



Applied hydrogen storage research and development: A perspective from the U.S. Department of Energy



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ABSTRACT

To enable the wide-spread commercialization of hydrogen fuel cell technologies, the U.S. Department of Energy, through the Office of Energy Efficiency and Renewable Energy's Fuel Cell Technology Office, maintains a comprehensive portfolio of R&D activities to develop advanced hydrogen storage technologies. The primary focus of the Hydrogen Storage Program is development of technologies to meet the challenging onboard storage requirements for hydrogen fuel cell electric vehicles (FCEVs) to meet vehicle performance that consumers have come to expect. Performance targets have also been established for materials handling equipment (e.g., forklifts) and low-power, portable fuel cell applications. With the imminent release of commercial FCEVs by automobile manufacturers in regional markets, a dual strategy is being pursued to (a) lower the cost and improve performance of high-pressure compressed hydrogen storage systems while (b) continuing efforts on advanced storage technologies that have potential to surpass the performance of ambient compressed hydrogen storage.

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1. Introduction

The U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE) Fuel Cell Technologies Office (FCTO) is dedicated to enabling the widespread commercialization of hydrogen and fuel cell technologies through basic and applied research, technology development and demonstration (RD&D), and through diverse efforts to overcome institutional and market challenges [1].

FCTO supports near-, mid-, and long-term RD&D efforts for hydrogen and fuel cell use across a variety of sectors addressing applications that include portable power systems, materials handling or specialty vehicle applications and ultimately, light-duty vehicles. Early market applications like stationary power and specialty vehicles are beneficial in enabling the development and commercialization of fuel cell electric vehicles (FCEVs) through public education about hydrogen and fuel cells, vendor supply chain development and real world experience in the performance of this technology. The Hydrogen Storage Program (Program)

within FCTO focuses on developing hydrogen storage technologies to enable cost-effective operation of fuel cell devices, including automobiles with a range of at least 500 km. This paper discusses the forthcoming deployment of FCEVs globally and how the DOE is addressing the need for focused development of materials capable of meeting material requirements for hydrogen storage to enable FCEVs performance on par with conventional vehicles.

Fuel cells were originally invented in the early 1800s with intense development in the late 1960s and early 1970s for the NASA Apollo program [2]. GM developed the first prototype fuel cell passenger car in 1966 and various automakers (Daimler, Honda, Ford, BMW, and Hyundai) developed their own versions through the following decades [2]. Today, FCEVs are once again at the forefront of alternative transportation approaches, with several major automakers committed to commercialization plans in the 2015–2017 timeframe. Hyundai has already leased their first Tucson Fuel Cell SUVs in Southern California [3] and Toyota and Honda will be offering hydrogen fuel cell models in 2015 [4]. The issue of infrastructure is being actively addressed with many countries providing funding, analysis, and station investment. Public-private partnerships have been established in the U.S. (H₂USA), Japan (HySUT), Germany (H₂Mobility), United Kingdom (UKH₂Mobility), and Denmark, Norway and Sweden (a combined

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effort under the Scandinavian H₂ Highway Partnership) [5]. In the U.S., eight states signed a Memorandum of Understanding to put 3.3 million zero-emission vehicles on the roads by 2025. California has devoted over \$45 million to 28 new hydrogen stations and plans to invest \$20 million annually through 2023 to reach a goal of 100 stations throughout the state [6]. FCEVs are truly on their way.

The successful commercialization of FCEVs requires that FCEVs meet customer's expectations and provide performance similar to conventional gasoline vehicles. FCTO has developed, through U.S. DRIVE, a government–industry partnership between the DOE, automakers, energy companies, and utilities, an extensive set of performance targets that would make FCEVs competitive across the majority of traditional vehicle classes. The onboard hydrogen storage targets for automotive applications were most recently updated in 2012 and a complete list of the targets and current status against gravimetric capacity, volumetric capacity, and storage system cost can be found in FCTO's Multi-Year Research, Development, and Demonstration Plan [7].

2. Discussion

2.1. Compressed H₂ storage is currently the most mature option for present and near-term deployment and automakers have incorporated 700-bar compressed hydrogen storage systems into their initially deployed commercial vehicles. A summary of performance for a current representative 700-bar compressed H₂ system is shown in Fig. 1 where the shaded areas indicate the extent to which individual performance metrics have been satisfied.

Based on standards developed in coordination with automotive, energy and gas companies, the initial hydrogen infrastructure will rely on fueling stations designed to refuel 700-bar compressed H₂ storage systems. Onboard hydrogen storage technology for automobiles in the present FCEV rollout is based on Type IV carbon fiber composite overwrapped pressure vessels (COPVs). Current compressed H₂ systems do not meet volumetric and cost targets

for hydrogen storage but are close to meeting gravimetric capacity targets and have been demonstrated in concept vehicles and demonstration projects. Despite being a relatively mature technology with robust performance, 700-bar compressed H₂ systems still require significant cost reductions to truly enable widespread commercialization of FCEVs and are not ideal for all vehicle platforms, particularly smaller vehicle models. Current costs for 700-bar compressed H₂ systems are \$17/kW h, more than double the ultimate storage target, with carbon fiber and balance-of-plant components accounting for over 90% of the cost [8].

The Program presently pursues a dual strategy to address the onboard vehicle storage challenge with efforts in (a) 700-bar compressed H₂ storage systems and (b) advanced technologies including cold/cryo-compressed H₂ and materials-based (metal hydrides, chemical hydrogen storage, and sorbents) hydrogen storage. Advanced materials-based storage has the potential to meet all the automotive targets but a timely, focused effort on development of materials with required properties is needed if FCEVs are to ultimately incorporate these technologies. The Program supports efforts in critical areas for compressed H₂ and materials-based systems to overcome barriers regarding cost, volume, weight, refill time, and cycle-life. Specific areas being addressed for compressed H₂ storage include cost reduction, primarily through development of lower cost carbon fiber composites, and improved system design and manufacturing. Specific areas being addressed for advanced materials-based systems include novel materials discovery through computational and experimental efforts and complete system modeling, engineering design and performance validation.

2.2. The Program supports efforts to reduce the cost of carbon fibers, focusing on lower-cost precursors for high-strength carbon fiber. At Oak Ridge National Laboratory (ORNL) for instance, work is being supported to develop high-manufactured volume textile-grade polyacrylonitrile (PAN) precursor fibers that are competitive with the specialty PAN precursor fibers that are used presently for high performance applications. This effort is anticipated to result in a carbon fiber cost reduction by as much as 25% [9]. A promising precursor material has been identified and conversion process

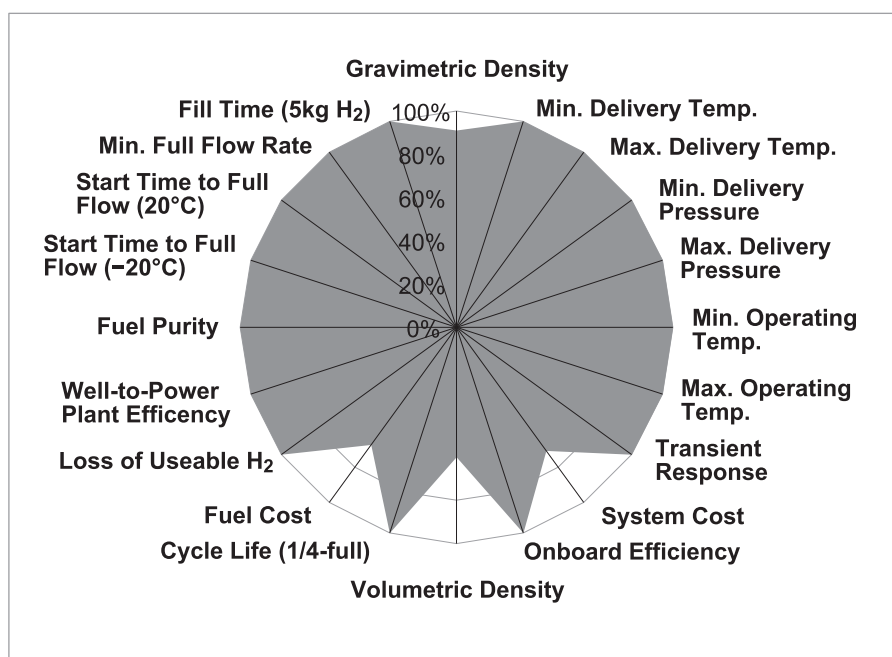


Fig. 1. Chart showing performance of a current 700-bar Type IV single tank system [8]. Shaded areas indicate the extent to which performance metrics have been achieved relative to 2017 DOE targets.

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