IX.3 Cost Benefits Analysis of Technology Improvement in Light-Duty Fuel Cell Vehicles

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Overall Objective

Quantify the impact of system improvements on energy consumption and economic viability of fuel cell electric vehicles (FCEVs).

Fiscal Year (FY) 2017 Objectives

- Quantify the fuel savings to the consumer that are attributable to improvements in fuel cell peak efficiency, and increases in weight ratio of usable hydrogen from a tank.
- Determine the breakeven point up to which the technology improvements are justifiable to the consumer.

Technical Barriers

This project addresses the following technical barriers from the System 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

(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 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 1.17: 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 2017 Accomplishments

- Evaluated the impact of FCTO funded technologies on vehicle fuel consumption for multiple vehicle classes and powertrains.
- Identified optimum technology levels where the fuel savings will offset the cost incurred in adopting a better technology.

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INTRODUCTION

FCEVs are commercially available in the United States and may achieve operational cost parity with conventional vehicles by 2025–2030 based on DOE's assumptions related to technology progress, market penetration, and production volumes. At present, fuel cells system peak efficiency reaches 60%, representing 85% of the "ultimate" target (70%) set by DOE. Future technology improvements, such as reduction of platinum group metals, are expected to reduce the cost in the long run. In the short term, various design choices are available with existing technologies to achieve tradeoffs between cost and efficiency. This study aims to evaluate various short-term design choices and quantify their impact on FCEV ownership and operational costs. The objective is to identify the optimum level of technology progress that creates sufficient savings to the consumer to justify the higher initial investment.

This analysis utilizes the results of a baseline scenario analysis study (BaSce) for fuel cell vehicles that quantified the fuel consumption benefits associated with achieving the DOE technology targets [1]. Although technology progress and cost reduction are expected to be achieved within the same time span, they are not usually accomplished through the same technology change. As fuel cell technology is currently focused on proton exchange membranes, the cost reduction is primarily achieved by reducing the quantity of platinum group metals needed as a catalyst. Reduction in platinum loading could adversely impact efficieny. The design choices considered in this study either achieve improved efficiency or reduce weight with incremental increases in the initial component cost.

APPROACH

This study assumes that present-day FCEVs meet or exceed DOE targets for 2015 on parameters such as peak efficiency of the fuel cell and weight ratio of usable hydrogen in the storage system. These vehicles already provide an alternative fuel vehicle with lower petroleum use and emissions compared to conventional vehicles, so further technology improvements should aim to make these vehicles competitive in terms of ownership cost.

Ownership Cost Assumptions

The vehicle costs were separated into initial cost and operational cost. Additional factors such as maintenance costs, depreciation, and cost of financing are assumed to be comparable across technologies. Over the 5-year service time of the vehicle, the fuel savings will yield monetary benefits to the consumer. The total present value (TPV) of the fuel will show whether the initial investment in improved technology is justified monetarily or not. The details of the TPV calculation assumptions are leveraged from previous work [2]. The increase in initial cost and the overall savings can be converted to \$/kW to determine the cost tolerance of the technology. An example of the analysis is illustrated in Figure 1.

RESULTS

The first step in this study was to understand how the various technology changes affect the fuel consumption of an FCEV, and the monetary impact over a 5-year ownership period. The following assumptions were considered:

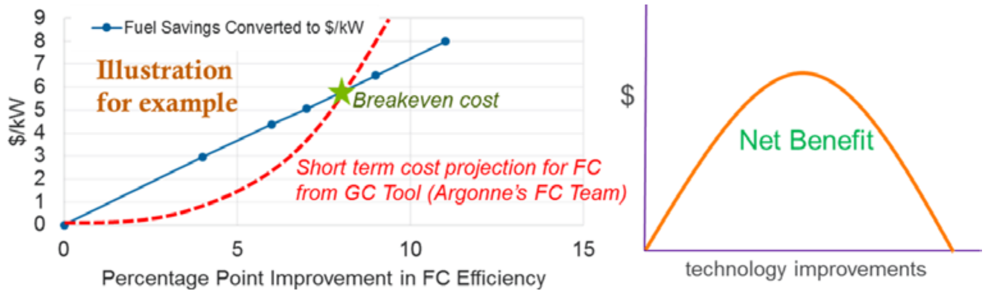
- Vehicle usage is assumed to be 14,000 miles per year.
- Hydrogen is expected to cost \$4/gge.
- A discount rate of 7% is assumed for the TPV calculations. This rate determines the present value of future cash flow. Based on this assumption, getting \$107 one year from now is same as getting \$100 today.

The default FCEV model from Autonomie [3] was used for this analysis. Although the impact on a hybrid vehicle and a plug-in hybrid vehicle with a 20-mile range (PHEV 20) were studied, since both powertrain show similar trends, we only show the results for the hybrid vehicle. We examine the impact of changes in vehicle usage and hydrogen cost later in this document.

Figure 2 shows the sensitivity of the TPV of fuel savings to the improvements in hydrogen storage and fuel cell efficiency. The efficiency term refers to the peak efficiency of the stack, usually at about 25% of the rated load. We computed the variation in operational efficiency as part of the simulation analysis. Achieving 70% fuel cell efficiency can save the consumer over \$600 in fuel costs over the 5-year period. For hydrogen storage, the improvement in weight ratio results in modest fuel savings, and even a 60% improvement in the current ratio of H_2 to tank mass only results in approximately \$100 worth of fuel savings. Therefore, the primary focus in storage technologies should be on reducing the cost of the components, even if doing so does not contribute to weight reduction. If the cost targets are achieved along with efficiency and weight ratio targets, the savings could be as high as \$4,000 compared to present day FCEVs.

Note that the component cost savings are not equivalent to the difference in vehicle selling price. In this study, we assume that the manufacturers will pass on the manufacturing cost savings to the consumers. Consumers will experience fuel cost savings directly; the TPV of fuel cost savings is computed to compare the value of future savings against the initial investment needed for the technology improvement.

Hydrogen storage technology changes are expected to reduce the cost of the tank and will be economically more attractive than the present scenario. This study focuses on the various design choices available for fuel cell efficiency



FC – fuel cell

FIGURE 1. Illustrated example for cost benefit analysis

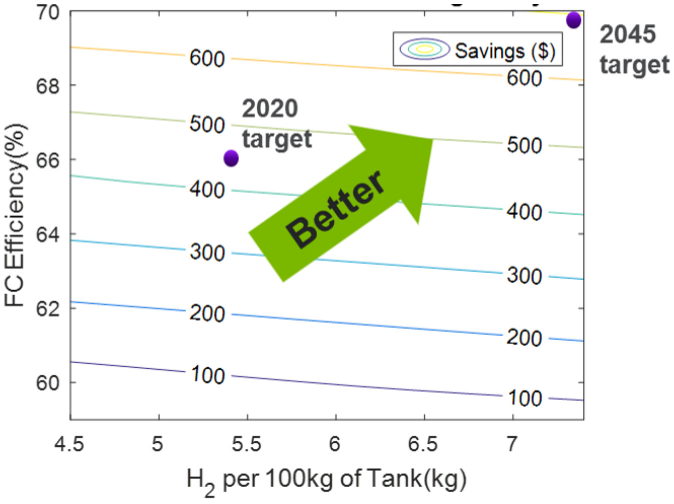


FIGURE 2. Sensitivity of TPV to improvements in H_2 storage and fuel cell efficiency

improvements. The savings due to efficiency improvement are fairly linear and proportional to the fuel cost. Figure 3 shows the TPV of fuel savings with improvement in efficiency.

Argonne's fuel cell experts developed multiple design choices representing today's technology. Figure 4 shows the tradeoffs between efficiency and cost for these choices. They are achieved by varying platinum loading as well as varying the parameters affecting the operating temperature and heat rejection from the stack. Table 1 summarizes the design choices from GC Tool.

The design choices are grouped based on their platinum loading. The second column in Table 1 shows the ratio of power output to the difference in operating and ambient temperature. Lower values for this ratio (resulting from higher temperature operation) are more efficient, but result in a higher manufacturing cost.

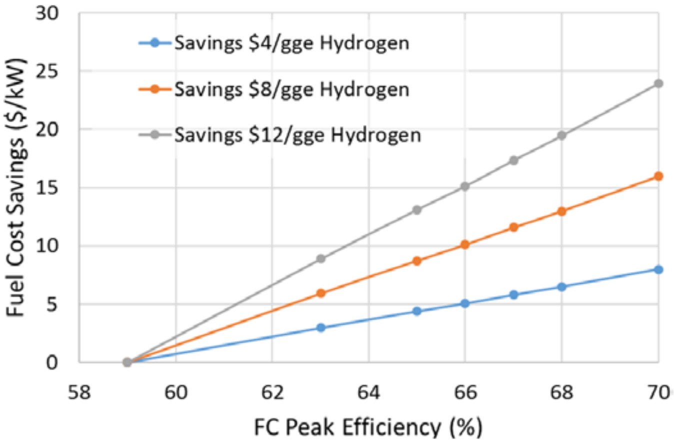


FIGURE 3. TPV of fuel savings with improvement in efficiency

TABLE 1. Design Choices Derived from GC Tool for Varying Platinum Loading and Thermal Considerations

Design Choices	Heat Rejection (kW/°C)	Platinum Loading (mg/cm^2)	Peak Efficiency (%)	Fuel Cell Cost ($/kW)
1a	1.0	0.1	61.7	56.9
1b	1.25	0.1	60.8	46.8
1c	1.45	0.1	60.5	44.9
1d	1.75	0.1	60.2	44.7
2a	1.0	0.2	62.9	58.8
2b	1.25	0.2	62.0	49.3
2c	1.45	0.2	61.7	47.2
2d	1.75	0.2	61.4	46.7
3a	1.0	0.4	64.1	68.6
3b	1.25	0.4	63.3	57.1
3c	1.45	0.4	62.9	53.9
3d	1.75	0.4	62.5	52.5

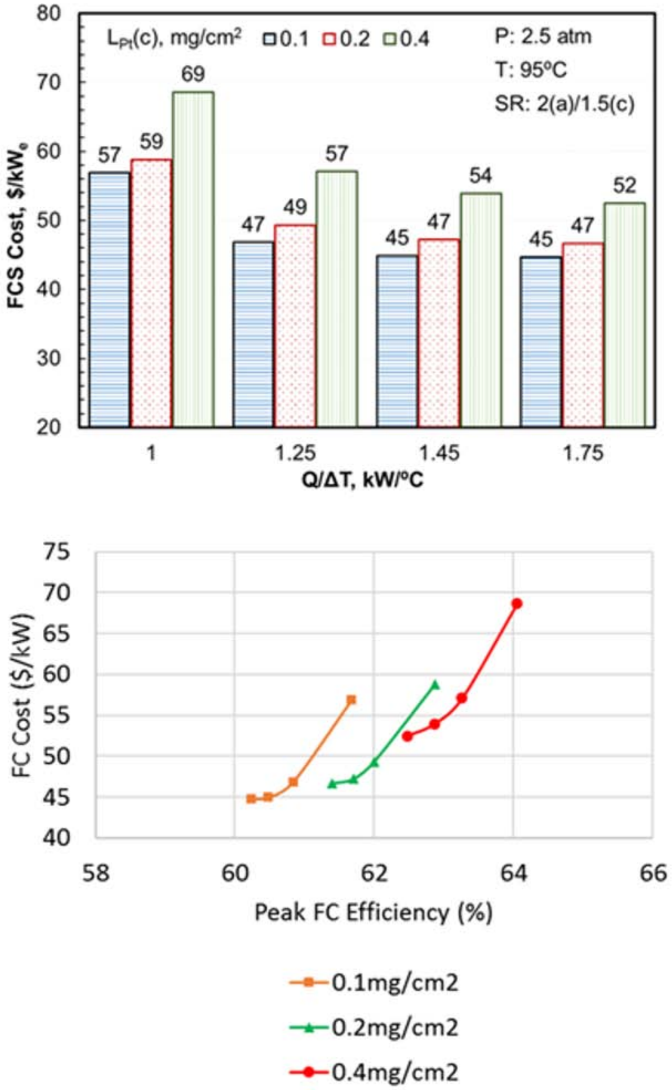
We assume that present fuel cells have a peak efficiency of 59% at a cost of $51.4/kW. This year, improvements have resulted in more efficient fuel cells, and some design choices achieve better efficiency at a lower cost compared to the baseline. Such lower-cost choices are obviously better than the present scenario; however, it is important to see which of these choices maximize the overall consumer savings. Combining the fuel savings TPV and the initial cost information quantifies the net savings associated with these design choices.

Figure 4 shows the cost and efficiency values from each design choice. A pareto front can be derived for the lower cost and higher efficiency choice, making some choices (1a, 2a) irrelevant, as lower-cost and higher-efficiency solutions are available.

Figure 5 shows the pareto front for the cost and efficiency tradeoff intersecting with the TPV of fuel savings associated with different fuel cost assumptions. This shows that at 63% peak efficiency at $54/kW is the limiting point beyond which the initial investment does not yield justifiable returns.

From the consumer's point of view, maximizing net savings is more important than achieving the highest possible efficiency. To understand the net savings, the difference between TPV of fuel savings and the incremental cost difference is examined in Figure 6. For three different fuel cost assumptions, we examine the consumer net savings.

Net savings is shown to depend on the hydrogen cost. At $4/gge, the most economical choice for the consumer is design choice 1d, which yields 60.2% peak efficiency at $44.7/kW. It is the least efficient choice available, but due to the reduction in initial cost of the fuel cell, net savings for the consumer is highest.



FCS – fuel cell system

FIGURE 4. Cost and efficiency impact of platinum loading and other design choices

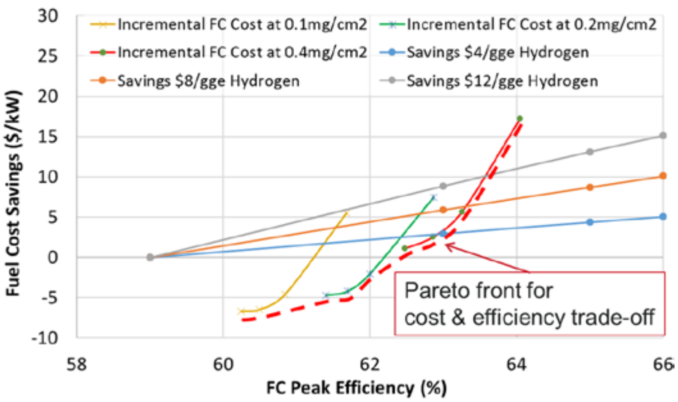


FIGURE 5. Comparing initial cost and the present value of future savings

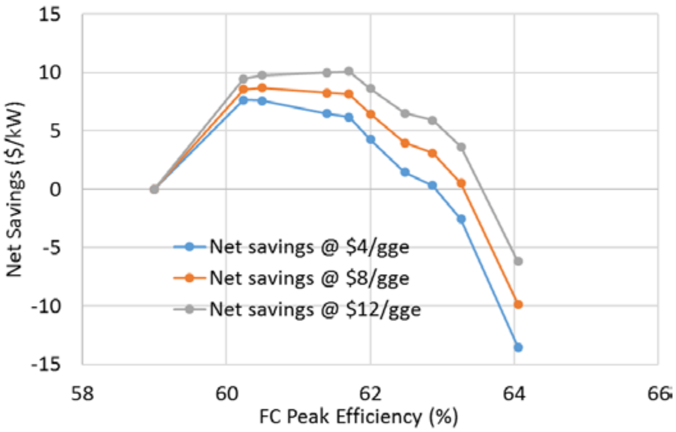


FIGURE 6. Net savings from design choices

For a higher fuel cost, say $12/gge, the cost of fuel saved offsets the initial investment and provides a 7% return on investment during the period of ownership. In this case, the maximum net benefit is design choice 2c, with a 61.7% peak efficiency and $47.2/kW. Note that many design choices yield net savings for the consumer, but the above-mentioned choices are the ones that maximize savings.

If the objective is to maximize efficiency while remaining economically viable, the design choice would be 3c. In this case, achieving 62.9% peak efficiency at a cost of $53.9/kW results in enough fuel savings to provide a 7% return on the investment made for efficiency improvements.

CONCLUSIONS AND UPCOMING ACTIVITIES

This study shows that for each analysis year, a technology level exists that maximizes benefits to the consumer. For the current technology choices, we identified the optimum design choices that maximize consumer savings. While fuel prices are uncertain, the trends associated with the net benefit of technology change are clearly understood.

Since the economic benefits are dependent on both the baseline and the future component technologies performance and cost, this study should be regularly updated when new information becomes available.

FY 2017 PUBLICATIONS/PRESENTATIONS

1. Vijayagopal, R., N. Kim, A. Rousseau, "Fuel Cell Powered Vehicles: An Analysis of How Technology Progress Affects the Technical and Economic Feasibility," Argonne Report ANL-17/07, May 2017.

2. Islam, E., A. Moawad, N. Kim, A. Rousseau, "Fuel Displacement and Cost Feasibility Study of Fuel Cell Vehicles Based on U.S. Department of Energy Targets," (paper accepted for presentation at the 30th International Battery and Fuel Cell Electric Vehicle Symposium and Exposition [EVS 30], Stuttgart, Germany, October 2017).

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1. Moawad, A., N. Shidore, A. Rousseau, *Assessment of Vehicle Sizing, Energy Consumption and Cost through Large Scale Simulation of Advanced Vehicle Technologies*, ANL/ESD-15/28, report to the U.S. Department of Energy, March 2016.

2. A. Vyas, "Plug-in hybrid electric vehicles: How does one determine their potential for reducing U.S. oil dependence?" (paper presented at the 23rd International Battery and Fuel Cell Electric Vehicle Symposium and Exposition [EVS 23], Anaheim, California, December 2–5, 2007).

3. Autonomie, available from www.autonomie.net.