IX.1 Impact of Fuel Cell System Peak Efficiency on Fuel Consumption and Cost

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Overall Objectives

- Quantify fuel displacement and cost of advanced hydrogen storage and fuel cell systems, in conjunction with advancements in the rest of the powertrain, as part of DOE Baseline and Scenario Analysis (BaSce)
- Quantify the fuel displacement and cost of advanced hydrogen storage and fuel cell systems, without considering advancements in the rest of the powertrain

Fiscal Year (FY) 2015 Objectives

- Build vehicle simulations using the individual component assumptions
- Run the simulations as part of the BaSce process over advancements in hydrogen tank, fuel cell, and the rest of the vehicle powertrain (the detailed analysis and report generation will be performed in FY 2016)
- Run simulations with advances in hydrogen tank and fuel cell technology while not considering advances in the rest of the powertrain
  - Provide detailed analysis on impact of fuel cell and hydrogen tank assumptions on the energy consumption, cost, component sizing, and vehicle weight

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

(E) Unplanned Studies and Analysis

Contribution to Achievement of DOE Systems Analysis Milestones

This project will contribute to 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 1.1: Complete an analysis of the hydrogen infrastructure and technical target progress for hydrogen fuel and vehicles. (2Q, 2011)
- Milestone 1.11: Complete analysis of the impact of hydrogen quality on the hydrogen production cost and the fuel cell performance for the long range technologies and technology readiness. (2Q, 2015)
- Milestone 1.12: Complete an analysis of the hydrogen infrastructure and technical target progress for technology readiness. (4Q, 2015)
- 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 1.17: Complete analysis of program technology performance and cost status, and potential to enable use of fuel cells for a portfolio of commercial applications. (4Q, 2018)
- Milestone 2.2: Annual model update and validation. (4Q, 2011 through 4Q, 2020)

FY 2015 Accomplishments

- Full vehicle simulations were performed to assess the vehicle energy consumption and cost of current and future fuel cell vehicles compared to conventional powertrains for different fuel cell systems.
- Compared to current conventional vehicles, fuel cell vehicles achieve similar weight and a fuel economy up to 4.5 times higher by 2025 or 1.7 times higher (if compared to same-year conventional vehicle).

- Current DOE targets for both fuel cell peak power (80 kW) and onboard hydrogen weight (5.6 kg) will exceed the requirements for most of the vehicle classes by 2025.
- Midsize fuel cell vehicles with advances in hydrogen tank and fuel cell technology were sized and simulation was performed to evaluate the benefits of fuel cells and storage without improvements from the DOE Vehicle Technologies Office (VTO).
- Advances in the fuel cell system alone lead to a fuel consumption benefit of 6.8 to 10.5%, a vehicle manufacturing cost reduction of 6.2 to 6.5%, and a reduction of hydrogen fuel mass of 6.2 to 9.1% by 2020.
- Advances in hydrogen storage alone lead to a fuel consumption benefit up to 0.2% and a vehicle manufacturing cost reduction of 2.6 to 2.9% by 2020.

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INTRODUCTION

Autonomie has been used by the U.S. Department of Energy to evaluate the vehicle energy consumption and benefits of a wide range of powertrain configurations, component technologies, and control strategies. In this study, the objective is to quantify the vehicle energy consumption and cost of fuel cell hybrid vehicles compared to conventional powertrains using two target scenarios: current and aggressive. The current scenario is based on a 60% peak efficiency fuel cell system while the aggressive scenario relies on higher fuel cell system efficiencies (up to 70%).

APPROACH

To properly assess the benefits of future technologies, different vehicle classes were considered: compact car, midsize car, small sport utility vehicle (SUV), medium SUV, and pickup truck. Different timeframes representing different sets of assumptions were simulated. For this report, we will show 'lab years' 2010, 2020, and 2045. It should be noted that lab year 2010 would reflect a vehicle available in the market in 2015 (current technology). Similarly, lab or simulation year 2020 would reflect a vehicle in the market in 2025, and a 2045 simulation vehicle would be in the market in 2050. For the actual study, lab years 2010, 2020, 2025, 2030, and 2045 were simulated, which would reflect model years 2015 (current technology), 2025, 2030, 2035, and 2050, respectively.

Additionally, to address uncertainties, a triangular distribution approach (low, medium, and high) was employed. For each component, assumptions (e.g., regarding efficiency, power density) were made, and three separate values were defined to represent the (1) 90th percentile, (2) 50th percentile, and (3) 10th percentile. A 90% probability means that the technology has a 90% chance of being available at the time considered. For each vehicle considered, the cost assumptions also follow the triangular uncertainty. For each vehicle case (particular class, technology uncertainty, simulation/show-case year), simulations were performed with evolution of all vehicle technology simultaneously. The above simulations were performed as a part of DOE VTO's BaSce process.

In addition, simulations were performed which involved evolution of the fuel cell and hydrogen tank with time (up to 2045) while maintaining technology of the rest of the powertrain at 2010 levels. This isolated the vehicle-level impacts of advancements in fuel cell and hydrogen tank technologies, contrasting the BaSce results where all technologies were evolving at the same time.

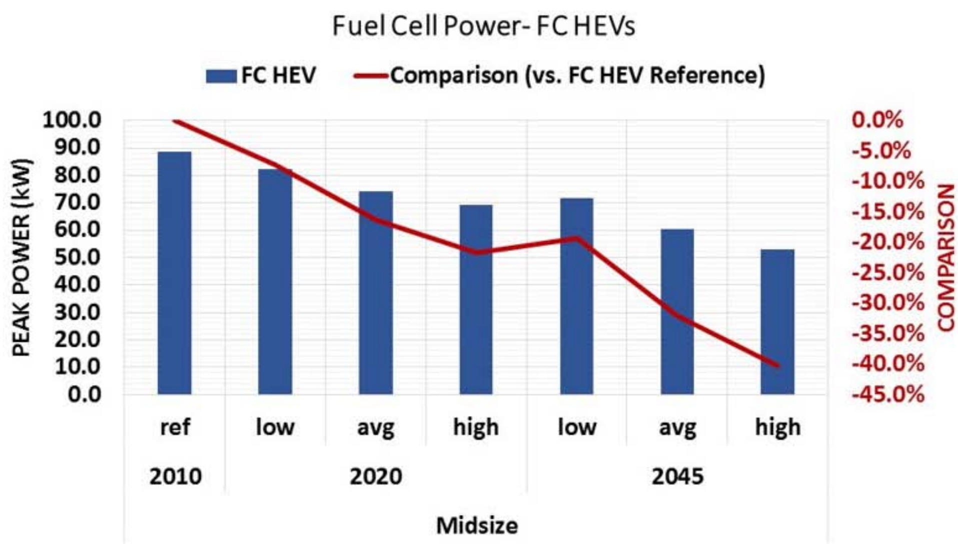
RESULTS

Baseline and Scenario Analysis

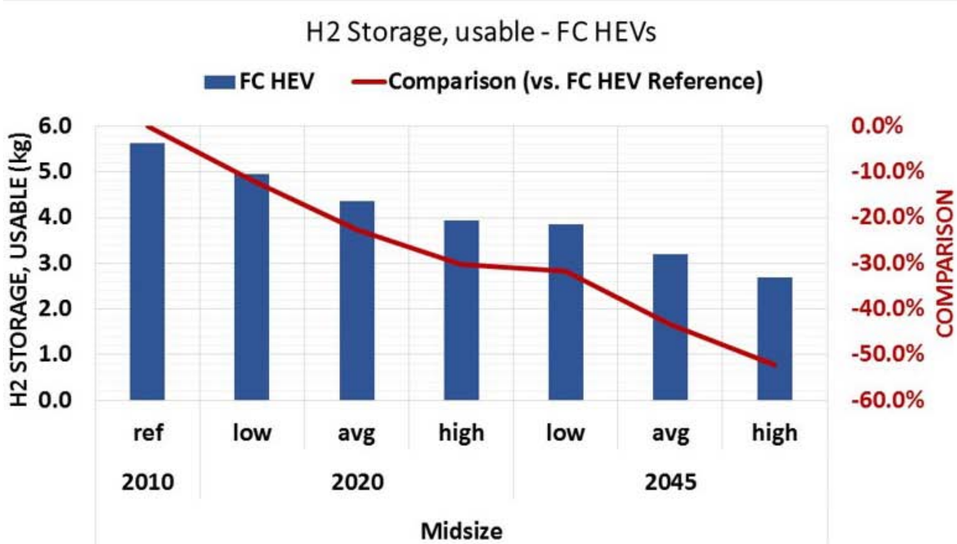
Based on assumptions of technology improvement for fuel cells and hydrogen storage, it can be seen that fuel cell system power required to meet the vehicle technical specification decreases significantly with time. Also, the required hydrogen fuel mass could drop by 50% by year 2045 (Figure 1). By 2045, the cost of fuel cell hybrid vehicles is comparable to conventional vehicles (Figure 2a). This cost decrease is mainly due to the decrease in the cost of the hydrogen tank. Due to the compounding effects of fuel cell improvements, hydrogen technology improvements, and improvement in the rest of the powertrain, fuel cell vehicles retain a fairly constant fuel economy advantage compared to conventional vehicles up to 160% over time (Figure 2b). Both figures show results for midsize class.

Fuel Cell and Hydrogen Storage System Only Analysis

In order to evaluate the potential of fuel cell and hydrogen tank technologies in isolation, the simulations of fuel cell vehicles for midsize class were performed in four iterations: with all technologies being 2015 (Ref.) (from BaSce results), improved hydrogen storage (H2) only (iteration 1), only improved fuel cell system (FC) (iteration 2), then both improved fuel cell and hydrogen storage (H2 + FC) (iteration 3), and finally all technologies (All: FC + H2 + electric machine + battery + lightweighting…) (iteration 4, from BaSce). Fuel cell vehicle weight decreases by 1 to 4% by 2045 without lightweighting or improvement in other component technology. The vehicle hydrogen storage has been sized to provide a range of 320 miles on the combined driving cycle (Urban Dynamometer Driving Schedule and Highway Fuel Economy Driving Schedule). Required onboard hydrogen fuel mass could drop by 15% due to the



(a) Fuel cell peak power, kW



(b) Hydrogen storage usable, kg

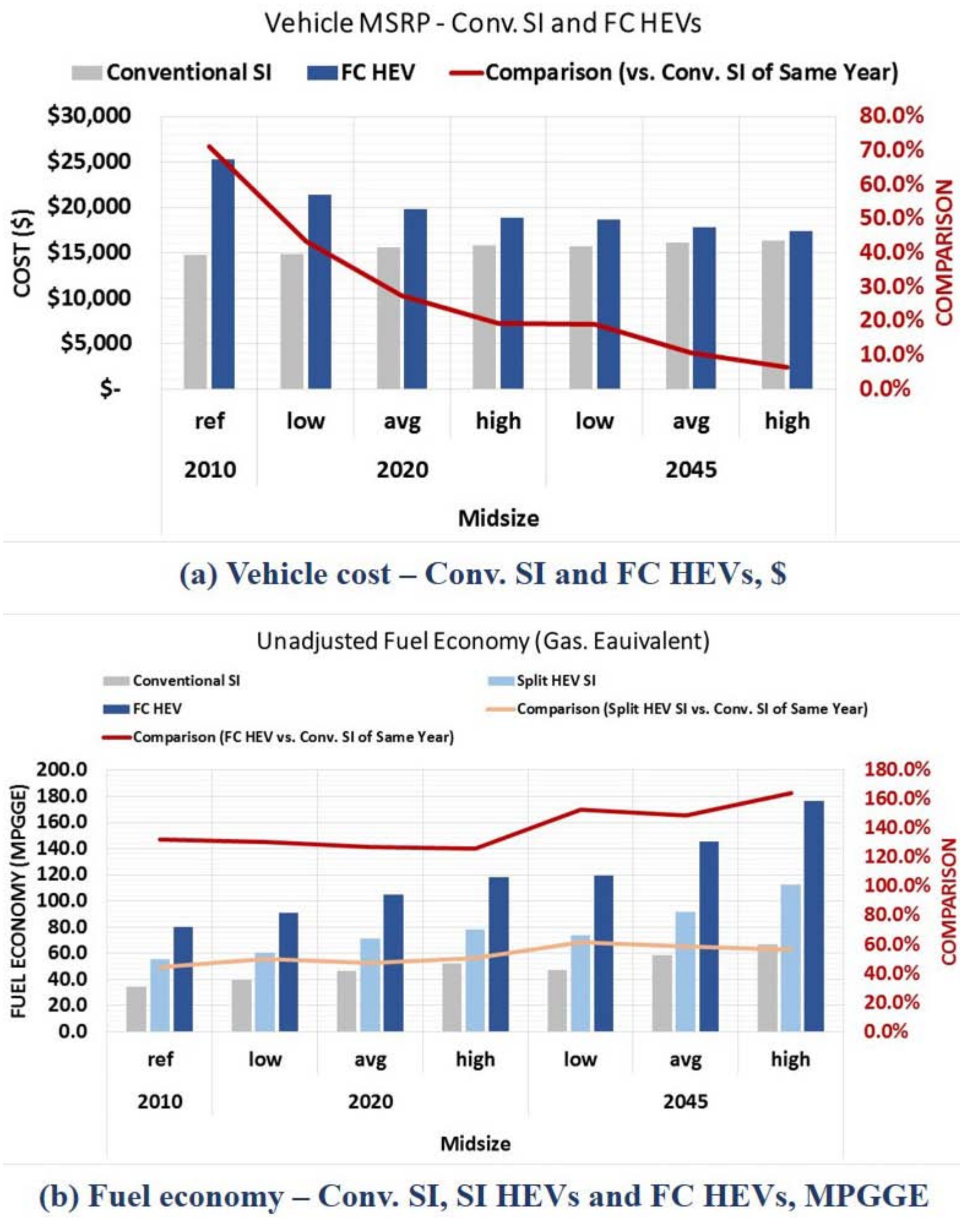
FC – fuel cell
HEV – hybrid electric vehicle
ref – reference

FIGURE 1. Evolution of fuel cell peak power and usable hydrogen storage for BaSce scenario

fuel cell system technology improvements only (Figure 3) by lab year 2020, i.e., showroom year 2025. Figure 4a shows the fuel cell system cost with the advances in hydrogen tank only, fuel cell technology only, and all technology improvements. The results show that fuel cell system cost could decrease by 50% due to the fuel cell system technology improvements only. As shown in Figure 4b, the fuel cell system improvements lead to significant fuel savings on the U.S. Environmental Protection Agency combined driving procedure. While better batteries, electric machine, and lightweighting help, fuel cell system improvements lead to significant fuel savings of about 40% by 2045.

CONCLUSIONS AND FUTURE DIRECTIONS

Two sets of vehicle simulations were performed to assess the vehicle energy consumption and cost of fuel cell vehicles compared to conventional powertrains. Different timeframes, fuel cell system peak efficiencies, and hydrogen storage assumptions were considered. For one set of simulations, all

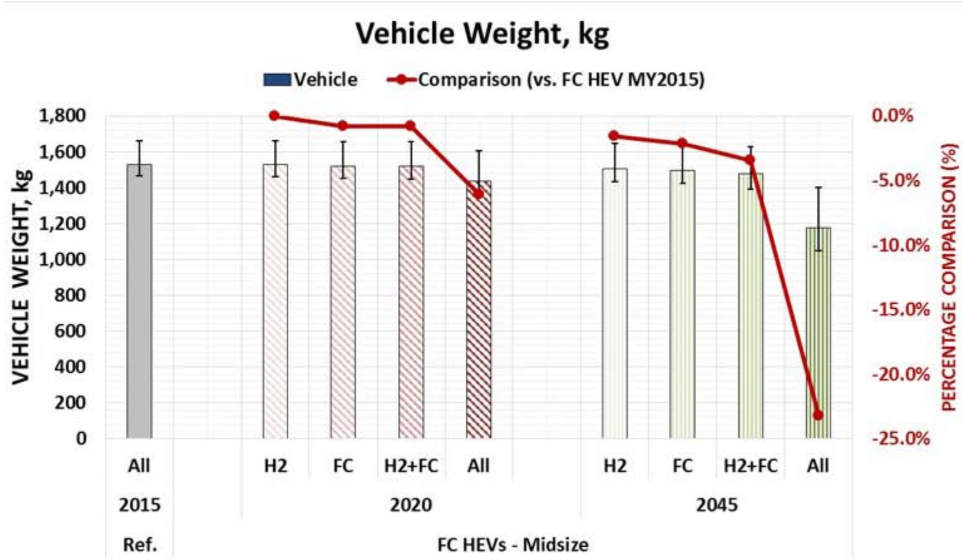


MSRP – manufacturer's suggested retail price
SI – spark ignition
Conv. – conventional
MPGGE – miles per gallon gasoline equivalent

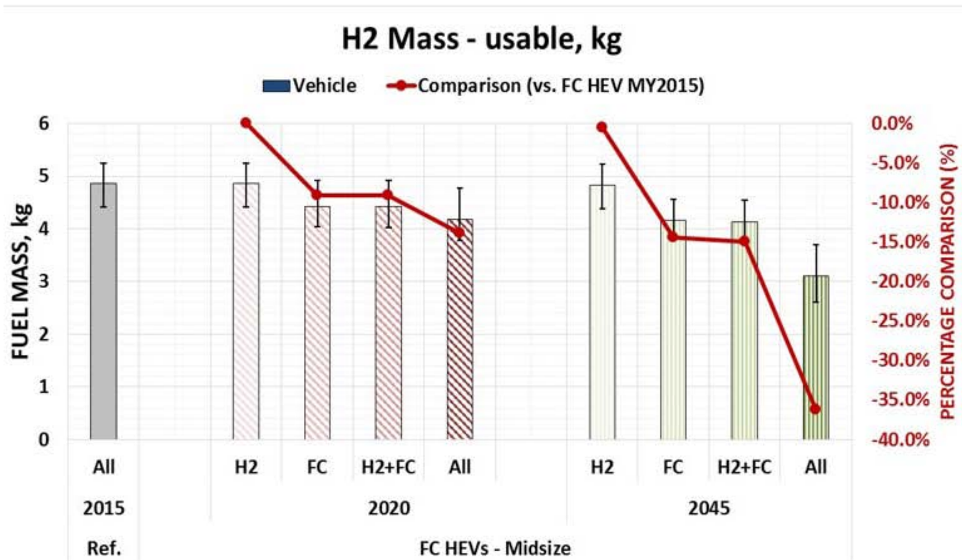
FIGURE 2. Evolution of fuel cell vehicle cost and fuel economy for BaSce scenario

vehicle assumptions (including drag coefficient, frontal area, glider mass, etc.) were varied with time (BaSce simulations), and for the second set of simulations, only fuel cell and hydrogen storage assumptions were varied with time.

- The BaSce simulation results showed that required hydrogen fuel mass could drop by 50% by showroom year 2050.
- With evolution in the fuel cell system, hydrogen tank, and the rest of the powertrain, by 2045 the cost of the fuel cell hybrid vehicles will be comparable to conventional vehicles, mainly due to the decrease in the cost of the hydrogen tank.
- When considering the impact of fuel cell and hydrogen storage system technology only (without considering



(a) Vehicle curb weight, kg



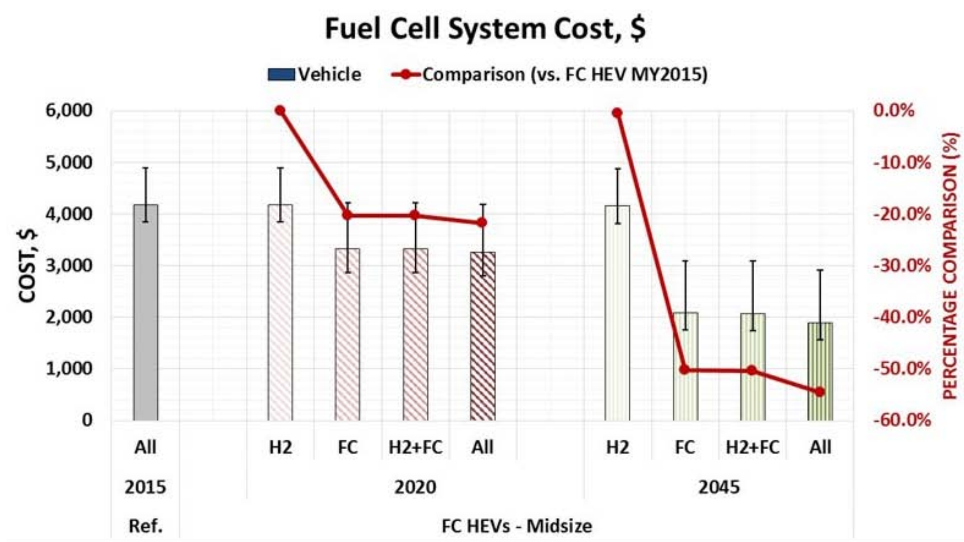
(b) Hydrogen storage usable, kg

FIGURE 3. Progression in vehicle curb weight and usable hydrogen storage due to improvements in fuel cell and hydrogen storage technology

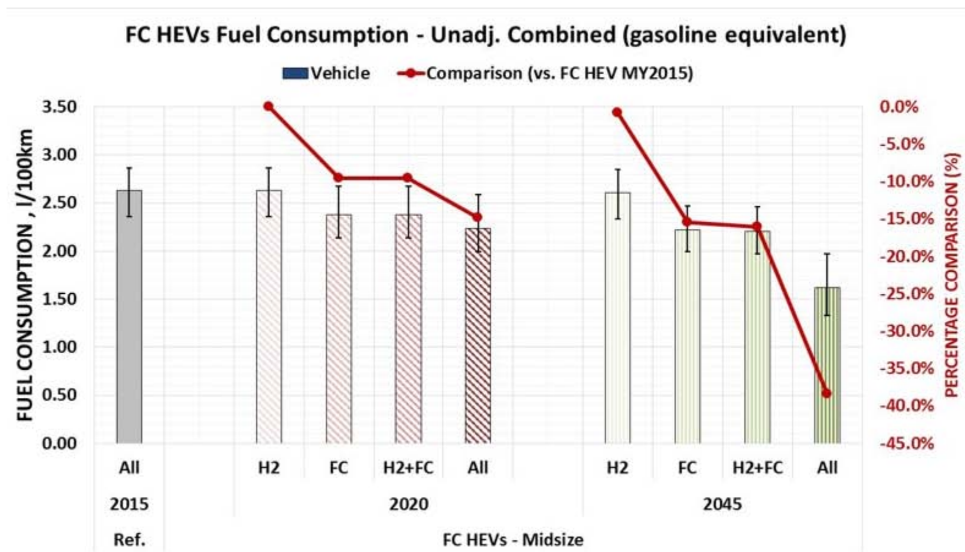
improvements in the rest of the powertrain), required hydrogen mass could drop by 1 to 4% by 2045.

- Under the same scenario (development fuel cell system only), fuel cell system cost could decrease by 50%.

For FY 2016, a thorough analysis of assumptions, component (fuel cell) and vehicle operation, and fuel economy benefits of fuel cell vehicles (compared to conventional and other advanced powertrains) will be published in the form of a comprehensive report for the BaSce simulations. In addition, requests for further analysis will be supported as part of the project.



(a) Fuel cell system cost, $



(b) Fuel consumption, l/100km

FIGURE 4. Progression in fuel cell system cost and vehicle fuel consumption considering improvements in fuel cell and hydrogen storage technology

FY 2015 PUBLICATIONS/PRESENTATIONS

1. Aymeric Rousseau, "Impact of Fuel Cell System Efficiency on Vehicle Energy Consumption and Cost." Presentation at the Annual Merit Review.

REFERENCES

1. ANL Report: Potential of Technologies for Displacing Gasoline Consumption by Light-Duty Vehicles through 2045 – September 2014.