

National Hydrogen Scenarios

How many stations, where, and when?

October 2017



H₂USA

Locations Roadmap Working Group

Disclaimer

Since fuel cell electric vehicles (FCEVs) went on sale to the public in California in the fall of 2015, auto original equipment manufacturers (OEMs) and hydrogen station developers have gained real-world experience about the refueling patterns and preferences of FCEV customers. In review of these learnings, OEMs and the State of California have developed target locations for the next phase of hydrogen station build-out in California. Similarly in the Northeast, OEMs are working with station developers and public stakeholders to coordinate next steps.

An understanding of consumer demand, balanced with sound business cases for new hydrogen stations, is essential in the successful build-out and growth of the hydrogen station network. This goal can be more readily attained by increasing communication between multiple stakeholders, including public officials, investors, auto OEMs, station developers, and other decision makers.

H₂USA members and working groups adhere to strict anti-trust guidelines. The information shared between Locations Roadmap Working Group members adhered to these anti-trust guidelines. Development of the analysis for this report occurred in parallel with the deployment of FCEVs into the early market. The resulting scenarios in this report represent the future potential of the network image. The contents of the present report therefore represent a very general means of achieving the common goal of hydrogen station network growth. Any forward-looking statements should not be interpreted as basis for making business decisions or investment decisions.

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Acronyms

EAM	Early Adopter Metric	mpge	Miles per gasoline gallon equivalent
FCEV	Hydrogen fuel cell electric vehicle	ROC	Rest of country
HRS	Hydrogen refueling station	ZEV	Zero-emission vehicle
LDV	Light-duty vehicle		

Executive Summary

Technological advances are transforming personal mobility, providing improved safety, automated driving, enhanced vehicle performance, and increased sustainability. Hydrogen fuel cells are a key technology option within this transformation. As fully zero-emission electrified vehicles, hydrogen fuel cell electric vehicles (FCEVs) can refuel in 3–5 minutes to a range of 360 miles or more and can be scaled from small sedans for personal use to large line-haul trucks and car or truck platforms in between. When compared to conventional gasoline vehicles, FCEVs provide a range of economic, energy security, public health, and environmental benefits for the nation without requiring consumers to compromise on vehicle size or performance (NRC 2013). Several FCEVs are commercially available today. However, the lack of convenient and extensive networks of hydrogen refueling stations is limiting market growth. A significantly larger network of retail hydrogen stations must be established before FCEVs can be sold to the general public in a broad, geographically diverse manner similar to conventional vehicles.

This report was developed within the framework of the U.S. public-private collaboration known as H₂USA, with approximately 50 partners committed to enabling hydrogen infrastructure for FCEV adoption. The report examines development scenarios for hydrogen station networks

needed to support a national rollout of FCEVs in the United States. As FCEV prices decrease and the variety of available FCEVs increases over the next 5–10 years, a select number of urban, state, and regional markets can help establish the station networks required for FCEV market growth. California is fully engaged in this station funding and deployment process today, and a number of other states are showing interest, primarily in the northeast but also in Hawaii, Texas, Ohio, and South Carolina to name a few. Based on experience over the

last two decades, California's successful planning and execution of coordinated FCEV adoption and hydrogen refueling station deployment can serve as a valuable resource for other states and regions in their hydrogen infrastructure development efforts. The following planning processes have been key ingredients of California's historical success:

1. **Quantify FCEV market potential and automaker commitments.**
2. **Establish financial support mechanisms for hydrogen refueling station investments.**
3. **Establish FCEV market support mechanisms.**
4. **Implement station network planning and coordination tools.**

The success of government-industry partnerships in California, along with comparable initiatives in Europe and East Asia, are laying the foundations for global FCEV market growth by funding hydrogen stations.

Although additional U.S. cities, states, and industry partnerships may follow a slightly different process, these four strategies have been demonstrated as successful methods to reduce investment risks and leverage the effectiveness of public and private funds in the development of hydrogen station networks.

In this report, an internally consistent analytic modeling method

simulates how station networks might develop across cities and regions, assuming that successful planning and coordination activities result in a rollout of FCEVs and stations similar to California's. The report's three scenarios capture some of the variations that might occur as FCEV markets and station networks expand.

In the Urban Markets scenario, FCEV markets are driven by a combination of consumer demand, initiatives implemented by individual cities, and stakeholder focus on the most promising urban markets. The State Success

Technological advances are transforming personal mobility, providing improved safety, automated driving, enhanced vehicle performance, and increased sustainability. Hydrogen fuel cells are a key technology option within this transformation.

scenario achieves a higher level of FCEV market adoption than does the Urban Markets scenario, with FCEV sales primarily driven by the Zero Emission Vehicle (ZEV) mandate and other market support mechanisms, which are complemented by strong stakeholder planning and coordination in ZEV states. The National Expansion scenario achieves the highest levels of FCEV adoption, with FCEV markets and station network development responding to consumer demand, strong market support initiatives implemented at city, state, and national levels, as well as aggressive stakeholder coordination and planning across economically integrated megaregions.

These scenarios are not forecasts of future market outcomes. Rather, they provide insight to various public and private stakeholders engaged in the planning and coordination required to help facilitate their own station networks, while reducing hydrogen station investment risks. Early markets for alternative fuel vehicles are widely acknowledged as difficult to develop—these scenarios are meant to help stakeholders better understand and potentially leverage California’s past lessons and ongoing efforts to build momentum for national FCEV market growth while respecting their own differences, processes, and local knowledge.

The following conclusions and insights are supported by the scenario results:

- **Robust networks of hydrogen stations must be established in advance of selling large volumes of FCEVs into any given urban area.** Following the rollout of stations planned for California, by 2025 a total of 320–570 additional stations would be required both in California and nationwide to enable significant FCEV market growth. Intensive stakeholder coordination and planning activities should precede the introduction of these initial stations to ensure progress toward a national milestone of “500 in 2025.”
- **There are multiple means of achieving FCEV market growth beyond California.** Although the ZEV mandate has been a key policy driver in California, high concentrations of early adopters in other cities and states—combined with track records of strong support for advanced vehicles—suggest many other markets are promising for FCEV sales and hydrogen station investments.
- **Large cities with high concentrations of early adopters and strong market support mechanisms, as demonstrated in California, are assumed to be the most promising markets for introducing FCEVs and hydrogen station networks.** With adequate market support mechanisms in place, these markets could prove to be the most promising options for rapidly achieving vehicle growth and substantial hydrogen demand, thereby reducing the financial risk posed to hydrogen station investors.
- **The market potential for hydrogen station networks is large.** The scenarios portray a national network of approximately 1,500–3,300 hydrogen stations by 2035, with a hydrogen capacity of 1.3 million to 3.4 million kg/day, serving 1.8 million to 4.5 million FCEVs. Assuming average hydrogen prices of \$8–\$10 per kg, annual revenues would be around \$3.0 billion to \$9.2 billion. Based upon the scenario results, the largest and most robust segments of these station networks would initially be located in a select number of major urban areas where a track record of surrogate vehicles has already paved the way for FCEVs.



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1 Introduction

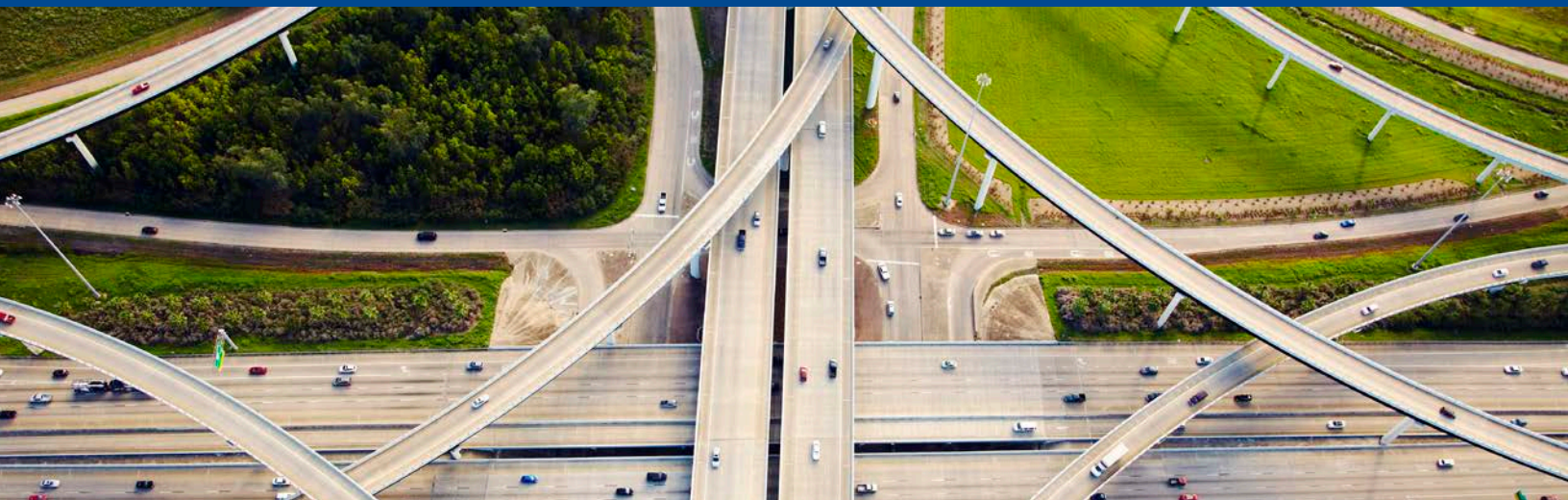
Hydrogen fuel cell electric vehicles (FCEVs) are one of several promising advanced transportation technologies that can help to address the nation's energy, economic, and environmental challenges. FCEVs are fully electric zero-emission vehicles: hydrogen stored onboard is converted into electricity by the fuel cell stack, and water is the only tailpipe emission. The high efficiency of fuel cell propulsion systems, combined with onboard hydrogen storage, enables FCEVs to be fully functional long-range, zero-emission vehicles—with the size, power, and range of conventional gasoline vehicles. Passenger FCEVs have a range of 300–350 miles and, unlike plug-in electric vehicles, can refuel in less than 5 minutes. Drivetrain components can be scaled cost effectively for use in a broad array of light, medium, and heavy duty vehicles. Because hydrogen can be produced from various energy resources—including domestic natural gas, nuclear, and renewables—FCEVs are a clean, secure, and sustainable substitute for conventional gasoline and diesel vehicles (NRC 2013).¹

The cost and performance of fuel cell powertrain technologies have improved dramatically over the past 15 years (Wilson et al. 2016). Today three passenger FCEVs are commercially available in California, by nature of progress with hydrogen station developments. These are: the Hyundai Tucson, Toyota Mirai, and Honda Clarity. These commercial vehicles build on experience accumulated by many automakers through

the development of prototype FCEVs and completion of several real-world retail consumer demonstration programs (FCHJU 2017; Wipke et al. 2012). Figure 1 shows commercially available and limited-production FCEVs. Additional light-duty FCEV makes and models will be introduced into these hydrogen station enabled markets in the near future.

The major barrier to widespread *national* deployment of FCEVs is the lack of convenient, extensive networks of hydrogen refueling stations (HRSs). The existing U.S. fleet of about 240 million gasoline-fueled light-duty vehicles (LDVs) is served by a network of 120,000–150,000 retail gasoline refueling stations (AFDC 2014; U.S. Census 2012; NACS 2015). This suggests a ratio of about 2,000 gasoline vehicles for every gasoline station. By comparison, at the end of 2016, 33 retail HRSs served approximately 1,000 FCEVs in the United States (CEC 2017a; Cobb 2017). Private companies, government agencies, and research institutions own and operate another 26 HRSs (AFDC 2017). Eight HRSs are serving 25 active fuel cell transit buses, and deployment of another 46 fuel cell buses is planned (Eudy et al. 2016). The vast majority of these early HRSs is concentrated in California, which has a total of 62 operational and under-construction stations (Figure 2) (AFDC 2017; CARB 2017). In 2016, Air Liquide and Toyota announced plans to install an initial network of 12 HRSs along a Northeast corridor extending from northern New Jersey through Boston (Air Liquide 2016). In early 2017, the California Energy Commission announced awards for 16 additional stations in California (CEC 2017c).

¹ For a brief introduction to hydrogen fuel cell technologies, see the U.S. Department of Energy's video, "Energy 101: Fuel Cell Technology," <https://energy.gov/eere/videos/energy-101-fuel-cell-technology>.



FCEVs commercially available today



Hyundai Tucson Fuel Cell Vehicle

May 2014, Commercially Available
265-mile range, 49 mpge, 100-kW max power

Photo from the California Fuel Cell Partnership



Toyota Mirai Fuel Cell Vehicle

October 2015, Commercially Available
312-mile range, 66 mpge, 113-kW max power

Photo from Toyota



Honda Clarity Fuel Cell Vehicle

December 2016, Commercially Available
366-mile range, 67 mpge, 103-kW max power

Photo from Honda

Examples of limited-production FCEVs



2008 Chevrolet Equinox Fuel Cell Vehicle

2008 Demonstration, Project Driveway, 100 Vehicles
200-mile range, 43 mpge, 94-kW max power

Photo from NREL 15340



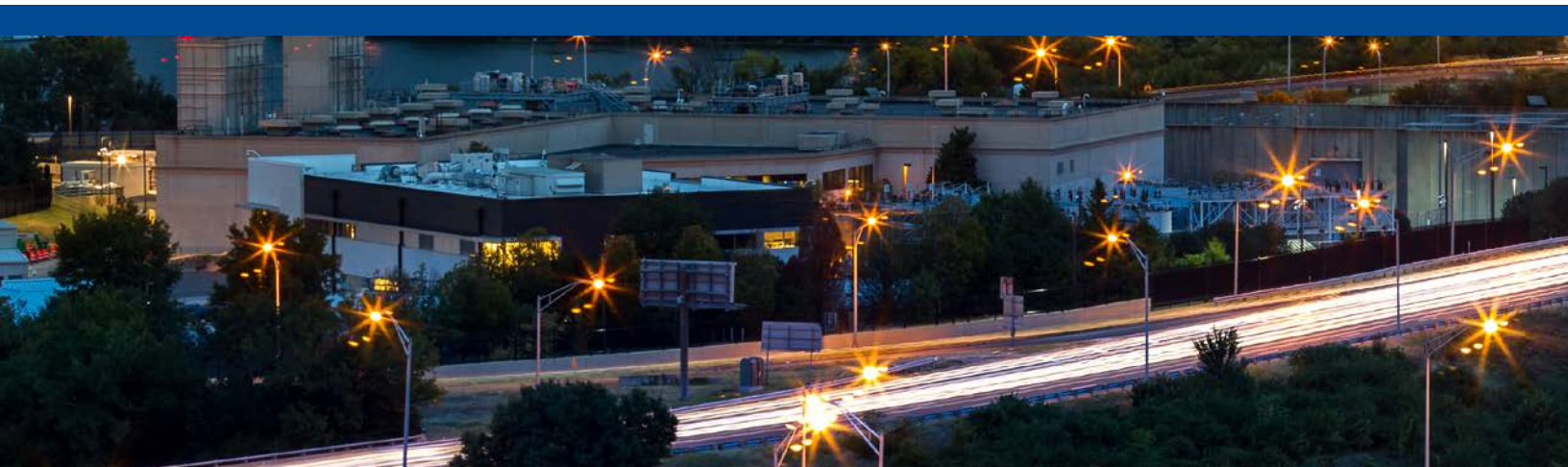
Mercedes Benz B-Class F-Cell

2002-2012, Multiple Generations

Photo from NREL 18281

Figure 1. Commercially available FCEVs (top) and examples of limited-production FCEVs (bottom)

Source: <http://www.fueleconomy.gov>



More information on FCEVs, the existing HRS network, and real-time tracking of station status for mobile applications can be found through H₂USA (<http://h2usa.org>), the California Fuel Cell Partnership (<http://cafc.org>), the Alternative Fuels Data Center (<http://www.afdc.energy.gov>), and the international H₂-Stations website maintained by Ludwig-Bölkow-Systemtechnik GmbH (<http://www.H2Stations.org>).

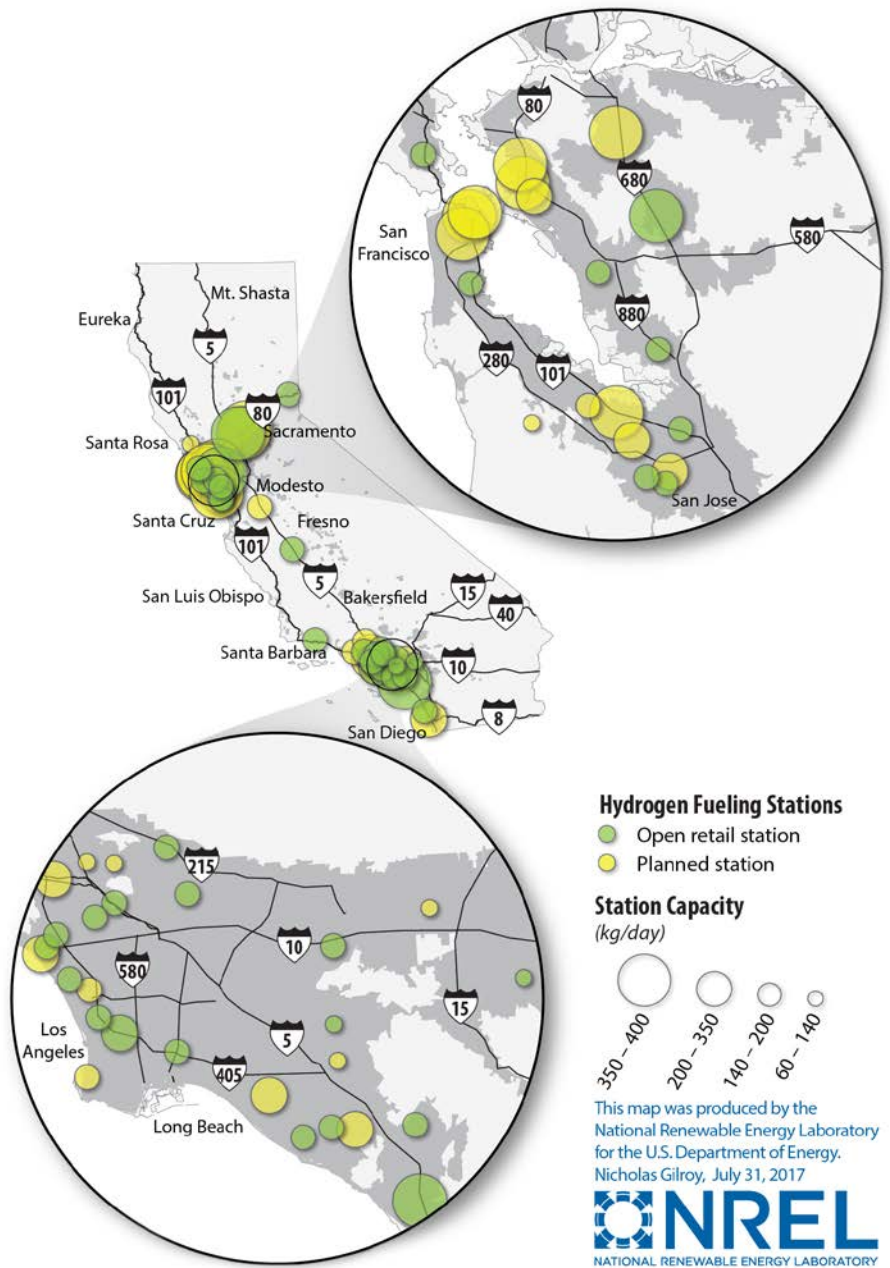


Figure 2. Existing and planned stations in Northern (top) and Southern (bottom) California (CEC 2017a; CEC 2017c; AFDC 2017; CARB 2017)

Source: NREL



1.1 International Context

Efforts to commercialize FCEVs in the United States are among the initiatives led by many governments and private corporations, with major concentrations in Europe, Japan, and South Korea (LBST 2017; HARC 2017; Schneider 2016; James and Karlsson 2016). Approximate

numbers of non-bus FCEVs, fuel cell buses, and hydrogen stations as of 2016 are reported in Table 1. Figure 3 shows the locations of existing and planned stations in Europe and East Asia.

Table 1. Status of hydrogen fuel cell electric vehicles and hydrogen refueling stations in 2016 and future planned stations by country

Country	2016 Status			Planned Hydrogen Stations
	FCEVs	FC Buses	Stations	
United States	1,186	25	53	100 in California by 2024, 15 in Northeast beginning in 2017
Germany	103	14	22	400 by 2023
Japan	573	Demo only	86	1,000 by 2025
France	110	-	5	
United Kingdom	37	8	7	
Scandinavia	40	5	10	21 by 2017
Total	2,049	52	183	

Sources: Schneider 2016; James and Karlsson 2016; CEC 2017; AFDC 2017; HARC 2017. Total FCEVs in the United States comprise the sum of sales in 2016 and 2015, as reported by Cobb (2017).

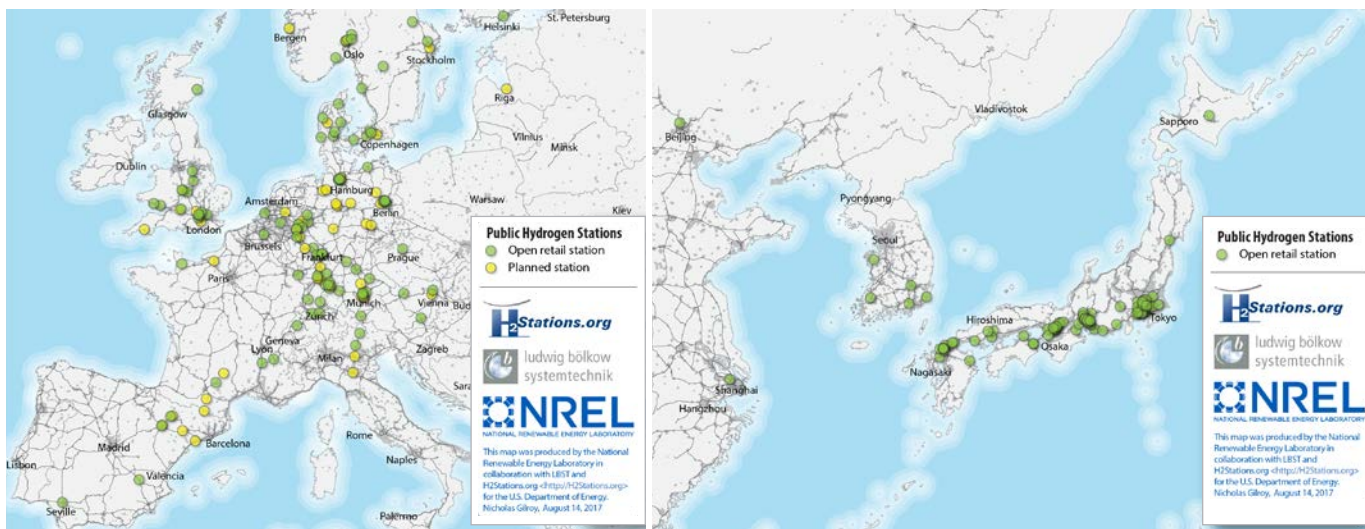


Figure 3. Existing and planned hydrogen refueling stations in Europe and East Asia (LBST 2017)

Source: NREL

1.2 Purpose of this Report

This report provides context and insight to stakeholders involved in the development of national HRS networks by examining the quantity, location, and deployment schedule of stations needed to satisfy consumer demand for FCEVs. The results of these scenarios can help guide plans to enable FCEV market growth. Three national scenarios are developed based on California's successful market transformation and planning processes. These scenarios illustrate how national FCEV markets and HRS networks might coevolve in space and time in response to various combinations of market demand, market support, and corporate strategy trends. The scenarios represent a range of possible futures, with the goal of enabling more informed decisions by various public and private stakeholders with different perspectives and priorities, ranging from near-term investors to long-term planning organizations.

Coordination and planning by public-private partnerships will be an essential part of the successful creation and acceleration of future markets for FCEVs and HRSs. Consumers are reluctant to buy FCEVs until the refueling infrastructure is well developed, and investment in alternative fuel infrastructure is only justified with assurance of a significant level of demand. Stakeholder coordination can reduce HRS network investment risks by increasing the probability of achieving high utilization rates and larger economies of scale, which are fundamental requirements for a successful business case. This business case must be achieved while establishing an infrastructure network sufficient in scale and geographic scope to enable strong FCEV market growth. As HRS

Coordination and planning by public-private partnerships will be an essential part of the successful creation and acceleration of future markets for FCEVs and HRSs.

networks coevolve with FCEV market growth, they must provide coverage to entire urban areas, link clusters of urban areas, and enable long-distance travel along interstate corridors.

These requirements highlight the interdependence

of stakeholder decisions, investment risks, and profit potential, and they emphasize the fundamental role of planning and coordination among multiple stakeholders. The scenarios presented here contribute to these collaborative efforts by examining the national expansion of HRS networks across different cities, regions, and time periods.

Scenario results provide preliminary and high-level answers to the following questions:

- **How many HRSs are needed to serve growing FCEV markets?** This question is addressed by examining initial coverage requirements for urban areas, total network capacity required to satisfy local demand, and geographic network expansion required to satisfy growth into mainstream consumer markets.
- **Where would HRSs need to be located?** This question is addressed at neighborhood, urban area, and regional scales, relying on previous analytic studies and new applications of detailed station location and national network expansion models. All scenarios include strong growth in California followed by a variety of expansion patterns into additional urban and regional markets.
- **When would new HRSs need to be deployed?** This question is addressed through three distinct rates of FCEV market growth, ranging from 23 million to 61 million passenger FCEVs deployed by 2050 (1.8 million to 4.5 million by 2035). For all new markets, initial coverage stations are established before FCEVs are introduced.

All three questions depend on assumptions about initial station coverage requirements for early FCEV adopters, average station sizes, the geographic extent of urban markets, consumer demographics, and rates of FCEV market growth. Each of the three scenarios resolves these interrelated factors through internally consistent simulations of FCEV adoption and HRS network expansion dynamics, drawing on empirical trends and updated plans from recent studies. The result is a set of complete national HRS network simulations, with temporally and spatially resolved HRS locations, sizes, and installation years as FCEV market shares increase over time and across different U.S. cities and regions.

This report reflects the perspectives of H₂USA Locations Roadmap Working Group members. The scenarios are intended to inform stakeholders involved in developing partnerships for local or regional HRS networks. The FCEV sales volumes discussed in each scenario, nationally and by region, do not necessarily suggest that sales are more or less likely to materialize in a given market. Instead, the trends and relationships discussed in each scenario provide insight into likely dynamics as HRS networks and FCEV markets coevolve. Specific investment decisions should be made based on the latest and most reliable market data and in response to progress with stakeholder coordination activities in

promising markets. For more information on investment opportunities, see the online H2FAST investment tool, the H₂USA website, and the Hydrogen Network Investment Plan (NREL 2017; H₂USA 2017; Eckerle and Garderet 2013).

The remainder of the report is organized as follows. Section 2 reviews California's successful market transformation process. Section 3 describes the elements of each scenario, and Section 4 presents scenario results. Finally, Section 5 summarizes key study takeaways. Supporting information on modeling methods is provided in a companion report (Bush et al. forthcoming).

2 The California Precedent

Because California leads the United States in the development of a successful passenger FCEV market and convenient HRS network, the present study is grounded in the research, processes, and empirical results that have emerged from California's experience. This experience is summarized in Figure 4 and the box at the end of this section, summarized as basic components and key ingredients that may prove useful to other U.S. states and regions.

Building on a long history of air-quality improvement efforts, California began setting aggressive advanced vehicle standards in the 1990s, including the Zero Emission Vehicle (ZEV) mandate, to address issues related to air quality, energy security, and climate change. The state government also began proactively supporting implementation of advanced and alternative fuel vehicles. In 2009, the California Fuel Cell Partnership—which includes automakers, energy companies, government agencies, fuel cell and hydrogen technology companies, and research and advocacy organizations—published a plan outlining the early introduction of FCEVs and HRSs in key geographic clusters with large numbers of expected early FCEV adopters. This led to the identification of early markets to be targeted by local HRS clusters (Ogden and Nicholas 2011; CaFCP 2012a; CaFCP 2014; Brown et al. 2015).

FCEVs are one aspect of California's overall goal to deploy 1.5 million ZEVs by 2025, as articulated in the state's ZEV Action Plan (CAGO 2016). Financial support today relies on public funds allocated through the California Energy Commission's Alternative and Renewable Fuel and Vehicle Technology Program, which is authorized to allocate \$20 million in program funds to HRSs each year (CEC 2016; CEC 2017a). In 2013 California signed a memorandum of understanding with seven additional states to pursue the multi-state ZEV Action Plan, with the goal of deploying 3.3 million ZEVs by 2025 in California, Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island, and Vermont (ZEV-PITF 2014). Each of these states, as well as Maine and New Jersey more recently, has adopted California's ZEV mandate regulation—thus, about 25%–30% of all new vehicles sold in the United States are subject to ZEV regulation (CARB 2017). Therefore, OEMs have an intrinsic business reason to help promote and advance ZEV infrastructure, for both battery electric vehicles and FCEVs. Sales of FCEVs result in necessary credits under the ZEV mandate, but a convenient HRS network must be in place first to allow an initial FCEV market launch and subsequent growth. While partnership arrangements, planning methods, and market support mechanisms may all vary across states and regions, the basic components shown in Figure 4

provide fundamental support for FCEV markets.

A wide variety of outreach, planning, analysis, and coordination activities has contributed to the successful establishment of FCEV markets in California. These have included fire marshal training by U.S. Department of Energy and California Fuel Cell Partnership staff, financial analyses of early station clusters (Ogden and Nicholas 2011; Eckerle and Garderet

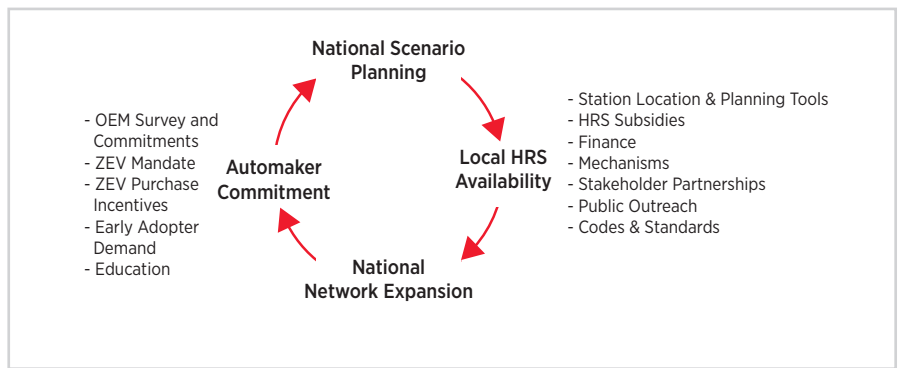


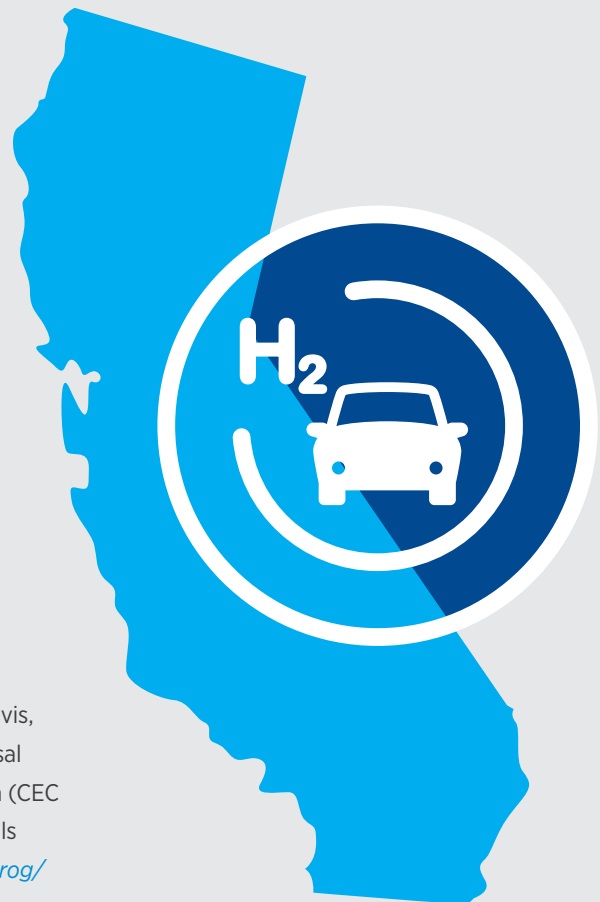
Figure 4. Basic components of a continuous cycle of support for early FCEV and HRS markets

2013), and long-term scenarios developed by the National Academy of Sciences (NRC 2008). Detailed descriptions of these activities can

be found in various reports and workshop proceedings (Melaina et al. 2008; NREL 2011; CaFCP 2017).

Key ingredients of California's strategic market success

1. Quantify near and mid-term FCEV intended market locations and vehicle volume potential by way of automaker commitments. This has been achieved through an annual survey of original equipment manufacturers required by the California Air Resources Board (CARB 2016).
2. Establish financial support mechanisms for HRS investments. These include direct capital subsidies as well as operation and maintenance grants provided by the California Energy Commission (CEC 2016). Assembly Bill 8 provides \$20 million per year in investment commitment toward HRSs.
3. Establish FCEV market support mechanisms. These include the ZEV mandate as the major market pull mechanism as well as direct vehicle subsidies as market push mechanisms. The Clean Vehicle Rebate Program is one example, offering a \$5,000 rebate for each FCEV purchased (CSE 2017).
4. Implement HRS network planning and coordination tools in collaboration with OEMs. Within California, these have included the University of California, Irvine's STREET model, the station coverage modeling conducted by researchers at the University of California, Davis, the National Renewable Energy Laboratory's SERA model, the proposal scoring methods used internally by the California Energy Commission (CEC 2017b), and the California Air Resource Board's CHIT and CHAT models (CARB 2016, available online at: <https://www.arb.ca.gov/msprog/zevprog/hydrogen/h2fueling.htm>).



3 Hydrogen Infrastructure Scenarios

Each of the three scenarios developed in this report—Urban Markets, State Success, and National Expansion—varies by the rate and geographic scope of HRS network investments. These infrastructure investments support FCEV market growth trends that vary based on responsiveness to consumer demand, policy drivers, and local and regional planning and coordination efforts. Each scenario is similar in that successful FCEV market growth is achieved through the coordinated rollout of vehicles and stations, ensuring a positive consumer experience and reducing station investment risks. Differences between the scenarios provide insights into infrastructure development trends that could result from the combined influences of market support mechanisms, consumer demand, and successful coordination and planning among automakers, fuel providers, station owners, investors, and government agencies.

3.1 Overview of Analytic Methods

All three scenarios assume strong future FCEV market growth in California followed by market expansion into other cities, states, and regions. Cities are modeled individually with respect to when and how many new stations are installed before FCEVs can be sold in large numbers. After establishing initial station coverage to satisfy the driving needs of early adopters (Melaina 2003; Nicholas, Handy and Sperling 2004), the number,

geographic extent, and average size of hydrogen stations increases in proportion to the growth in FCEV sales for any individual city. Total nationwide FCEV sales are different for each scenario, as is the distribution of sales between regions and cities. Hydrogen station network expansion modeling assumptions rely upon the most recent trends in new station installations, and draw from planning guidelines developed over many years by various California stakeholders (CEC 2017a; CEC 2017c; CARB 2016; Brown et al. 2015; CaFCP 2012a; Ogden and Nicholas 2011).

As summarized in Table 2, HRS networks are described in terms of three geographic scales, each of which is useful for analyzing different types of market and infrastructure development trends: urban areas, regions, and megaregions. FCEV sales and use are resolved at the urban area scale,² with sales rates varying between regions, which include California, the other ZEV states, and the rest of the country based on presumed future influence of state government policies. Megaregions—integrated regional economies that extend across conventional political boundaries—are useful in capturing large-scale infrastructure and market development trends. Table 2 also indicates the three time periods over which the scenarios are analyzed.

² The U.S. Census Bureau defines urban areas as densely populated urbanized areas of 50,000 or more people. In the present report, urban area also includes urban clusters, which are based on the same criteria but with 2,500–50,000 people (<https://www.census.gov/geo/reference/ua/uafaq.html>).

Table 2. Scenario geographic scales and time periods

Geographic Scales	Time Periods
<p>Urban areas</p> <ul style="list-style-type: none"> • U.S. Census designations <p>Regions</p> <ul style="list-style-type: none"> • California (CA) • Other states adopting the ZEV mandate (ZEV) • Rest of the country (ROC) <p>Megaregions</p> <ul style="list-style-type: none"> • As proposed by the Regional Plan Association (RPA 2017) 	<p>Early Markets (2015–2025)</p> <p>Expansion (2025–2035)</p> <p>Long-term Growth (2035–2050)</p>

Urban area populations are illustrated in Figure 5 by circles (totaling 224 million people), with circle color indicating the region. The ZEV region includes states other than California that have adopted the ZEV mandate: Connecticut, Maine, Maryland, Massachusetts,

New Jersey, New York, Oregon, Rhode Island, and Vermont. The color density of the 11 megaregions shown in Figure 5 indicates frequency and geographic extent of household vehicle commuting patterns between cities (Nelson and Rae 2016).

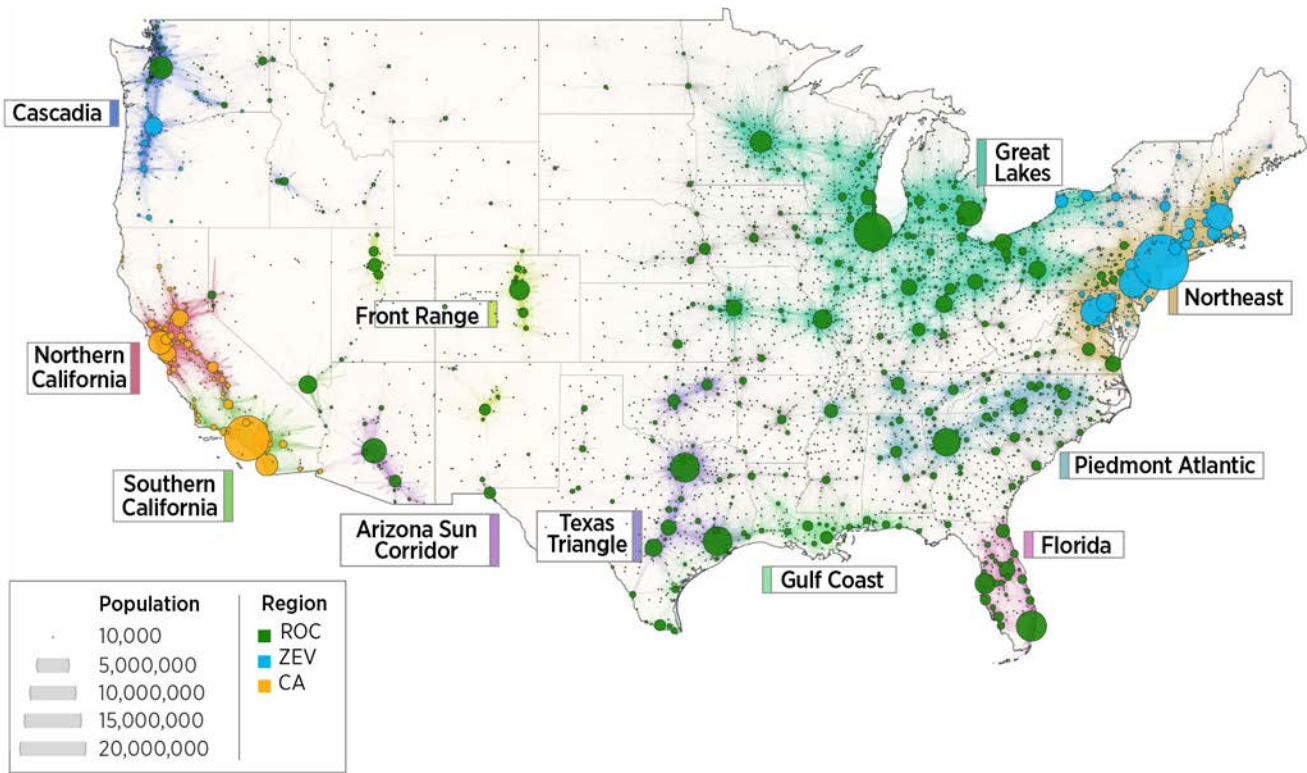


Figure 5. U.S. population across urban areas and regions. Megaregions indicate frequency and geographic extent of household vehicle commuting patterns.

Source: NREL

3.2 Scenario Results

The scenarios assume three distinct FCEV market growth futures followed by a simulation of the HRS network expansion required to support the resulting hydrogen demand. The market growth rates are not forecasts of future outcomes. Instead, they illustrate how national station networks might develop over time as FCEV markets grow in response to a variety of future market conditions. By taking into account a relatively wide range of market influences and infrastructure development patterns, the scenarios are intended to be useful to a broader set of stakeholders. Each scenario is described below, and market influences for each scenario are summarized in Table 3.

Urban Markets—Local Demand and Metropolitan Area Initiatives

Focused infrastructure investments respond to a combination of highly concentrated early adopters and market support mechanisms implemented by a select number of major metropolitan areas. The result is rapid growth within a relatively small number of large urban markets, followed by slower diffusion into nearby cities and across megaregions. Although the select urban areas experience rapid market growth, overall national growth is slower than in the other two scenarios.

Table 3. Market influences by scenario

Market Influence	Urban Markets	State Success	National Expansion
Dominant market drivers	Support at local and municipal levels combined with strong early adopter demand	ZEV mandate and other state market support mechanisms	Combination of strong local, state, and national market support mechanisms
Coordination and planning	Investments focused on most promising metropolitan markets	Strong coordination across ZEV mandate states	Strong coordination and planning across all regions
Consumer adoption	High concentrations of early adopters guide market development	FCEV adoption primarily driven by ZEV mandate	Adoption moves quickly from concentrated early adopters and ZEV mandate states to broad megaregion markets
HRS network expansion	Gradual expansion from promising urban markets to nearby cities	Focus on ZEV mandate states, with gradual expansion into additional markets	Strong stakeholder planning and coordination reduces investment risks, allowing rapid network expansion
FCEV sales per year (millions) and total urban area market share (%) in 2050			
United States	3.1 M (23%)	5.0 M (35%)	8.9 M (59%)
California (CA)	1.0 M (49%)	1.3 M (64%)	1.7 M (84%)
Other ZEV States (ZEV)	0.9 M (26%)	1.9 M (56%)	1.9 M (57%)
Rest of Country (ROC)	1.2 M (10%)	1.9 M (14%)	5.3 M (41%)

State Success—Creating Markets through Regulation

In this scenario, implementation of the ZEV mandate and other state market support mechanisms are assumed to be significant drivers of market growth. HRS network investments are guided through highly coordinated efforts across states, resulting in strong FCEV market growth. Larger urban markets outside states offering policy support grow more slowly. Urban markets in the western Cascadia, Front Range, and Arizona Sun Corridor megaregions open and grow relatively quickly owing to market spillover from California and Oregon, while cities with very high early adopter concentrations take the lead in other regions. The result is relatively rapid growth in a select number of states followed by more moderate growth across the rest of the country.

National Expansion—Unleashing Market Forces

By combining highly coordinated planning and development efforts with aggressive market support mechanisms, rapid FCEV market growth is assumed to

occur across megaregions. HRS network investments respond to the combined influence of highly concentrated early adopters, the ZEV mandate, other market support mechanisms, and successful stakeholder coordination and planning activities at the national and megaregion scales. Most major urban markets open quickly, followed by strong local spillover into smaller nearby cities within all megaregions.

Table 3 summarizes the market influences that define each scenario. These influences capture the major influences on how FCEV markets and HRS networks expand geographically and over time. The bottom of Table 3 shows the corresponding annual FCEV sales and urban area market share in 2050 for the United States and each region (CA, ZEV, and ROC). Additional details on FCEV market share influences by scenario and region are provided in Section 3.3. Section 3.4 discusses how HRS network expansion responds to the resulting FCEV market trends. A companion report provides additional details on the modeling assumptions and analytical methods used to develop each scenario (Bush et al. forthcoming).

3.3 Fuel Cell Electric Vehicle Market Growth Scenarios

FCEV sales are assumed to follow an “s-curve” growth pattern, with relatively slow adoption in early years giving way to rapid growth and eventual market saturation (Rogers 1995; Lund 2006). This pattern is realized at the urban area level and at the regional and national scales. National sales of FCEVs out to 2050 are shown in Figure 6 with reference to total U.S. LDV sales. Initial (2016–2022) sales in the State Success scenario match FCEV sales estimates in California from recent automaker surveys. Sales in the Urban Markets and State Success scenarios reach approximately 3 million and 5 million FCEVs per year by 2050, respectively. The sales trajectory in Urban Markets is approaching saturation near 2050, while sales in State Success are still growing strongly by 2050. Sales in the National Expansion scenario are at about 9 million FCEVs per year by 2050, roughly half of all LDV sales, and still experiencing relatively strong growth.

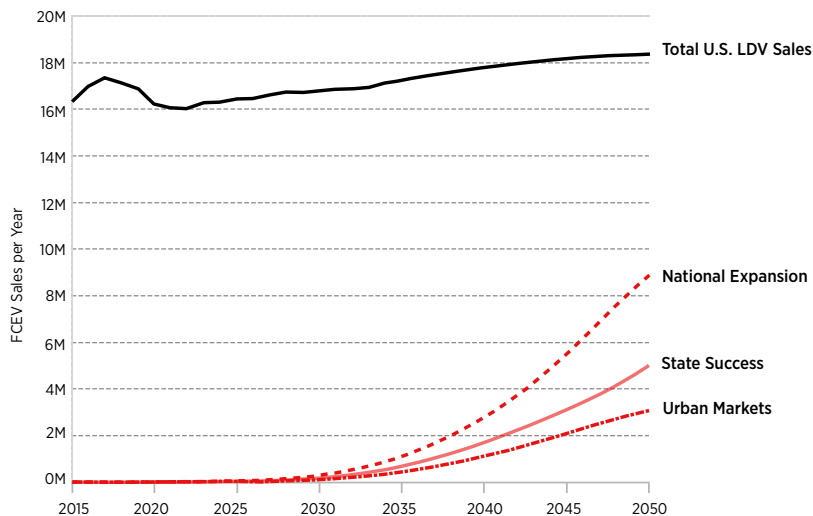


Figure 6. FCEV sales by scenario compared with total U.S. LDV sales

A more detailed depiction of these sales projections is shown by region in Figure 7. The top set of panels indicates that within the Early Markets time period (2015–2025), FCEV sales in the Urban Markets and State Success scenarios are significantly lower than those in the National Expansion scenario. Most of the sales are into California markets in each scenario, with the State Success scenario having minimal sales into ROC markets. The middle set of panels shows sales for the Expansion time period (2015–2035), and has a different scale on the vertical axis: 1.5 million FCEVs per year, compared with 100,000 FCEVs per year in the Early Market time period. Sales into ROC markets are still minimal in the State Success scenario, but ROC and ZEV sales begin stronger growth in the Urban Markets and National Expansion scenarios. California sales still dominate the FCEV market by 2035. The bottom set of panels shows FCEV sales in the Long-term Growth time period (2015–2050), adjusting to a scale of 10 million FCEVs per year on the vertical axis. By 2050, FCEV sales in State Success are nearly double those in Urban Markets, and sales in National Expansion are nearly double those in State Success. These sales are roughly equally divided among the



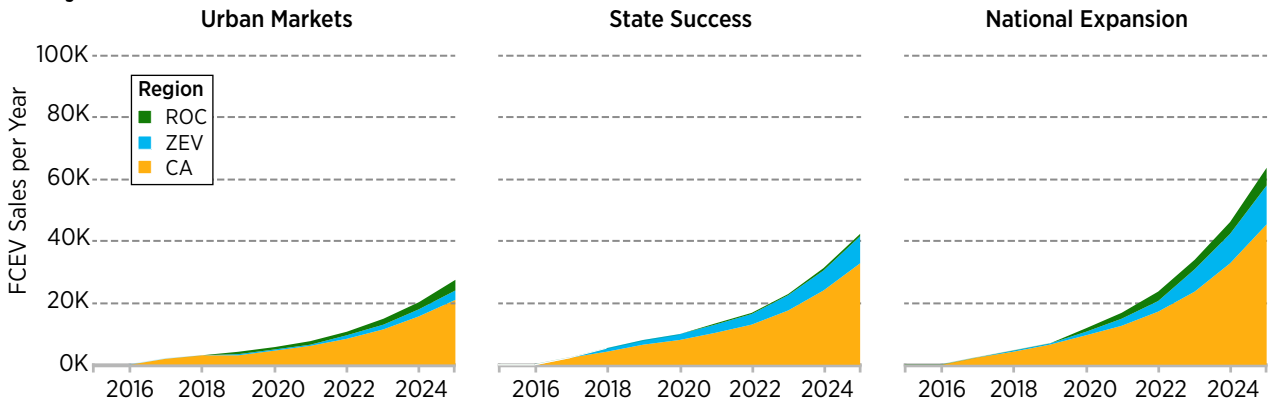
three regions in the Urban Markets scenario, while the ZEV states play a larger role in the State Success scenario and the ROC region becomes the dominant market in the National Expansion scenario.

The rate of growth in the National Expansion scenario is comparable

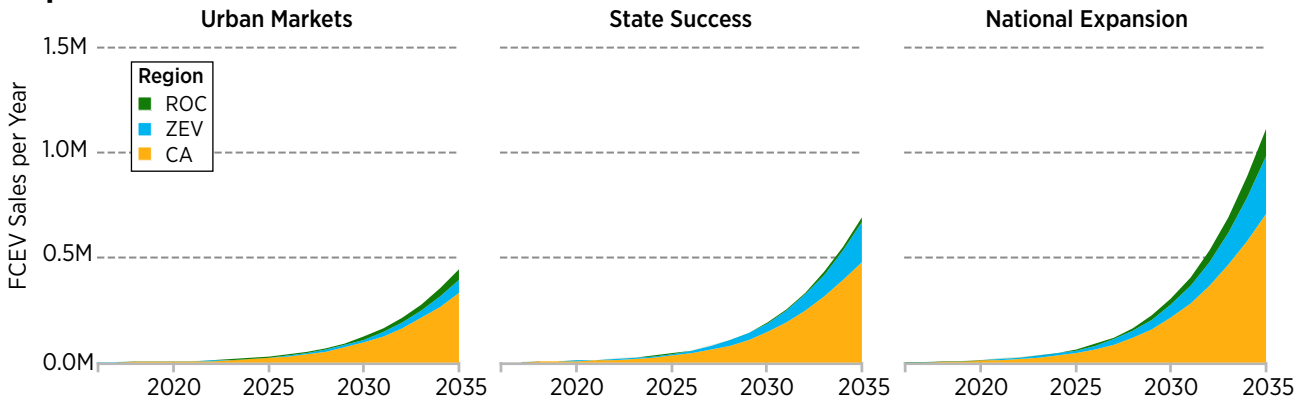
to growth in the FCEV success scenario developed in a report from the National Academy of Sciences (NRC 2013). In that study, annual sales of 10 million FCEVs were achieved through aggressive market growth between 2015 and 2036, approximately 15 years earlier than

the National Expansion scenario sales trend indicated in Figure 7. The National Expansion scenario is therefore more conservative than the 2013 NRC estimate of feasible FCEV market growth under favorable market and policy conditions.

Early Markets



Expansion



Long-term Growth

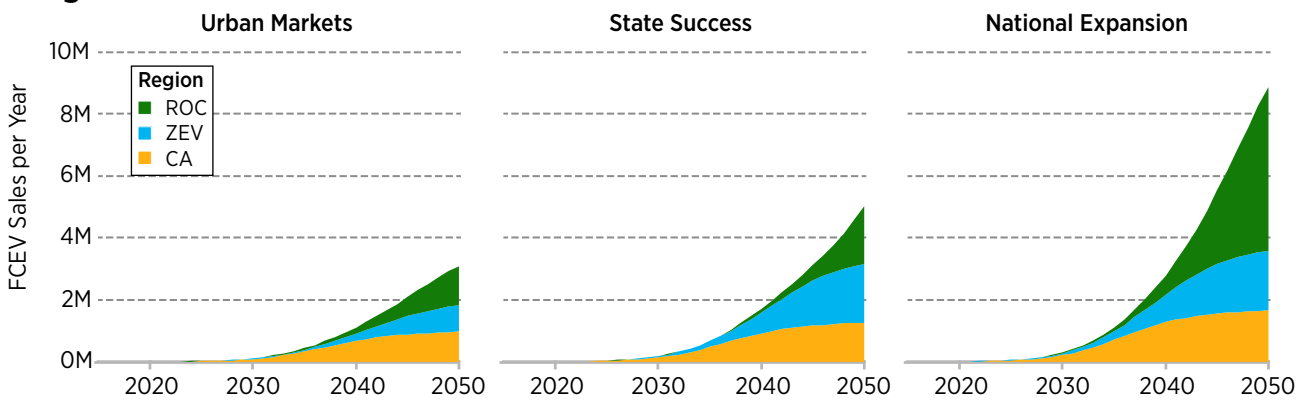


Figure 7. Breakdown of FCEV sales by period and region

Note: The scale of the vertical axis changes between each of the three periods.

3.4 Hydrogen Station Network Development

The first three market influences summarized in Table 3—market drivers, coordination, and adoption—indicate major influences on FCEV market success in each of the three scenarios. The fourth influence—HRS network expansion—describes the refueling infrastructure deployment that responds to FCEV market growth. The rollout of FCEVs and HRS networks in ZEV and ROC cities and megaregions is assumed to follow patterns similar to the planned rollout in California, although delayed in time and adjusted for variations in consumer demographics. Three main dynamics influence infrastructure supply simulations: (1) the influence of early adopters, (2) the requirement for activation stations to open urban markets to large FCEV sales volumes, and (3) the sequence in which additional urban markets are opened over time. Each dynamic is reviewed below.

Early Adopter Influence—Because so few FCEVs have been deployed to date, future consumer demand for FCEVs is projected by analyzing empirical data on historical sales of other advanced vehicles (including hybrid electric and plug-in electric vehicles) and luxury vehicles as well as the prevalence of high-income households. The result is a consumer demand metric referred to as the Early Adopter Metric (EAM), which serves as a proxy for where FCEV sales are likely to be strongest and, therefore, where and how many new stations must be built to activate FCEV market growth. Early adopters are critical to initial market development in all three scenarios. However, the scenarios differ in the extent to which network development patterns depend on the influence of early adopters compared with the other market drivers summarized in Table 3. The EAM is a unitless metric, indicating the spatial distribution and density of early adopters.³ The EAM does not influence the rate of FCEV market growth.

³ Analytically, EAM is resolved at the ZIP-code level based on vehicle registrations and Census household income. EAM is determined by giving 50% weight to the number of hybrid electric, plug-in hybrid electric, and pure battery electric vehicle registrations, 25% weight to luxury vehicle registrations, and 25% weight to average household income. For the sake of exposition, it is assumed that one out of five consumers falls into the early adopter category, resulting in a spatial representation of 63 million potential early adopters in more than 600 urban areas.

Activation Station Requirements—For early FCEV markets to be successful, consumers must be confident in the availability of convenient local and regional HRS networks (Melaina 2003; Nicholas, Handy and Sperling, 2004). During the early years of FCEV introduction, convenience for early adopters is of primary concern. Based on the analytic approach used to develop the California Fuel Cell Partnership Roadmap (see Section 2), a certain number of market activation stations must be installed before OEMs will begin unique dealership outreach and marketing of FCEVs, allowing them to be sold in large volumes into a given urban area. The coverage of activation stations must enable most early adopters to live within a 6-minute drive of a station (Nicholas et al. 2004; Melaina et al. 2013; CaFCP 2014; Brown et al. 2015). This approach tends to result in one or more activation stations being clustered in neighborhoods with high concentrations of early adopters. Additional activation stations provide refueling availability across the larger urban area, resulting in a network that satisfies the refueling needs of most early adopters. An example of how activation stations might be distributed across an urban area is shown in Figure 8, with 36 stations serving early adopters in Seattle. These activation stations represent approximately 5% of all gasoline stations serving the urban area indicated in the map.

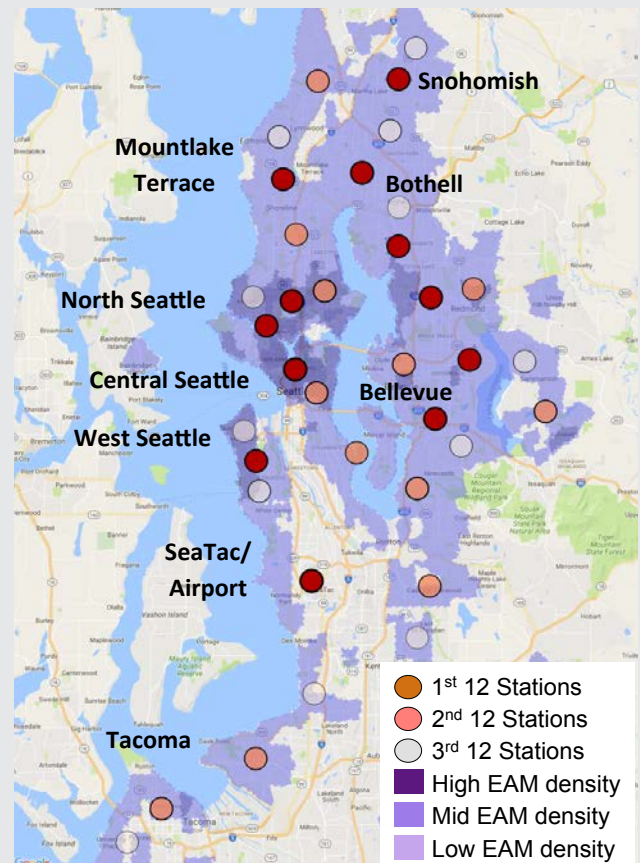
Urban Market Sequencing—More than 600 urban areas are prioritized based on the density of early adopters (EAM per square mile) and the number of early adopters served by the activation stations required in any given city (EAM per activation station). The rationale behind this sequencing approach is that capital is the limiting factor in determining the most effective station investments, whether it is provided by government agencies through subsidies or directly by private investors. Cities with both large numbers of early adopters and high densities of early adopters, measured as a ratio of early adopters per activation station, are opened to new FCEV sales before other cities. In addition, cities in close proximity to these high-priority cities are also prioritized, although this effect is stronger in the National Expansion and State Success scenarios than in the Urban Markets scenario, where

Activating Greater Seattle

It is estimated that 36 hydrogen stations could provide sufficient refueling availability for early adopters such that large volumes of FCEVs could be sold into the Greater Seattle market. The map indicates high densities of early adopters (darker shades of purple) as well as the location (circles) of the first 12 stations (red), second 12 stations (salmon), and third 12 stations (gray).

The first 12 stations include four clusters: four stations in North, Central, and West Seattle; four stations running through Bellevue north to Bothell; and three northern stations extending from Mountlake Terrace to Snohomish; and a station at the airport. The airport in SeaTac serves as a destination station and is therefore distinct from the other high EAM density stations. Additional activation stations reinforce these clusters, provide connectivity across outlying urban areas, and extend south to Tacoma.

Figure 8. Market activation station example: Seattle, Washington (Map data: Google)



FCEV markets are strongly influenced by market support mechanisms provided by individual cities. Following this sequence of prioritization, new cities are activated as the volumes of FCEV sales shown in Figure 6 and Figure 7 increase over time. The result is that large cities with high concentrations of early adopters receive the first activation stations and large volumes of FCEV sales.

Additional cities are then activated as total FCEV sales in a given region increase over time. The modeling methodology companion report includes a more detailed discussion of the city sequencing methodology (Bush et al. forthcoming).

4 Scenario Results

Each of the scenarios represents a successful rollout of FCEVs and HRS networks into major urban areas across the United States. All three scenarios involve strong FCEV and HRS growth in California followed by expansion into other regions and urban areas. The total FCEV stocks and HRSs installed are shown by scenario in Figure 9 for three time periods, each represented by a panel with FCEV stock in the upper bar charts and total stations in the lower bar charts. The panel on the left indicates results at the end of 2025, the middle panel shows results at the end of 2035, and the panel on the right shows results by 2050. The magnitude and geographic distribution of FCEV stocks and HRS network expansion vary among the three scenarios. In succession, each scenario involves greater market growth in California accompanied by increased market growth in either the ZEV or ROC markets. The Urban

Markets scenario expands into both ROC and ZEV large metropolitan areas early, with significant growth at the end of both 2025 and 2035, but relatively limited growth nationally by 2050. The State Success scenario involves strong early growth in ZEV markets followed by delayed growth in ROC markets. The National Expansion scenario involves rapid growth in all three regions, reaching the greatest number of stations and FCEVs by 2050.

Again, these scenarios are not predictions of future market outcomes. Instead, they are intended to stimulate discussions about HRS network requirements and provide insights into how those networks might coevolve with a growing national FCEV market.

An HRS network will provide convenient refueling access to a share of the total population based on how many stations are deployed and the population density of

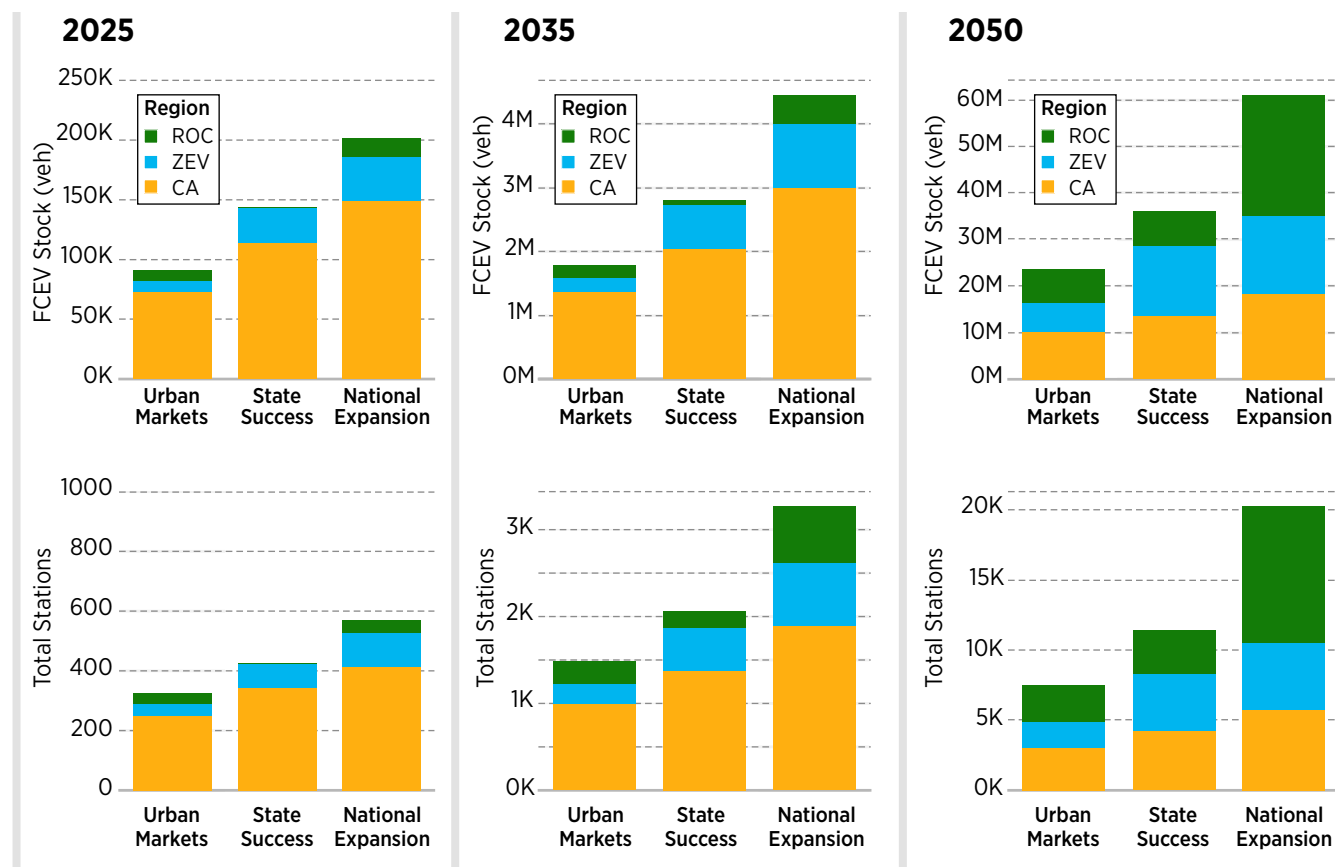


Figure 9. Number of FCEVs on the road and total HRSs by scenario and region

Note: The scale of the vertical axis changes between each of the three periods.

the area in which they are deployed. Each HRS covers a physical area, enabling access to the refueling network to all of the people living, working, or driving within that area. Using detailed traffic simulations, Nicholas and Ogden (2006) estimate a correlation between station availability and city demographics. Based on an extrapolation of these results, it is estimated that each station can provide convenient access for an area of approximately 6 square miles (Melaina et al. 2013). Figure 10 shows the population with access to a

convenient HRS for the different scenarios over time, which is proportional to the number of stations deployed in each urban area in a particular year divided by the number of stations required to cover the entire urban area surface, assuming that each station can cover up to 6 square miles. As the HRS network expands, the population enabled approaches the total population in each region, opening up greater market opportunities for FCEV adoption.

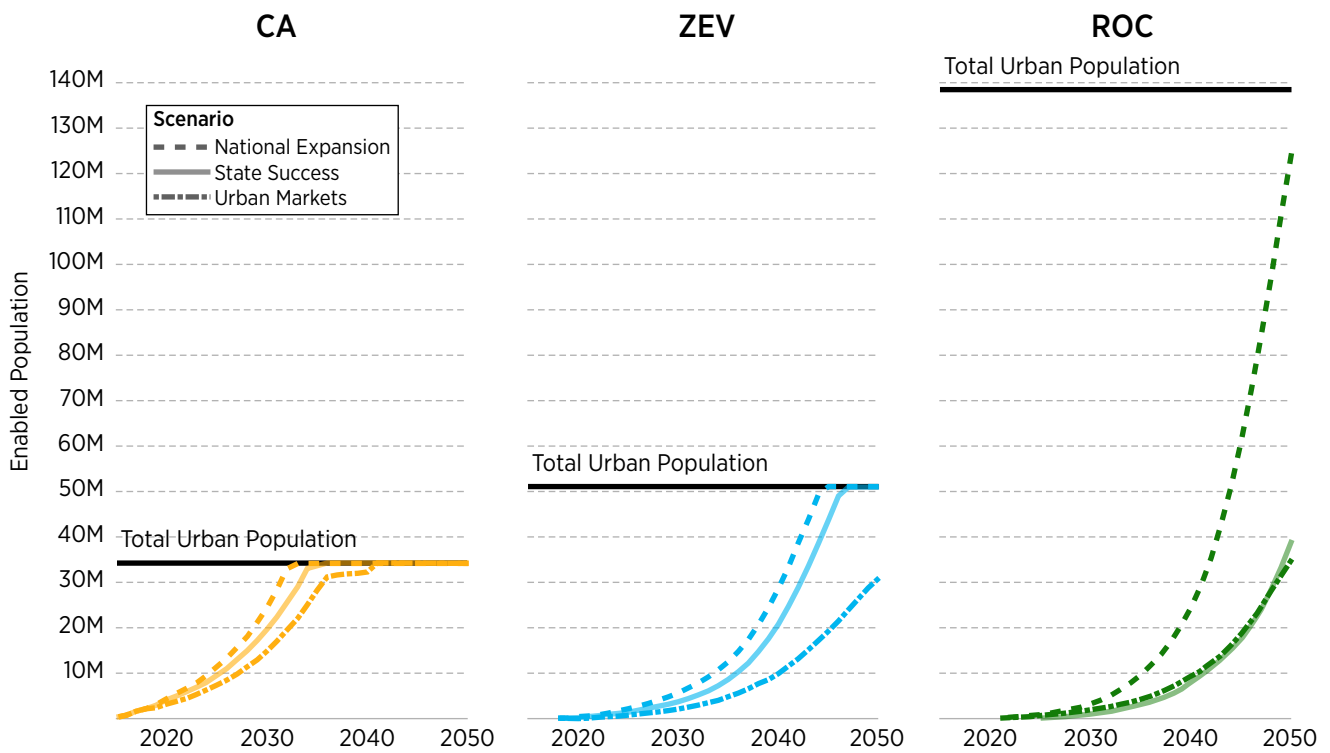


Figure 10. Population with access to hydrogen refueling by scenario

The discussion below details HRS deployment over time in the three scenarios, illustrating how many stations are needed to support different FCEV market-adoption trends, where these stations are needed, and when they are needed. This discussion relates to several figures below. Figure 11 shows the number of stations and the average capacity of installed stations for select urban areas in 2025. Figure 12 shows the same for 2035, and Figure 13 shows the same for 2050. The extent of market megaregions is also indicated, following the color-coding depicted in Figure 5.

Early Markets (2015–2025):

Initial station deployment allows for early FCEV adoption in select cities. Station sizes tend to be small when opening new urban markets in order to reduce capital costs while ensuring sufficient station availability.

In the early years, the HRS network is limited to California and a few other metropolitan areas, depending on the expansion followed in the different scenarios. Overall, 320–570 HRSs are deployed, supporting 90,000–200,000 FCEVs and providing 9 million to 14 million people access to convenient station networks. Major cities activated by 2025 are similar in California (multiple cities) and the ZEV region (including New York, Boston and Portland) in all three scenarios, but the cities activated differ in the ROC region. Chicago, Miami and Denver are activated in the Urban Markets and National Expansion scenarios, while only Seattle is activated in the State Success scenario, due to a high density of early adopters. In addition, the strong market growth in California in the National Expansion scenario results in market spillover and activation of Las Vegas by 2025.

Expansion (2025–2035):

National coverage varies significantly across scenarios, and station utilizations begin to reach high values.

In this mid-term period, the HRS network expands significantly, reaching 1,500–3,300 total stations, supporting 1.8 million to 4.5 million FCEVs, and providing 38 million to 57 million people access to convenient station networks. The sequence of activating different urban areas varies between scenarios, based upon the market influences described in Table 3. For example, Chicago plays a significant role in the Urban Markets scenario, with 47 stations and an average station size of 790 kg/day. By comparison, Chicago has only 26 stations with an average size of 470 kg/day in the State Success scenario, owing to a more focused expansion in the ZEV states, and it reaches 56 stations with an average capacity of about 1,000 kg/day in the National Expansion scenario. New York City, which is in a ZEV state, experiences the opposite, with more and larger stations deployed in the State Success scenario than in the Urban Markets scenario. The National Expansion scenario remains the most aggressive scenario for all urban areas. In particular, station deployment surges under the National Expansion scenario in Los Angeles (the largest FCEV market across all scenarios), pulling ahead of the State Success scenario's Los Angeles deployment and even further ahead of the Urban Markets scenario's deployment.

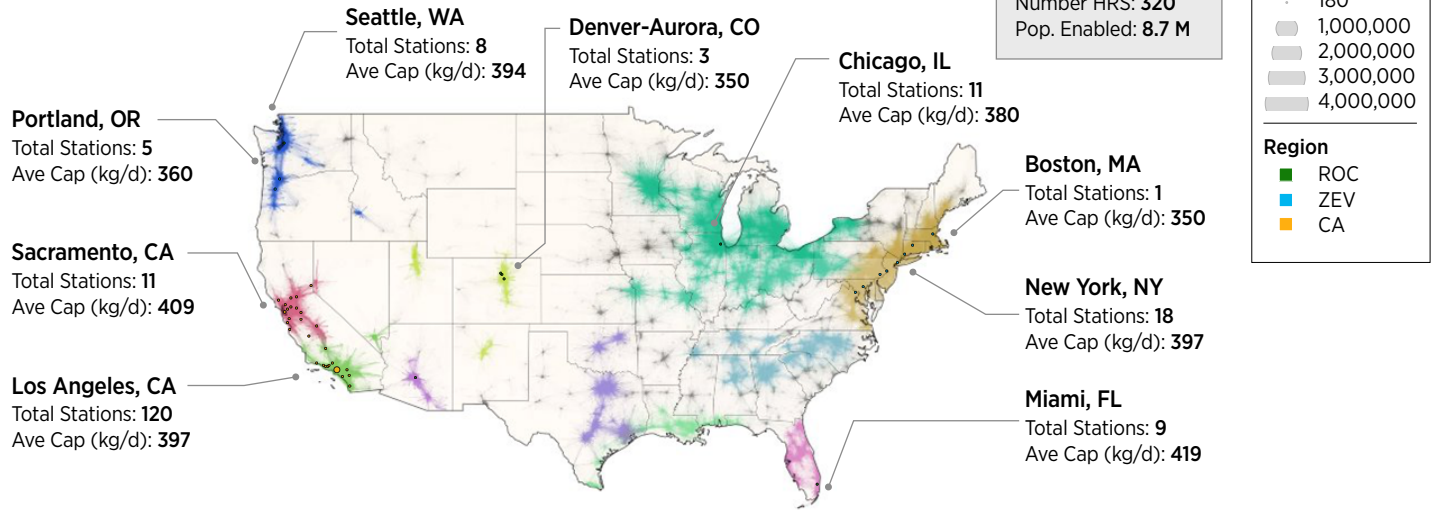
Long-term Growth (2035–2050):

Fully developed markets have FCEVs in the tens of millions and HRSs in the tens of thousands. Spatial coverage varies significantly across scenarios, while HRS networks tend to be highly utilized on average.

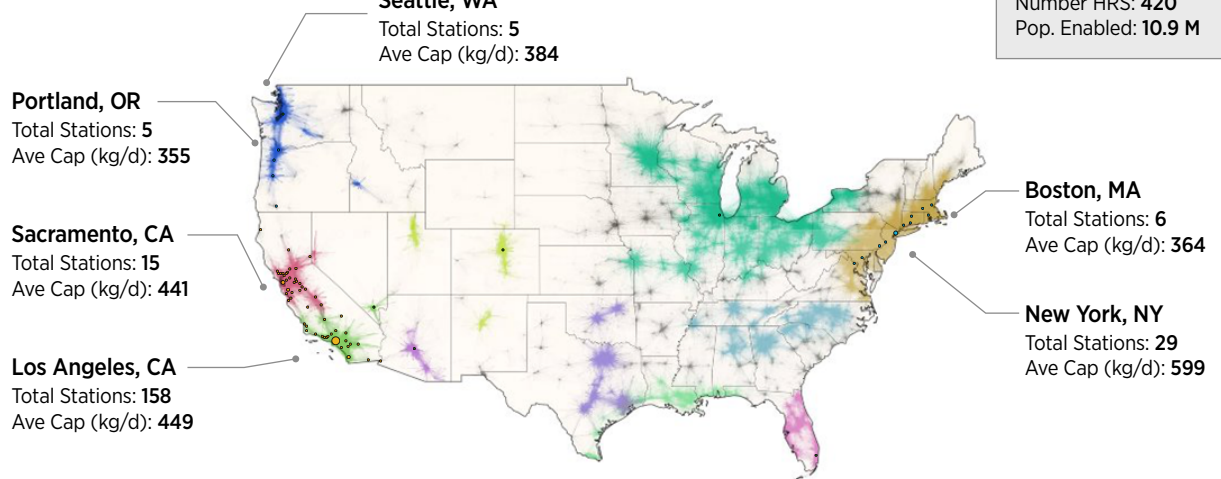
By 2050, 7,800–21,000 stations are deployed, supporting 23 million to 61 million FCEVs and enabling reliable station access for 100 million to 215 million people. With the benefit of economies of scale achieved through high volumes of hydrogen demand, large stations become dominant in many major urban areas under all three scenarios. The overall coverage is dictated by the market influences described in Table 3, resulting in an extensive and successful HRS network in all three scenarios.

Results for 2025

Urban Markets



State Success



National Expansion

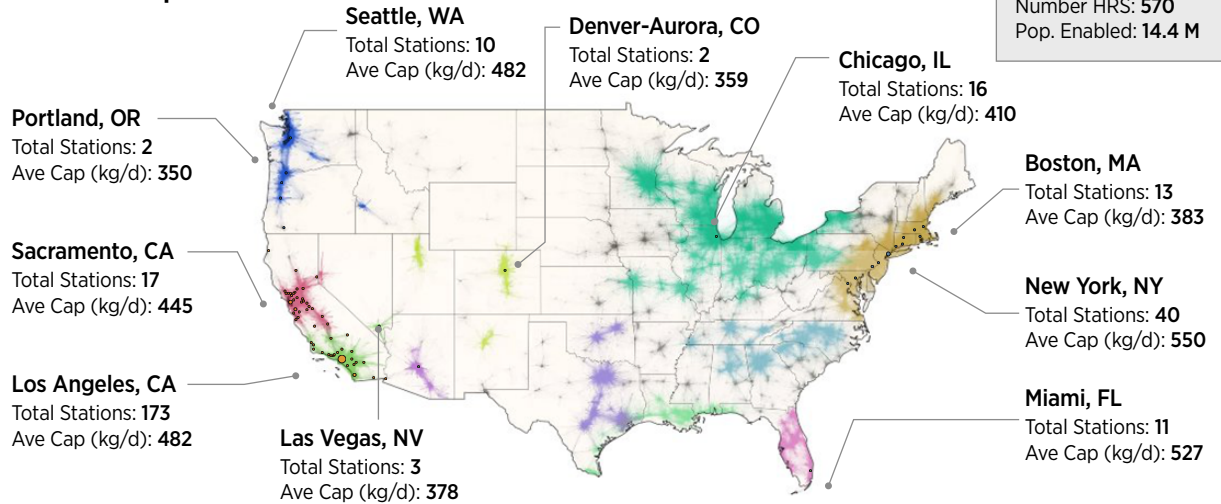


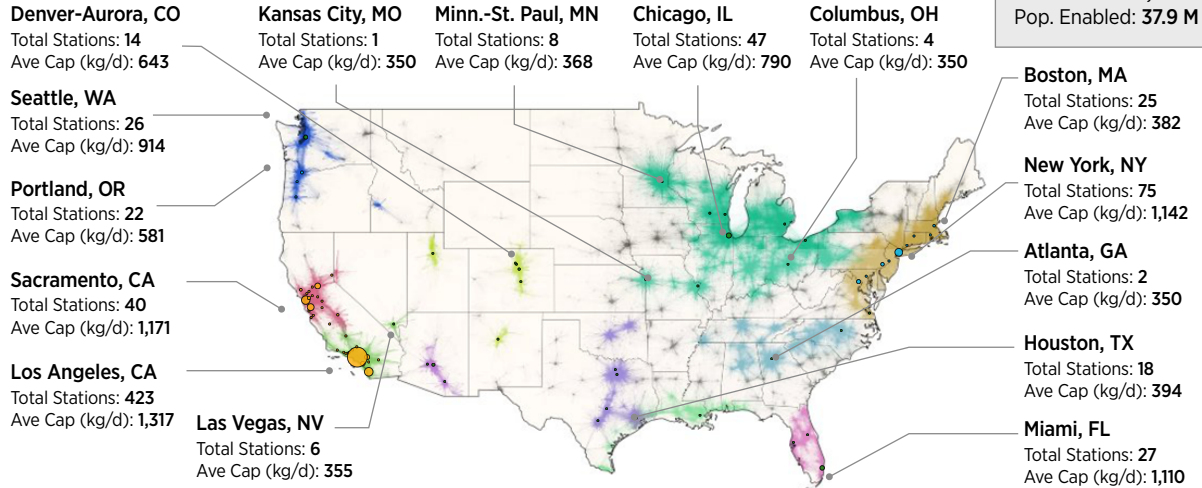
Figure 11. Number of stations and average capacity for select urban areas in 2025

Source: NREL

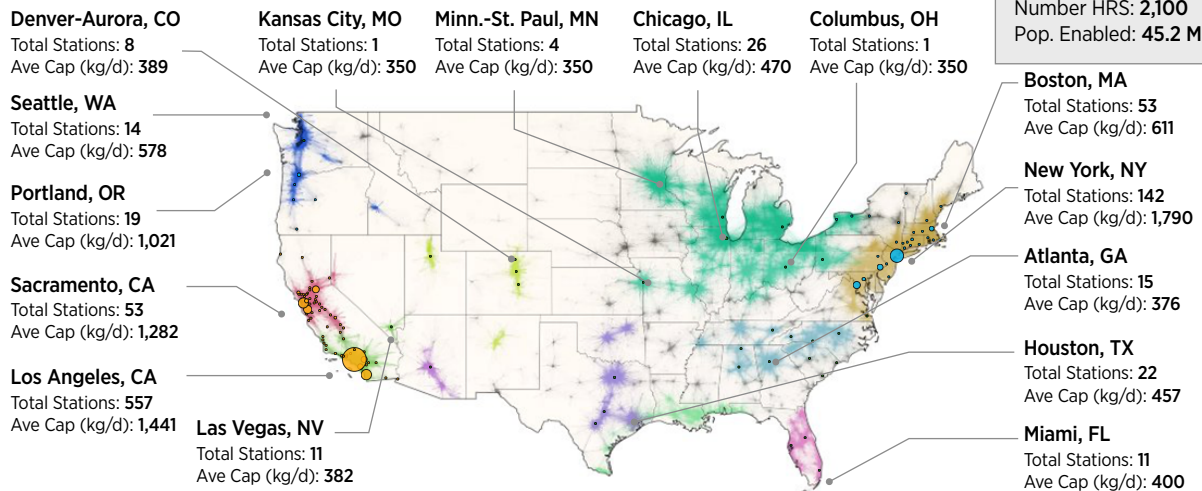
Note: Connector and destination stations needed to support regional travel are not indicated.

Results for 2035

Urban Markets



State Success



National Expansion

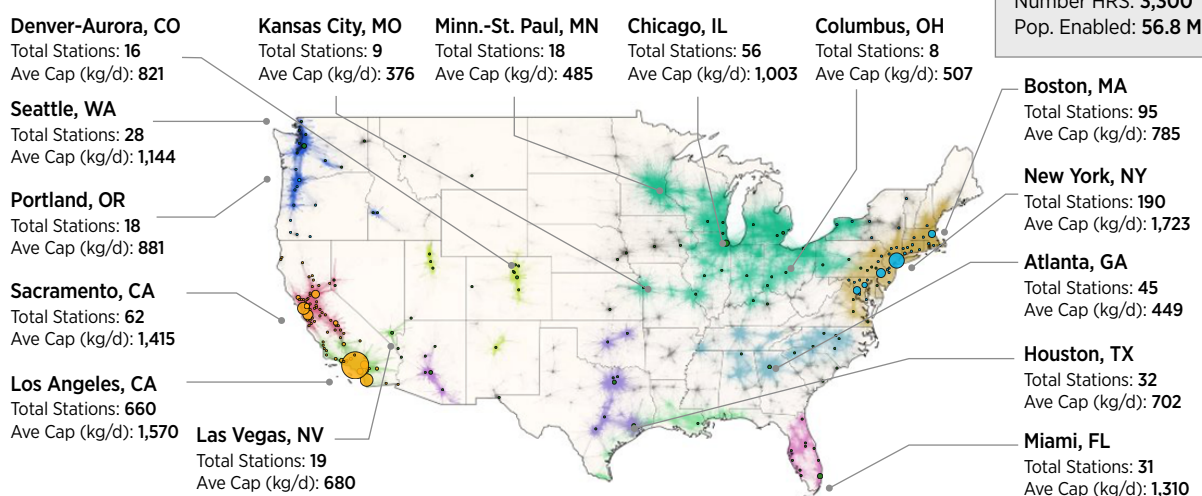


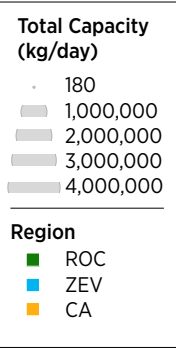
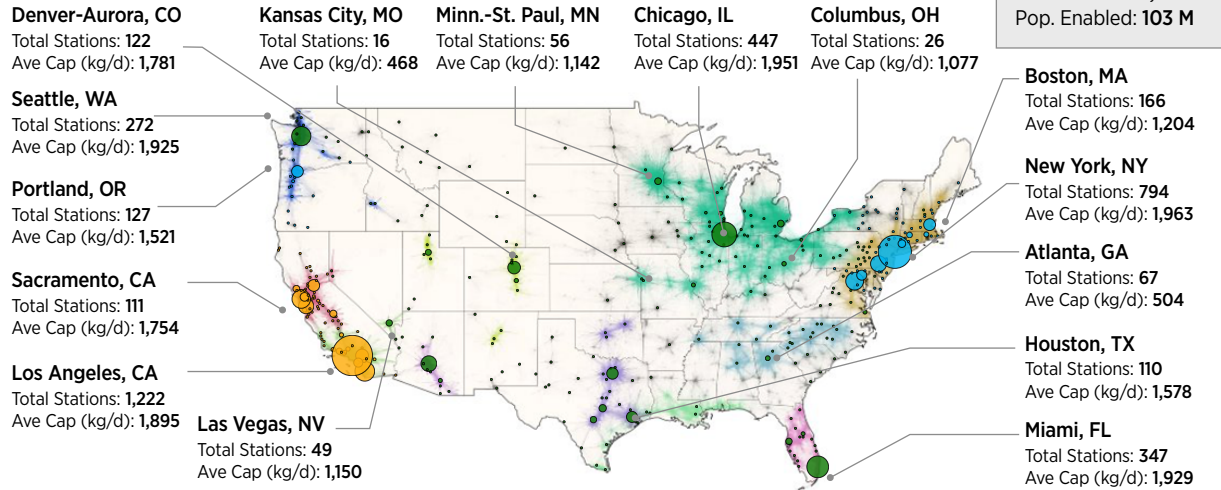
Figure 12. Number of stations and average capacity for select urban areas in 2035

Source: NREL

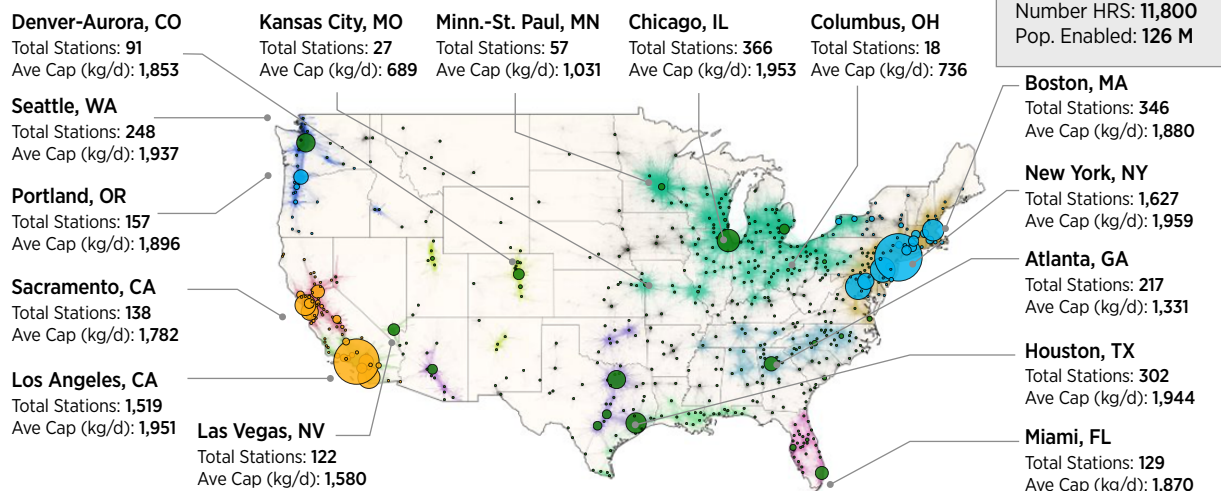
Note: Connector and destination stations needed to support regional travel are not indicated.

Results for 2050

Urban Markets



State Success



National Expansion

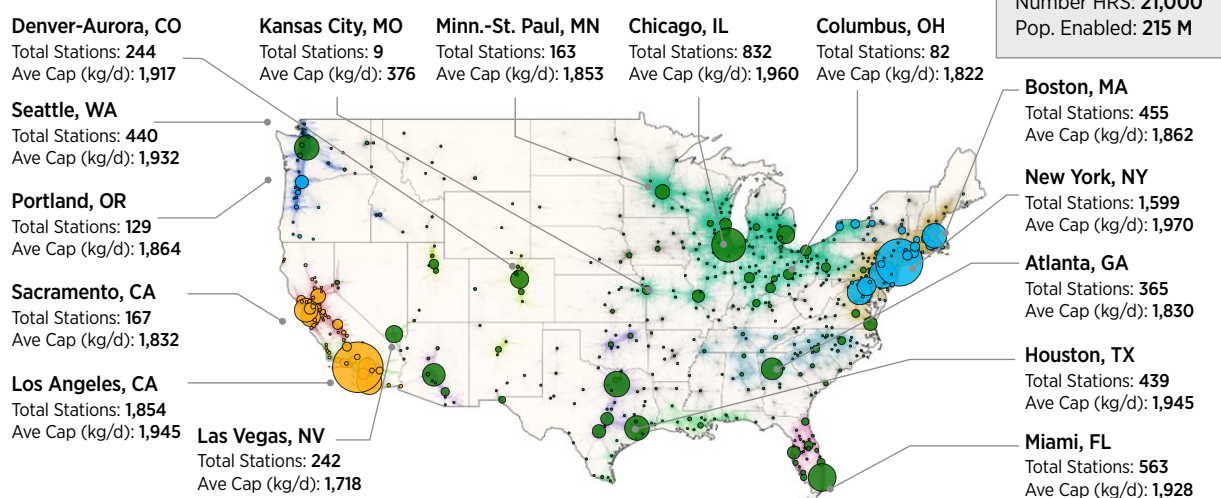


Figure 13. Number of stations and average capacity for select urban areas in 2050

Source: NREL

Note: Connector and destination stations needed to support regional travel are not indicated.

5 Summary and Conclusions

Widespread deployment of FCEVs can provide a range of economic, energy security, public health, and environmental benefits for the nation without requiring consumers to compromise on vehicle size or performance. This study examines the development of HRS networks needed to support a national rollout of FCEVs in the United States. As FCEV prices decrease and the variety of available FCEVs increases over the next 5–10 years, a few urban, state, and regional markets will establish the HRS networks required for FCEV market growth. California is fully engaged in this process today, and a number of other states are showing interest, primarily in the northeast but also in Hawaii, Texas, Ohio, and South Carolina to name a few. Based on experience over the last two decades, California’s successful planning and execution of coordinated FCEV adoption and HRS can potentially help guide other states and regions in their hydrogen infrastructure development efforts. The following are key ingredients of California’s historical success:

- 1. Quantify FCEV market potential and automaker commitments.**
- 2. Establish financial support mechanisms for HRS investments.**
- 3. Establish FCEV market support mechanisms.**
- 4. Implement HRS network planning and coordination tools.**

The success of government-industry partnerships in California, along with comparable initiatives in Europe and East Asia, are laying the foundations for global FCEV market growth. While additional U.S. cities, states, and industry partnerships may follow a slightly different process, it is recommended that these four steps be followed to help reduce investment risks and leverage the effectiveness of public and private funds in the development of HRS networks.

Although additional U.S. cities, states, and industry partnerships may follow a slightly different process, the California experience suggests that these four steps can help to reduce investment risks and leverage the effectiveness of public and private funds in the development of HRS networks.

In this report, developed under the framework of the U.S. public-private collaboration, H₂USA, an internally consistent analytic modeling method simulates how HRS networks might develop across cities and regions, assuming that successful planning and coordination activities result in a rollout of FCEVs and stations similar to California’s. The report’s three scenarios capture some of the variations that might occur as FCEV markets and HRS networks expand. In the Urban Markets scenario, FCEV markets are driven by a combination of consumer demand, market support mechanisms implemented by individual cities, and stakeholder focus on the most promising urban markets. The State Success scenario achieves a higher level of FCEV market adoption than does the Urban Markets scenario, with FCEV sales primarily driven by the ZEV mandate and other market support policies, which are complemented by strong stakeholder planning and coordination in ZEV states. The National Expansion scenario achieves the highest levels of FCEV adoption, with FCEV markets and HRS network development responding to consumer demand, strong market support mechanisms at city, state, and national levels, and aggressive stakeholder coordination and planning across economically integrated megaregions. These scenarios are not forecasts of future market outcomes. Rather, they provide insight to various public and private stakeholders engaged in the planning and coordination required to reduce HRS network investment risks. Early markets for alternative fuel vehicles are notoriously difficult to develop—these scenarios are meant to help stakeholders leverage and learn from California’s ongoing efforts to build momentum for national FCEV market growth.

Scenario results are presented for three periods: Early Markets (2015–2025), Expansion (2025–2035), and Long-Term Growth (2035–2050). Each period may be of interest to different stakeholders. Table 4 shows summary results by period for the following: number of FCEVs on the road, total HRSs, hydrogen demand, total HRS network capacity, network utilization, average station capacity, and population served.

Table 4. Summary of scenario results by period

Year	Scenario Characteristic	Urban Markets	State Success	National Expansion
2025	FCEV Stock	91,000	144,100	201,200
	Demand [kg/day]	63,800	102,100	143,400
	Total Stations	320	420	570
	Total Network Capacity [kg/day]	121,700	178,700	249,200
	Network Utilization	52%	57%	58%
	Ave. Station Capacity [kg/day]	380	420	440
	Population Enabled [millions]	8.7	10.9	14.4
2035	FCEV Stock	1,790,000	2,800,000	4,460,000
	Demand [kg/day]	1,020,000	1,590,000	2,530,000
	Total Stations	1,500	2,100	3,300
	Total Network Capacity [kg/day]	1,340,000	2,090,000	3,360,000
	Network Utilization	76%	76%	75%
	Ave. Station Capacity [kg/day]	890	1,000	1,010
	Population Enabled [millions]	37.9	45.2	56.8
2050	FCEV Stock	23,500,000	36,000,000	61,100,000
	Demand [kg/day]	9,200,000	14,200,000	24,000,000
	Total Stations	7,800	11,800	21,000
	Total Network Capacity [kg/day]	11,800,000	18,200,000	30,800,000
	Network Utilization	78%	78%	78%
	Ave. Station Capacity [kg/day]	1,520	1,540	1,470
	Population Enabled [millions]	103.0	125.8	214.8

The following conclusions and recommendations are supported by the scenario results:

- Robust networks of HRSs must be assured, and established in advance of selling large volumes of FCEVs into any given urban area.** Following the rollout of stations planned for California, the scenarios suggest that other urban areas would need to install a total of 320–570 stations nationwide to enable significant FCEV market growth by 2025. Intensive stakeholder coordination and planning activities must precede the introduction of these initial stations.
- There are multiple means of achieving FCEV market growth beyond California.** Although the ZEV mandate is a key market driver, high concentrations of early adopters in other cities and states—combined with track records of strong support for advanced vehicles—make many other urban and regional markets promising for FCEV sales and HRS investments.
- Large cities with high concentrations of early adopters and strong market support mechanisms are the most promising markets for introducing FCEVs and HRS networks.** With adequate market support mechanisms in place, these urban areas are the most promising options for rapidly achieving substantial hydrogen demand, thereby reducing the financial risk posed to HRS network investors.
- The market potential for HRS networks is large.** The scenarios portray a national network of approximately 1,500–3,300 hydrogen stations by 2035, with a hydrogen capacity of 1.3 million to 3.4 million kg/day serving 1.8 million to 4.5 million FCEVs. Assuming average hydrogen prices of \$8–\$10 per kg, annual revenues would be around \$3.0 billion to \$9.2 billion. The largest and most robust segments of these station networks would initially be located in a select number of large urban areas.

Appendix:

H₂USA Background and Locations Roadmap Working Group Membership

About H₂USA

H₂USA is a public-private partnership to promote the commercial introduction and widespread adoption of FCEVs across the United States by addressing hurdles to establishing hydrogen fueling infrastructure.

H₂USA contributes to:

- Establishing necessary hydrogen infrastructure and leveraging multiple energy sources for hydrogen production, including natural gas and renewables
- Deploying FCEVs across the United States
- Improving U.S. energy and economic security
- Reducing greenhouse gas emissions
- Developing domestic sources of clean energy and creating jobs in the United States
- Validating new technologies and creating a strong domestic supply base in the clean energy sector.

H₂USA Participants

H₂USA participants support the development of hydrogen infrastructure and deployment of FCEVs across the United States. Participants include the stakeholders indicated below. Organizations indicated with an asterisk have representatives on the Locations Roadmap Working Group.

- Applied Research Center: Hydrogen*
- Air Liquide*
- American Gas Association
- Argonne National Laboratory (ANL)*
- Baker Institute at the University of Tennessee, Knoxville*
- The Business Council for Sustainable Energy
- California Air Resources Board (CARB)*
- California Energy Commission (CEC)*
- California Fuel Cell Partnership (CaFCP)*
- Center for Advanced Research, South Carolina
- Christensen Consulting Group*
- Connecticut Center for Advanced Technology, Inc.*
- Daimler*
- Electric Drive Transportation Association (EDTA)
- Fiat Chrysler Automobiles (FCA)
- Fuel Cell & Hydrogen Energy Association (FCHEA)*
- General Motors (GM)
- Global Automakers*
- Hawaii Natural Energy Institute (HNEI)
- Honda R&D Americas*
- Hydrogenics*
- HydrogeNXT
- Hyundai*
- Idaho National Laboratory (INL)
- Intelligent Energy
- ITM Power
- Kalibrate*

- Kobelco
- Lawrence Berkeley National Laboratory (LBNL)
- The Linde Group
- Massachusetts Hydrogen Coalition*
- McPhy Energy
- Mercedes-Benz
- National Association of Convenience Stores (NACS)*
- National Renewable Energy Laboratory (NREL)*
- Nel*
- Nissan Technical Center North America*
- Northeast States for Coordinated Air Use Management (NESCAUM)*
- Oak Ridge National Laboratory (ORNL)
- Ohio Fuel Cell Coalition (OFCC)
- Pacific Northwest National Laboratory (PNNL)
- PDC Machines
- Plug Power
- Proton OnSite
- Sandia National Laboratories (SNL)*
- Savannah River National Laboratory (SRNL)
- SCRA Applied Technologies
- Toyota*
- U.S. Department of Energy (DOE)
- United Hydrogen*
- University of California, Irvine, National Fuel Cell Research Center*
- Volkswagen
- Wire Tough Cylinders, LLC
- Zero Carbon Energy Solutions*

**Representation on Locations Roadmap Working Group (LRWG)*

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National Hydrogen Scenarios

How many stations, where, and when?

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