IX.4 Hydrogen Analysis with the Sandia ParaChoice Model

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Project Start Date: October 1, 2014
Project End Date: Project continuation and direction determined annually by DOE

Overall Objectives

- Model the evolving market penetration potential of fuel cell electric vehicles (FCEVs) and hydrogen fuel.
- Assess the factors that influence the competition between FCEVs, conventional vehicles, and other alternative vehicle technologies such as battery electric vehicles.
- Assess impacts of FCEV market penetration and hydrogen production pathways on greenhouse gas (GHG) emissions and petroleum consumption.
- Provide context for the role of policy, technology development, infrastructure, and consumer behavior on the vehicle and fuel mix.

Fiscal Year (FY) 2016 Objectives

- Conduct scenario analyses to understand and provide context for the market penetration potential of FCEVs, hydrogen demand, costs, and production pathways.
- Conduct parametric analyses to understand sensitivities and tipping points driving FCEV sales, emissions, and hydrogen consumption and production.
- Examine market penetration of FCEVs and competition between FCEVs and alternate powertrains in different market segments.

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section of the Fuel Cell Technologies Office (FCTO) Multi-Year Research, Development, and Demonstration Plan.

(A) Future Market Behavior

(C) Inconsistent Data, Assumptions and Guidelines

(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's Analysis section of the FCTO Multi-Year Research, Development, and Demonstration Plan.

- Milestone 1.1: Complete an analysis of the hydrogen infrastructure and technical target progress for hydrogen fuel and vehicles. (2Q, 2011)
- Milestone 1.12: Complete an analysis of the hydrogen infrastructure and technical target progress for technology readiness. (4Q, 2015)
- Milestone 1.13: Complete environmental analysis of the technology environmental impacts for hydrogen and fuel cell scenarios and technology readiness. (4Q, 2015)
- 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 2.2: Annual model update and validation. (4Q, 2011 through 4Q, 2020)

FY 2016 Accomplishments

- Submitted "Fuel Cell Electric Vehicles: Drivers and Impacts of Adoption" for publication in *Energy Policy*. Following analyses conducted therein, where impact on vehicle sales or future petroleum or emissions were assessed as appropriate:
  - Baseline/business as usual scenario analysis
  - Low cost electrolysis scenario analysis
  - Carbon tax scenario analysis
  - Future oil price and natural gas price trade space analysis
  - Future battery price and fuel cell price trade space analysis
  - FCEV vehicle cost and clean electrolysis cost trade space analysis

- FCEV purchasing incentive parametric and scenario analyses
- Global sensitivity correlation coefficient analysis
- FCEV utopia scenario analysis

- Assessed impact of FCEVs on GHG emissions on scenarios with and without compressed natural gas vehicles.
- Added modeling capability for parametric efficiency analysis of FCEVs isolated from efficiency analyses of other electric vehicle powertrains.
- Parametric assessment of impact of increased efficiency for FCEVs on FCEV sales and GHG emissions.
- Assessment of market driven infrastructure growth rates on FCEV sales.
- Beginning assessment of segment specific market competition for FCEVs.

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INTRODUCTION

In the coming decades, light-duty vehicle options and their supporting infrastructure must undergo significant transformations to achieve aggressive national targets for reducing petroleum consumption and lowering greenhouse gas emissions. FCEVs, battery and hybrid electric vehicles, and biofuels are among the promising advanced technology options. In addition, natural gas vehicles, fueled with domestically produced natural gas, have significant potential to displace petroleum use in the light-duty vehicle mix. This project examines the market penetration of FCEVs in a range of market segments, and in different energy, technology, and policy futures. Analyses are conducted in the context of varying hydrogen production and distribution pathways, as well as public infrastructure availability, fuel (gasoline, natural gas, hydrogen) and electricity costs, vehicle costs and fuel economies to better understand under what conditions, and for which market segments, FCEVs can best compete with battery electric and other alternative fuel vehicles.

APPROACH

The ParaChoice model simulates the dynamic interaction and evolution of the light duty vehicle stock, fuel production, and energy supplies through 2050. At its core, ParaChoice is very simple, taking inputs for current vehicle price and vehicle price projections, fuel prices, etc., and asking a set of modeled consumers at each time step which powertrain vehicles are the least expensive options given their driving habits and the cost of inconvenience for finding alternative fueling stations or being stuck with a very short range vehicle. The choice model structure is similar to [1] and [2]. In implementation, we model the fuel sector internally capturing the feedback between fuel production pathways, refueling infrastructure, and the vehicle market. Additionally, the market is segmented by state, vehicle size, population density, driver intensity, and dwelling type to capture consumer and fuel production and price market niches

In order to explore uncertainty, sensitivities to inputs, and trade spaces, we run the core model thousands of times with varying inputs. The model is designed to vary parameters of uncertain variables easily to facilitate these analyses. These parametric analyses provide insights that are not as easily accessible to individual scenario-focused studies.

RESULTS

Our primary result and accomplishment in the last year was the formal write up and analysis of the drivers and impacts of FCEV market adoption using the ParaChoice model. This formal manuscript was reviewed and iterated upon internally by experts at Sandia, by DOE stakeholders, and then submitted to *Energy Policy* under the title "Fuel Cell Electric Vehicles: Drivers and Impacts of Adoption." The analyses conducted for this work and written in this work support the FCTO objectives and work towards FCTO milestones. In particular, the manuscript addresses the potential market competition and drivers for FCEVs, the potential GHG emissions impacts, the interplay between the vehicle market and the fuel production pathways, and potential impacts of policy and technology. We leverage our parametric capabilities to address market uncertainties and to identify tipping points and trade spaces. The following analyses are detailed in the work:

- Baseline/business as usual scenario analysis
- Low cost electrolysis scenario analysis
- Carbon tax scenario analysis
- Future oil price and natural gas price trade space analysis
- Future battery price and fuel cell price trade space analysis
- FCEV vehicle cost and clean electrolysis cost trade space analysis
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One interesting finding from our study shows that future FCEV sales are much more sensitive to FCEV vehicle costs than to the cost of clean hydrogen. Figure 1, shows the

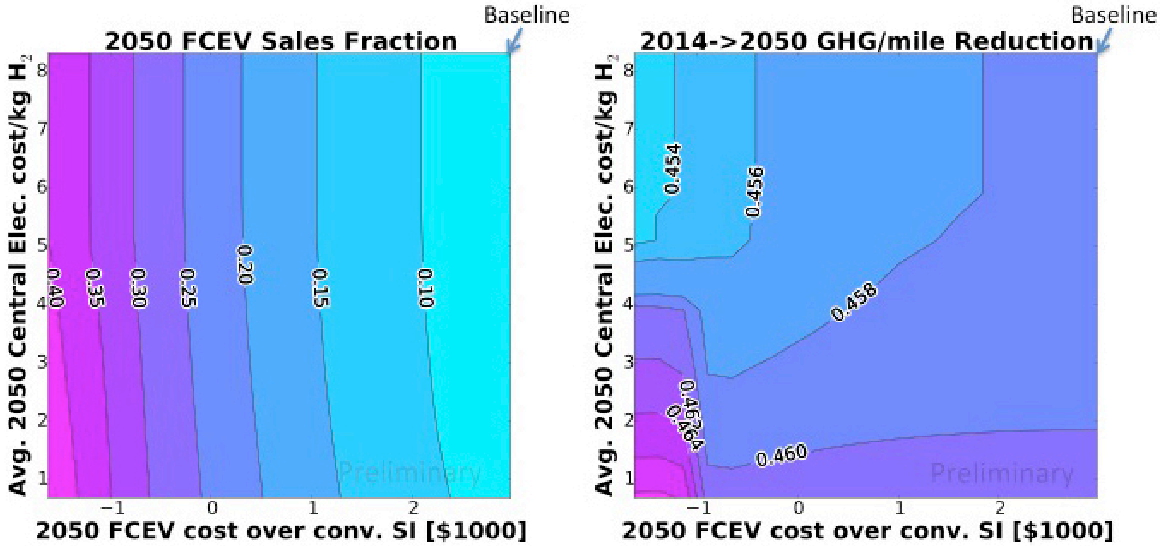

FIGURE 1. Impact of fuel cell vehicle price and hydrogen price on (a) fuel cell electric vehicle sales and (b) fleet wide emissions, showing the sensitivity of sales to vehicle price and relative insensitivity to fuel price

sensitivity of 2050 FCEV sales (left) and fleet wide emissions (right) to FCEV costs as compared to conventional vehicle costs (horizontal axes) and the pump fuel cost of hydrogen generated with dedicated wind power (vertical axes). 2050 FCEV sales fractions increase much more substantially with decreasing vehicle price than with decreasing fuel price. However, GHG emissions increase with increasing FCEV sales unless the renewable hydrogen is inexpensive. This is because natural gas reformation is a more commercially viable hydrogen production pathway than electrolysis in the baseline case. Therefore, while FCEVs are less carbon intensive than conventional, non-hybrid vehicles, they are only comparably carbon intensive to non-plug-in gasoline hybrids and compressed natural gas vehicles, and more carbon intensive than low and mid-range plug-in hybrids and full battery electric vehicles.

Additionally in this last year, we have added new capabilities to the ParaChoice model and conducted additional analyses in support of the FCTO Systems Analysis program goals. In particular, we conducted an assessment of FCEV market competition with the other alternative vehicle powertrains, finding more competition with compressed natural gas vehicles than others. We also performed an assessment of FCEV impact in a scenario without compressed natural gas vehicles. We have added modeling capability to allow parametric efficiency analysis of FCEVs and found (preliminary) that efficiency increases in FCEV powertrains can lead to both increased sales and decreased fleet wide emissions, even in cases where vehicle cost must increase to accommodate the efficiency boost. Results are shown in Figure 2. We have also examined the impact of renewable mandates (preliminary), finding that a renewable mandate for hydrogen production is an effective tool for driving down fleet wide GHG emissions. Results are shown in Figure 3.

CONCLUSIONS AND FUTURE DIRECTIONS

Fuel cell electric vehicles play a role in the future light duty vehicle mix, diversifying the fuel source and options to consumers. With improved FCEV efficiency, technology improvements in renewable hydrogen production, or renewable mandates for hydrogen production, FCEVs can contribute to a lower carbon future as well.

Future work includes a publication showing pathways to lower GHG emission futures through FCEVs. Additional future work includes ParaChoice modeling refinements for hydrogen pricing at low demand, and the inclusion of at home hydrogen refueling and analysis of potential benefits of the same.

FY 2016 PUBLICATIONS/PRESENTATIONS

1. Rebecca S. Levinson and Todd H. West, "Hydrogen Analysis with the Sandia ParaChoice Model." Presentation at the Annual Merit Review.

REFERENCES

1. Lin, Zhenhong and Greene, David L. "A Plug-In Hybrid Consumer Choice Model with Detailed Market Segmentation." Transportation Research Board 10-1698, 2010.

2. Struben, Jeroen and Sterman, John D. "Transition challenges for alternative fuel vehicle and transportation systems." Environment and Planning B: Planning and Design, 35:1070–1097, 2008.

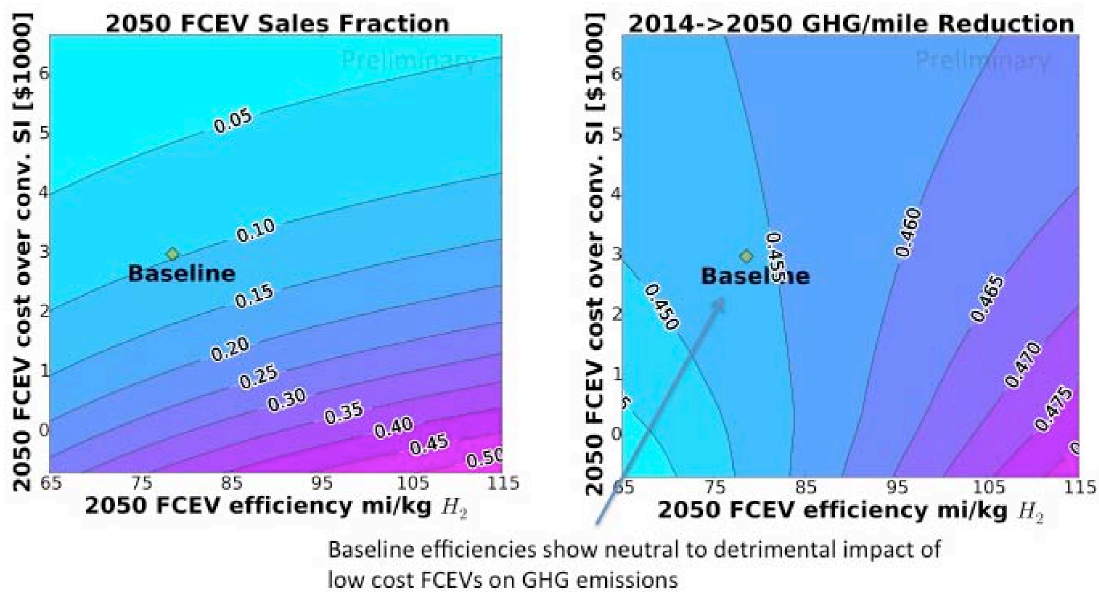

FIGURE 2. Impact of fuel cell vehicle price and efficiency on (a) fuel cell electric vehicle sales and (b) fleet wide emissions, showing the positive impact of efficiency on both sales and emissions, even if efficiency improvements necessitate a slight vehicle price increase

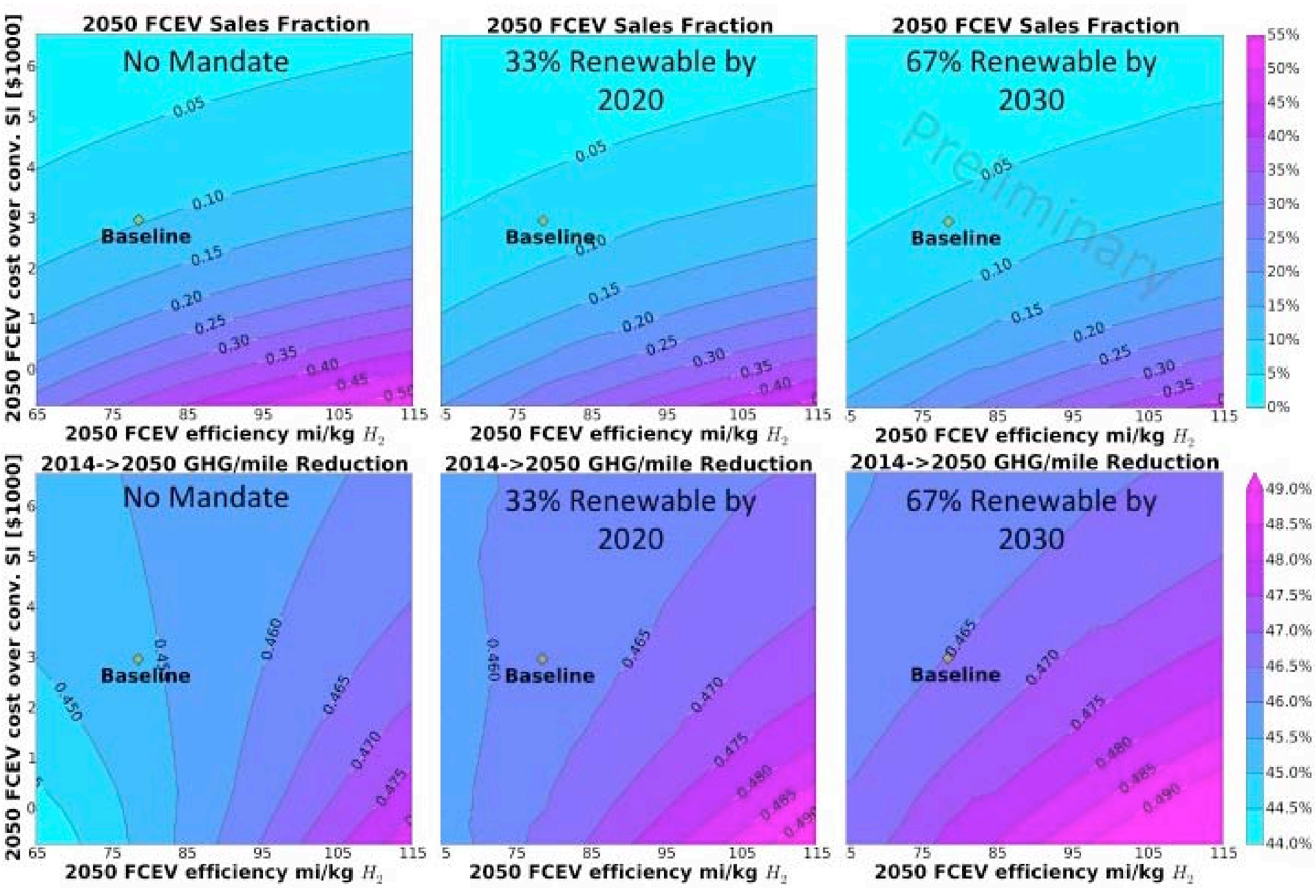

FIGURE 3. Impact of renewable fuel mandate on fuel cell vehicle price and efficiency trade space, showing the positive impact of a renewable mandate on fleet wide emissions, even at the detriment of fuel cell electric vehicle sales