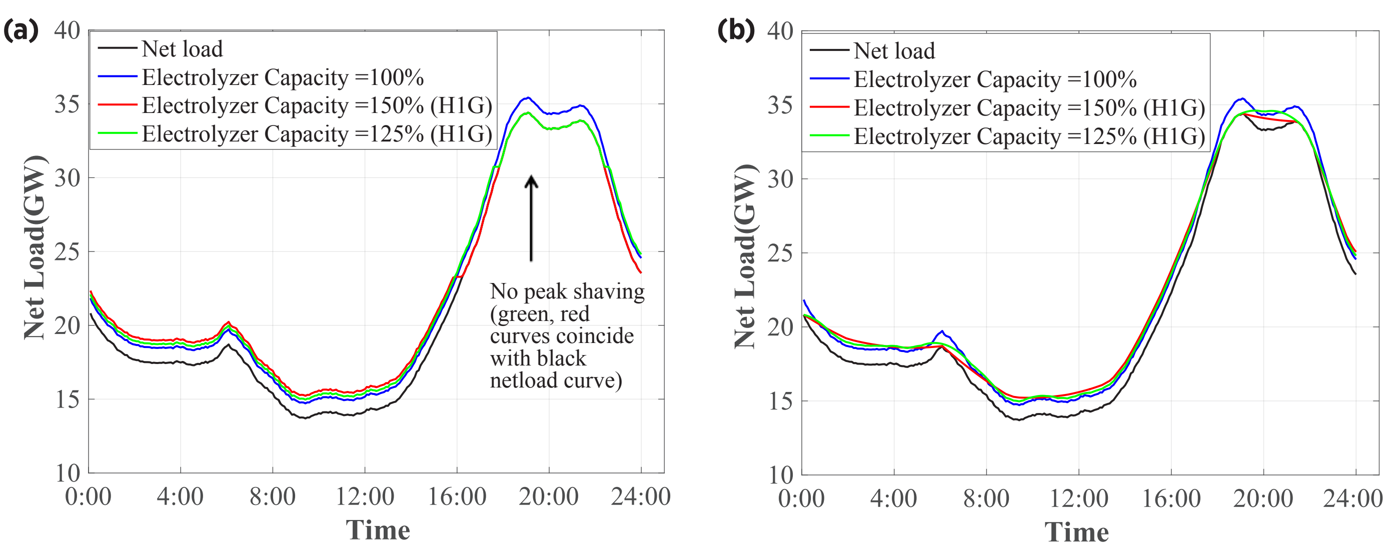

FIGURE 2. Illustration of grid support in California for 2025 net load, 1.5 million FCEVs and controllable electrolytic production of hydrogen for (a) peak shaving and valley filling, and (b) ramping mitigation

Preliminary results from the hydrogen station model developed at NREL (e.g., electricity consumption by component and component pressures) will be used to compare various station configurations for grid support (Figure 3). Electricity consumption is from compression, cooling, and other plant components. National Utility Rate Database information [6] has also been incorporated into the RODeO modeling tool previously developed at NREL. This model uses mixed-integer linear programming to determine best operation of hydrogen station and generation equipment, and this inclusion of utility rate structures allows RODeO to determine the ideal operation strategy and resulting cost for a specific utility. An example of electrolyzer operation for several Pacific Gas and Electric Company (PG&E) utility rates is shown in Figure 4, assuming that the electrolyzer produces 90% of its maximum yearly rated capacity. Comparing with the yearly cost patterns of PG&E tariff sheets shows that this behavior avoids high price hours and focuses on low price hours to minimize both demand and energy charges [7].

CONCLUSIONS AND UPCOMING ACTIVITIES

The team has made progress on developing several sub-models for the H2VGI tool set, looking at: vehicle deployment scenarios, FCEV drivetrains, fueling demand from large vehicle populations, and fueling station components that demand electricity. An initial case study has also been developed, where the potential grid support that hydrogen produced from electrolysis can provide to California's net load curve is depicted.

Upcoming activities include publishing initial results on first case study to quantify the scale of opportunity for hydrogen–vehicle–grid integration; developing material for second case study to address the benefits and shortcomings, from an electrical perspective, between different hydrogen system configurations (e.g., on-site vs. centralized production); and incorporating hydrogen resource modules (e.g., electrolytic hydrogen generation, fuel cells, etc.) into the PLEXOS production cost model for preliminary assessment of the impacts and benefits that flexible hydrogen resources can provide to the electricity grid.

FY 2017 PUBLICATIONS/PRESENTATIONS

1. Sam Saxena, Dai Wang, Max Wei, Giulia Gallo, Josh Eichmana, Matteo Muratoria, Fernando Dias, Stevic Svetomir, "Integrated Systems Modeling of the Interactions between Stationary Hydrogen, Vehicles, and Grid Resources," presented at the 2016 DOE Annual Merit Review and Peer Evaluation Meeting, Washington, D.C., June 2017.

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1. B. Bush, M. Melaina, M. Penev, and W Daniel, "SERA Scenarios of Early Market Fuel Cell Electric Vehicle Introductions: Modeling Framework, Regional Markets, and Station Clustering," National Renewable Energy Laboratory, Colden, CO, United States, NREL/TP-5400-56588, 2013.

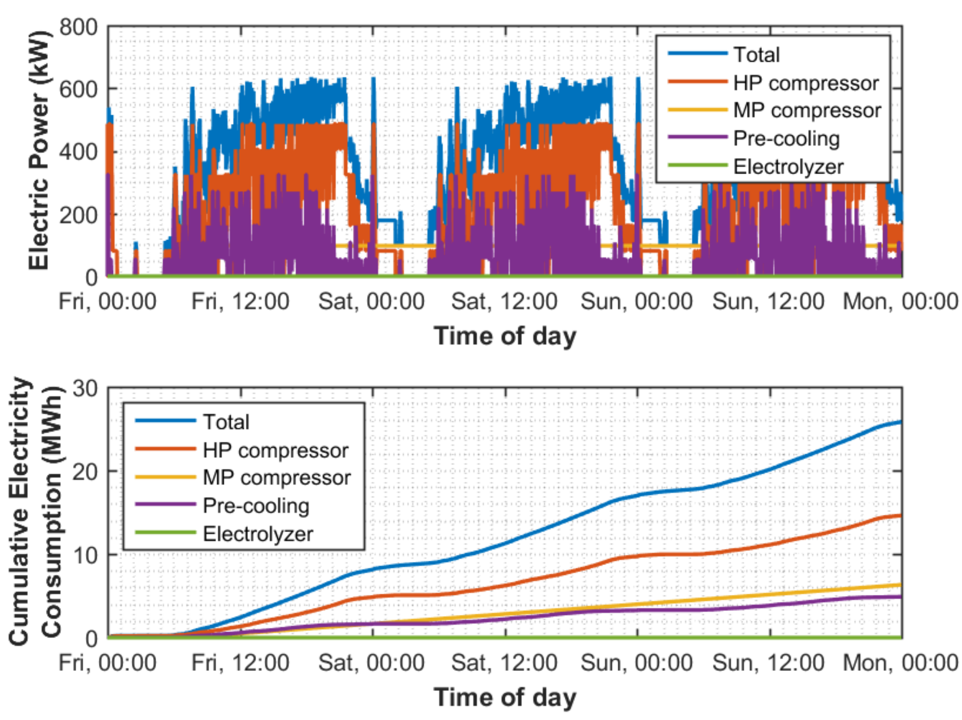

FIGURE 3. Example output from hydrogen station electricity consumption and grid support model

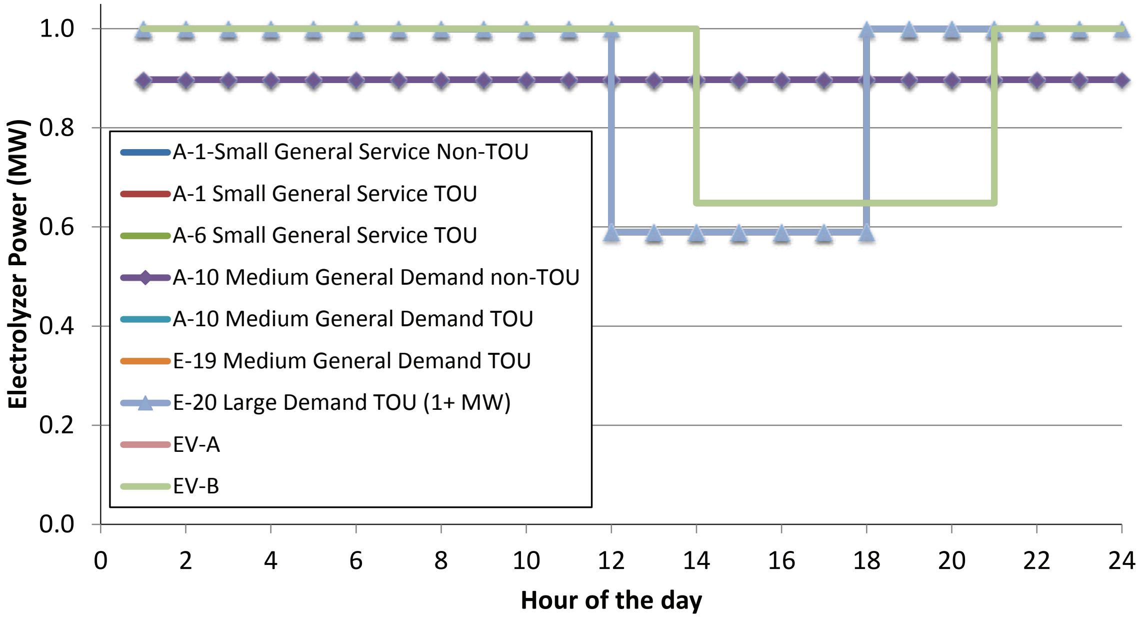

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FIGURE 4. Example electrolyzer optimal operation from RODeO for several Pacific Gas and Electric retail utility rates

2. California ISO 2016, "What the duck curve tells us about managing a green grid," https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf.

3. J. Eichman and F. Flores-Espino "California Power-to-Gas and Power-to-Hydrogen Near-Term Business Case Evaluation," National Renewable Energy Laboratory Technical Report NREL/TP-5400-67384 December 2016.

4. LBNL 2017, V2G-Sim model, http://v2gsim.lbl.gov/.

5. National Household Travel Survey, "National Household Travel Survey," 2009.

6. OpenEI Utility Rate Database, http://en.openei.org/wiki/Utility_Rate_Database.

7. Rate information for PG&E E20 can be found here: http://en.openei.org/apps/USURDB/rate/view/574dbcac5457a3d3795e629f.