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Advancing Hydrogen Fueling Infrastructure in the U.S.

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Summary

As the U.S. seeks to reduce greenhouse gas (GHG) emissions, widespread fuel-cell electric vehicle (FCEV) infrastructure deployment will enable FCEVs to fully mature as a low-emission, long-distance vehicle. Several challenges complicate infrastructure deployment, including site selection, deployment costs, and perceptions around safety. Successful infrastructure planning and deployment in California, New York and in the northeast provide valuable insights to help streamline and advance deployments elsewhere. With a focus on investment, state policy, supply chain expansion and holistic planning, FCEVs will soon stand alongside BEVs and PHEVs as cornerstones of low-emission transportation system that is safe, convenient and operationally efficient.

Keywords: deployment, hydrogen, infrastructure, United States of America, ZEV (zero emission vehicle)

1 Driving Down Greenhouse Gas Emissions

In the U.S., transportation accounts for 27% of greenhouse gas (GHG) emissions, with light-duty vehicles generating the largest share [1]. To reduce GHG, twenty states plus Washington DC have GHG emissions targets [2] and several are exploring multiple vehicle clean technologies to help reach their GHG reduction goals.

1.1 Adopting Complementary Technologies

An analysis by the California Air Resources Board (ARB) indicates that fuel cell electric vehicles (FCEVs), battery electric vehicles (BEVs), and plug-in hybrid electric vehicles (PHEVs) using low carbon biofuels are the three most viable candidates for near-zero carbon transportation. However, GHG reduction in transportation is not a one-car-fits-all solution. Regionally, ideal zero-emission vehicle (ZEV) types vary relating to infrastructure, fuel generation, and distribution pathways. As the ARB observes, all three low-carbon vehicle technologies will be necessary to achieve California's GHG reduction target.

Each of the complementary technologies is at different points of maturity. The progress made the last six years in the BEV industry is significant in terms of available grants, infrastructure development, and consumer adoption. The FCEV industry, which is the focus of this paper, can draw from BEV successes to achieve a similar strong consumer foothold, with support from automakers, industry leaders, and government.

1.2 FCEV Technology

The ARB indicates that significant advancements have occurred in FCEVs and hydrogen stations since just 2014 [3]. This outcome is due to the financial backing of progressive states, technology evaluation conducted by science and engineering teams, and global automakers, whose confidence in FCEV technologies inspired them to invest billions into FCEV research, development, and demonstration (RD&D). Through these efforts, the FCEV market is advancing. Hyundai began leasing its Tucson FCEV to customers in June 2014, and in October 2015, Toyota began deliveries of its Mirai FCEV to California customers. Honda will have its own FCEV (Clarity) available to customers by the end of 2016. Many automakers have voiced support for FCEVs including Daimler, Nissan-Renault, General Motors, Ford, Audi, BMW, and Volkswagen, and several of these companies presented concept cars at recent auto shows and are actively engaged in fuel cell RD&D.

Compared to BEVs, FCEVs offer a different driving and fueling experience, which enables expansion of ZEV options to meet a wider range of consumer preferences. Fuel cell technology is scalable to a range of vehicles including compact cars, large sedans, SUVs, minivans and even larger ZEVs, such as buses. FCEVs have great driving ranges, short refueling times and perform consistently regardless of climate with no loss of range or performance [4]. These operational characteristics assure drivers that FCEVs could serve as their primary local and long-distance vehicle.

Alongside the progress of the FCEV market, hydrogen production processes are also advancing. While natural gas is still the primary production source of hydrogen, the use of renewable resources like solar, wind, biomass, and biogas to produce hydrogen is evolving. These renewable energy resources are amply available to supply FCEV markets and will generate hydrogen via a carbon-free, sustainable fuel stream that slashes GHGs [5]. In vehicle use, hydrogen fuel creates almost zero criteria pollutants, which means GHG emissions associated with FCEVs are at least half of those from conventional gasoline vehicles. When renewable resources produce hydrogen for FCEVs, GHGs fall more than 80% and reduce petroleum by up to 99% per vehicle [6].

2 The Urgency for Hydrogen Infrastructure

The strong performance and air quality benefits of FCEVs help to explain the dramatic projected growth in FCEV consumer adoption in California, which serves as a touchstone for other states. Department of Motor Vehicles Registrations and automaker reports indicate that 300 FCEVs were on the road in California at the end of 2015. A recent survey by the Air Resource Board (ARB) and FCEV automakers estimates that 10,500 FCEVs will be on the road by the end of 2018; that number escalates to 34,300 by the end of 2021. This year, California plans to construct new hydrogen fuel stations, bringing their number to 51 located across the state. However, these stations will not provide enough fueling capacity to meet projections beyond 2018 [7].

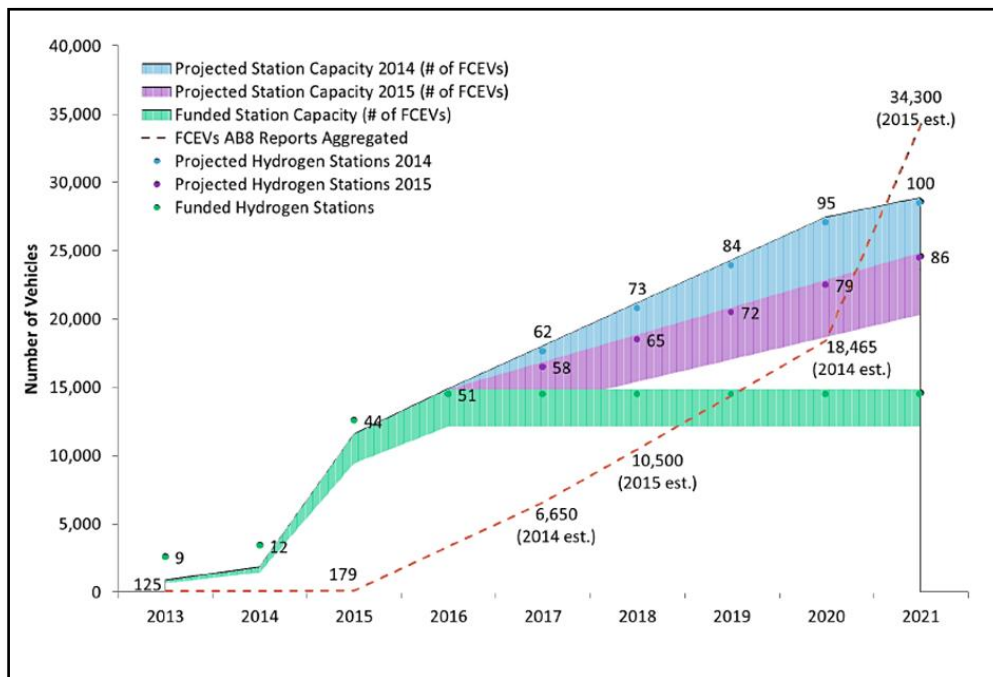


Figure 1 Projected Hydrogen Station Number and Capacity

California's projected shortfall demonstrates the critical need for hydrogen infrastructure. Towards meeting these needs, initiatives like H₂USA and H₂FIRST promote FCEVs and expand hydrogen infrastructure. However, challenges related to site development and the cost of infrastructure development prohibits rapid deployment across multiple metropolitan areas.

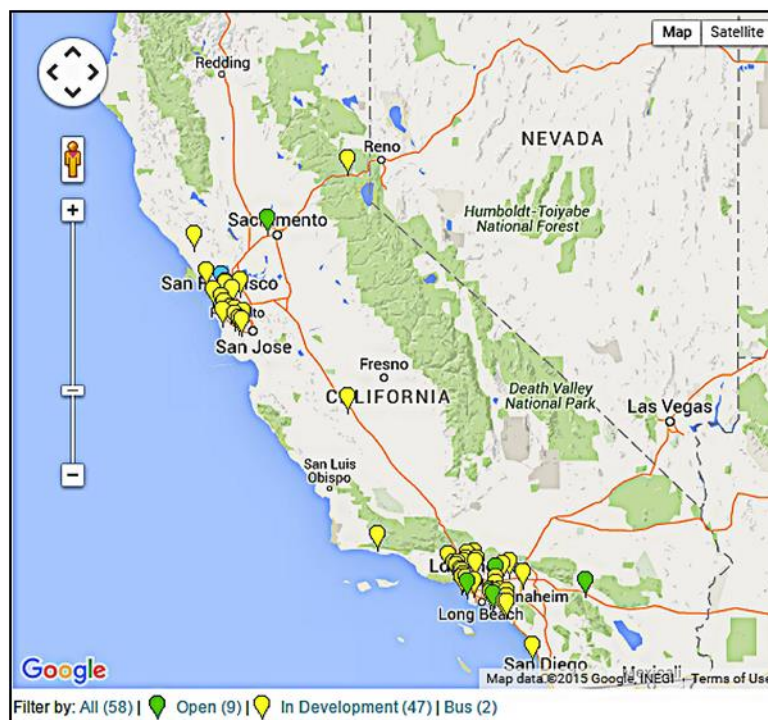


Figure 2 Hydrogen Stations in California [8]

3 Overcoming Hydrogen Infrastructure Deployment Challenges

Successful hydrogen infrastructure development is not solely a matter of integrated construction—selecting ideal sites, assuring public access, community technology education, cost, and state policies are critical elements that underpin convenient and serviceable networks. Unlike BEV adopters, FCEV consumers will not have the option to recharge at home, which emphasizes the need for model sites at convenient locations. Deploying well-sited infrastructure is a shared responsibility—from communities and consultants to automakers, fuel providers, and the government.

3.1 Site Selection

Zoning, permitting, site features, and constructability are important factors to consider when evaluating potential sites for fuelling components, structures, and public use. Informed site selection translates into stations that are functional, ideally located, and built with the community in mind.

In the northeast, Air Liquide and Black & Veatch are siting and constructing 12 hydrogen-fuelling facilities, with land use along the planned “hydrogen highway” ranging from densely urban to rural; both land uses carry their own set of benefits and limitations. In urban settings, the available lots are limited, costly, and sometimes too small to accommodate the equipment and the 18-wheeler trucks required to fill the hydrogen tanks. Given the population density, urban sites are commonly located near sensitive structures and uses, such as a school or hospital. One advantage to urban environments, like New York, is the ample staff dedicated to city zoning and permitting, which can accelerate approvals.

Conversely, rural areas offer numerous sizable sites removed from sensitive structures and services, although sensitive environments like wetlands and protected habitat can be problematic. Small, rural towns do not always have dedicated staff, which can slow the approval process.

In the west, FirstElement Fuel and Black & Veatch are deploying 19 hydrogen-fuelling stations in California. Experience and insight into hydrogen fuelling equipment configuration, noise, and construction approach helped Black & Veatch plan around encountered site constraints and develop mitigation strategies that reduced noise and traffic impacts to surrounding communities. In some locations, innovation is necessary. Black & Veatch compressed the footprint to accommodate small sites and reduced noise impacts to sensitive populations through a unique block wall enclosure.

Common across both regions is the challenge of competing uses at the potential sites. Given the limited space at most gas stations, many station owners must choose between hydrogen infrastructure and another type of revenue stream, such as a car wash. Additionally, the complexity of station ownership can impede site selection, slowed by the numerous layers of supervisory control and required approvals at some stations. The approval process at independently owned stations is more straightforward because their authorization structure is less complicated.

3.2 Public Access and Convenience

Assuring convenient public access at stations is critical to support consumer adoption. Many hydrogen station sites are co-located at shopping malls and in gas stations with convenience stores along major roads. These locations not only boost consumer awareness of station presence but also increase retail traffic as consumers may choose to shop while their car is filling. Moreover, retail owners that co-locate hydrogen stations receive positive press and recognition as a supporter of innovative technology. Placement of stations in high-traffic areas near retail centres generates a “win-win” for consumers and commercial enterprises.



Figure 3 Co-Locate Stations to Benefit Consumers and Commercial Enterprises

3.3 Community Education and Safety

Despite a misleading reputation that stems from the 1937 Hindenburg event, hydrogen has a long history of use across industries. Currently, the U.S. produces over 9 million tons of hydrogen each year, and uses 3.2 trillion cubic feet of hydrogen yearly to make every day products such as glass, soap and toothpaste. The National Aeronautics & Space Administration (NASA) has used hydrogen as a fuel since the 1950s, and the U.S. government and industry have designed and conducted safety tests for vehicles and transportation fuels for decades [9].

After 13 years of testing and development with the international automotive and hydrogen industry, including BMW, Daimler, Hyundai, and Toyota, the Society of Automotive Engineers (SAE) published J2601, “Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles.” The standard serves as the baseline for commercial fuelling at 35 MPa (300 bar) and 70 MPa (700 bar) and establishes safety limits and performance requirements for gaseous hydrogen fuel dispensers. SAE also published J2799, “Hydrogen Surface Vehicle to Station Hardware and Software,” which specifies the communications hardware and software requirements for fuelling Hydrogen Surface Vehicles and is intended to be used in conjunction with J2601 and J2600, “Compressed Hydrogen Surface Vehicle Fueling Connection Devices” [10]. In the

U.S., researchers at the National Institute of Standards and Technology (NIST) developed a prototype field test standard to test the accuracy of hydrogen fuel dispensers [11].

Regardless extensive study, decades of successful use, and safety protocols, hydrogen technology commercialization requires stakeholder education to engender support and confidence among consumers, dealer staff and technicians, community officials, and first responders. To this end, Black & Veatch discusses National Fire Protection Association (NFPA) hydrogen site design standards and safe practices with local officials and emergency responders during the site selection process. Many fire department staff request to review designs to ensure compliance with standards, and Black & Veatch grants review to ensure stakeholder acceptance

3.4 Deployment Cost

Hydrogen fuelling stations are costly to construct, owing to the low-production volume of specialized equipment. Looking ahead, equipment and installation costs will likely begin declining near 2020 and could drop by 50% in 2025 due to increased demand for hydrogen stations worldwide. As the market becomes stronger over time, hydrogen infrastructure deployment will become more efficient with greater economies of scale, which will lower installation costs [12]. In the meantime, the industry needs funding support to keep pace with projected hydrogen adoption. Analysis reveals that \$160 million is needed to align with adoption rates and capacity projections presented in Figure 1 [13]. These costs pertain to California build-out scenarios, but provide a good reference point for other states in the U.S.

Looking back at the establishment of BEV infrastructure, the various charging networks also launched with funding uncertainty. Recognizing resource scarcity as a massive impediment to creating a self-sustaining BEV network, several governments and industry agents provided funding and grants for the West Coast Electric Highway and other deployments, including the U.S Department of Energy, California Energy Commission (CEC), and the states of Washington and Oregon. Multiple EV Service Providers (EVSPs), awarded grants, such as ChargePoint, Aerovironment, NRG EVgo and the Blink Network. Automakers like Tesla also provided BEV infrastructure investment, realizing that without adequate infrastructure, consumers would overlook their innovative vehicle designs. Operating from a similar belief, Toyota and Honda are funding hydrogen infrastructure, which could serve as a catalyst to other Original Equipment Manufacturers (OEMs). Despite the BEV paradigm, the federal government has not yet provided funding for FCEV infrastructure.

3.5 State Policies

Progress at the state level begins with policies, programs and funding that support FCEV adoption. Progressive states demonstrate a commitment to their goals, whether they are GHG reduction or consumer adoption of new technology. States that develop programs and policies that provide benefits to the state while assisting FCEV technologies serve as examples of how infrastructure deployment, technology adoption, and consumer benefits can be achieved. The Table 1 highlights the top five states for FCEV program support.

Table 1 Progressive FCEV State Programs [14]

STATE	GRANT/REBATE/CREDIT
California	\$20 million annual commitment for 100 FCEV stations. ARB voted to expand incentive funds for Clean Vehicle Rebate Program (CVRP) to offer \$5,000 per rebate and \$6,500 for low-income FCEV consumers. CEC awarded \$46.6 million for 28 new FCEV stations.
Connecticut	H2Feuls grant of \$450,000 for FCEV stations in Hartford area. Connecticut Hydrogen and Electric Automobile Purchase Program (CHEAPR) rebate up to \$3,000 per lease or purchase. Bonuses to dealers who sell FCEVs.
Colorado	A generous \$6,000 ZEV credit in place until 2021.
Massachusetts	\$2 million allocation to Massachusetts Offers Rebates for Electric Vehicles (MOR-EV), including FCEVs. Rebates up to \$2,500 per purchase or lease.
Pennsylvania	Up to \$1,000 rebate for FCEVs (while rebate allocation lasts)

4 Project Highlight: FCEV Infrastructure Deployment in California, New York, and the Northeast

With support from Toyota and Honda, Black & Veatch is working with FirstElement Fuel to construct 19 hydrogen stations throughout the State of California. Toyota is also supporting Air Liquide to construct an initial 12 stations in the northeast. These projects represent a bold first step to bring FCEV stations to consumers in the U.S. who want a zero-emission option for their cars. As FCEV infrastructure advances, these early projects serve as deployment examples, offering lessons learned that apply to future installations, such as these:

- The CEC’s desired timeline for station development—from the funding announcement to a completed station that is open for use—is 24 months [15]. This timeline emphasizes the need for strong program management and Engineering, Procurement and Construction (EPC) services that encompass detailed design engineering, permitting, procurement and expediting; construction and construction management; quality control/quality assurance; and start-up and training.
- Design-build projects of this complex size and scope should emphasize consistent design and installation to ensure standardized sites and equipment, which simplifies future upgrades and equipment change-out.
- Site characteristics, such as size constraints or proximity to wetlands, can necessitate additional studies and documentation, which can delay the selection process. Using a “red flag” assessment to narrow potential sites with the fewest site limitations is a valuable time-saver.

- Negotiating leases with owners proceeds more smoothly when teams have a working knowledge of real estate site audits, title, leasing, right-of-way, zoning, and permitting/due diligence requirements and processes.
- FirstElement Fuel and Black & Veatch focused on development of processes and templates that maximized repeatable design and deployment elements for rapid and cost-effective implementation.



Figure 4 Hydrogen Infrastructure Deployment is Complex and Requires Strong Program Management



Figure 5 Siting and Designing Stations with the Community in Mind is Essential for Public Acceptance

5 Shifting into Gear for the Future

The FCEV industry has made remarkable progress and momentum is building. Our capacity to provide an extensive infrastructure network continues to escalate, authenticated station-by-station as new sites are selected, funded, constructed and commissioned in California, New York, and the northeastern states. To capitalize on this groundswell of market movement, the industry needs to advance in three key areas.

- The per-station cost of construction prohibits rapid deployment. To reduce station component costs, supply chains should be expanded and enhanced to produce lower-cost parts without loss of performance; reduce hydrogen compression costs; standardize station designs, and streamline the permitting process [16].

- Currently, financing is a bottleneck to hydrogen infrastructure and market maturity. To achieve widespread FCEV adoption, automakers need to follow the leadership demonstrated by Toyota and Honda and invest in the infrastructure. Deployment investment in the BEV industry led by Tesla, Nissan and BMW are proven success stories of multi-stakeholders engagement.
- Think holistically when planning infrastructure. Given the geographic and cultural differences in the U.S., ideal ZEV technologies and infrastructure deployment could vary region to region. For this reason, corridor planning across regions will expand infrastructure deployment with reduced investment risk, coordinated technology application, and full energy and environmental benefit [17]. Holistic planning will also prepare the industry for advances in connected transportation, public transportation, transportation of goods and integrated systems, which enable true efficiencies across cities, regions and the U.S.

Collaboration and continued advancement of FCEV technology research, financial backing, and deployment protocols and approaches will enable FCEVs to fully mature. These factors of support will allow FCEVs to stand alongside BEVs and PHEVs as cornerstones of low-emission transportation system that is safe, convenient and operationally efficient.

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