U.S. Department of Energy Hydrogen and Fuel Cell Technology Perspectives

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Abstract: Hydrogen and fuel cell technologies are part of an 'all-of-the-above' portfolio of activities within the United States Department of Energy (DOE). As a result of research and development (R&D) at national laboratories, companies and universities worldwide, commercial systems have now been demonstrated in multiple applications across transportation, stationary, portable power, and industrial sectors. This paper provides a summary of the technology status versus DOE targets along with a snapshot of commercial applications within the United States. Additional R&D needs and plans are described within the context of DOE's H2@Scale initiative, an effort to enable large scale production, delivery, storage, and utilization of hydrogen across applications and sectors. Opportunities to accelerate progress are summarized through partnerships and collaborations such as the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), a partnership among government agencies across more than nineteen member countries.

Key Words: Hydrogen, fuel cells, DOE, Department of Energy, H2@Scale, H2atScale, IPHE

Background

Hydrogen and fuel cell technologies have seen tremendous commercial success in recent years, with more than 10,000 commercial fuel cell light duty passenger cars sold or leased worldwide, as of early 2019. More than 6,400 of these cars are in the United States, demonstrating the potential for a significant U.S. market, particularly in California. In addition, several other states are demonstrating interest including several Northeastern states, as well as Ohio, Hawaii, Colorado, Utah, Texas, and others – not only for vehicles but for energy storage and other applications.

Hydrogen is receiving increased attention for its role as an energy storage medium to enable greater penetration of intermittent renewables like wind and solar, as well as operation of baseload power plants, such as nuclear power. Such applications can increase the supply of hydrogen from diverse domestic resources and pave the way for lower cost hydrogen infrastructure. The U.S. already has three large scale geological caverns to store hydrogen, including the world's largest hydrogen storage cavern in Texas; over 1,600 miles of dedicated hydrogen pipelines; and nearly a dozen large scale liquefaction plants, including three soon to be constructed. In terms of hydrogen fueling stations, approximately 40 commercial retail stations are currently open in California with plans for up to 200 by 2025 to meet the projected growth in fuel cell cars. Several have been constructed in other states and one to two dozen are planned in the Northeast.

Another noteworthy development in the U.S. has been the growth in early markets, specifically hydrogen fuel cell forklifts. DOE cost-shared the demonstration of several hundred fuel cell forklifts starting nearly a decade ago and today there are over 23,000 commercial systems with over 13 million hydrogen fuelings to date.

Backup power for cell phone towers is another example with thousands of units deployed, though not as commercially competitive as material handling equipment. However, the cost and availability of hydrogen infrastructure are key challenges and efforts are underway to address a number of issues, primarily affordability, reliability, and performance, as well as regulatory barriers such as codes and standards.

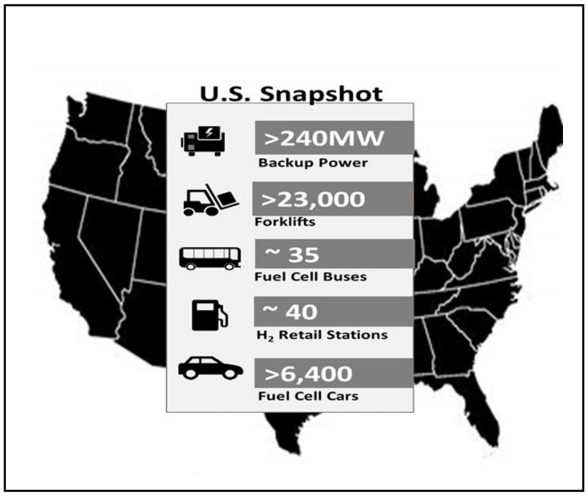

Figure 1: Examples of Hydrogen and Fuel Cell Technology Deployments in the United States

H2@Scale

DOE's H2@Scale concept [1], storing energy from solar or wind in the form of hydrogen, can help reduce curtailment and provide options not possible with conventional energy storage such as batteries. The H2@Scale vision as developed by DOE and its national laboratories aims to demonstrate the additional value possible when generating hydrogen from primary resources, enabling hydrogen to be on parity with today's electric grid or natural gas grid.

Today, the U.S. produces roughly 10 million metric tons of hydrogen, mostly from steam methane reforming of natural gas. However, opportunities exist for many times this generation capacity using diverse resources such as renewables, as well as nuclear power and other fossil fuels.

Technology Status versus DOE Targets

Over the last three decades, DOE has set rigorous market-driven targets to help guide the R&D community. These targets are set with industry input and based on what is necessary to achieve parity with conventional commercial technologies or emerging advanced technologies in terms of cost, performance and other consumer expectations.

Figure 2 shows an example of current status and targets for automotive fuel cell cost, hydrogen production cost, and on-board vehicular hydrogen storage cost. Every year, DOE assesses that state-of-the-art technology and projects cost at different manufacturing volumes to help determine additional R&D needs. The Figure shows that while high volume projections are starting to approach the DOE targets, the low volume estimates still show that costs are too high. Therefore, the DOE program focuses primarily on early stage R&D to enable advances in components such as catalysts, membranes, electrodes and other materials research for the entire hydrogen and fuel cell value chain.

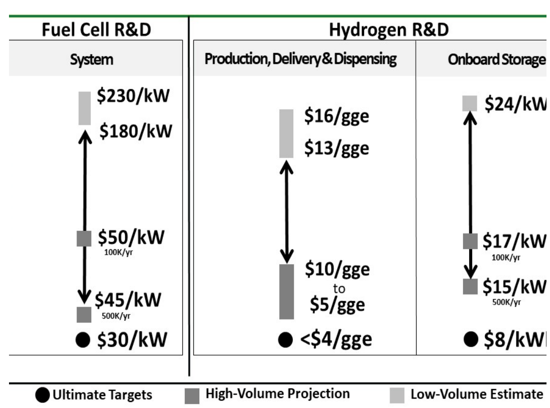

Figure 2: DOE Targets versus Status [2]

The ultimate cost target is \$30/kW to be competitive with gasoline internal combustion engines in the U.S. and Figure 2 shows that high volume projections for state-of-the-art lab technology is \$50/kW (at 100,000 units per year) and \$45/kW (at 500,000 units per year). The \$180/kW to \$230/kW estimate is based on today's on-the-road technology (modeled after an assessment of commercial vehicles, e.g., the Mirai, using publicly available information), and at low volume projections.

As for hydrogen production, Figure 2 shows that the ultimate DOE target is \$4/gge (gasoline gallon equivalent, which is also approximately equivalent to one kilogram of hydrogen) for fuel cell cars to be competitive with gasoline and advanced hybrid vehicles in the U.S. market, where gasoline prices are relatively low. Using natural gas to produce hydrogen, results in a hydrogen cost of only about \$2/gge due to the low cost of natural gas in the U.S. Another \$3/gge is projected (at high volumes) for gaseous delivery via tube trailers and for compression and dispensing into fuel cell vehicles using 700 bar hydrogen storage tanks. This results in about \$5/gge if projected to high volumes. The \$10/gge cost status refers to hydrogen from electrolysis (\$5/gge) plus an additional \$5 for hydrogen delivered. This high volume delivery cost is approximately the same using pipelines or liquid tankers, based on the latest analysis and industry feedback. These cost projections are updated periodically based on technology improvements as well as refinement of models and assumptions.

Despite the relatively low modeled costs discussed above (which are projected costs at high volumes), the purchase price of hydrogen at the pump today for consumers currently refueling fuel cell vehicles is as high as \$16/gge. These costs will continue to change as supply and demand changes, as technology cost is reduced, as more suppliers and options become available, and as drivers for renewable hydrogen are updated, depending on regional policies.

Finally, Figure 2 shows that the hydrogen storage target for storing hydrogen onboard fuel cell vehicles, while simultaneously achieving a driving range of more than 300 miles – required for the U.S. market – is \$8/kWh. The high-volume cost status is \$17/kWh (for 100,000 units per year) and \$15/kWh (for 500,000 unit per year) based on carbon fiber composite tanks storing 700 bar (10,000 psi or 70 MPa) hydrogen [3]. The \$24/kWh estimate assumes 10,000 units per year manufacturing volumes. The cost of carbon fiber is the largest contributor to the cost of today's high-pressure hydrogen storage tanks. In all these cases, improving affordability is key and DOE continues to focus on investing in research and development (R&D), particularly early-stage R&D to reduce cost while improving performance and reliability.

R&D Portfolio and Plans

Sustained investment across a broad portfolio enables continued R&D progress. Figure 3 shows DOE's fiscal year 2019 funding plans based on congressional appropriations under the Fuel Cell Technologies Office within DOE's Office of Energy Efficiency and Renewable Energy.

The Hydrogen Fuels R&D and Fuel Cells R&D subprograms have continued for multiple years and will continue to focus on early-stage R&D such as catalysts, membranes, electrodes, as well as materials for advanced water splitting and hydrogen storage. The newest subprogram established in fiscal year 2019 is Infrastructure R&D to accelerate progress in infrastructure related components and systems. For instance, dispenser and compressor reliability, as well as cost, can be improved significantly to help address challenges of hydrogen infrastructure.

Systems integration R&D is another growing area of emphasis, particularly related to electrolyzers and the grid, aligned with the H2@Scale initiative. Additional areas continue such as Safety, Codes and Standards, as well as Technology Acceleration (which includes H2@Scale related work and manufacturing R&D to reduce the cost of various components), and Systems Analysis.

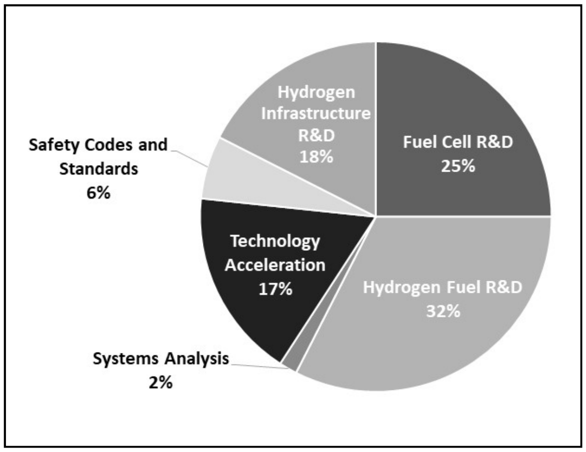

Figure 3: Fiscal Year 2019 Funding for US DOE Fuel Cell Technologies Office

One of the areas that requires increased global collaboration is Safety, Codes and Standards. As the international interest grows and new players from various countries start to ramp up commercialization, the harmonization of codes and standards will be critical to ensure a robust and affordable supply chain for the global market.

The DOE program also emphasizes the importance of promoting lessons learned and best practices in hydrogen safety. For instance, the program developed H2Tools.org to disseminate information and its Hydrogen Safety Panel, established 15 years ago, is now being emulated and expanded. Such information sharing is fostered by international partnerships which bring together stakeholders and their counterparts from multiple countries.

Several coordinating bodies at the federal, state and regional level, along with industry stakeholders and associations are working to accelerate progress towards mutual energy, economic, and environmental goals. One such partnership, established in 2003 to focus solely on hydrogen and fuel cells at the government level, is the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE). IPHE has 18 countries and the European Commission as partners and continues to add members [4]. It provides a forum for sharing information on initiatives, policies and technology status, as well as on safety, regulations, codes, and standards to accelerate the cost-effective transition to the use of hydrogen and fuel cells in the economy.

The IPHE has held numerous workshops and stakeholder events, bringing together more than a thousand experts from over 25 countries to identify challenges, impact potential, and opportunities for hydrogen and fuel cells. Examples of recent topics include: Energy Storage, Smart Cities, and Fuel Cells as Backup Power for Telecommunications. To foster coordination in the critical area of hydrogen infrastructure, IPHE members hold an annual Hydrogen Infrastructure workshop that includes government and industry experts to identify gaps and potential strategies to address them. Two working groups (Education and Outreach as well as Regulations, Codes, Standards, and Safety) include experts from multiple countries to share information and address some of the key challenges to accelerating progress in hydrogen and fuel cells.

During the last several months, other international activities have catalyzed more interest in hydrogen, including Ministerial level engagement among multiple countries. As technology progresses, hydrogen and fuel cells will continue to enable positive impact across sectors and economies worldwide. Continued R&D will help reduce costs and improve performance to allow these technologies to be commercially viable at scale.

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References
[1] U.S. Department of Energy H2@Scale Initiative website and references therein, https://www.energy.gov/eere/fuelcells/h2-scale

[2] S. Satyapal, U.S. Department of Energy, Hydrogen and Fuel Cells Program, Annual Merit Review and Peer Evaluation Meeting (2018) Proceedings, and references therein available at https://www.energy.gov/sites/prod/files/2018/10/f57/01_satyapal_plenary_2018_amr_0.pdf

[3] Ordaz, et al, DOE Program Record 15013, (2015),https://www.hydrogen.energy.gov/pdfs/15013_onboard_storage_performance_cost.pdf

[4] International Partnership for Hydrogen and Fuel Cells in the Economy, www.iphe.net