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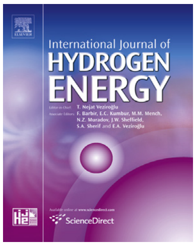

Hydrogen refueling station compression and storage optimization with tube-trailer deliveries

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ABSTRACT

Hydrogen refueling stations require high capital investment, with compression and storage comprising more than half of the installed cost of refueling equipment. Refueling station configurations and operation strategies can reduce capital investment while improving equipment utilization. Argonne National Laboratory developed a refueling model to evaluate the impact of various refueling compression and storage configurations and tube trailer operating strategies on the cost of hydrogen refueling. The modeling results revealed that a number of strategies can be employed to reduce fueling costs. Proper sizing of the high-pressure buffer storage reduces the compression requirement considerably, thus reducing refueling costs. Employing a tube trailer to initially fill the vehicle's tank also reduces the compression and storage requirements, further reducing refueling costs. Reducing the cut-off pressure of the tube trailer for initial vehicle fills can also significantly reduce the refueling costs. Finally, increasing the trailer's return pressure can cut refueling costs, especially for delivery distances less than 100 km, and in early markets, when refueling stations will be grossly underutilized.

Introduction

Background

In the United States, the transportation sector is the second-largest consumer of energy, after the electric power sector, accounting for about 28% of the total energy expended [18]. The transportation sector is heavily dependent on petroleum, which accounts for 97% of its energy sources. Of this petroleum, 56% is imported to U.S. refineries [18]. This dependence on crude oil underscores three transportation sector needs that must, ideally, be met by alternative energy sources [1]: energy security [2], environmental sustainability, and [3] economic vitality [14]. Federal and State governments in the United States have been addressing these needs by mandating higher fuel economy standards for automobiles and funding research on alternative fuels such as hydrogen, electricity, and biofuels [17]. The new corporate average fuel economy (CAFÉ) standards require U.S. manufactures of vehicles to improve the minimum fuel economy of their passenger vehicles from 36.7 miles per gallon (MPG) in 2017 to 54.5 MPG in 2025 [29]. Hydrogen fuel cell electric vehicles (FCEVs) with certification fuel economy of more than 80 miles per gallon of

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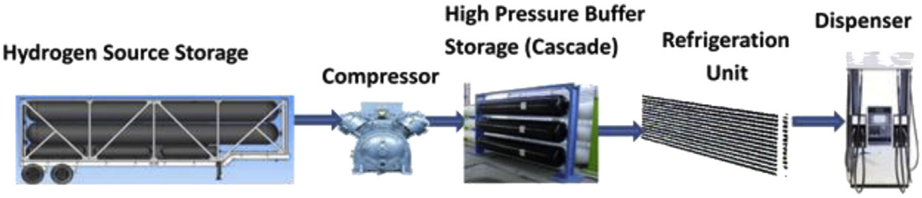

Fig. 1 – Schematic of hydrogen refueling station.

gasoline equivalent (MPGGE) can play an important role in achieving the 54.5 MPG fuel economy target in 2025. Further, state level initiatives such as the zero emissions vehicle (ZEV) mandate by State of California requires major automakers to ramp up their sales of ZEVs from 4.5% in 2018 to 22% by 2025 [4]. Other states that follow California emissions rules may choose to adopt the ZEV mandate as well. ZEVs are either hydrogen FCEVs or battery electric vehicles (BEVs). FCEVs have several advantages over BEVs, including longer driving range on a single tank fill, fast refueling, and better performance in cold weather.

Hydrogen is a clean fuel with significant potential to reduce U.S. demand for petroleum fuels because it can be produced from a variety of domestically available non-fossil and renewable sources. Fuel cells efficiently convert hydrogen into electricity with a peak efficiency of about 60% [10]. The electricity produced is subsequently used to power electric motors for vehicle propulsion. This process is more efficient than thermal efficiency of heat engines and results in a fuel economy gain of 183% compared to gasoline internal combustion engine vehicles [25]. Hydrogen FCEVs are being developed by many automobile original equipment manufacturers (OEMs) for early market deployment in the 2015–2017 timeframe to meet California's ZEV mandate and to satisfy various FCEV deployment initiatives in Japan, Germany, and other European countries. Many governments have already completed projects to demonstrate and validate the technical feasibility of FCEVs [3,15,24].

The demand for hydrogen must be supported by provision of sufficient infrastructure. Construction of supporting infrastructure might not be profitable during the initial deployment of FCEVs because of the high capital investment required to build hydrogen refueling stations (HRS) and underutilization of the installed infrastructure in early FCEV markets. Thus, many governments have initiated public-private partnerships to demonstrate the economic viability of the hydrogen infrastructure needed for pre-commercial deployment of FCEVs. The H_2 Mobility initiatives in Europe by Germany, the United Kingdom, and France; the H_2 USA initiative co-launched by the United States Department of Energy (DOE); and the Japan Hydrogen & Fuel Cell (JHFC) (Phase 3) initiative are examples of international efforts that promote the coordinated deployment of HRS and FCEVs [13,21,34]. Germany and Japan plan to deploy 50 and 100 HRS by 2015, while California plans to deploy a network of 68 HRS by 2015 to support OEMs' plans to roll out hydrogen FCEVs [3,5,33].

Almost all OEMs agree that gaseous hydrogen stored onboard at a pressure of 70 MPa is the appropriate option to enable an FCEV driving range of over 300 miles (480 km) on a single fill [17]. Fast refueling of 70-MPa tanks requires significant refrigeration, compression capacity, and high-pressure storage equipment at the refueling sites. The Society of Automotive Engineers (SAE) developed the SAE J2601 refueling protocol that defines safety limits and performance requirements for gaseous hydrogen refueling; the protocol covers a wide range of refueling pressures as well as ambient and precooling temperatures [31]. The fact that refueling costs are dominated by compression and storage requirements [16] motivated the current investigation of optimum hydrogen refueling station compression and storage configurations.

Objective

The cost for HRS accounts for half or more of the total cost of hydrogen delivery [27]. Fig. 1 shows the main components of an HRS: a hydrogen storage system that stores hydrogen to meet daily demand, a high-pressure buffer storage system (also known as cascade storage) to deliver gaseous hydrogen to the vehicle tank, a compressor that pressurizes hydrogen from the storage source pressure to the buffer storage pressure (typically higher than vehicle's maximum service pressure), a refrigeration system that pre-cools the hydrogen gas being dispensed into the vehicle's tank, a dispenser that manages the flow of hydrogen to the vehicle's tank, as well as various controls and safety equipment.

Fig. 2 provides estimates of HRS total installed cost, showing the contribution of each component to the total capital investment for various station capacities. The cost estimates in the figure are based on vendor quotes for large purchased quantities (~100 units) and incorporate a backup

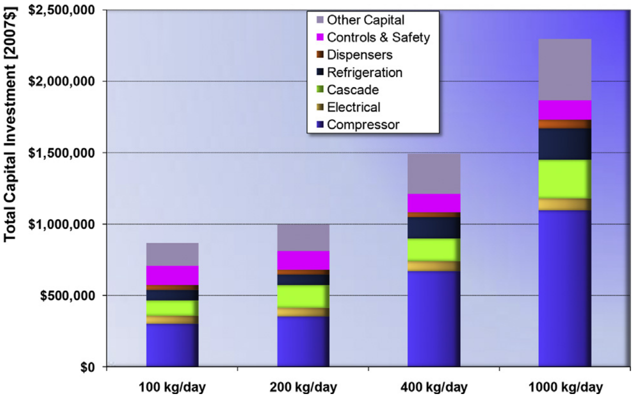

Fig. 2 – Estimated hydrogen refueling station costs for various capacities [16].