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Plug-in fuel cell electric vehicles: A California case study

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ABSTRACT

Plug-in fuel cell electric vehicles (PFCEVs) combine features of battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs). With a 40-mile battery electric range (BER), the PFCEV provides unusually efficient driving. The BER also affords convenient recharging. The fuel cell and hydrogen fuel facilitate long range and quick refueling, removing range anxiety. With a small battery and fuel cell, the PFCEV maintains weight low and efficiency high. Thereby, PFCEVs are economically competitive with other vehicles and unusually efficient. This paper uses California as a case study of PFCEV deployment due to regulations that make it the first deployment area of alternative vehicle technology. If all vehicles in California today were PFCEVs, the hydrogen required would be significantly less than current hydrogen production for petroleum refining in California, and the electricity used would be 19% of California's current total demand. The BER capability suggests fewer hydrogen fueling stations needed to fuel PFCEVs compared to non-plug-in FCEVs. These results suggest that PFCEVs are an attractive candidate as the principal vehicle owned by the majority of the motoring public in the electric vehicle era.

Introduction

Motivation

The transportation sector is the second-largest emitter of greenhouse gases (GHGs) in the Unites States, responsible for more than a quarter of GHG emissions [1]. Furthermore, nearly two-thirds of the transportation GHG emissions are associated with light-duty vehicles [2]. Transportation is also responsible for 38% of the criteria air pollutants (CAPs) in the U.S [3]. For these reasons, the reduction of GHGs and CAPs from personal and other light-duty vehicles is a major goal of both regulatory agencies and automobile manufacturers. Several options are available today to achieve this goal, but all have drawbacks. For example, the conventional gasoline hybrid electric vehicle (HEV) does not offer the dramatic emissions reductions of other alternative vehicles and does not allow for zero or near-zero emissions driving. A more advanced alternative vehicle, the battery electric vehicle (BEV), sacrifices attributes that typical drivers do not want to give up, such as driving range and quick refueling. The fuel cell electric vehicle (FCEV) is emerging to provide both the range and short fueling times to which the public is accustomed, but the fueling infrastructure is at an early stage. An alternative vehicle without such drawbacks that would increase adoption, increase efficiency, and reduce the requirements for infrastructure would accelerate the market transformation.

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Current advanced alternatives and their issues

Three major advanced alternative vehicle types are available today: plug-in hybrid electric vehicles (PHEVs), BEVs, and FCEVs. While each of these offers the potential to reduce emissions compared to conventional vehicles, each also has its own issues that impair both the required reductions in emissions and driver convenience.

PHEVs rely on gasoline and an internal combustion engine, but have a moderately-sized battery to provide a modest battery electric range (BER),[1] on the order of 20 miles. The battery leads to higher overall efficiency and a reduction in CO_2 emissions by 25% in the near future and 50% in the long-term compared to conventional hybrid vehicles [4]. This is a significant improvement considering HEVs already have a battery in their powertrain. Enlarging the battery, allowing recharging from an external electricity source, and enabling a modest BER results in significant emission reductions compared to HEVs. The issue with PHEVs is they still use combustion engines, run on gasoline, and emit CAPs. This makes PHEVs an attractive transition vehicle, but not a long-term solution toward achieving transportation emissions goals.

BEVs have a large battery as their sole energy source, zero tailpipe emissions (in fact, no tailpipe), and high efficiency. However, BEVs have short range and long charging times [5]. While drivers can conveniently recharge BEVs at home, the BEVs' overall emissions depend on the emission characteristics of the electric grid. With the current trend of increasing clean renewable power such as wind and solar, emissions associated with BEVs are decreasing. Unfortunately, this does not resolve the issues associated with shorter-than-conventional driving range and long charge times.

FCEVs use a fuel cell as the engine and hydrogen as the fuel. As a result, they have zero tailpipe emissions, and a range and fueling time comparable to conventional gasoline vehicles. However, FCEVs are less efficient than BEVs on a life-cycle basis due to the inefficiencies associated with the hydrogen supply train. While the majority of hydrogen is currently produced from natural gas [6], electrolysis with renewable power that might otherwise be curtailed is promising for the future production of renewable hydrogen as well as the production of hydrogen from water resource recovery facilities and land-fills [7,8].

One significant challenge for both BEVs and FCEVs is charging and fueling infrastructure, today limited to select regions in the world where alternative vehicle markets are just now emerging. While in an incipient state today, electric charging and hydrogen fueling stations are expected to rapidly develop as the market evolves.

In-depth analyses on the preceding alternative vehicles, their efficiencies, and their emissions can be found in prior studies [9,10,11].

A variation to the current alternative vehicle options is the PFCEV, namely an FCEV with the capability of a plug-in BER (Fig. 1). By combining the attractive features from all three advanced alternative vehicles discussed above, PFCEVs overcome the issues that each have individually. PFCEVs have a moderately-sized battery to allow for some BER and charging from the electric grid, and they also have a small fuel cell to use as a range extender. For more details on the PFCEV powertrain dynamics, which is beyond the scope of this paper, consult prior work [12,13]. Studies have shown the PFCEV to be among the cleanest vehicle types, making it an interesting vehicle type to study further [14,15].

A summary of the key characteristics of each of these advanced alternative vehicles is provided in Table 1.

To evaluate the PFCEV concept, this study addresses the electricity and hydrogen needed to fuel a California population of light-duty PFCEVs in contrast to BEVs and FCEVs, as well as the emissions associated with each of these vehicle types. The results reveal the benefits and drawbacks of each of the advanced alternative vehicle types with respect to their fuel use and emissions, applied to the state of California which is a major area of interest for alternative vehicle technology due to strict emissions regulations. The analysis also sheds light on whether or not PFCEVs are a viable candidate as a commercial vehicle.

Methodology

The National Renewable Energy Laboratory's (NREL's) FASTSim vehicle simulator was used to model the performance and fuel economy of the PFCEV [16]. FASTSim can determine the performance, mileage, and emissions of a vehicle given its powertrain characteristics [17]. The preset configuration of the Chevrolet Volt in FASTSim was first modified to resemble a PFCEV. Secondly, the fuel converter efficiency profile was changed to match that of current FCEVs, with a maximum efficiency of 62% [18]. Third, the general shape of the efficiency vs. power curve was changed to match the curve of a fuel cell as depicted in the literature, namely moving the peak efficiency to lower power levels and having a more linear downward slope [19]. The weight of the vehicle was changed to reflect the components of a PFCEV.

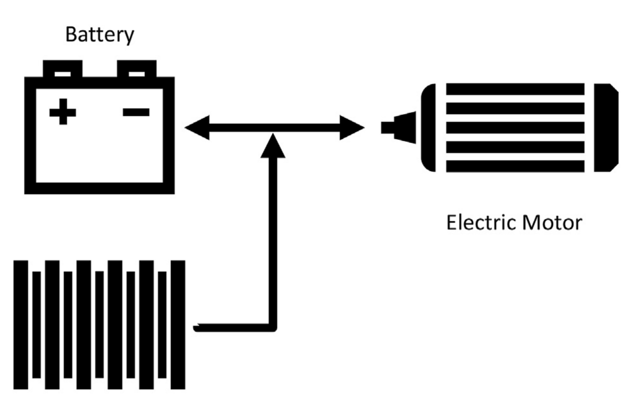

Fig. 1 – Simplified powertrain schematic of PFCEV.

[1] BER. While the battery is the only source of electric power in the PHEV powertrain, this is not the case for the plug-in fuel cell electric vehicle. Therefore, the conventional acronym AER is not adequate to describe driving range powered by the battery of a vehicle. The new acronym BER is used to distinguish between the battery and the other power source, whether it is electric or not.

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