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 the impacts of FCEV market penetration and hydrogen production pathways on greenhouse gas 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) 2017 Objectives

- Add additional detail to the fuel price sub-model of the ParaChoice model.
- Conduct scenario analyses to understand and provide context for the market penetration potential of FCEVs, hydrogen demand, costs, and production pathways.
- Complete sensitivity analysis, varying factors including station availability, fuel cost, efficiency, or technology cost.
- Conduct parametric analyses to understand sensitivities and tipping points driving FCEV sales, emissions, and hydrogen consumption and production.
- Analyze hydrogen prices and FCEV sales in response to various coal and natural gas futures.

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

(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 Fuel Cell Technologies Office 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 2017 Accomplishments

- Updated the hydrogen production and pricing sub-model in ParaChoice vehicle simulation.
  - Incorporated new pricing and emissions data from the Macro-Systems Model.
  - Incorporated feedback from the Vehicle Technologies Office concerning obsolete distributed production pathways.
  - Incorporated smaller station size detail for lower demand, industrial hydrogen supply.

- Conducted scenario assessments of hydrogen production pathways, hydrogen price, FCEV sales, and fleet emissions in a baseline case and in cases with different coal and natural gas price futures.
- Performed parametric assessment of the response of hydrogen price and FCEV sales to coal and natural gas futures.
- Matched a simulated seeding of hydrogen station growth to the H_2USA Urban Scenario, and updated the ParaChoice simulation's initial hydrogen station data to present day values.
- Added modeling capability for parametric analysis of the market response of hydrogen infrastructure growth to FCEV sales.
- Performed parametric assessment of the impact of suppressed or stimulated hydrogen infrastructure growth in response to FCEV sales on FCEV sales.

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INTRODUCTION

In the coming decades, light-duty vehicle options and their supporting infrastructure must undergo significant transformations to achieve aggressive petroleum consumption reduction and lower greenhouse gas emissions. FCEVs, battery and hybrid electric vehicles, and biofuels are among the promising advanced technology options. 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, ethanol, 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 with a long refueling time. The choice model structure is similar to that of Lin and Greene [1] and Struben and Sterman [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, dwelling type, and workplace charging ability 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

In FY 2017, we updated the ParaChoice hydrogen price production sub-model using inputs from the Hydrogen Macro System Model [3] and AEO [4] to inform full-scale (50,000 kg/d) hydrogen production for various station sizes and commodity prices. *Hydrogen and Fuel Cells: The US Market Report* [5] was used to determine hydrogen prices for nascent hydrogen markets in the sub-model. With the updated model, we then analyzed the influence of uncertain commodity price futures on hydrogen fuel prices for vehicles. Sample results are show in Figure 1 for full-scale production in central production plants and dispensation at 1,500 kg/d stations. The two pathways shown are steam methane reformation of natural gas (SMR) and coal gasification with sequestration of carbon (COAL + SEQ). Three scenarios are shown for each production pathway, one showing the nominal AEO case, one showing a case where the price of the feedstock commodity (natural gas or coal) is twice as expensive as projected by 2050, and one where the feedstock commodity is half as expected as projected by 2050. One can conclude from the figure that, for nominal AEO projections, SMR is the preferred production pathway for hydrogen, leading to the least expensive fuel. However, uncertainties in the AEO projections may render coal gasification plus sequestration a more economically preferable production pathway, lowering the carbon footprint of hydrogen fuel. If delivery and dispensing technologies can be lowered, it will benefit both pathways equally.

Expanding on the trade between commodity prices and fuel prices, we show the full carbon and natural gas tradespace in Figure 2. Figure 2a shows the simulated national average hydrogen price in 2050 given consumer demand and in response to a range coal and natural gas prices. Figure 2b shows the corresponding 2050 FCEV sales. (For all parameters other than coal and natural gas prices, assumptions are held to ParaChoice's baselines, which reflect the Autonomie [6] low technology, low uncertainty case and correspondingly pessimistic policy and investment options.) Because hydrogen can be produced via multiple pathways, Hydrogen prices are robust to commodity prices, remaining

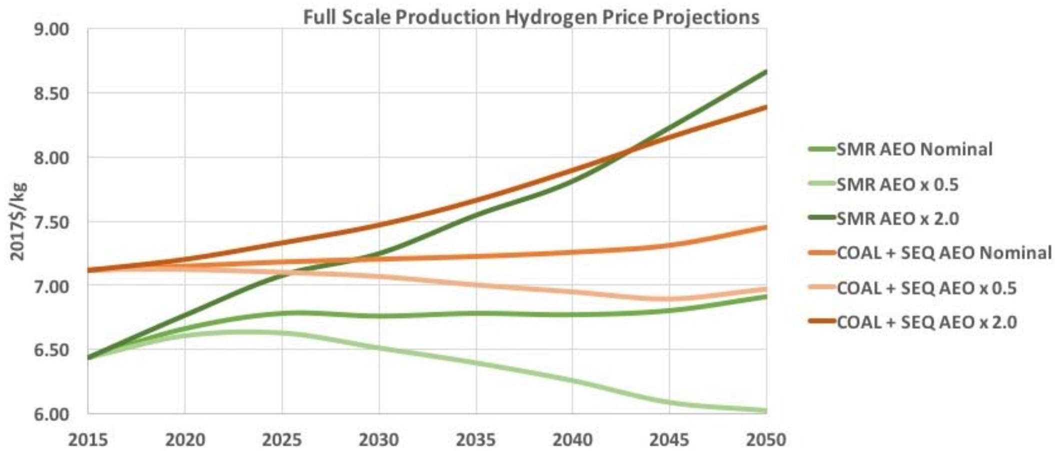


FIGURE 1. Hydrogen price projections under different production pathways and commodity price scenarios

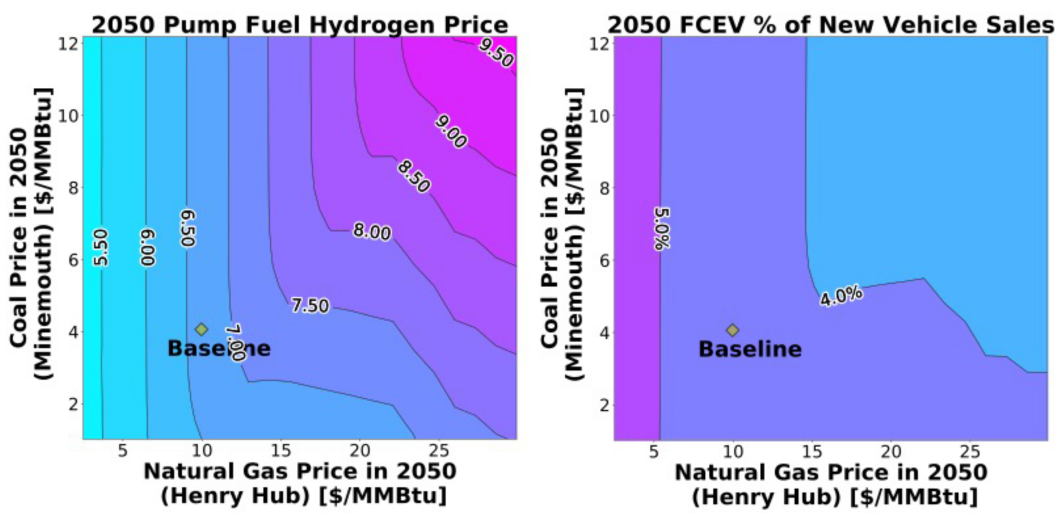
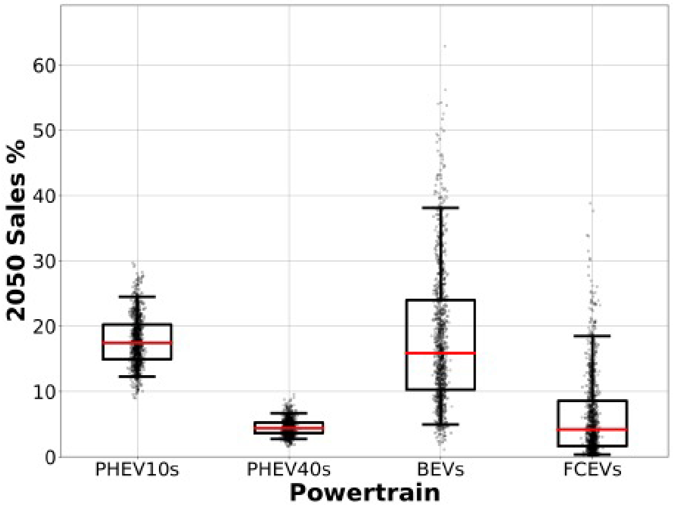


FIGURE 2. 2050 hydrogen prices (left) and FCEV sales (right) for tradespace of coal and natural gas prices

low even if either natural gas or coal prices are unexpectedly high. Only if both natural gas and coal prices are high will hydrogen prices rise substantially. The exception is for very extreme natural gas prices; since existing industrial hydrogen is produced via SMR, high natural gas prices raise industrial hydrogen prices for the early market, lowering demand. If hydrogen demand is insufficient, dedicated hydrogen production for FCEV use will not be built, and the reliance on expensive natural gas will continue, creating a negative feedback loop. FCEV sales largely follow the trend of hydrogen prices.

FCEV sales are subject to a wide range of drivers, which we explore in depth with the ParaChoice model. Technology price and efficiency uncertainties, energy price uncertainty, and modeling and behavioral assumptions such as consumer payback period and penalties all drive the future vehicle sales uncertainties shown in Figure 3. Monte Carlo uncertainty analysis can only constrain 2050 FCEV sales between 0.3% and 19% in 90% of scenarios; sales futures for FCEVs are highly uncertain. Scenarios with the greatest number of FCEV sales are ones with the lowest FCEV technology prices, the lowest logit choice exponent (consumer sensitivity to price), the lowest cost penalties (consumer sensitivity to infrastructure scarcity or range anxiety), the highest oil prices, the greatest FCEV efficiencies, the lowest conventional engine efficiencies, and the greatest hydrogen infrastructure growth rates. These results imply that the greatest gains to FCEV sales might be had for investments that lead to FCEV technology cost reduction or efficiency improvements, infrastructure expansion, or community education to reduce the perceived requirement for hydrogen infrastructure.



BEV – battery electric vehicle; PHEV – plug-in hybrid electric vehicle

FIGURE 3. Uncertainty in 2050 alternative energy vehicle sales. Shown are 1,024 scenarios (black dots) from a Monte Carlo analysis of technology, energy, behavior, and modeling parameters. Boxes show 25th/75th percentiles. Whiskers show 5th/95th percentiles. Red line shows median.

CONCLUSIONS AND UPCOMING ACTIVITIES

Fuel cell electric vehicles play a role in the future light duty vehicle mix, diversifying the fuel source and options to consumers. How large a role they can play is highly uncertain, but might be guided through directed technology investment. The hydrogen that fuels these vehicles may be produced via multiple pathways, and thus it is likely that hydrogen fuel prices can stay low through many uncertain commodity futures.

Future work for this project would include a write-up of our full results for the program office and participation in the multi-lab Baseline and Scenerio Analysis (BaSce) scenarios. Multi-lab scenario analysis in support of BaSce will continue into FY 2018.

FY 2017 PUBLICATIONS/PRESENTATIONS

1. Levinson, Rebecca S. et al., "Hydrogen Analysis with the Sandia ParaChoice Model." Presentation at the Annual Merit Review, June 2017.

2. Levinson, Rebecca S., Dawn K. Manley, and Todd H. West, "History v. Simulation: An analysis of the drivers of alternative energy vehicle sales." SAE Int. J. Alt. Power 5(2), 2016.

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

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5. M. Ruth, M. Laffen, and T.A. Timbario. Hydrogen pathways: Cost, well-to-wheels energy use, and emissions for the current technology status of seven hydrogen production, delivery, and distribution scenarios. Technical Report NREL/TP-6A1-46612, National Renewable Energy Laboratory, September 2009.

6. A. Moawad, N. Kim, N. Shidore, and A. Rousseau. Assessment of Vehicle Sizing, Energy Consumption, and Cost through Large-Scale Simulation of Advanced Vehicle Technologies. Argonne National Laboratory, Argonne, IL, March 2016.