XI.4 Comparing Infrastructure Costs for Hydrogen and Electricity

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Fiscal Year (FY) 2012 Objectives

- Develop consistent retail infrastructure cost estimates for hydrogen refueling stations (HRS) and electric vehicle supply equipment (EVSE)
- Compare retail costs on a common transportation energy service basis: per vehicle mile traveled
- Compare retail costs on a common early market adoption basis: fuel service to 10% of all light-duty vehicles in a typical 1.5 million person city in 2025
- Establish an analysis basis that can be extended to a dynamic and regional representation of retail costs across all major U.S. urban areas

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Future Market Behavior

(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 Program Multi-Year Research, Development and Demonstration Plan:

- Milestone 1.4 (Systems Analysis Task 1: Perform Studies and Analysis): Complete evaluation of fueling station costs for early vehicle penetration to determine the cost of fueling pathways for low and moderate fueling demand rates. (4Q, 2012)

FY 2012 Accomplishments

- The analysis framework provides a side-by-side comparison of HRS and EVSE retail infrastructure costs in 2025 when 10% of light-duty vehicles (LDVs) in a city with 1.5 million persons (equal to 120,000 LDVs) are either plug-in electric vehicles (PEVs, including battery electric vehicles [BEVs] and plug-in hybrid electric vehicles [PHEVs]) or hydrogen fuel cell electric vehicles (FCEVs).
- Annual levelized capital costs for HRS and EVSE are essentially indistinguishable given the uncertainty and variability around input assumptions. These costs fall within the range of 2.5–6.0 cents per mile, with central values of 3.0–3.2 cents per mile.
- Comparisons of two distinct EVSE scenarios suggest that, given optimistic assumptions about utilization rates, a *Robust Public* EVSE infrastructure with significant Level 2 work and public fast charging can be as capital intensive as a *Home Dominant* EVSE infrastructure with most electricity provided by charging at home.
- When including a consistent representation of vehicle performance and costs [1], total vehicle and fuel costs per mile range from 21 to 34 cents per mile. Within this range, PHEVs and hybrid electric vehicles (HEVs) have slightly lower costs per mile than conventional internal combustion engine (ICE) gasoline vehicles (Figure 4). Costs for FCEVs and BEVs are 2–6 cents per mile higher than those for PHEVs and HEVs.
- Cost differentials are reduced significantly when including a cost penalty of $150 per tonne of CO_2 equivalent (tCO_2e) greenhouse gas emissions, assuming hydrogen from natural gas, electricity from a business-as-usual grid [2], and conventional gasoline.

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Introduction

Advanced LDVs fueled by either hydrogen or electricity offer significant social benefits, including reductions in greenhouse gas (GHG) emissions, improved energy security, and improved air quality. Both fuel types have zero tailpipe emissions and can be produced from a diversity of domestic energy resources. One of the key barriers to introducing hydrogen and electric vehicles is the upfront capital cost of retail fuel supply equipment. We develop a simple apples-to-apples framework to compare capital costs for HRS and EVSE for early market introduction scenarios in 2025. Results are highly dependent upon a number of uncertain and variable input assumptions, including units required per vehicle, utilization rates, and cost reductions due to experience. Our findings suggest that HRS and EVSE capital costs are similar on a per-vehicle-mile-traveled basis. When accounting for total vehicle and fuel costs, hydrogen and electric vehicles are slightly more expensive than HEVs running on gasoline. Additional benefits of hydrogen and electricity, such as reduced GHG emissions or improved energy security, would likely need to be taken into account to reach cost parity with gasoline HEVs.

Approach

The simple cost estimation framework incorporates key variables that influence costs per mile driven and per equivalent early market share. The fueling service provided by EVSE and HRS is fundamentally different; while HRS may provide a level of convenience comparable to gasoline refueling stations various types of EVSE have distinct levels of convenience and accessibility. In an attempt to compare these services on a consistent cost basis, optimistic assumptions were made about the utilization of each HRS or EVSE unit. These assumptions correspond to very high, but feasible, utilization rates, which translate into relatively low capital costs per vehicle mile traveled. A mismatch in the joint deployment of vehicles and refueling equipment would result in higher costs per mile than those estimated in this study. Due to the variety of EVSE options and the uncertainty of how EVSE infrastructure will evolve to meet consumer needs, two EVSE deployment scenarios were developed: *Home Dominant* and *Robust Public*. A greater quantity of electricity is delivered to vehicles through Level 2 work and public fast charging stations in the *Robust Public* scenario compared to the *Home Dominant* scenario. Of all PEVs, 20% are BEVs in the *Home Dominant* scenario and 30% are BEVs in the *Robust Public* scenario.

Because both HRS and EVSE will undergo cost reductions in the near-term as the number of units deployed increases, our analysis framework assumes provision of fuel for 10% of LDVs in a city of 1.5 million persons in the year 2025. This early market adoption phase includes 120,000 LDVs fueled either by hydrogen as FCEVs or, in another case, by electricity as a mix of BEVs and FCEVs. We estimate the number of HRS and EVSE units required per FCEV or PEV, which provides a basis for the utilization rates discussed below. Unit costs for EVSE are based primarily upon near-term costs [3], with reference to some long-term cost estimates, and applying a 15% capital and installation cost reduction due to experience and economies of scale. Unit costs for HRS are based upon results from recent input from industry on near-term station costs [4].

The EVSE and HRS infrastructure required to support 120,000 PEVs or FCEVs depends upon assumptions about refueling convenience, vehicle miles traveled (VMT) per year, and utilization rates. Hydrogen is used in FCEVs and electricity is used in PEVs, including BEVs and PHEVs, with the latter fueled with both electricity and a liquid fuel such as gasoline or biofuel. A key assumption unique to this study is the VMT on electricity per year for PEVs. We assume that early adopters within the first 10% of the LDV market will attain significant utility from vehicle electrification, driving more electric miles per year than would be driven in typical households. This assumption, indicated in Figure 1, results in a reduction in the cost per mile driven for PEVs. In addition, we assume that some additional electric VMT are induced in the *Public Robust* scenario. For HRS we assume an average station utilization rate of 75% and VMT per year equivalent to gasoline vehicles, which is optimistic given the changes in supply and demand that are likely to occur during early market growth.

Results

Because the majority of PEVs are assumed to be PHEVs, and because PHEVs are partially fueled by gasoline (Figure 1), the total VMT on electricity is less than the VMT on hydrogen for the same 120,000 LDVs deployed as either PEVs or FCEVs. This difference is reconciled by dividing total capital costs for HRS and EVSE by the number of miles driven on hydrogen or electricity, respectively. Results are summarized in Figure 2 with annual VMT shown on the left-hand vertical axis and with stacked bars, and with levelized retail capital costs per mile shown on the right-hand axis and with dots. Gasoline fuel costs, for the gasoline miles driven by PHEVs, are indicated for the two PEV scenarios. Fewer gasoline miles are driven in the *Robust Public* scenario due to induced electric miles (Figure 1) and the larger market share for BEVs. Capital costs per mile are nearly identical for hydrogen and electricity retail infrastructure.

For electricity and hydrogen we distinguish between capital costs associated with retail infrastructure and other costs associated with upstream fuel supply. These “Station” and “Fuel” costs are summarized in Figure 3 for the *Home Dominant* scenario and are compared with gasoline fuel costs for PHEVs, HEVs, and ICEs on a per-mile-driven basis. Key assumptions underlying these cost results are provided in [3], and include fuel costs from the Annual Energy Outlook (AEO) for 2025 and vehicle fuel economies from [1]. We assume that hydrogen is delivered to the HRS at a cost of \$3.00/kg. As indicated, BEV and PHEV costs per mile are 16%–19% lower than FCEV fuel costs, while ICE fuel costs are ~\$0.04 per mile higher (50%) than FCEV or HEV fuel costs. The error bars indicated in Figure 3 are only for the

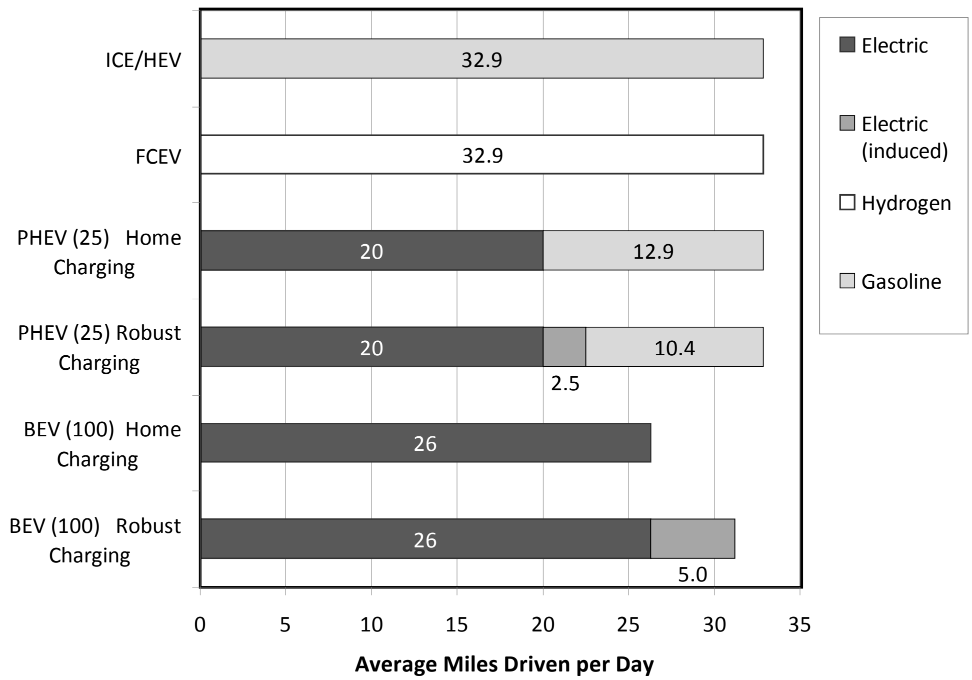

FIGURE 1. Average miles driven per day for LDVs, assuming a high percentage of electric miles for ideal PEV households within the early 10% of the LDV market

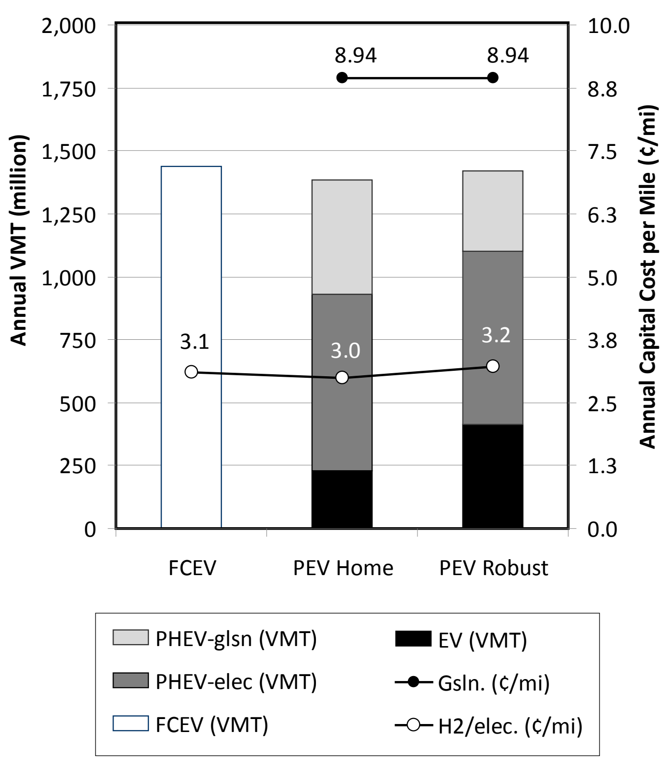

FIGURE 2. Annual vehicle miles traveled for all FCEVs or PEVs in three scenarios, gasoline costs per mile for PHEVs, and levelized capital costs per mile for corresponding HRS and EVSE retail infrastructure

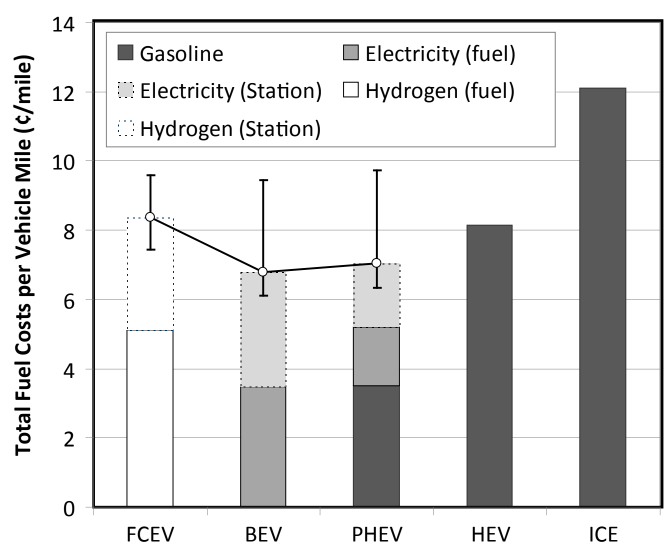

FIGURE 3. Total fuel costs per mile for hydrogen, electricity, and gasoline by vehicle type. "Station" costs refer to retail infrastructure, and "fuel" costs are additional upstream production and delivery costs.

capital cost estimates associated with HRS and EVSE, not for uncertainty or variation in upstream fuel costs. EVSE costs only include the equipment installed onsite and do not include any upstream investments.

Fuel costs can be combined with levelized vehicle costs per mile in 2025 by averaging vehicle cost estimates from

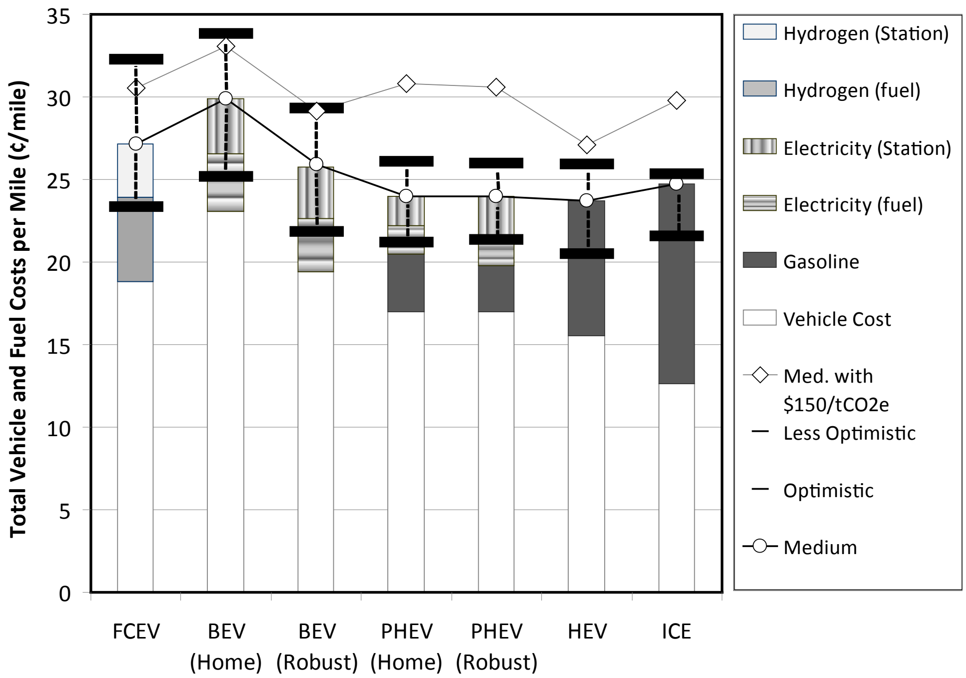

FIGURE 4. Total vehicle and fuel costs, with sensitivities for vehicle cost and fuel economy. GHG price signal result is based upon business-as-usual electricity (from AEO), hydrogen from natural gas, and a conventional gasoline blend.

DOE for years 2020 and 2030 [1]. These costs are shown in Figure 4, with error bars representing ranges associated with high and low vehicle cost estimates as well as high and low vehicle fuel economies [1]. As shown, vehicle and fuel costs per mile are slightly higher for FCEVs and BEVs, with higher BEV utilization (VMT per year) reducing levelized costs in the *Robust Public* scenario. Introducing a hypothetical \$150/tCO_2e price signal greatly reduces cost differentials between vehicle types, though HEVs running on gasoline retain a 6%-22% cost advantage over other vehicle types.

Conclusions and Future Directions

A simple apples-to-apples comparison of HRS and EVSE capital costs on a per-vehicle-mile-traveled basis suggests that the capital intensity of hydrogen and electricity retail infrastructure is comparable in the context of an early market adoption scenario where 10% of LDVs are either FCEVs or PEVs in 2025. Results suggest that HRS and EVSE capital costs are similar on a per-vehicle-mile-traveled basis, and when total vehicle and fuel costs are accounted for hydrogen and electric vehicles are slightly more expensive than HEVs running on gasoline. These results are based upon optimistic assumptions about electric miles driven per year per PEV (Figure 1), assuming that the first 10% of the LDV market includes households demanding high electric VMT per year. Future work will include the following:

- Extend the comparison framework to incorporate variability of inputs across U.S. geographies, including fuel costs, consumer preferences, resource availability, and spatial dynamics associated with retail equipment deployment.
- Explore how fueling behavior and the premium consumers place upon convenience might influence the dynamic rollout of retail infrastructure and vehicle deployment.
- Develop more in-depth analysis of business decisions to invest in retail infrastructure.

References

1. DOE (2012). Total Costs of Ownership of Future Light-Duty Vehicles. U.S. Department of Energy, DE-FOA-0000592. Retrieved February 17, 2012, from https://www.fedconnect.net/fedconnect/?doc=DE-FOA-0000592&agency=DOE.

2. EIA (2012). Annual Energy Outlook 2012. U.S. Energy Information Administration, Report Number DOE/EIA-0383(2012), available at http://www.eia.gov/forecasts/aeo/.

3. Melaina, M.W. (2012). Comparing Infrastructure Costs for Hydrogen and Electricity, DOE Annual Merit Review, available at http://www.hydrogen.energy.gov/annual_review12_analysis.html.

4. Melaina, M.W. (2012). Hydrogen Refueling Infrastructure Cost Analysis, DOE Annual Merit Review, available at http://www.hydrogen.energy.gov/annual_review12_analysis.html.