X.5 Impact of Fuel Cell System Peak Efficiency on Fuel Consumption and Cost

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Project End Date: September 30, 2014

Overall Objectives

- Quantify the fuel displacement and cost of advanced fuel cell systems.
- Evaluate benefits of aggressive fuel cell system peak efficiency compared to the current target of 60% from an energy consumption and cost point of view.

Fiscal Year (FY) 2014 Objectives

- Study the impact of different fuel cell system targets on the vehicle energy consumption and cost using Autonomie.
- Develop specific fuel cell systems using high fidelity GCTool model for different mass activity to understand the impact of higher efficiency on component design and cost versus linear scaling approach.
- Build vehicle simulations using the individual component assumptions.
- Run the simulations and present detailed analysis related to energy consumption, cost, component sizing and vehicle weight, hydrogen tank effects, etc.
- Understand the impact of the fuel cell system and hydrogen storage performance and cost requirements compared to other powertrain technologies to ensure successful commercialization path.
- Provide guidance for long-term requirements for peak power and onboard hydrogen weight.

Technical Barriers

This project addresses the following technical barriers from the System 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 Fuel Cells 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 2014 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.
- Aggressive fuel cell system peak efficiency targets could increase fuel economy from 10 to 14% while slightly decreasing cost.

- Compared to current conventional vehicles, fuel cell vehicles achieve similar weight and a fuel economy up to 5 times higher by 2030 or 1.5 times higher (if compared to same year conventional powertrains).
- Current DOE targets for both fuel cell peak power (80 kW) and onboard hydrogen weight (5.6 kg) will exceed the requirements for most vehicle classes by 2030.

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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 or 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 scenarios relies on higher fuel cell system efficiencies (up to 68%).

APPROACH

To evaluate the fuel efficiency benefits of advanced powertrains, each vehicle is designed on individual component assumptions to meet the same vehicle technical specifications (i.e. acceleration, gradeability…). The fuel efficiency is then simulated on the Urban Dynamometer Driving Schedule (UDDS) and Highway Fuel Economy Test (HWFET). The vehicle costs are calculated using the aggregated cost of each component.

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 set of assumptions were simulated. We will show in this report 2013 and 2030 timeframes. 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. The current study includes micro hybrids as they are introduced to substitute conventional vehicles starting from 2030 (medium uncertainty case).

RESULTS

The assumptions described below have been defined on the basis of inputs from experts and the U.S. DRIVE targets. Table 1 shows the different fuel cell system assumptions evolution overtime used as inputs to the simulation model.

The fuel cell system costs are driven by the following equation:

$$(1246.5 \bullet x \bullet S^{0.2583} + P \bullet \mathbf{y}) \bullet FC_{pwr} \bullet \left(\frac{FC_{pwr}}{80}\right)^{z}$$

Where *x, y* and *z* are coefficients and *P* is the platinum price, *S* is the stack unit per year and FC_{pwr} is the fuel cell power. The costs are assumed for high production volumes (500,000 per year).

Table 2 shows the different hydrogen storage assumptions.

Vehicle Weight

The simulation results show that fuel cell vehicles' weight will be close to conventional vehicles of the same year by 2030 (Figure 1). The comparison of both fuel cell system target scenarios show aggressive fuel cell system peak efficiency impacts total vehicle weight by less than 1% compared to the constant 60% peak efficiency target. Most of the light weighting comes from onboard hydrogen weight reduction.

All the vehicles' hydrogen storage systems have been sized to provide a range of 320 miles on the combined driving cycle (UDDS and HWFET). Figure 2 shows that aggressive fuel cell system peak efficiency leads to 13%

TABLE 1. Fuel Cell System Assumptions

Parameter	Units	2013			2030		
		Low	Med	High	Low	Med	High
Specific Power FC* system	W/kg	400	400	400	580	660	740
Power Density	W/L	410	410	410	600	730	980
Peak FC Efficiency at 25% Rated Power (Aggressive Projection)	%	60	60	61	65	67	68
Peak FC Efficiency at 25% Rated Power (Constant Efficiency)	%	60	60	60	60	60	60
Platinum Price	$/Troy Oz	1,800	1,800	1,800	1,800	1,400	1,100

*FC – Fuel Cell System

TABLE 2. Hydrogen Storage Assumptions

Parameter	Units	2013			2030		
		Low	Med	High	Low	Med	High
System Gravimetric Capacity	**Useable kWh/kg**	1.41	1.41	1.41	1.5	1.67	1.96
	Useable kg H_2/kg of Tank System	0.042	0.042	0.042	0.045	0.050	0.059
System Volumetric Capacity	**Useable kWh/L**	0.947	0.947	0.947	1.27	1.5	1.6
	Useable kg H_2/L	0.028	0.028	0.028	0.038	0.045	0.048
Cost	**$/Useable kg H_2**	769	769	769	418	334	267
Percentage H_2 used in Tank	**%**	95	95	95	97	97	97
Range on combined, adjusted miles/ gasoline gallon equivalent	**miles**	320	320	320	320	320	320

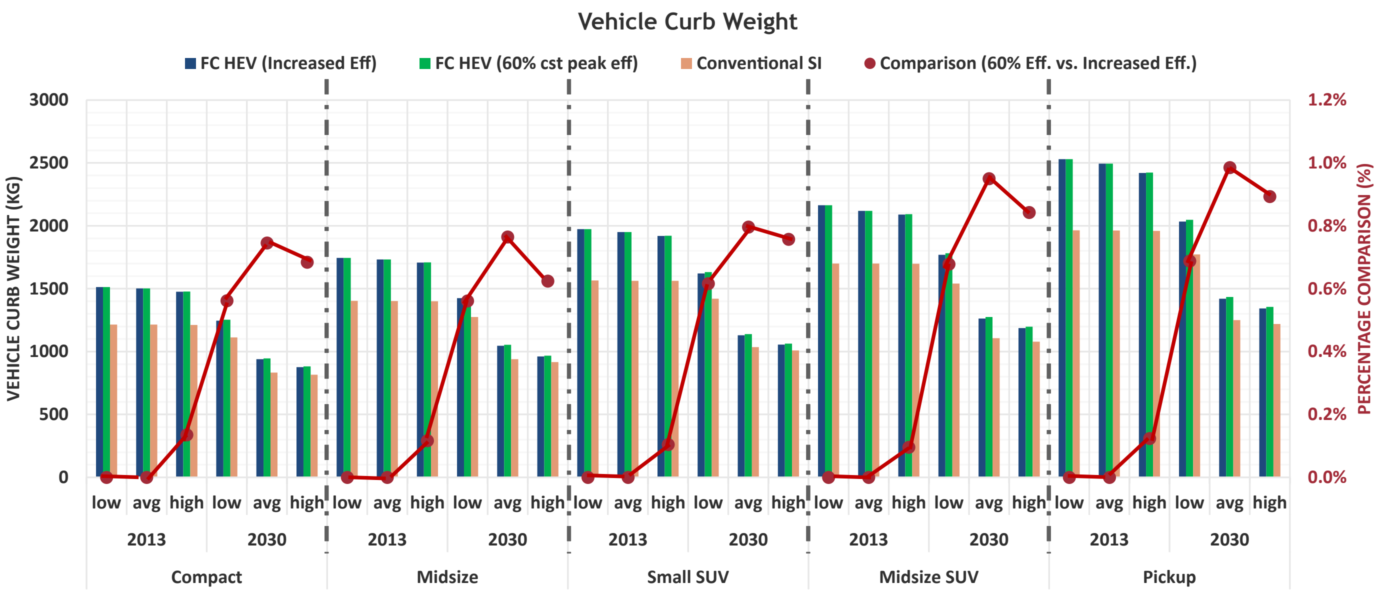

FIGURE 1. Vehicle Curb Weight (kg)

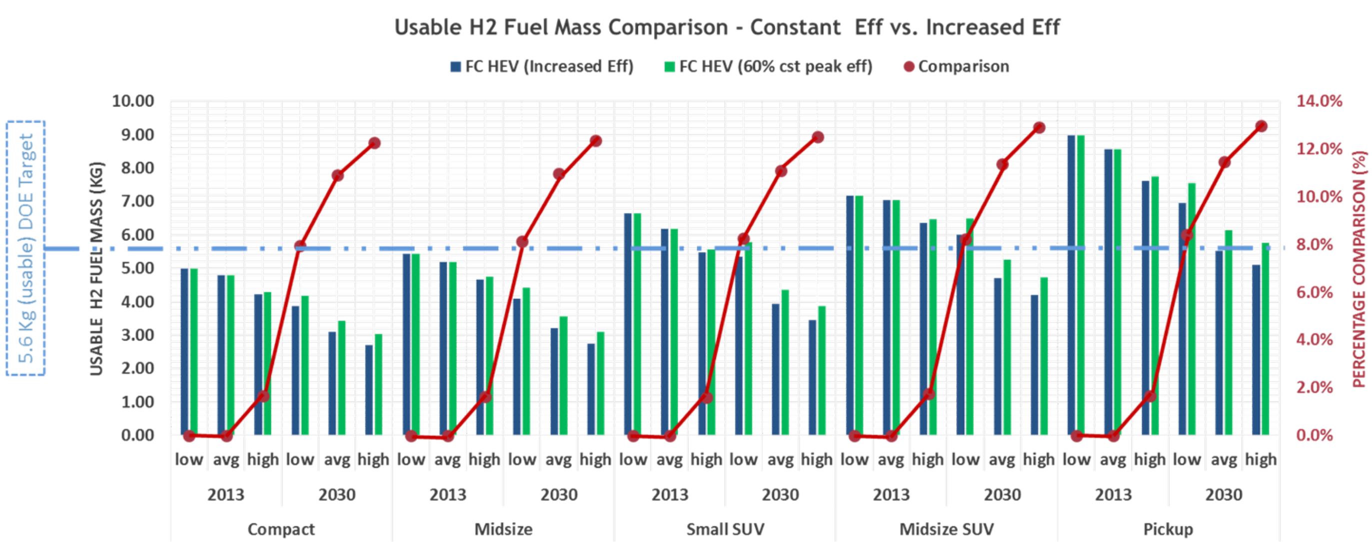

FIGURE 2. Hydrogen Usable Fuel Mass (Kg)

reduction in onboard hydrogen weight by 2030. One also notices that the shows that the current DOE target of 5.6 kg of usable hydrogen exceeds the range requirements for most vehicles by 2030.

Vehicle Energy Consumption

While aggressive fuel cell systems requirements have a small impact on vehicle weight, they do provide significant benefits on the vehicle energy consumption side. As shown in Figure 3, by 2030, advanced fuel cell systems will show about 12 to 13% of fuel economy benefit compared to the 60% peak efficiency case. When compared to the 2013 conventional reference vehicle, fuel cell hybrid electric vehicles (HEVs) could be up to 5 times more fuel efficient by 2030. Even with 60% fuel cell system peak efficiency targets, fuel cell HEVs still are up to 4 times more fuel efficient than today's conventional baseline.

As shown in Figure 4, when vehicle fuel cell HEV fuel economy gasoline equivalent ratios are compared to conventional of the same year, fuel cell HEVs fuel economy tend to get closer to the respective conventional gasoline vehicle of the same year (ratio closer to 1.5) versus a ratio of 2 in 2013. The fact that the ratios are decreasing with time points to the fact that advanced conventional vehicle energy

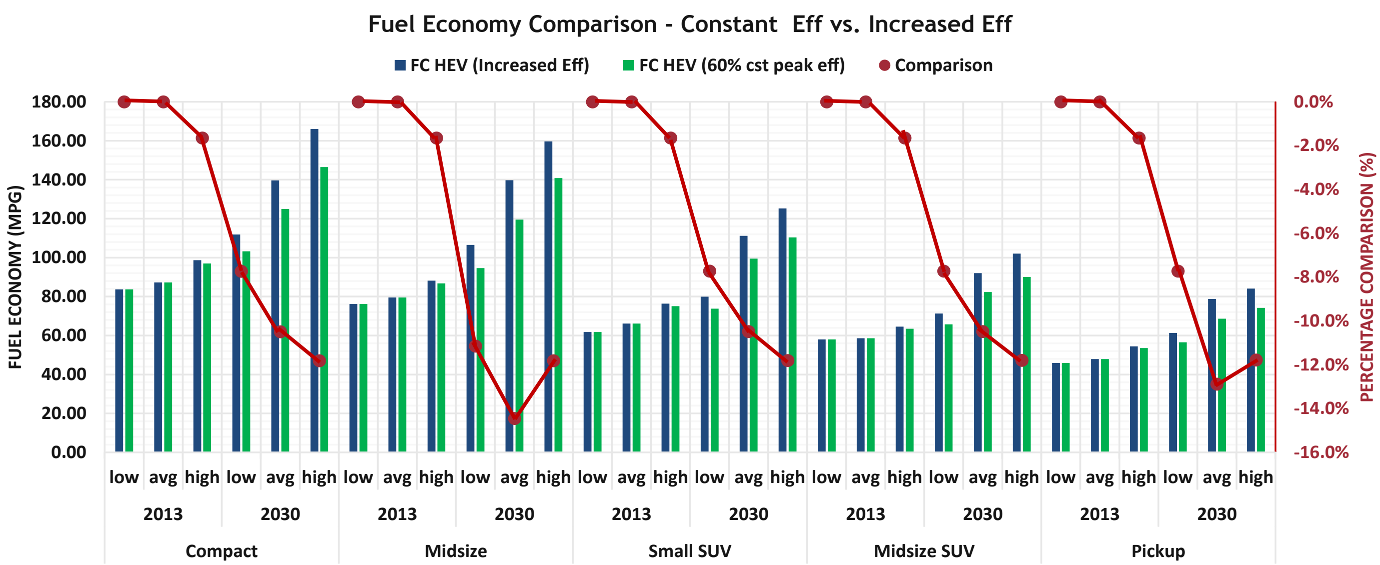

FIGURE 3. Vehicle Fuel Economy (MPGGE)

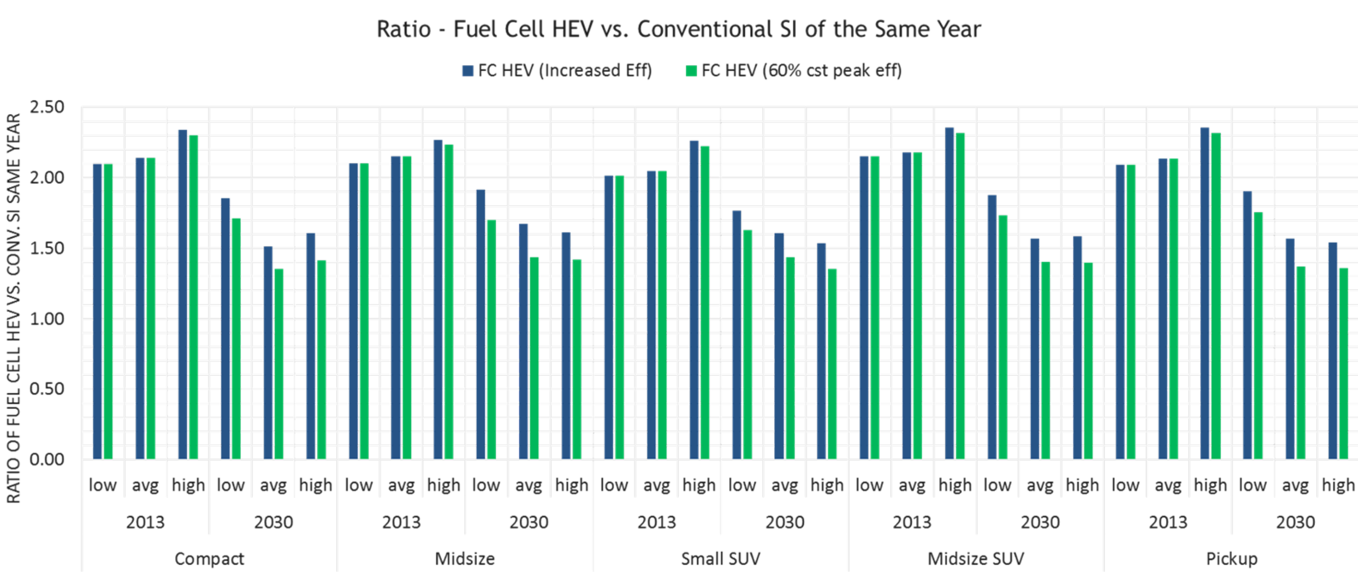

FIGURE 4. Ratio of Fuel Cell HEV vs. Conventional Gasoline of the Same Year

consumption is expected to improve faster than the one of fuel cell vehicles.

The previous trend can be explained by looking at individual system average efficiencies over the UDDS cycle. As shown in Figure 5, gasoline engines get more competitive as their average cycle efficiency significantly increases by 2030. Note that micro hybrids (start/stop systems) are introduced in 2030, which will also contribute to the reduction of the vehicle energy consumption ratio. The figure also shows that aggressive fuel cell peak efficiency targets (i.e. 68% vs. 60%) could provide up to 14% of fuel cell system average cycle efficiency increase on the UDDS cycle by 2030.

Figure 6 shows the fuel cell vehicle manufacturing cost of the different fuel cell systems considered. Manufacturer suggested retail price (MSRP) values have been computed, where the retail price equivalent value is set to 1.5 times the manufacturing cost. The results show that aggressive fuel cell

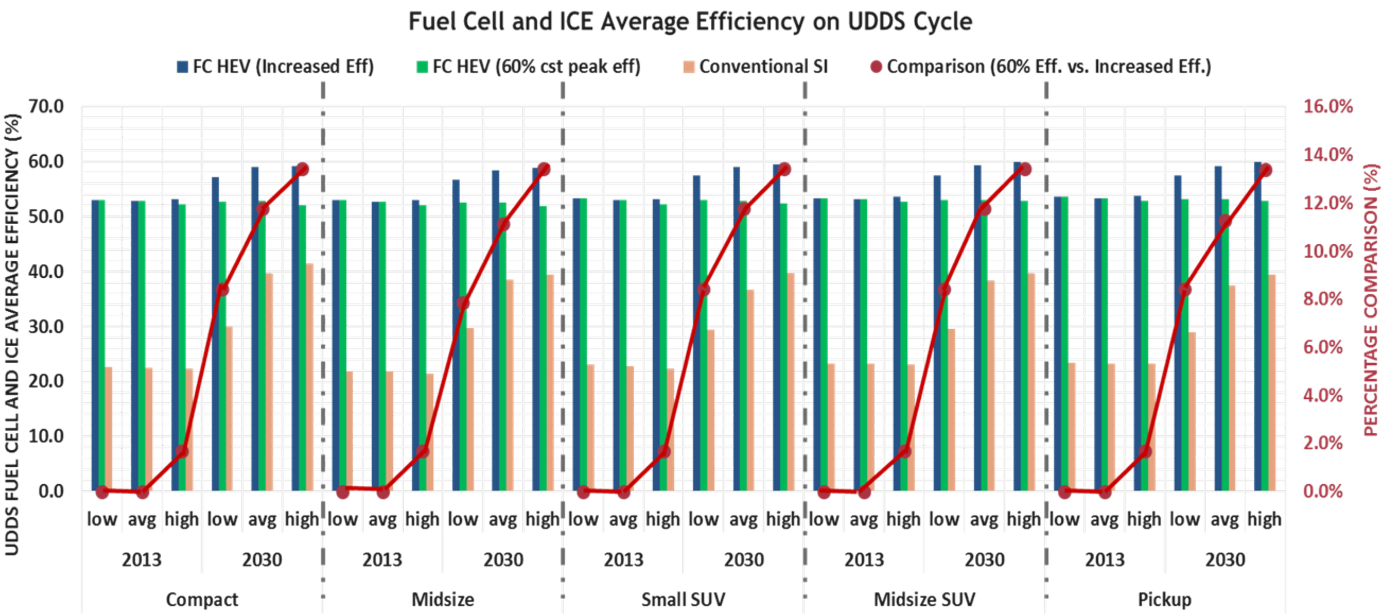

FIGURE 5. Fuel Cell and Engine Average Efficiency on the UDDS Cycle

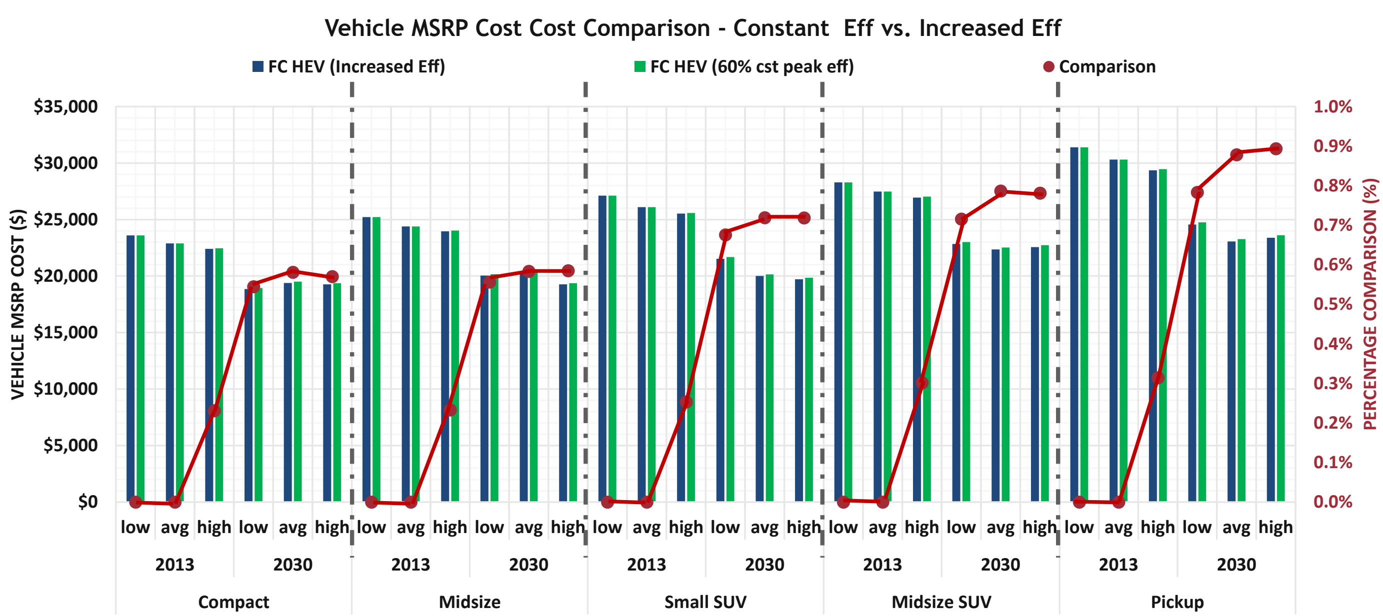

FIGURE 6. Fuel Cell Vehicle Cost

system peak efficiency could provide small cost benefit by 2030 (less than 1%).

CONCLUSIONS AND FUTURE DIRECTIONS

Full vehicle simulations were performed to assess the vehicle energy consumption and cost of fuel cell vehicles compared to conventional powertrains. Different timeframes (current and 2030) as well as fuel cell system peak efficiencies (constant 60% vs. aggressive cases up to 68%) were considered. The results showed that:

- Aggressive fuel cell system peak efficiency targets could increase fuel economy from 10 to 15% while slightly decreasing cost.
- The cost decrease is mostly due to the decrease of hydrogen tank cost (8 to 13%)
- Compared to conventional vehicles, fuel cell vehicles achieve similar weight and a fuel economy up to 4x higher by 2030.
- Current DOE targets for both fuel cell peak power (80 kW) and onboard hydrogen weight (5.6 kg) will exceed the requirements for most vehicle classes by 2030.

FY 2014 PUBLICATIONS/PRESENTATIONS

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