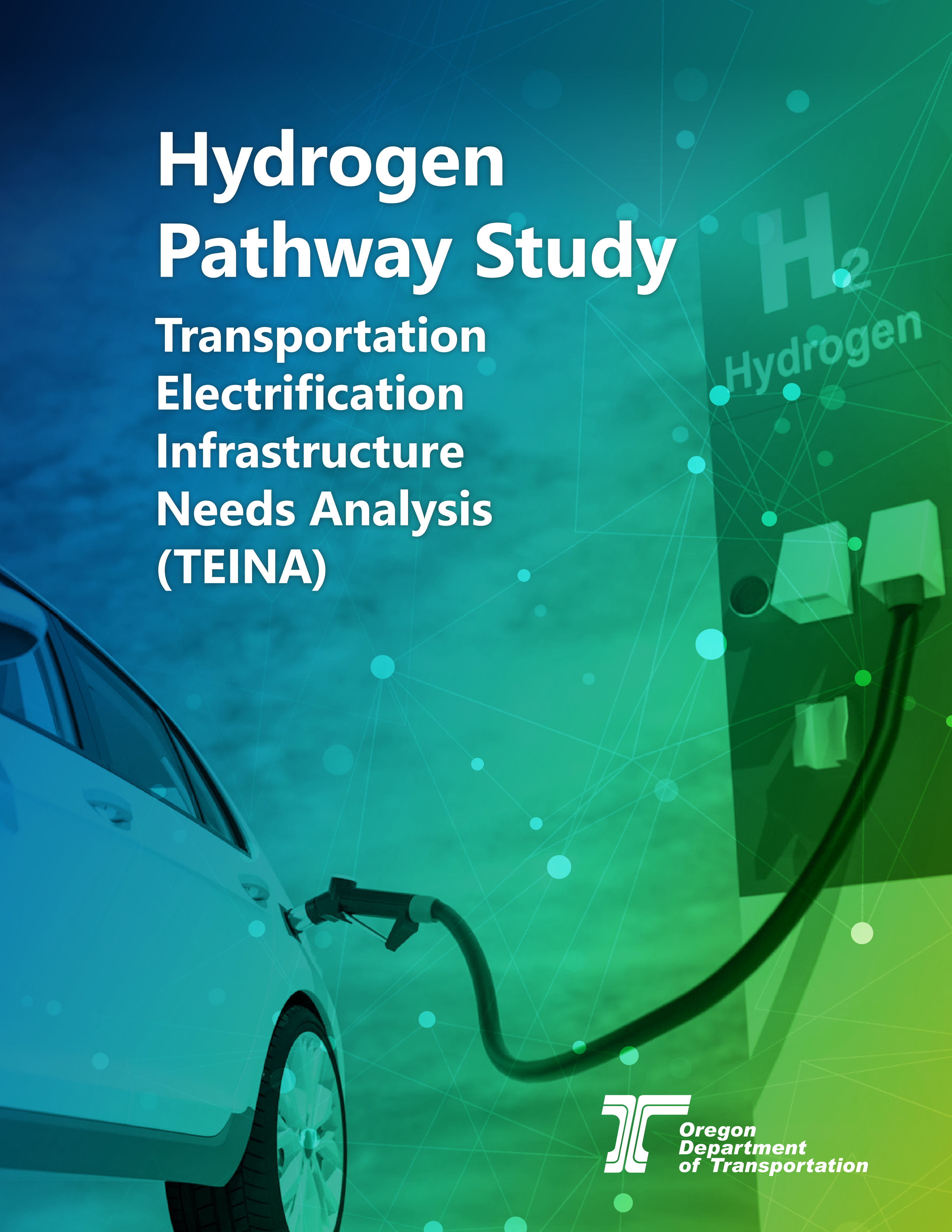
Hydrogen Pathway Study

Transportation Electrification Infrastructure Needs Analysis (TEINA)



Oregon Department of Transportation

Hydrogen Pathway Study

Transportation Electrification Infrastructure Needs Analysis (TEINA)

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Foreword

This report was produced by the Oregon Department of Transportation's Climate Office under the guidance and direction of Mary Brazell (Agency Project Manager), Suzanne Carlson (Climate Office Director), and Jillian DiMedio. The consultant project team that assisted the Climate Office in the production of this report included Wayne Kittelson (project manager) and Susan Mah, Kittelson & Associates (prime contractor); and Britta Gross and Aradhana Gahlaut, RMI. The project received additional feedback and suggestions from an Advisory Group consisting of Greg Alderson, Portland General Electric; Michael Graham, Columbia-Willamette Clean Cities Coalition; Nathan Hill and Diego Quevedo, Daimler Trucks; Whit Jamieson and Rhett Lawrence, Forth; Chris Kroeker, NW Natural; Victoria Paykar, Climate Solutions; Bill Peters, Department of Environmental Quality; Esther Pullido and Kate Hawley, Pacific Power; Evan Ramsey, Bonneville Environmental Foundation; Juan Serpa Munoz, Eugene Water & Electric Board; Jairaj Singh, Unite Oregon; Rebecca Smith, Oregon Department of Energy; and Martina Steinkusz, Renewable Hydrogen Alliance. The Oregon Department of Transportation and the consultant project team acknowledge with sincere appreciation the feedback and suggestions provided by the Advisory Group members while also noting that the members were not asked and have not formally endorsed the content of this Study.

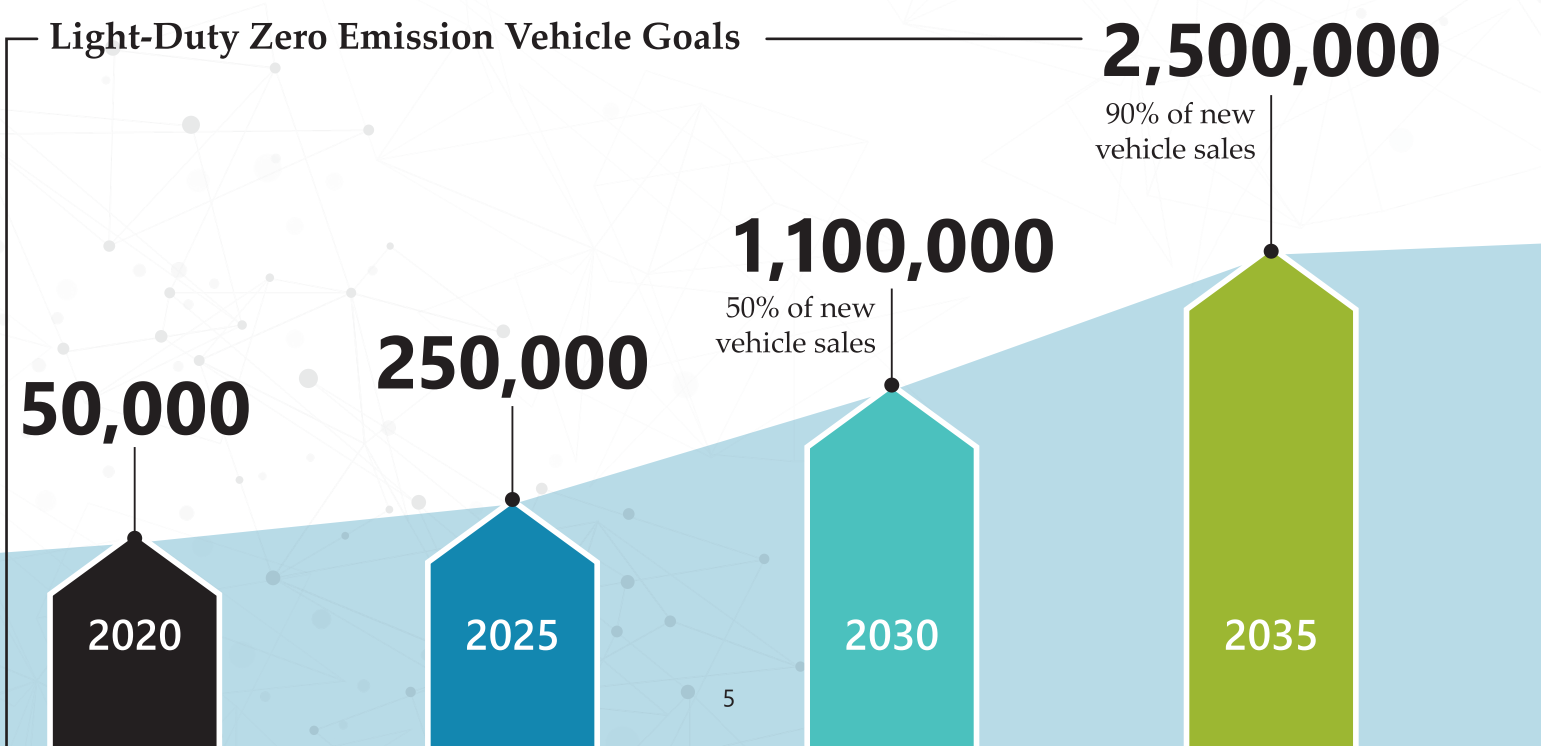
Executive Summary

Transitioning to electrically-powered vehicles can quickly reduce greenhouse gas (GHG) emissions from driving. Vehicles that are powered by electricity are referred to as zero-emission vehicles or ZEVs. ZEVs will play an important role in helping meet the GHG reduction targets in Oregon, where the transportation sector is responsible for nearly 40 percent of the state's GHG emissions.

The electricity used by ZEVs can be stored in batteries or generated in real time through the use of a fuel cell. A fuel cell electric vehicle, or FCEV, is a fully electric vehicle that generates its own electricity by combining oxygen from the air with hydrogen from an onboard storage tank, emitting only water vapor and heat from the vehicle. Both battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs) are viable technologies that have already reached the consumer market. The BEV market is currently much larger and more mature, but the FCEV market is growing and is becoming more cost-competitive as the industry scales. In addition to providing a zero-emission solution, fuel cell vehicle technology offers several key advantages, including longer driving range and quicker fueling times. These are increasingly attractive features when addressing the more challenging on-road mobility use cases such as long-haul trucking.

In support of electrically-powered vehicles and reduced GHG emissions, Oregon established a series of zero-emission vehicle adoption goals in Senate Bill 1044 as shown in **Figure 1**. These goals culminate with 90 percent of light-duty vehicle (LDV) sales within the state being ZEVs by 2035.

Figure 1. Light-Duty Zero Emission Vehicle goals established in Senate Bill 1044 (Oregon Department of Transportation, 2021)



In July 2021, the Oregon Department of Transportation (ODOT) released the Transportation Electrification Infrastructure Needs Analysis (TEINA), which quantified the charging infrastructure needed to achieve the goals set forth in Senate Bill 1044. The TEINA estimates were based on the assumption that the ZEV targets shown in **Figure 1** would be met entirely by battery electric technology. This Study considers an additional scenario in which a percentage of Oregon's ZEV sales are met by hydrogen fuel cell electric vehicles, and then assesses the fueling infrastructure needs to support this potential fleet of hydrogen cars, trucks and buses.

As in the earlier TEINA study, this focused look at hydrogen fueling needs assumes only a top-down state requirement. It does not reflect a bottom-up fleet needs assessment, nor an estimate of what is possible or likely to happen relative to transitioning to a hydrogen-based on-road mobility system. Thus, the implementation timeline presented in this Study could be quite different from what occurs, including a significant acceleration due to external factors. For example, more concerted hydrogen-related efforts of federal, state, or local governments could accelerate the projected timeline, as could a more rapid development of the zero-emission interests and needs of industry and fleets.

The goal of this Study is to inform future efforts in Oregon by providing an overview of current hydrogen activities in the light-duty, medium-duty, and heavy-duty transportation sectors today; the requirements and estimated capital costs of building out a hydrogen fueling station network to meet state goals; and recommendations that Oregon might consider to support an evolving hydrogen market going forward. As in the earlier TEINA study, upstream hydrogen production and delivery, though a critical consideration in developing an overall hydrogen strategy, is not addressed in this study. The Oregon Department of Energy (ODOE) is currently conducting a parallel study, due to the state legislature by September 2022, of the benefits and barriers to the production and consumption of renewable hydrogen in Oregon.

This Study found a supportive policy landscape in Oregon, where hydrogen and fuel cell vehicles are recognized in state goals, clean vehicle rebates and clean fuels credit programs. There is broad stakeholder interest in locally and renewably produced hydrogen. There is also growing fleet and utility interest in opportunities and potential solutions offered by both hydrogen and fuel cell electric vehicles. Among other activities in Oregon, this Study describes the hydrogen-related efforts of the Portland area transit system (TriMet), Eugene Water & Electric Board (EWEB), and Daimler Trucks North America. Fleet operators seem to be coalescing around a common interest in finding zero-emission solutions to the more challenging on-road mobility use cases, including longer transit bus routes, fleets with continuous 24/7 operations, and long-haul trucking. Where battery technology today can quite easily solve most mobility needs, these challenging scenarios are causing fleets to investigate potential hydrogen fuel cell solutions.

As in the original TEINA study, the targets for light-duty vehicles (LDV) are based on the state's SB 1044 goals - adjusted to assume that FCEVs make up 5% of urban LDV ZEVs in 2035. Since SB 1044 does not, however, provide state targets for transit buses, medium-duty or heavy-duty vehicles, this Study has adopted the same methodology used in the original TEINA study for projecting ZEVs for these additional use cases to ensure a consistent approach. This Study assumes 10% of the ZEV buses in TEINA are fuel cell buses, and it assumes 10% of all medium-duty truck electric vehicle miles traveled (e-VMT) and 25% of all heavy-duty truck e-VMT is met by hydrogen fuel cell electric trucks. The 2035 targets assumed by use case are summarized in **Table 1.**

Table 1. 2035 FCEV Target Assumptions by Use Case

Use Case	Target Assumptions
Light-Duty Vehicles	5% of urban light-duty ZEVs are FCEVs
Transit Buses	10% of TEINA e-buses are FCEVs
Medium-Duty Vehicles	10% of medium-duty TEINA e-VMT are FCEVs
Heavy-Duty Vehicles	25% of heavy-duty TEINA e-VMT are FCEVs

Note: The LDV Highway Corridor use case is a function of the daily traffic of the LDV use case.

This target-driven analysis determined that 47 public hydrogen fueling stations would be required in 2035 to serve hydrogen vehicles in the light-duty vehicle sector. An additional 19 fueling stations would be required to serve medium-duty and heavy-duty vehicles, including both transit buses and the additional demand from Washington and California's Class 8[1] hydrogen trucks that travel across Oregon's highway system. The capital cost of establishing this network is estimated at $232.5 million.

Table 2. H_2 Fueling Station Infrastructure Costs (Cumulative)

		2025		2030		2035		
Use Case	Assumed Capital Cost/ Station	# Stations	Total Capital Cost	# Stations	Total Capital Cost	# Stations	Total Capital Cost	Assumed Capacity
Light-Duty Vehicles: Urban	$1.9M	0	0	1	$2M	33	$63M	1,500kg
Light-Duty Vehicles: Corridor	$1.9M	6	$11M	7	$13M	14	$27M	1,500kg
Total Light-Duty Vehicles		*6*	*$11M*	*8*	*$15M*	*47*	*$90M*	
Medium-Duty Vehicles	$7.5M	0	0	1	$7.5M	8	$60M	5,000kg
Heavy-Duty Vehicles	$7.5M	0	0	1	$7.5M	6	$45M	5,000kg
Transit Buses	$7.5M	0	0	1	$7.5M	5	$37.5M	5,000kg
Total Medium-and Heavy-Duty Vehicles		*0*	*0*	*3*	*$22.5M*	*19*	*$142.5M*	
Capital Costs Total			**$11M**		**$37.5M**		**$232.5M**	

1 *A "Class 8" truck is a Heavy-Duty truck with a Gross Vehicle Weight Rating (GVWR) of 33,001 pounds or more.*

The modeling performed for this Study has assumed a relatively slow startup to FCEV deployments in Oregon in the pre-2025 timeframe due to several factors: the lack of current FCEV product availability across sectors; the constrained hydrogen vehicle production capacity of automakers; and the limited geographic areas of FCEV deployment (e.g. automakers are currently focused on California). Beyond 2025, FCEV ramp-up curve an exponential growth curve to meet 2035 targets. Although these targets may appear conservative, the lead time necessary to install five public hydrogen fueling stations by 2025 would require preparatory activities to begin very soon. Furthermore, the availability of hydrogen fueling infrastructure is an important prerequisite to developing the fuel cell vehicle market in the first place. These factors, combined with others discussed in this Study, can significantly influence the pace of FCEV adoption and the broader use of hydrogen across the state and region.

This Study recommends a phased approach to actions that can be taken in the near-term (2022-2023), mid-term (2024-2027), and the longer-term (2028-2035). These actions will establish a collaborative relationship between Oregon's state agencies and other leading public and private stakeholders that is key to understanding the evolving market needs. Given the rapidly growing need to transition to a zero-emission economy, this Study also suggests the leading market indicators to watch for critical signs that the fuel cell vehicle market is evolving sooner or more rapidly than is projected in this analysis. This awareness will allow Oregon to more effectively plan for a future hydrogen fuel cell vehicle market.

Table 3. Study Recommendations

	Near-term (2022-2023)	**Mid-term** (2024-2027)	**Longer-term** (2028-2035)
KEY ACTIONS	• Assess hydrogen market regularly and coordinate interests • Engage with regional stakeholders • Support industry-led technology demonstrations and pilot projects • Support policies enabling FCEVs and local, low or zero-carbon hydrogen production • Ensure statewide regulations and processes enable FCEVs and hydrogen fueling infrastructure siting	• Establish a statewide hydrogen planning effort • Coordinate fleet interests in hydrogen • Coordinate a regional corridor • Develop and invest in pilot projects • Consider establishing targets • Pursue federal funding opportunities	• Continue to leverage the statewide hydrogen planning effort • Continue to support regional coordination • Transition from pilot projects to scale • Establish a consumer and fleet awareness program

WATCH FOR
(Leading Indicators)

Commercial fleet activity – interest in pilots, FCEV purchase announcements	**OEM activity –** expanding FCEV production and geographical footprint	**California activity –** heavy-duty highway corridor investments encouraging interstate travel	**Fueling provider activity –** station network announcements, investments, fueling/ fleet/OEM partnerships	**H_2 production activity –** utility engagement, ramp-up in local hydrogen production, improving H_2 economics	**Federal policy –** major funding commitments, stricter heavy-duty emission standards

Introduction

In Oregon, much like nationally, the transportation sector is the largest source of greenhouse gas (GHG) emissions, comprising 40% of emissions. To avoid the worst impacts of climate change and meet the state climate goal of an 80% reduction of GHG emissions by 2050, the rapid electrification of Oregon's transportation sector is vital.[2] In March 2020, Governor Brown signed Executive Order 20-04, directing 19 state agencies to implement sweeping actions to combat climate change. Transportation electrification features prominently in the order, including long-term planning for electric vehicle charging infrastructure through ODOT's Transportation Electrification Infrastructure Needs Analysis (TEINA), released in July 2021. This report assessed the charging infrastructure required to meet the state's zero emission vehicle (ZEV) adoption goals established in Senate Bill 1044 – namely, that light-duty ZEVs represent 90% of new car sales by 2035. TEINA assumed that Oregon's ZEV targets would be met by battery electric vehicle technology. This study considers an additional scenario whereby a percentage of ZEV sales across the light-, medium- and heavy-duty sectors are met by hydrogen fuel cell electric vehicles (FCEVs) and assesses the fueling infrastructure needs to support this potential fleet of hydrogen cars, trucks and buses in Oregon.

As in the original TEINA study, this focused look at hydrogen fueling needs assumes a top-down requirement that hydrogen fuel cell vehicles meet a portion of the state's ZEV goals by 2035. It does not reflect a bottom-up fleet needs assessment, nor an estimate of what is likely to happen relative to transitioning to a hydrogen-based on-road mobility system. The goal of this paper is to inform hydrogen infrastructure development efforts in Oregon by providing an overview of hydrogen activities in the light-, medium-, and heavy-duty transportation sector today, the requirements and estimated costs of building out a hydrogen fueling station network to support the modeled FCEV scenarios, and recommendations in the short, medium and long term that Oregon might consider to support an evolving hydrogen market going forward. As in the earlier TEINA study, upstream hydrogen production and delivery, though a critical consideration in developing an overall hydrogen strategy, is not specifically addressed here.

This paper reflects analysis and scenario modeling performed by RMI. The hydrogen and fuel cell vehicle landscape analysis, fueling considerations and costs, and recommendations have been informed through academic and government literature research, industry-provided literature and interviews with hydrogen stakeholders across the government, industry and non-profit sectors.

This Study is composed of six sections:

1 Hydrogen Activity Landscape

2 Current FCEV Product Inventory

3 FCEV Modeling and Analysis

4 FCEV Fueling Needs and Costs

5 Special Considerations

6 Recommendations

2 *Oregon's climate goals, originally established in 2007 by House Bill 3543, were updated by Governor Brown through Executive Order 20-04 and include: GHG emissions reduction of 45% below 1990 levels by 2035 and GHG emissions reductions of 80% below 1990 levels by 2050.*

Section 1: Hydrogen Activity Landscape

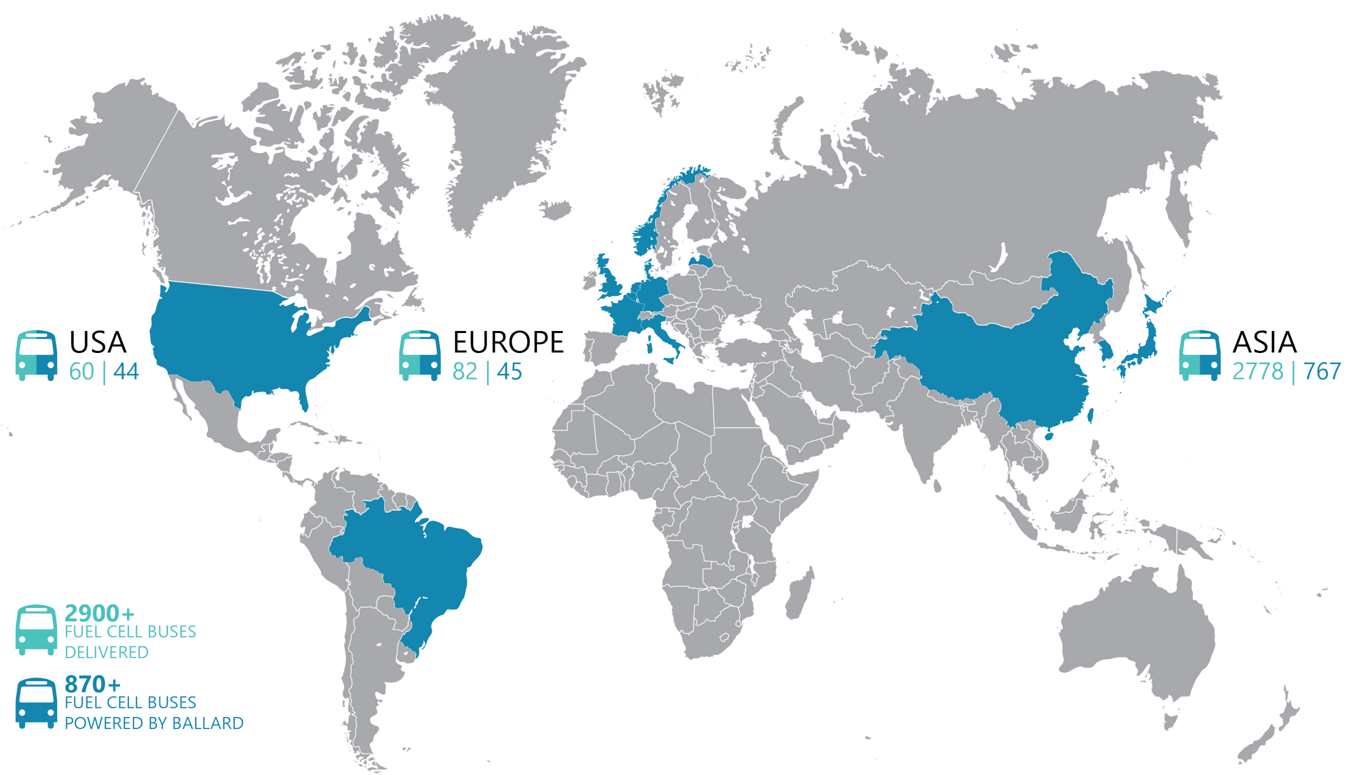
This section provides an overview of the major ongoing and planned hydrogen-related activities of interest to Oregon across the light-, medium-, and heavy-duty vehicle sectors. Following a brief overview of the global trends, there is a more comprehensive look at efforts in North America. In the U.S., California has developed the broadest portfolio of policies and hydrogen initiatives and offers the largest hydrogen fueling station network. Beyond California's leading efforts, there is growing interest in hydrogen in North America, most notably in Washington, Oregon, British Columbia, and the Northeast United States. This section aims to focus on the policies and activities most responsible for driving progress towards a robust hydrogen fuel cell vehicle market.

GLOBAL LANDSCAPE

Globally, there is increasing hydrogen fuel cell vehicle activity in Europe, Japan, South Korea, and China, particularly in the area of commercial trucks and buses. According to a white paper from EVTank, (Zang, 2021), at the end of 2020 there were 578 public and private hydrogen refueling stations operating globally: 200 refueling stations in Europe (100 in Germany), 142 in Japan, 60 in South Korea, 101 in China (primarily serving buses and trucks), and 75 in North America. EVTank projects that the number of hydrogen fueling stations in China will exceed 1,000 by 2025 and 5,000 by 2035. Shanghai alone plans to have 100 hydrogen refueling stations by 2023 and Beijing plans to have 74 stations by 2025. The European Green Deal captures Europe's commitment to investments in a hydrogen economy, targeting 6 GW of electrolyzer capacity by 2024 (producing up to 1 million tons/yr of renewable hydrogen) and 40 GW of capacity by 2030. Further evidence of the growing global attention on hydrogen is provided by the Hydrogen Council (a global hydrogen industry coalition), which finds that 18 governments (70 per cent of global GDP), "have developed detailed strategies for deploying hydrogen energy solutions" (Hydrogen Council, 2020).

Hydrogen activity across public transit fleets is particularly robust and growing. As displayed in **Figure 2** below, there are currently close to 6,000 hydrogen fuel cell buses in operation around the world (California Fuel Cell Partnership, Undated).

Figure 2. Fuel Cell Buses Worldwide

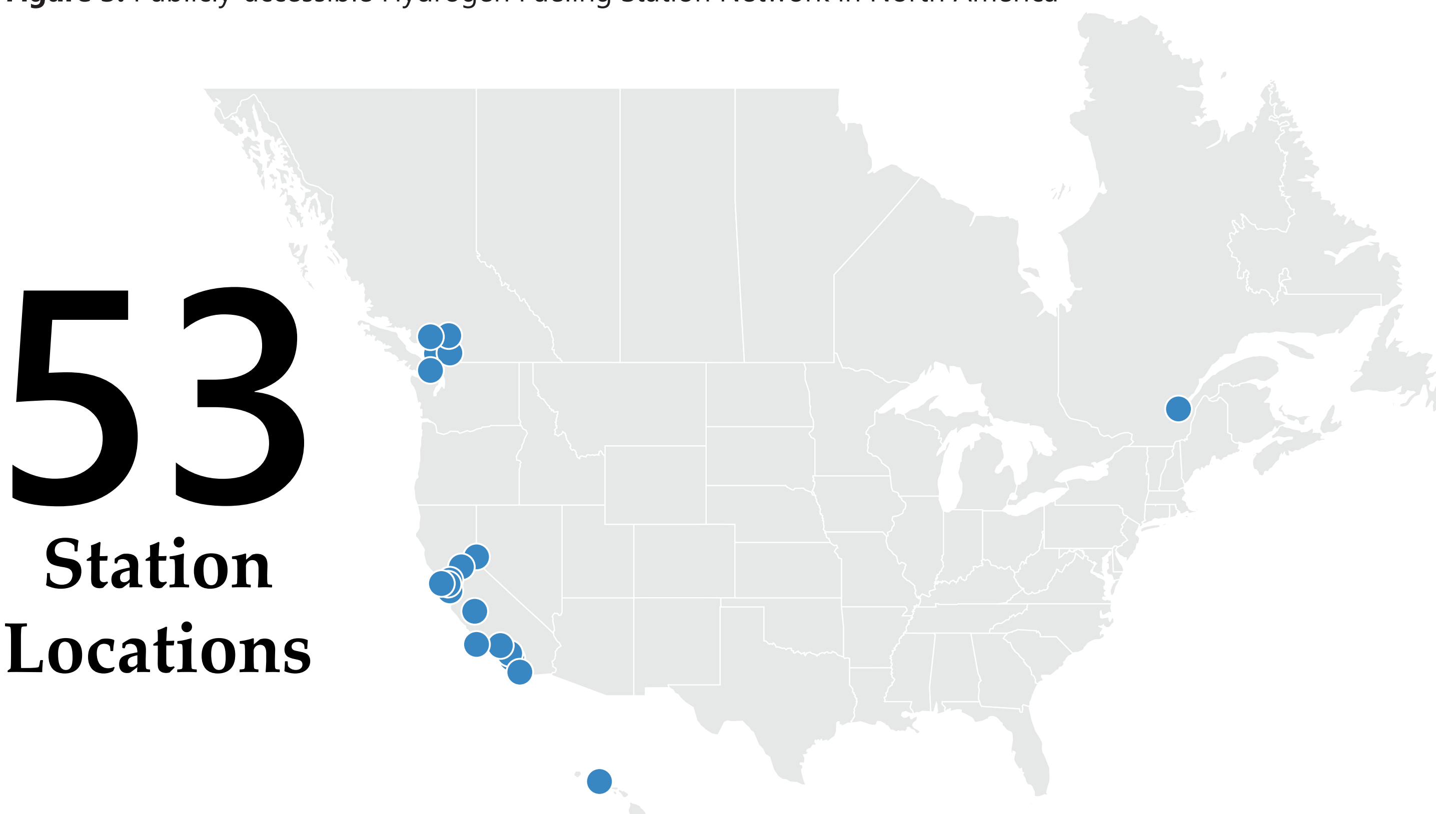


NORTH AMERICAN LANDSCAPE

Fuel cell electric vehicles (FCEVs) have been commercially available in California since 2015. This commercial deployment of FCEVs from Toyota, Honda, and Hyundai followed more than a decade of intensive FCEV technology development by the world's leading automakers that included a large number of demonstration and pilot projects, including a sustained effort by the U.S. Department of Energy. Fuel cell technology in transit buses evolved simultaneously through numerous pilot projects. Meanwhile, battery vehicle technology was quickly advancing and costs rapidly declining. To many stakeholders, this presented a clearer, near-term path to zero-emission vehicles – as evidenced by the quickly expanding U.S. battery electric vehicle market. Battery technology is well-suited to the performance requirements of most vehicles – particularly lighter vehicles and vehicles with shorter driving range needs. However, hydrogen FCEVs provide another pathway to zero-emission vehicles and fuel cell technology offers several key performance advantages, including longer driving range, less sensitivity to cold temperatures, and quicker fueling times. These are important considerations, particularly when addressing the most challenging on-road mobility use cases such as long-haul trucking and longer transit routes. This potential to serve as a zero-emission solution across the transportation sector, including for the most challenging use cases, has resulted in a sustained interest in hydrogen fuel cell vehicle technology. As such, FCEV pilots are increasingly common, especially in regions that are pursuing climate commitments.

Across the U.S., an examination of existing publicly-accessible hydrogen stations demonstrates California's leadership in deploying an increasingly robust hydrogen fueling network. According to the Department of Energy's Alternative Fuel Data Center's Station Locator (United States Department of Energy, 2021), there are currently 53 publicly operating hydrogen fueling stations in North America (**Figure 3**) - 47 are located in California, one in Hawaii, and five in Canada (four in Vancouver/ Victoria; one in Quebec). All stations support light-duty hydrogen fuel cell electric vehicles. There are additional behind-the-fence stations supporting private light-duty vehicle fleets, buses, trucks, and forklifts – and some of these key efforts will be discussed later in this section.

Figure 3. Publicly-accessible Hydrogen Fueling Station Network in North America



CALIFORNIA

As of October 2021, there were 11,674 fuel cell vehicles sold or leased in the U.S. (California Fuel Cell Partnership, 2021). Of these, the California Air Resources Board (CARB) estimates approximately 8,000 are active on California's roads. According to the EV Sales Dashboard provided by the Alliance for Automotive Innovation (Alliance for Automotive Innovation, 2021), following several years of cautious, yet steady, FCEV sales in California, there was an increase in year-over-year sales in the first three quarters of 2021 (**Figure 4**). This can be perhaps partly explained by pent-up demand for FCEVs (and EVs in general) following sales decreases during COVID-19, but there is certainly a growing interest across consumers and fleet operators in zero-emission vehicle choices.

There are also 48 fuel cell buses operating in California and another 58 buses in development.

Supporting all these vehicles are:

- 52 hydrogen fueling stations, 47 of which are available to the public, with another 127 retail hydrogen fueling stations in some stage of development
- Four retail truck fueling stations in construction and five additional stations funded, but not yet in development
- At least three behind-the-fence fueling stations for transit bus fleets

California is expected to have more than 176 open-retail hydrogen fueling stations by 2026 (California Air Resources Board, 2021). **Figure 5** shows California's current open-retail hydrogen fueling station network (United States Department of Energy, 2021).

California's efforts to drive towards a zero-emission transportation system are notable not only because of the sizable funding committed to advancing public-private efforts, but also due to the sheer magnitude of legislative, regulatory, incentive, procedural and structural efforts to advance the transition.

Figure 4. Annual FCEV Sales in California through September 2021

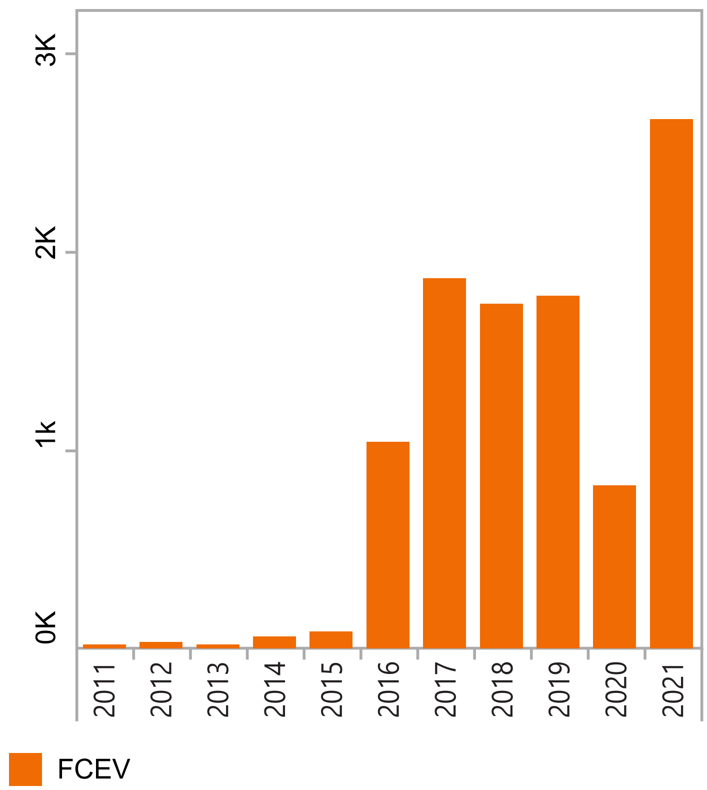


Figure 5. Open-retail Hydrogen Fueling Stations Currently Operating in California

Hydrogen-supportive legislation and policies in California

California has established a wide portfolio of legislation and programs designed to promote and fund the transition of on-road vehicles to battery and fuel cell electric. The primary policies encouraging hydrogen fuel cell vehicle and fueling station growth are highlighted below.[3]

- **Assembly Bill 8 (AB 8)/CARB's Annual AB 8 Report** – AB 8 is the State's longest-running program to support hydrogen fueling station network development, enabling the deployment of light-duty FCEVs. As part of this provision, CARB must complete an annual analysis of the current progress and projected future development of California's hydrogen fueling station network required to encourage the growth of the fuel cell vehicle market. CARB issues an annual report to the California Energy Commission (CEC) that includes the number of stations, geographic areas where stations are needed, and minimum operating standards, such as number of dispensers and filling pressures. Based on the number of hydrogen fueling stations deemed necessary in CARB's AB 8 report, the CEC is then authorized, through its Clean Transportation Program, to spend $20 million per year to fund up to 100 retail hydrogen fueling stations. The program is authorized through January 1, 2024.

- **Hydrogen Refueling Infrastructure (HRI) provision** – in 2019, in addition to increasing the state target to 200 hydrogen stations by 2025, the HRI crediting provision was established in the Low Carbon Fuel Standard (LCFS) program to support early hydrogen fueling network development. An important aspect of this LCFS provision is that it provides credits based on the capacity of the station rather than on the amount of hydrogen dispensed. This is especially important in the early years of the network when there are fewer fuel cell vehicles to take up station capacity.

- **Zero-Emission Transit Bus Requirement** – By 2040, all public transit agencies must transition to 100% zero-emission bus fleets, including battery electric or fuel cell electric technologies.

- **Renewable Hydrogen Requirement** – California Senate Bill 1505 first established a renewable content requirement of 33.3 percent for all hydrogen fueling stations receiving State funding. The LCFS program's HRI provision, passed later, increased the requirement to a minimum 40 percent renewable requirement for stations participating in the program. The CEC's latest grant funding solicitation (GFO-19-602), which provides the necessary funding to complete the 100-station commitment under AB 8, also adopted the 40 percent minimum requirement.

- **EnergIIZE Commercial Vehicles (Energy Infrastructure Incentives for Zero-Emission Commercial Vehicles)** – the California Energy Commission has established a $50 million multi-year project (referenced as the CEC EnergIIZE Project) to develop a concierge-like model to provide public and private truck and bus fleet operators with technical and financial assistance as they plan their charging and hydrogen refueling infrastructure needs.

- **California Fuel Cell Partnership (CaFCP)** – This is a government/industry collaboration founded in 1999 and aimed at expanding the market for hydrogen fuel cell electric vehicles. Staff from member organizations (including automakers, hydrogen fuel and infrastructure providers) participate on standing committees and project teams to help ensure that vehicles, stations, regulations and people are in step with each other as the market grows.

3 The Alternative Fuel Data Center (AFDC) is one of the primary sources for the state policies listed in this and the following state sections, and readers are encouraged to refer to the more comprehensive list (United States Department of Energy, 2021).

Current and announced hydrogen projects in California

In addition to the buildout of California's hydrogen station network to support its growing light-duty vehicle market, California is also accelerating efforts to develop the hydrogen fuel cell electric truck and bus markets. Highlights of key truck and bus projects in California include the following:

California Truck Programs

- **NorCAL ZERO project** – a consortium of partners, including First Element and Hyundai, have been awarded grants from CARB, CEC, the Alameda County Transportation Commission and the Bay Area Air Quality Management District to deploy 30 heavy-duty Hyundai XCIENT fuel cell electric trucks and deploy a high-capacity hydrogen fueling station adjacent to the Port of Oakland (The Center for Transportation and the Environment, 2021). Glovis America, a logistics service provider, will be the fleet operator of these trucks that will service the entire northern California region. The station will be capable of supporting up to 50 Class 8 trucks and back-to-back fueling.

- **Shore to Store (S2S) project** – Five Class 8 fuel cell electric drayage trucks and two hydrogen fueling stations are now operating at the Ports of Los Angeles and Long Beach under the $41 million Zero and Near Zero Emissions Freight Forwarding (ZANZEFF) project sponsored by the state of California. The project will be expanded over time to include another five hydrogen-fueled trucks. The Kenworth T680 Class 8 trucks are powered by a Toyota fuel cell electric drivetrain. Fleet operators participating in this project include Toyota Logistics Services, Southern Counties Express, UPS and Total Transportation Services. Shell is building two heavy-duty hydrogen fueling stations in Wilmington and Ontario to support the ZANZEFF Shore to Store project (The Port of Los Angeles, 2018), (The Port of Los Angeles, Undated Fact Sheet).

- **Southern California Pilot** – Hyundai Motor was awarded a $500,000 grant from the South Coast Air Quality Management District (with additional funding provided by the U.S. Environmental Protection Agency) to demonstrate two Class 8 Xcient Fuel Cell heavy-duty trucks, used for long-haul freight operations between warehouses in Southern California, for a 12-month period.

- **Nikola and TravelCenters of America** – This partnership announced tentative plans to co-develop heavy-duty hydrogen fueling stations at two existing Southern California sites by Q1 2023. Stations are intended to be available to any truck customer and will use a common industry standard for heavy-duty truck fueling (Nikola, 2021).

California Bus Programs

There are currently 48 hydrogen fuel cell electric buses operating across four bus fleets in California:

- **AC Transit (Alameda Contra Costa Transit District)** – AC Transit in the San Francisco Bay Area currently operates 21 hydrogen fuel cell-electric buses. They also operate two hydrogen stations in Emeryville and Oakland, which are capable of fueling 65 buses and 13 buses back-to-back, respectively. AC Transit continues to expand its hydrogen fleet, recently ordering an additional 20 Xcelsior CHARGE H_2 fuel cell electric buses from NFI's New Flyer (AC Transit, 2021).

- **Orange County Transportation Authority (OCTA)** – OCTA operates 10 hydrogen fuel-cell electric buses and the "largest transit-operated hydrogen fueling station in the United States", with the ability to fuel 40-50 buses (scalable to 100). This $22.9 million program follows an earlier fuel cell bus pilot program at OCTA (Orange County Transportation Authority, 2021).

- **SunLine Transit Agency** – the Palm Springs area transit agency currently operates 16 hydrogen fuel cell 40' electric buses – 11 El Dorado National Axess buses and five New Flyer Xcelsior XHE40 buses. SunLine aims to build its fleet entirely of hydrogen fuel cell buses (SunLine Transit Agency, Undated).

- **UC Irvine** – operates one hydrogen fuel cell electric bus on campus.

California/West-Coast Renewable Hydrogen Production Developments

- **Western States Hydrogen Alliance (WSHA)** – formed in 2020, WSHA is an industry alliance focused on advocating for policies supporting hydrogen fuel cell vehicles in medium- and heavy-duty applications.

- **Plug Power** – Plug Power is planning to build a liquid hydrogen facility in Fresno County, California, capable of producing 30 metric tons of liquid green hydrogen daily and serving West Coast customers. The facility will use a new 300 megawatt solar farm to power a 120 megawatt electrolyzer, and plans to begin operations in early 2024. (Plug Power, 2021)

- **Air Liquide** – is investing $200 million to build a renewable liquid hydrogen plant in North Las Vegas, capable of producing 30 tons of liquid hydrogen per day – the equivalent of fueling 42,000 Fuel Cell Electric Vehicles (FCEVs) on the West Coast. The plant is expected to serve the complete range of zero emission vehicles (ZEVs). (Air Liquide, 2020)

WASHINGTON

Hydrogen-supportive legislation in Washington

In general, the ZEV policies and incentives in the Washington are technology-neutral and apply equally to battery electric and fuel cell electric vehicles.

- **Green Transportation Grant Program** – The Washington State Department of Transportation (WSDOT) offers grants for projects that reduce the carbon intensity of the Washington transportation system, including the transition to a hydrogen fuel cell vehicle fleet, modification or replacement of facilities for hydrogen fueling, and the construction of hydrogen fueling infrastructure.

- **Alternative Fueling Infrastructure Grant Program** – WSDOT offers competitive grants to strengthen and expand the West Coast Electric Highway network, including hydrogen fueling infrastructure along highway corridors.

- **Fuel Cell Electric Vehicle and Infrastructure Tax Credit** – the state sales and use taxes do not apply to FCEV batteries, fuel cells and related infrastructure investments.

- **Senate Bill 5588 (2019)** – authorized the production, distribution and sale of renewable hydrogen by public utility districts (PUDs)

- **Senate Bill 5000 (2021)** – establishes an eight-year statewide pilot project for the reduction of sales tax on purchases of FCEVs (extending a similar exemption on vehicle sales tax that purchasers of battery EVs receive). Beginning July 1, 2022, 50% of the retail sales and state use tax of 6.5% does not apply to the sale or lease of the first 650 new FCEV passenger vehicles, light-duty trucks, and medium-duty passenger vehicles powered by fuel cells. Additionally, all used FCEV sales and leases are exempt from the tax.

- **Tacoma Power Electrofuel Tariff** – the nation's first pilot rate of a lower cost tariff to support the production of electrofuels, such as the production of hydrogen from carbon-free electricity, which can be used to store electricity for later use.

- **Climate bills** – Washington recently passed two separate climate bills that may influence hydrogen activities: the "Climate Commitment Act" (SB 5126), a Cap/Trade & Invest bill that places a price on carbon; and the "Clean Fuels Bill" (HB 1091) that progressively reduces the carbon content of fuels and rewards carbon reductions with tradable credits. Both programs are expected to generate revenue to fund enhancements to the existing transportation system and will become effective in January 2023 following a rule-making process.

Current and announced hydrogen projects in Washington

While there are no existing retail fuel stations and no commitments from automakers to deploy FCEVs in Washington, there is growing interest in hydrogen production and hydrogen fuel cell vehicles. Several of the potentially more impactful hydrogen activities currently being planned, include:

- **Douglas County PUD** – a pilot project to build a 5MW electrolyzer that will leverage the Wells Hydroelectric Project and support renewable hydrogen production near Baker Flats, East Wenatchee. Douglas County PUD will be the first county-owned public utility in the state to produce its own hydrogen as a result of SB 5588. Production of renewable hydrogen was expected in late 2021.

- **Chehalis Hydrogen Fueling Station** – the first hydrogen fueling station in Washington state will be built with a combined $4.45 million in grants from the Centralia Coal Transition Board and the state Legislature's supplemental capital budget. Project partners include the Bonneville Environmental Foundation (BEF), the Douglas County PUD, the Renewable Hydrogen Alliance and Toyota Motor North America. Additionally, in a memorandum of understanding between the Port of Chehalis and Twin Transit, the hydrogen fueling station may be located on port property, potentially at a site located just off I-5. The station is expected to be completed within the next year and will support personal and heavy-duty vehicles, including a small fleet of Twin Transit hydrogen fuel cell buses expected in 2023.

- **Washington Maritime Blue** – is leading a Greater Pacific Northwest regional consortium of public and private stakeholders to leverage the region's green energy resources to transform the region into a global hub for green hydrogen technology, including the production and use of hydrogen in heavy-duty applications such as maritime shipping, in drayage fleets at ports, in long-haul trucking fleets, and in public transit fleets, as well as for aerospace and stationary uses.

- **Puget Sound Energy and Mitsubishi Power** – a joint development agreement to collaborate on the implementation of large-scale, carbon-free renewable generation and storage, including green hydrogen production, storage assets, and transportation facilities (building on Mitsubishi Power and Magnum Development's grid-scale green hydrogen storage project introduced in May 2019 in Delta, Utah)

- **PACCAR of Bellevue, WA** is a recent recipient of the U.S. DOE's Supertruck 3 program. This $33 million award will fund the development of 18 Class-8 heavy-duty battery electric and fuel cell vehicles (United States Department of Energy, 2021).

BRITISH COLUMBIA, CANADA

British Columbia is the "first province in Canada to release a comprehensive hydrogen strategy" and as such rounds out the Pacific Northwest as a region of important hydrogen activity. Of special note:

- **B.C. Hydrogen Strategy –** The Government of British Columbia released its B.C. Hydrogen Strategy, "A sustainable pathway for B.C.'s energy transition" in July 2021 (Government of British Columbia, 2021). The plan provides "a blueprint for how renewable and low-carbon hydrogen will support its climate goals and create new jobs in B.C.'s growing clean-tech sector."

- **B.C. Hydrogen Strategy Actions –** Part of CleanBC, the B.C. Hydrogen Strategy "includes 63 actions for government, industry and innovators to undertake during the short term (2020-25), medium term (2025-30) and long term (2030 and beyond). The strategy's immediate priorities include scaling up production of renewable hydrogen, establishing regional hydrogen hubs and deploying medium- and heavy-duty fuel-cell vehicles."

- **Hydrogen BC –** is the regional branch of the Canadian Hydrogen and Fuel Cell Association (CHFCA) in British Columbia. "Established with the support of the BC Government, Hydrogen BC is comprised of a public-private partnership with the mandate to promote the rollout of fuel cell electric vehicles (FCEVs) and hydrogen fueling stations (HFS) in the province."

NORTHEAST STATES

The Northeast is another region of hydrogen interest and activity. Though there are no large deployments of fuel cell vehicles in this region, there has been progress on establishing a hydrogen fueling station network to support this anticipated vehicle market. Furthermore, there have been efforts to ensure a renewable source of hydrogen for the region; for example, all the hydrogen at Air Liquide retail-facing stations is 100% renewable (hydroelectric). As in other regions, many utilities in the Northeast are engaged in hydrogen in some capacity. As for policies, state EV rebates and incentives are generally neutral and apply equally to battery electric and fuel cell electric vehicles. A few additional noteworthy policies and activities are noted below.

Hydrogen-supportive legislation in the Northeast States

- **CT Zero Emission Bus Implementation Plan** – The Connecticut Department of Transportation (CTDOT), in consultation with the Connecticut Center for Advanced Technology, developed the Connecticut Hydrogen and Fuel Cell Deployment Transportation Strategy: 2011-2050 to identify strategies to expand the availability and use of hydrogen fuel and renewable energy sources. The strategy includes a plan to implement zero emission buses on a statewide basis, including the identification of specific locations for hydrogen fueling stations along state highways and other locations.

Current and announced hydrogen projects in the Northeast States

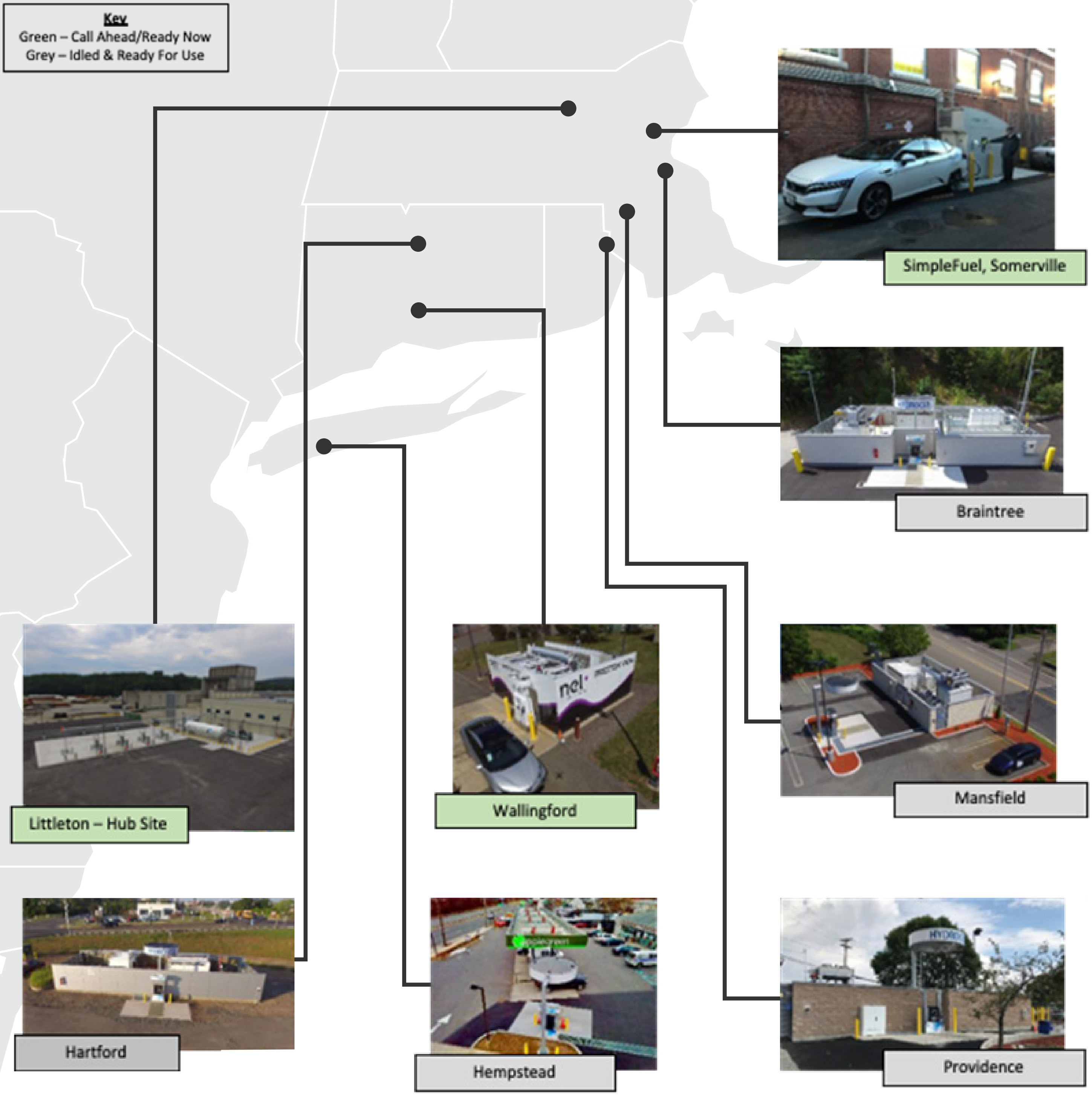
- **CT/MA/NY/RI Hydrogen Fueling Stations** – as shown **Figure 6** below, there are eight hydrogen sites capable of supporting vehicle fueling in this region - three are currently call-ahead-and-reserve stations and five are idled (but operationally ready) while waiting for auto and truck makers to begin deploying fuel cell vehicles into the Northeast market. Several additional sites are being actively surveyed. The region has been working with automakers to begin retail deployment of vehicles, which some believe hinges on a long-awaited regulation change from the Massachusetts Department of Transportation to allow hydrogen fuel cell vehicles to travel through Boston's tunnel system. This change is expected to occur in early 2022.

- **Air Liquide Electrolyzer** – is completing the installation of a 20MW Proton Exchange Membrane (PEM) electrolyzer at its existing hydrogen production facility in Becancour, Quebec, which will be the world's largest PEM electrolyzer in operation. The facility uses hydro-electricity — a renewable power — and is expected to provide green hydrogen to support the Northeast mobility and industry markets.

- **Hydrogen Forklifts** – There is a growing deployment of hydrogen fuel cell forklifts for use at distribution centers throughout the U.S. This includes numerous sites in NY, MA, CT and NH, all of which have onsite liquid hydrogen storage tanks and employ indoor dispensers at 350 bar pressure.[4] Major users in this region include Walmart, Amazon and Sysco.

4 The bar is a metric unit of pressure, with 1 bar being equivalent to normal atmospheric pressure. Because hydrogen is a very lightweight gas under normal conditions, it takes up a large volume unless stored under pressure. Common pressures used in FCEV dispensing are 350bar and 700 bar.

Figure 6. Northeast Hydrogen Fueling Infrastructure



Source: Massachusetts Hydrogen Coalition

OREGON

Hydrogen-supportive legislation in Oregon

The policy landscape in Oregon is inclusive and supportive of hydrogen and fuel cell vehicles. For example, the state's ZEV targets allow for both battery and fuel cell electric vehicles, as do the state fleet procurement requirements, and the Clean Fuels Program offers credits to the producers of low-carbon transportation fuels, including hydrogen. The following highlight policies in Oregon that support the hydrogen industry:

- **Senate Bill 333 (2021) –** Directs the Oregon Department of Energy (ODOE) to conduct a study of the benefits and barriers to the production and consumption of renewable hydrogen in Oregon. The study is due to the legislature by September 2022.

- **Clean Vehicle Rebate Program** – provides rebates to Oregon residents, businesses, non-profit organizations and government agencies for the purchase or lease of plug-in hybrid electric vehicles (PHEVs) and zero emission vehicles (ZEVs), including FCEVs. HB 2165, which passed in the 2021 Legislative session, includes an increase from $50k to $60k of the maximum allowable retail price of FCEVs to qualify for Oregon's standard and Charge Ahead vehicle rebates.

- **Clean Fuels Program (CFP)** – launched by the Oregon Department of Environmental Quality (DEQ) in 2016, the CFP aims to reduce the average amount of carbon intensity of transportation fuels used in Oregon by replacing high carbon fuels such as gasoline and diesel with low or zero carbon substitutes such as electricity or low-carbon hydrogen. Producers of low-carbon fuels earn credits through the Program which can then be sold, reducing operating costs.

- **Advanced Clean Trucks (ACT) Rule** – passed in November 2021, the ACT rule requires medium- and heavy-duty vehicle manufacturers to sell zero-emission vehicles as a certain percentage of sales, beginning with the 2025 model year, with percentage increases each year through 2035, reaching 55% for Classes 2b-3; 75% for Classes 4-8; and 40% for Class 7-8 Tractors. Note: As a result of this new rule, the trucking sector is likely to be increasingly interested in policies and initiatives that ensure the availability of the charging and hydrogen fueling infrastructure necessary for compliance.

- **The Heavy-duty Low-NOx Rule** – also passed in November 2021, this rule imposes new air pollution standards on new heavy-duty diesel and non-diesel engines sold in the state, requiring a 75% reduction in nitrogen oxide (NOx) emissions in new trucks beginning with the 2024 engine model year, and a 90% reduction beginning with the 2027 engine model year. The rule also requires lower particulate matter 2.5 (PM2.5) standards for these engines, resulting in a 50% reduction in 2024.

- **House Bill 3055 (2021)** – Allows natural gas utilities to recover hydrogen-related infrastructure investments.

Current and announced hydrogen projects in Oregon

While there are no existing retail fuel stations and no commitments from automakers to deploy FCEVs in Oregon, there is growing interest in hydrogen production and hydrogen fuel cell vehicles. Several of the potentially more impactful hydrogen activities currently being planned, include:

- **FHWA Alternative Fuels Corridor Program Designation** – Oregon's portion of I-5 was successfully designated as "corridor pending" for hydrogen through the U.S. Department of Transportation's Federal Highway Administration's (FHWA) fifth round of the Alternative Fuels Corridor Program.

- **Eugene Water & Electric Board (EWEB)** – is partnering with NW Natural and the Bonneville Environmental Foundation to explore the development of a large 2-10 MW renewable hydrogen production facility. The hydrogen production facility will demonstrate how renewable and low-carbon electricity can be transformed into "green" hydrogen, through a process called "power-to-gas" and used to decarbonize the region's space heating and transportation sectors (Eugene Water & Electric Board, 2020).

- **Portland TriMet** – has completed a "Hydrogen Fuel Cell Bus Feasibility Study" and is now seeking funding for a hydrogen fuel cell bus pilot project (TriMet, 2021).

- **Lane Transit District (LTD)** – having invested in 30 BEVs for their 100 bus fleet, Lane Transit has also expressed interest in hydrogen fuel cell technology as a potential solution to extend range capability (Columbia Willamette Clean Cities Coalition, 2021), (Eugene Register-Guard, 2021)

- **Avangrid** – has proposed a concept to leverage the Klamath Cogeneration Plant for green hydrogen production, including an approximately 20 MW electrolyzer to enable a two percent blend of green hydrogen into the plant's fuel supply. The goal would be to generate 3,000 metric tons of green hydrogen annually.

- **Coastal Hydrogen Offshore Wind Study Proposal** – A project team including POET (lead), the Port of Coos Bay, and NW Natural is in the early stages of developing planning scenarios that would use 3 GW of offshore wind (OSW) with a large-scale 500 MW electrolyzer to produce renewable hydrogen. The project is seeking funding and there is no set date for electrolysis construction, but in order for the project to qualify for the federal Investment Tax Credit of 30% by 2030, 5% of the capital expenditures must be spent by 2025. This project is likely to capitalize on the recently-passed House Bill 3375, which authorized a 3 GW OSW development project.

- **Daimler Trucks North America (DTNA)**, based in Portland, Oregon, is a recent recipient of the U.S. Department of Energy (DOE) SuperTruck 3 awards. This $26 million award will fund the development and demonstration of two Class 8 hydrogen fuel cell electric trucks with a targeted range of 600 miles and 25,000-hour durability (United States Department of Energy, 2021).

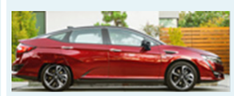
- **Distribution Centers** – Hydrogen fuel cells are also being used in material handling equipment (including forklifts) at Amazon locations in Salem, OR and at other distribution centers across the Pacific Northwest.

Section 2: Current FCEV Product Inventory

Readily available and accessible FCEV products are a critical prerequisite to the development of a vibrant and sustainable fuel cell electric vehicle industry. This section of the Study presents an inventory of the FCEV products currently being produced or planned for production by vehicle manufacturers around the world. Although this inventory is among the most comprehensive listings of FCEV products currently available, it is likely to be incomplete and quickly outdated because of the rapidity with which the industry is evolving. Even so, it serves an important purpose in this Study by helping to characterize the current maturity level of the hydrogen fuel cell electric vehicle market across light-duty, medium-duty, and heavy-duty vehicle sectors, including buses.

Tables 4 through 7 present the product inventory developed under this effort and identify, to the extent available, important key features associated with each vehicle.[5] The tables include a column identifying the availability of each vehicle. It is important to note that “availability” is different than “accessibility”, which reflects the ability of customers to acquire the product in their geographic location. Vehicle manufacturers today are generally limiting FCEV production (this is certainly the case in the light-duty vehicle segment) and are focusing that distribution on specific geographies where a critical mass of supporting infrastructure, financial incentives, and market goals can be achieved before scaling up production levels and expanding the distribution landscape. As a result, it can be very difficult to acquire specific FCEV products in locations such as Oregon. This situation will improve over time, but for now it is an important contributing factor to the slow ramp-up of FCEV activity in Oregon that is projected in Section 3 (Modeling & Analysis).

Table 4. Inventory of Current and Planned FCEV Product Offerings for Light-Duty Vehicles

Make	Model	Market	Available	Range (mi)	H_2 Capacity	Fuel Economy-MPGe (city/hwy/comb)	Class/ Type	More Information
LDV								
Honda	**Clarity**	US	Discontinued in 2021	360 mi	5.46 kg	77/67/72	Light-Duty Vehicle	
Hyundai	**Nexo Bue**	US	Yes	380 mi	6.33 kg	65/58/61	Light-Duty Vehicle	
Hyundai	**Nexo Limited**	US	Yes	354 mi	6.33 kg	59/54/57	Light-Duty Vehicle	
Toyota	**Mirai XLE**	US	Yes	402 mi	5.6 kg	76/71/74	Light-Duty Vehicle	
Toyota	**Mirai Limited**	US	Yes	357 mi	5.6 kg	67/64/65	Light-Duty Vehicle	
BMW	**i Hydrogen Next “X5”**	EU	2022				Light-Duty Vehicle	

5 Data sources used to construct the table include the following: (California HVIP, 2021), (Drive to Zero, 2021), (United States Department of Energy, 2021), (GoElectricDrive, 2021), and (United States Department of Energy, 2021).

Table 5. Inventory of Current and Planned FCEV Product Offerings for Buses

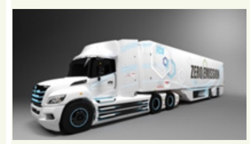
Make	Model	Market	Available	Range (mi)	H_2 Capacity	Fuel Economy-MPGe (city/hwy/comb)	Class/ Type	More Information
Buses								
Caetano	**H_2. City gold**	EU		250 mi		From 6 kg/100 km	Transit Bus	
Eldorado	**Axess (35ft)**	US	Yes	260 mi			Transit Bus	
Eldorado	**Axess (40Ft)**	US	Yes	260 mi			Transit Bus	
Hyundai	**Elec City**	Korea		300 mi	845 liter		Transit Bus	
Hyzon	**Coach Bus**	US/EU		<500 mi			Transit Bus	
New Flyer	**Xcelsior XHE60 (60ft)**	N/A	Yes	300 mi	60 kg		Transit Bus	
New Flyer	**Xcelsior XHE40 (40ft)**	N/A	Yes	300 mi	37.5 kg		Transit Bus	
Rampini	**H80**	EU	In development	125 mi			Transit Bus	
Solaris	**Urbino 12**	EU	2021	220 mi			Transit Bus	
US Hybrid	**H2 Ride 30**	US		125 mi			Bus/Van	

Make	Model	Market	Available	Range (mi)	H_2 Capacity	Fuel Economy-MPGe (city/hwy/comb)	Class/ Type	More Information
Buses								
US Hybrid	**H2 Ride 32**	US		200mi			Bus/van	
Van Hool	**A330 Fuel Cell**	EU	2021	220-250 mi			Transit bus	

Table 6. Inventory of Current and Planned FCEV Product Offerings for Additional Buses (US Import Less Likely)

Make	Model	Market	Available	Range (mi)	H_2 Capacity	Fuel Economy-MPGe (city/hwy/comb)	Class/ Type	More Information
Additional Bus Makers (US import less likely)								
Changsha Sunda	**Hydrogen Fuel bus**	China		310 mi			Transit Bus	
Tata Motors	**Starbus Fuel Cell**	India	2024		14.5 kg		Transit Bus	
Yinlong	**Bus 8.5m FCEV**	China	Yes	62 mi			Bus	
Yinlong	**Bus 10.5m FCEV**	China	Yes	336 mi			Transit Bus	
Yinlong	**Bus 12m FCEV**	China	Yes	280 mi			Bus	
Zhong Tong		China	Yes	218 mi			Transit Bus	

Table 7. Inventory of Current and Planned FCEV Product Offerings for Medium- and Heavy-Duty Vehicles

Make	Model	Market	Available	Range (mi)	H_2 Capacity	Fuel Economy-MPGe (city/hwy/comb)	Class/ Type	More Information
MD and HD Trucks								
Cummins & Navistar JV		US	In Development	300 mi			Heavy-Duty Vehicles – Class 8	
Daimler (w/Volvo JV)	**GenH2**	EU/NA	2027	600 mi			Heavy-Duty Vehicles – Class 8	
E-Trucks Europe	**H2**	EU		75 mi			Medium-Duty Vehicle – Garbage Truck	
Esoro	**BZ-LKW**	EU	In Development	250 mi	31 kg		Heavy-Duty Vehicles – Class 8	
Hino (with Toyota FC)	**HINO FC Truck**	US	In Development (2021)					
Hyundai	**HDC-6 Neptune (concept)**		Concept	250 mi				
Hyundai	**XCient**	US/EU	Eu-Avail US - 2023	EU-250 mi US-500 mi	EU - 31kg US - TBD			
Hyundai	**Mid-Size FCEV**	Korea		373 mi	25 kg		Medium-Duty Vehicle – Garbage Truck	
Hyzon	**Heavy-duty**	US/EU	Yes	250-380 mi	30 kg		Heavy-Duty Vehicles – Class 8	
Hyzon	**Medium-duty**	US/EU	Yes	250-380 mi			Medium-Duty Vehicle	

Make	Model	Market	Available	Range (mi)	H_2 Capacity	Fuel Economy-MPGe (city/hwy/comb)	Class/ Type	More Information
MD and HD Trucks								
Kenworth (w/ Toyota)	**T680**	US	Demo	150-350 mi	30 kg		Heavy-Duty Vehicles – Class 8	
Mitsubishi Fuso	**Vision F-cell**	Japan	Late 2020s	186 mi			Medium-Duty Vehicle	
Nikola tre	**Day Cab**	US	2023	500 mi	70 kg		Heavy-Duty Vehicles – Class 8	
Nikola Two	**Sleeper Cab**	US	2025	900 mi	110 kg		Heavy-Duty Vehicles – Class 8	
US Hybrid	**H2 Cargo**	US	Yes	125 mi			Medium-Duty Vehicle – Cargo Van	
Workhorse (w/ Plug Power)	**EGEN**	US	Pilot	160 mi			Medium-Duty Vehicle – Class 5-6	

Section 3: Modeling & Analysis

The analysis and results presented in this section describe the modeled "what if" scenario assuming a 5% penetration of hydrogen fuel cell vehicles in the state's 2035 zero-emission vehicle goals, which applies to light-duty vehicles. Further assumptions regarding the targets for the additional use cases studied are described below. Five transportation use cases from TEINA were modeled in the hydrogen analysis, including LDV Urban, LDV Highway Corridor (I-5, I-84, I-82, US 20, US 26, US 97, US 101), MD trucking (Local Commercial), HD trucking (long-haul transport), and transit buses. This analysis did not investigate the school bus, e-micro mobility, Rural or Disadvantaged Communities use cases as defined in TEINA.

Target Assumptions

As in the original TEINA study, the targets for light-duty vehicles (LDV) are based on the state's SB 1044 goals - adjusted to assume that FCEVs make up 5% of LDV ZEVs in 2035. For the purpose of determining hydrogen fueling station needs, it was further assumed that FCEV adoption in the LDV sector would begin in urban areas, as is the case in California. This is largely a function of where automakers have focused their marketing and outreach efforts and where hydrogen fueling stations have been concentrated. Thus, in this study, 5% of 2 million urban LDVs, or 100,000 LDVs, are assumed to be FCEVs in 2035. The LDV Highway Corridor use case is a function of the LDV use case and assumes that 5% of the average daily traffic of LDVs is made up of FCEVs (using Annual Average Daily Traffic - or AADT - on the major interstate highway corridors in Oregon as an input). Since SB 1044 does not provide state targets for transit buses, medium-duty or heavy-duty vehicles, this Study has adopted the same methodology used in the original TEINA study for projecting ZEVs for these additional use cases to ensure a consistent approach. This Study assumes 10% of the ZEV buses in TEINA are fuel cell buses, and it assumes 10% of all medium-duty truck vehicle miles traveled (VMT) and 25% of all heavy-duty truck VMT is met by hydrogen fuel cell electric trucks. The 2035 targets assumed by use case are summarized as follows:

Table 8. Target Assumptions by Use Case

Use Case	Target Assumptions
Light-Duty Vehicles	5% of urban light-duty ZEVs are FCEVs
Transit Buses	10% of TEINA e-buses are FCEVs
Medium-Duty Vehicles	10% of medium-duty TEINA e-VMT are FCEVs
Heavy-Duty Vehicles	25% of heavy-duty TEINA e-VMT are FCEVs

Note: The LDV Highway Corridor use case is a function of the daily traffic of the LDV use case.

These analytical targets were determined as a result of interviews and discussions with the Advisory Group, industry stakeholders, and others. The estimated targets shown above reflect a general consensus that FCEVs are likely to play a larger role in electrifying the more challenging transportation sectors of transit buses and trucking. Therefore, the analysis assumed a more aggressive set of FCEV penetration levels for these use cases. In the case of the heavy-duty trucking analysis, the North American Council for Freight Efficiency (NACFE) was also consulted, resulting in the higher assumption of 25% of total HDV ZEV miles – as fuel cell trucks are likely to be used to take on the longest and most challenge trucking routes.

FCEV Ramp-up

For modeling purposes, it was necessary to estimate both the 2035 endpoints described in the previous section and assumptions about when FCEVs begin to ramp-up. The analysis assumes a relatively slow startup to FCEV deployments in Oregon due to several factors: the lack of current FCEV product availability across sectors; the constrained hydrogen vehicle production capacity of automakers (only 12,000 cars and 48 buses have been deployed to date, according to the CaFCP); and the limited geographic areas of FCEV deployment (automakers are currently focused on California). Beyond 2025, the ramp-up curve follows an exponential growth curve to meet 2035 targets. This analysis has assumed similar ramp-up timelines for LDVs, MDVs, and HDVs. As is discussed later in Section 6 (Recommendations), it will be critical to watch for a number of key market leading indicators that could cause these adoption curves to accelerate in Oregon much more rapidly than is projected in this analysis.

Methodology and Modeling Results

The following paragraphs describe the methodology used to model and project the growth of hydrogen fuel cell vehicles and the supporting fueling station infrastructure required in Oregon over the next 14 years. TEINA projections regarding ZEVs and electric vehicle miles traveled (e-VMT) were used to set FCEV fleet and VMT targets in this analysis as well, based on the assumptions outlined in the previous paragraphs. An exponential growth model was employed to calculate the annual adoption of FCEVs in each vehicle class in Oregon counties to meet the targets defined for 2035. These vehicle fleet and e-VMT numbers were then used to estimate annual hydrogen demand and the resultant number of fueling stations required to support that demand.

This analysis has treated the demand for each use case independently. In other words, it has not optimized fuel demand in a way that contemplates fueling stations being used to serve vehicles from more than one use case. Therefore, the paragraphs that follow present the results of this modeling analysis separately for Urban LDVs, Highway Corridors, medium- and heavy-duty trucks, and transit buses.

Urban Light-Duty Vehicles

The light-duty FCEV target in this study is assumed to be 5% of urban electric LDVs in 2035 as in the TEINA study - i.e., 80,000 light-duty FCEVs. **Figure 7** shows that both FCEVs and the corresponding fueling stations grow exponentially beginning in 2030. Based on typical commercial hydrogen fueling station sizes today, a 1,500 kg daily hydrogen capacity station is assumed to support urban LDV fueling in the early years. A minimum demand threshold of 325 light-duty FCEVs per county (corresponding to a minimum daily hydrogen demand of 200 kg) was used in the model to trigger the need for a fueling station within the county. This results in a requirement of **33 1,500 kg capacity stations** to support the estimated 80,000 light-duty FCEVs in Oregon's urban and most populous counties by 2035.

Figure 7. Light-Duty FCEVs & H_2 Fueling Stations in OR: 2020 - 2035

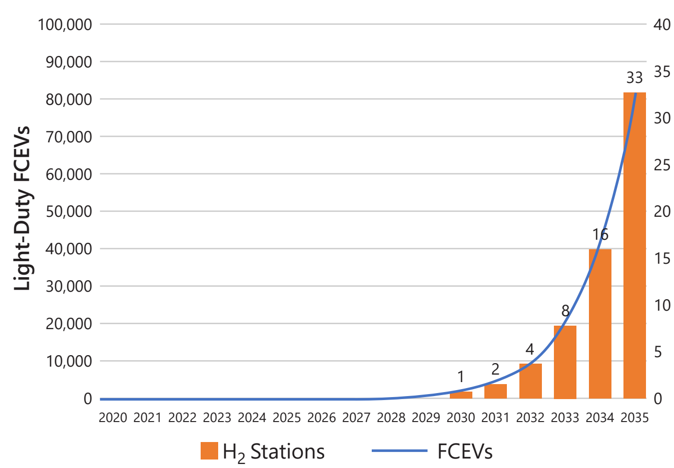
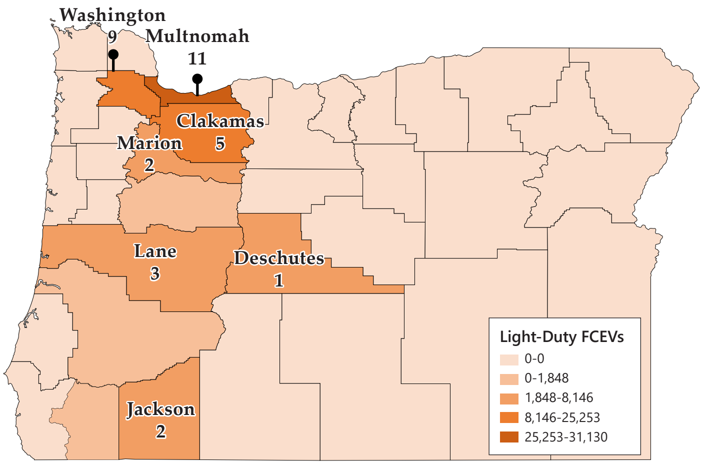


Figure 8 shows estimated FCEV and fueling station numbers for 2035. As also observed in TEINA, the number of FCEVs is typically proportional to the population of the county (and the number of vehicle registrations).

Figure 8. H_2 Fueling Stations Serving Urban Light-duty Fuel Cell Vehicles in Oregon by 2035



Highway Corridors

The LDV Highway Corridor analysis assumed that 5% of average LDV ZEV daily traffic was made up of FCEVs. This analysis used Annual Average Daily Traffic (AADT) data on major interstate highway corridors in Oregon as an input and estimated the hydrogen demand resulting from the projected traffic volume on each highway segment.

Proportional to current trends, the I-5, I-84 and US-26 Alternative Fuel Corridors are expected to experience the heaviest FCEV demand in 2035. A Highway Corridor station was triggered in this analysis when at least 100 FCEVs were estimated to be traveling on the Highway Corridor segment, corresponding to a minimum daily demand of 500 kg over the length of the corridor. All light duty vehicles traveling on corridors in Oregon, whether starting their trips within or out of state, are assumed to refuel with 30% more energy than is required to complete their trips. A 30% positive adjustment was applied to hydrogen fueling demand on highway corridors to account for this additional demand. This is consistent with the calculation of highway corridor electricity demand in the TEINA study. Using this threshold, 14 1,500 kg capacity stations are estimated to be required to support all light-duty FCEVs on the 2,200 miles of highway corridors in Oregon by 2035 (**Figure 9** and **Table 9**).

Figure 9. Highway Corridors in Oregon Analyzed for Light-Duty H_2 Fueling Stations

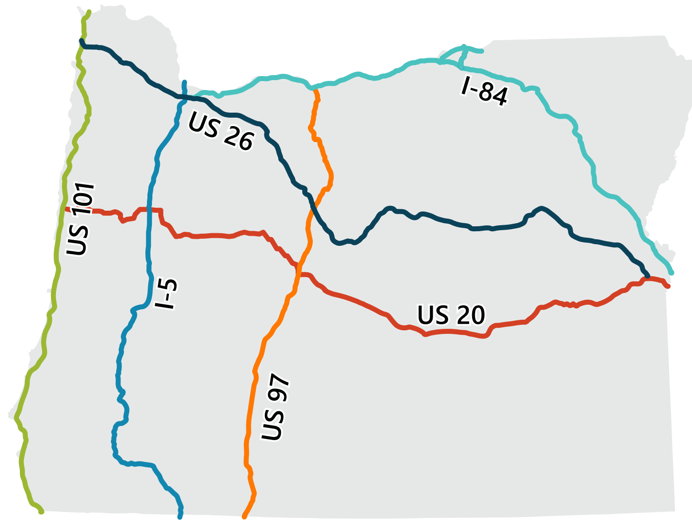


Table 9. H_2 Fueling Stations by Highway Corridor to Support Light-Duty FCEVs in Oregon by 2035

Highway	2035	Daily Traffic (1000s)	Length (miles)
US 97	1	40	291
US 101	1	70	350
US-20	1	42	449
I-5	5	176	308
I-84 & I-82	4	72	387
US 26	2	82	453
Total	14	482	2,238

Medium- and Heavy-Duty Trucks

For medium-duty and heavy-duty trucks, the analysis was based on daily VMT per county as this is believed to lead to a better estimate of demand than vehicle registrations. The 2035 targets are set to 10% of the TIENA electric VMT share for medium-duty trucks and 25% for heavy-duty trucks. These numbers also align with estimates from the North American Council for Freight Efficiency (NACFE) for the highest mileage trucks per weight class that would be the most suitable candidates for replacement by FCEVs.

Based on TEINA's target-driven approach, FCEV demand by trucks is projected to increase after 2030 and to grow exponentially after 2032, as shown in **Figure 10**. Larger 5,000 kg daily hydrogen capacity stations will meet the early market needs of these truck classes balanced with some important geographical distribution of stations. Station need in each county was estimated based on a minimum daily hydrogen fueling demand of 1,500 kg, equivalent to a minimum threshold of 25 trucks in each class passing through the county. Using these inputs, **14 5,000 kg capacity stations** would be required to support fuel cell freight activity in Oregon by 2035.

Figure 11 maps the counties with sufficient medium-duty trucking demand in 2035 to result in the installation of fueling stations. Local truck activity in each marked county can be supported by a single 5,000 kg capacity station – an indicator of the expected size of the market.

Figure 12 maps the counties with a sufficiently high level of interstate heavy-duty truck activity to warrant the installation of a fueling station.

Figure 11. H_2 Fueling Stations by County Serving Medium-Duty Fuel Cell Trucks in Oregon by 2035

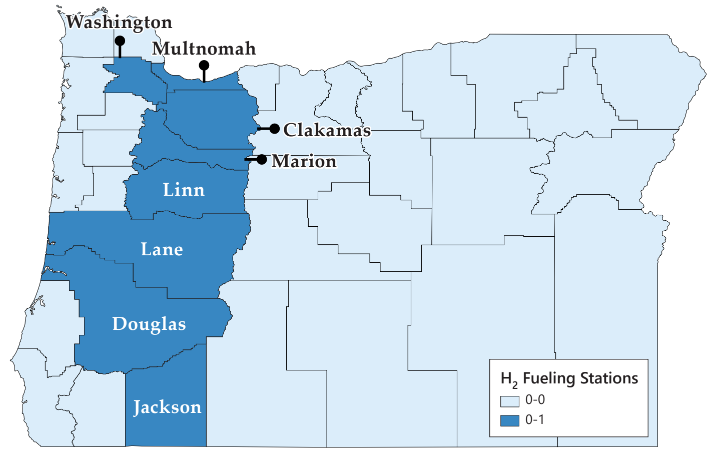


Figure 12. H_2 Fueling Stations by County Serving Heavy-Duty Fuel Cell Trucks in Oregon by 2035

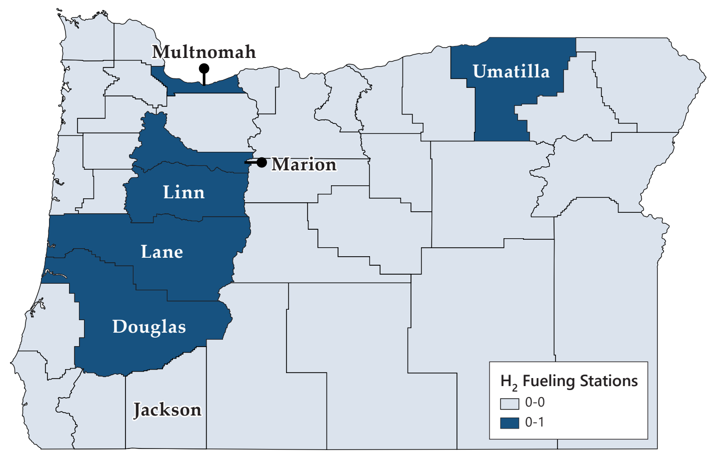
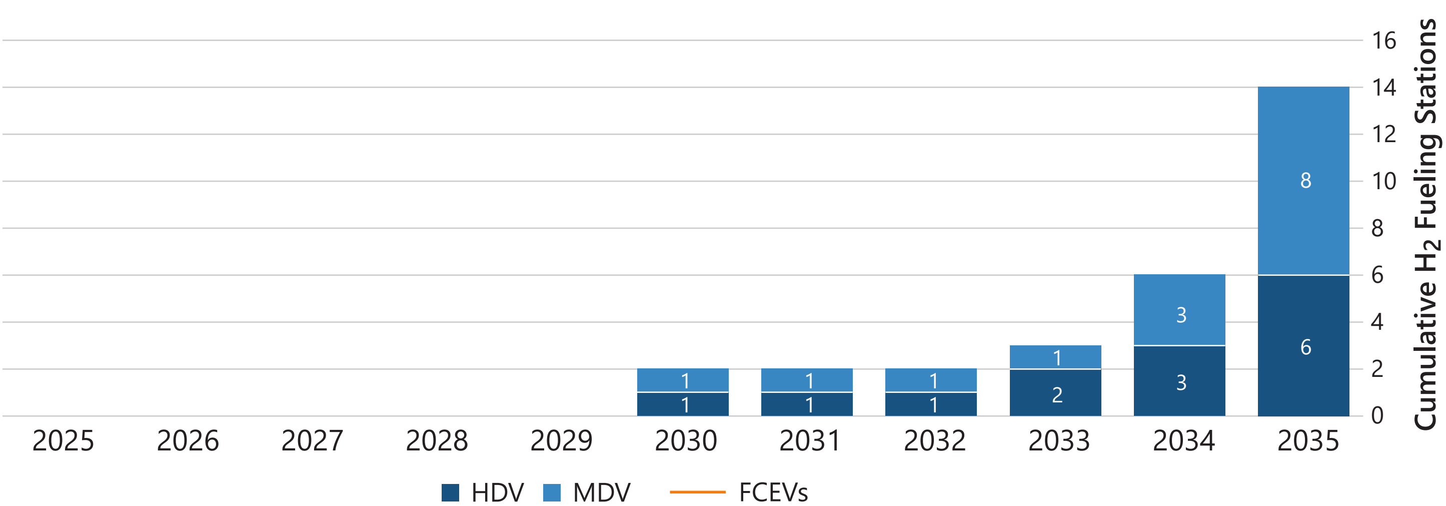


Figure 10. Medium- & Heavy-Duty FCEV H_2 Fueling Stations in OR: 2025 - 2035



Transit Buses

The FCEV transit bus target for 2035 is defined to be 10% of the ZEV transit buses projected in TEINA, which is not sufficient to drive large-scale fueling stations until 2030. The modeling results indicated that five 5,000 kg daily hydrogen capacity stations would be sufficient to support an estimated 200 fuel cell buses in Oregon by 2035 (**Figure 13**).

Figure 13. FCEV Buses & Fueling Stations in OR: 2025-2035

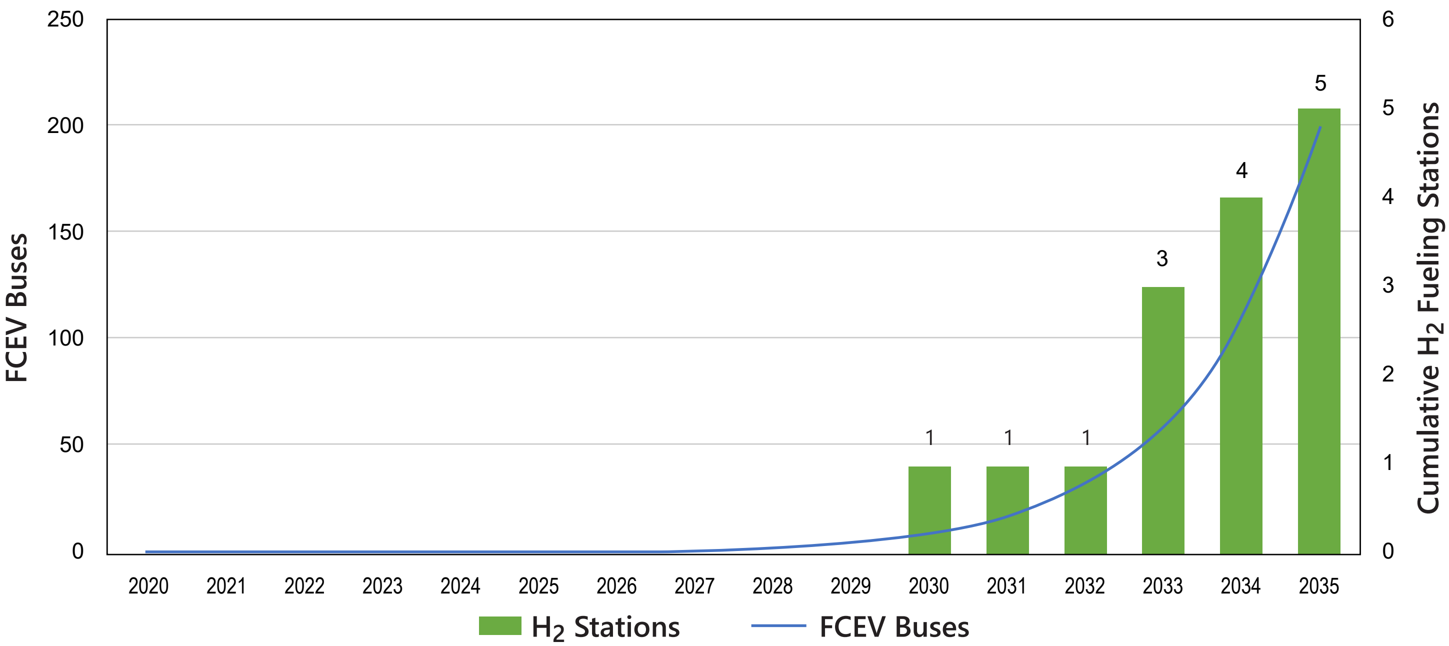
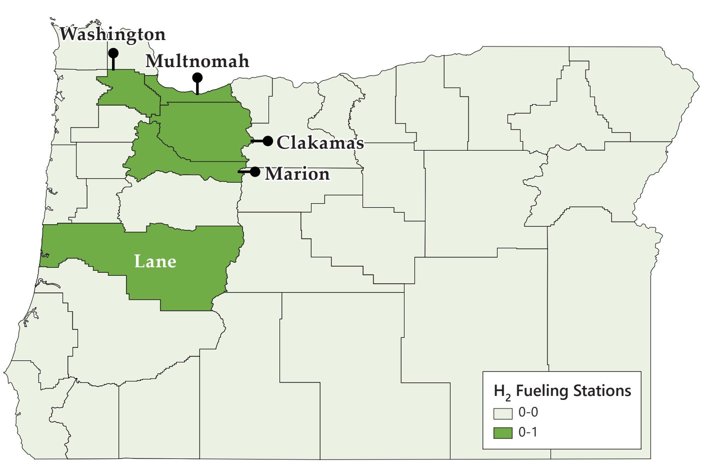


Figure 14 maps the counties where bus demand is expected to be sufficient to warrant hydrogen fueling stations. As is shown in the map, fuel cell buses are projected to be deployed in the most populous counties, which is also proportional to the current size of transit fleets operating in these counties.

Figure 14. H_2 Fueling Stations by County Serving Fuel Cell Transit Buses in Oregon by 2035



It is important to note that the modeling assumed a uniform distribution, on a percentage basis, of the FCEV buses across all transit agencies in the state. This assumption resulted in a wide distribution of the FCEV buses across many fleets, so that many of these fleets did not possess a large enough number of FCEV buses to support even a single hydrogen fueling station by 2035. It is more likely, however, that hydrogen bus fleets will evolve at different rates across the different transit agencies. More specifically, a few large transit agencies, such as TriMet or Lane Transit District (LTD), could pursue a more aggressive hydrogen strategy on a quicker timetable than many of the smaller transit agencies. To the extent this happens, station fueling needs will evolve in a more concentrated and localized manner than has been projected by this analysis.

Modeling Summary

The resultant total hydrogen fueling station demand, inclusive of all modeled use cases, is presented in **Table 10**. Station results were derived analytically and are based on input assumptions regarding the 2035 targets and the ramp-up rate to these targets. In reality, many factors can influence hydrogen fuel cell electric vehicle adoption by consumers, public fleet operators, trucking fleet operators, and transit agencies in Oregon. Section 6 (Recommendations) provides a more robust discussion of the recommendations and leading indicators influencing the growth of the hydrogen vehicle market.

Table 10. Summary of Modeled Results – Hydrogen Fueling Stations Required by Use Case (Cumulative)

	2025	**2030**	**2035**
Use Case	# Stations	# Stations	# Stations
Light-Duty Vehicles: Urban	0	1	33
Light-Duty Vehicles: Corridor	6	7	14
Medium-Duty Vehicles	0	1	8
Heavy-Duty Vehicles	0	1	6
Transit Buses	0	1	5
Total	**6**	**11**	**66**

Note: The hydrogen fueling needs presented in this study are the result of a capacity analysis that estimated the number of stations required to serve an assumed number of FCEVs. It is not a projection of what is likely to happen or a recommendation of what should happen. As such, the timeline presented in this Study could be quite different than what occurs.

Section 4: Hydrogen Fueling Needs Assessment & Costs

This section describes the needed characteristics of hydrogen fueling stations and the estimated capital investment required to support the modeled scenarios described in the previous section.

Hydrogen at a fueling station can either be produced onsite or delivered in gaseous or liquid form. A hydrogen fueling station typically requires a hydrogen storage tank at its facility as well as a compressor and dispensing equipment to further pressurize the stored hydrogen and dispense it into vehicles. Some hydrogen fueling stations may choose to store hydrogen in liquid form, as a liquid storage tank holds nearly nine times more hydrogen than a gaseous tank. In this case, the hydrogen fueling station must also have equipment to convert the liquid hydrogen back into a gaseous form for fueling purposes. Onsite hydrogen production can be performed by small steam methane reformation (SMR) systems or electrolysis. Both can be as small as the footprint of one to two 40-foot shipping containers and each site must determine the right size for its needs. Regardless of the production method that is used, the hydrogen will follow the same storage, compression and dispensing process to move into a vehicle as fuel (Gladstein, Neandross & Associates, 2021).

Hydrogen Fueling Infrastructure Characteristics and Needs – Light-Duty Vehicles

As mentioned above, light-duty hydrogen fueling stations may be supported by a combination of liquid or gaseous on-site hydrogen storage.[6] Liquid storage is typically associated with larger-capacity stations capable of dispensing more than 1,000kg per day. Today, these larger-capacity liquid stations commonly have four fueling nozzles, whereas gaseous stations often offer two fueling nozzles. All hydrogen FCEVs in the U.S. light-duty vehicle sector today are capable of being fueled at 700bar pressure (vs. 350bar pressure), delivering faster fueling to vehicles.

Regarding station lead times, based on California's relatively substantial experience, it takes roughly 12-24 months to build a station once funding has been secured. Station permitting can account for much of this lead time; stations today typically move from shovel contact to open within 4-6 months after the permit has been issued by the local Authority Having Jurisdiction (AHJ).

For the past 20 years, California has worked closely with the hydrogen industry (car manufacturers, hydrogen producers, station providers) through organizations such as the CA Fuel Cell Partnership, to plan and design a hydrogen fueling station network for light-duty vehicles. This coordinated effort has resulted in a market-driven cluster approach, siting hydrogen fueling stations in key urban areas with additional highway connector stations to support intercity travel. **Figure 15** (United States Department of Energy, 2021), illustrates this urban clustering approach, with a dense network of stations in the Los Angeles and San Francisco metropolitan areas and a highway connector station located at Harris Ranch in Coalinga, CA – roughly 200 miles from both Los Angeles and San Francisco. Due to the typical driving range of 350-400 miles for light-duty FCEVs and given the quick refueling capability of dispensed hydrogen, highway stations placed at 200-mile intervals along corridors are sufficient to support a nascent but growing hydrogen FCEV market.

For modeling purposes, a 1,500 kg/day station capacity was assumed for urban and highway hydrogen fueling stations alike, matching California's Harris Ranch station with a single dispenser (dual nozzles at 350bar and 700bar). In the future, however, it is likely that highway corridor stations will be sized for larger hydrogen capacity and more fueling nozzles – similar to the gasoline station network today.

6 In DOE's 2020 analysis of 111 funded proposals for newly planned hydrogen stations in California, 63 stations are planning liquid hydrogen storage and 48 are planning gaseous hydrogen storage (United States Department of Energy, 2020)

Figure 15. California's Urban, Market-centric Approach to a Hydrogen Fueling Network

Given the station characteristics above and the assumptions outlined in Section 3 (Modeling & Analysis), this modeling finds that by 2035, 47 hydrogen stations (33 for urban vehicles and 14 for Highway Corridors) will be required to support a 5% hydrogen FCEV penetration across light-duty zero emission vehicles. This modeling and analysis effort reflects a hydrogen demand-driven approach based on Oregon's state ZEV targets, whereas California has worked with industry stakeholders to apply a market-driven approach as described above to leverage hydrogen fueling stations to drive FCEV awareness and consumer-adoption (as well as meeting overall demand) in urban areas. As Oregon considers investments, it is worth noting that different levels of investment may be appropriate under a market-oriented approach. As further described in Section 6 (Recommendations), Oregon stakeholders can gain a deeper understanding of how to develop an FCEV market by joining public/private organizations such as the California Fuel Cell Partnership (CaFCP).

Hydrogen Fueling Infrastructure Characteristics and Needs – Medium- and Heavy-Duty Vehicles

Unlike the light-duty vehicle market for hydrogen FCEVs, the medium- and heavy-duty vehicle market is not homogeneous. There are notable differences between the fueling requirements for return-to-base vehicles versus the fueling needs of long-distance vehicles that do not regularly return to base. As hydrogen is more likely to be a preferred technology solution for battery-challenged use cases, such as long-haul heavy-duty freight movement, 24/7 point-to-point goods movement, and longer-distance transit bus routes, the private depot and public fueling solutions must be tailored to address different transportation use cases. The critical consideration is to design a fueling system that does not compromise vehicle operations in these segments and to leverage hydrogen's quick fueling advantage to ensure fueling is convenient. In addition, as with all fueling infrastructure, it is important to design redundancy into the system from the beginning. Stations should have multiple fueling positions (i.e., nozzles) to anticipate vehicle demand and ensure queuing does not become an issue. As there are so few hydrogen stations today serving the MDV and HDV sectors, station lead times are less understood than for the LDV sector. Some factors, such as the larger expected footprints and less urban, less congested locations, could drive shorter lead times, but the additional complexity and scale of these stations, the additional construction required, and the higher electrical infrastructure demands could also drive longer lead times. Regardless, streamlined station permitting and industry experience at scale will be critical to driving shorter lead times in this sector.

Whereas return-to-base fleets, such as those found across transit bus fleets and local commercial goods movement, may rely on 350bar depot fueling, longer-haul trucks are likely to rely on a public fueling infrastructure system that delivers faster fueling rates at 700bar and that aims to ensure 10-15min fills and enough fuel for at least 600-700 miles of range – more than double the amount of fuel needed for transit buses. Interviews with manufacturers and fleets revealed that, over the long term, onboard liquid hydrogen might deliver a higher-performing solution for long-haul trucking and it remains an open question and area of research in the industry.

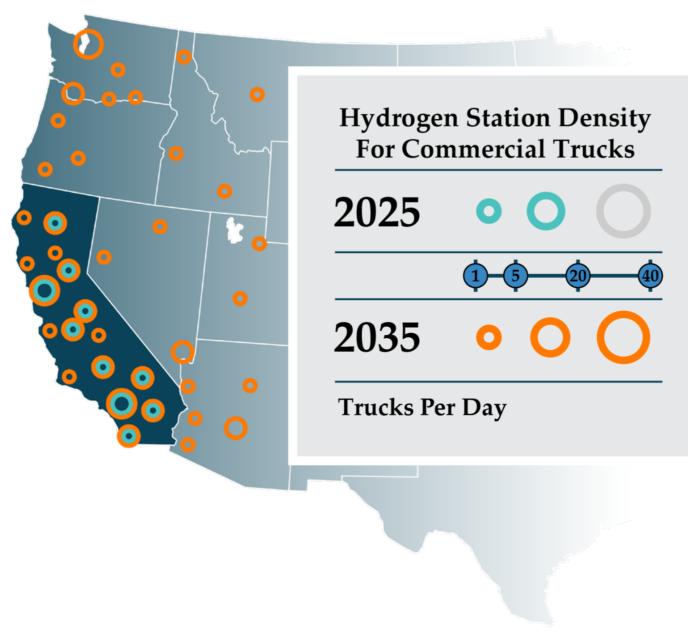
Case Study: TriMet

Portland's transit bus agency, TriMet, recently completed a hydrogen modeling and feasibility study to better understand how to achieve a zero-emission bus fleet given the large variability in the distances their buses travel in a given day. Approximately 15% of TriMet's vehicles travel more than 200 miles per weekday and 40% of their fleet travels more than 150 miles. Given that 200 miles is an ambitious range for a battery electric bus today and given TriMet's route topography, anticipated passenger loads, and weather conditions (particularly the cold-weather impacts on battery vehicle range), TriMet believes it can serve about half of its fleet with currently available battery electric bus technology. Transitioning the remainder of its fleet to battery electric vehicles would require both faster chargers and more than a 1:1 replacement of its buses – that is, they would need to increase their bus fleet to meet all route needs with battery electric buses. As an alternative, TriMet is investigating using hydrogen fuel cell buses for that portion of the fleet that travels more than 150 miles per day. In the modeling study, TriMet assumed one aggressive scenario that would convert up to 50% of its transit bus fleet to hydrogen and determined that four hydrogen fueling stations would be required (one at each of its depots) to serve this fleet.

A public hydrogen fueling network for long-haul heavy-duty freight movement does not yet exist, even in California. However, it is instructive to consider California's plans and strategic thinking in this area. A recent CaFCP report outlines a fueling station strategy for heavy-duty trucking that includes a network of 200 fueling stations supporting 70,000 heavy-duty Class 8 trucks by 2035, as illustrated in **Figure 16** (California Fuel Cell Partnership, 2021). These highway corridor stations are spaced approximately 100-150 miles apart. The CaFCP envisions this network of public hydrogen stations will be built along California's major highway transportation corridors and will extend into neighboring states (including Oregon) post-2025. This highway corridor strategy is unlike the strategy for LDVs described above, which is focused on building and encouraging the growth of FCEV markets, beginning in urban centers. For heavy-duty trucking, the focus is on replicating today's gas station (or truck stop) experience to deliver fueling that is similarly quick, convenient, affordable and seemingly ubiquitous.

Given these station characteristics and the assumptions outlined in Section 3 (Modeling & Analysis), RMI's modeling finds that 19 stations will be required to support the modeling assumptions outlined in **Table 8** for medium-duty vehicle, heavy-duty vehicle and transit buses. This includes five stations serving transit, eight stations serving medium-duty vehicles and six stations serving heavy-duty vehicles.

Figure 16. CaFCP's Envisioned Station Network to Support 70,000 Hydrogen Fuel Cell Electric Trucks



Hydrogen Fueling Infrastructure Cost Estimates - LDV and MDV/HDV

In this study, we are considering only the initial capital investment required to establish a hydrogen fueling network. These early capital costs will likely be met by a combination of private and public investors, including the federal government. Large federal investment opportunities, such as the proposed Build Back Better plan (in a state of uncertainty as of this writing), could significantly accelerate investments in hydrogen fueling infrastructure. Among other things, an early version of this plan included a $3/kg tax credit for hydrogen. And while the cost of hydrogen, and operating costs in general, are critical factors for consumers and fleet operators and can represent much more significant costs over time than the initial station investment, the focus of this study is to provide a rough estimate of the upfront cost of establishing a hydrogen fueling station network for Oregon's planning purposes. It should also be noted that the cost estimates used here are expected to decline over time with advancements in technology and as economies of scale are reached.

As the use of hydrogen in the transportation sector is still a niche and early market, the relatively few stations that have been built have varied widely in cost and those costs have been significantly changing over time (as discussed later in this section). For the purposes of estimating the upfront fueling station investment, we have used the following cost figures as estimates:

LDV public fueling station: $1.9 million for a station dispensing 1,500 kg/day

- A recent DOE analysis of the 111 new hydrogen stations to be funded in California shows plans for stations storing hydrogen in gaseous form and dispensing 700-1,000 kg/day cost $1.4 million and larger stations storing hydrogen in liquid form dispensing up to 1,620 kg/day cost between $1.9-$4.2 million. For estimating purposes in this study, we have assumed the median capacity and cost of these 111 California stations in various stages of development (United States Department of Energy, 2020).

MDV and HDV public fueling station: $7.5 million for a station dispensing 5,000 kg/day

- There is much less available data on the cost of hydrogen stations serving larger vehicles and, as virtually all stations are one-offs, economies of scale are not yet evident in the market. As a result, there is a wide range of specifications and costs associated with medium- and heavy-duty station projects. Three available data points were utilized to arrive at this cost estimate:
    - Shell Hydrogen's planned heavy-duty vehicle and rail multi-modal station will cost an estimated $6.8 million. This station consists of 3x350bar and 3x700bar fueling positions as well as a 250bar dispenser for a rail car and will be capable of delivering 5,000 kg/day (gaseous fuel delivery).
    - Orange County Transportation Authority's (OCTA) station with 4,536 kg of liquid hydrogen storage cost roughly $6 million and delivers hydrogen at 350bar pressure (fueling time 6-10 minutes). Note: there are additional costs to fill trucks at 700bar (e.g. additional compression hardware needed).
    - First Energy's NorCal Zero station will have a hydrogen capacity of 1,610 kg/day at 700 bar pressure and will support up to 50 trucks with an average fill of 30 kg (a 60kg fill will take less than 15 minutes). Air Liquide will truck in liquid hydrogen from their production facility in Nevada, and the station will vaporize and dispense gaseous hydrogen at 700 bar pressure. The cost of the station is $8.2 million.

Table 11 summarizes the key station specifications and capital cost assumptions for all modeled use cases.

Table 11. Hydrogen Fueling Station Specifications and Capital Cost Assumptions

Light-duty – Industry Median*	
Station Capacity (daily)	1,500 kg
# Fueling Positions (typical)	2-4
Station Capital Cost	$1.9M
Medium- and Heavy-duty – Truck and Bus**	
Station Capacity (daily)	5,000 kg
# Fueling Positions (typical)	8
Station Capital Cost	$7.5M

* *DOE Analysis of California LDV Stations*

** *Shell H2, OCTA, NorCal Zero datapoints*

Estimated Fueling Infrastructure Investment Requirements

Based on these assumptions, the needed upfront investment in hydrogen fueling station infrastructure required to meet the modeled FCEV penetration rates is estimated to be, cumulatively, $11 million by 2025, $37.5 million by 2030 and $232.5 million by 2035, as shown in **Table 12**. That is, by 2025, six hydrogen stations at a cost of $11 million will serve the LDV market. By 2030, a total of eight LDV stations are required, or two additional stations serving LDVs, and three stations serving medium- and heavy-duty vehicles, at an additional investment cost of $26.5 million. By 2035, an additional 39 LDV stations and 16 stations serving medium- and heavy-duty vehicles are needed. The cumulative capital cost of a hydrogen fueling station network serving light-, medium- and heavy-duty vehicles as modeled in Oregon in 2035 is an estimated $232.5M.

Table 12. Cumulative Hydrogen Fueling Station Capital Costs by Use Case

Use Case	Assumed Capital Cost/ Station	2025 # Stations	2025 Total Capital Cost	2030 # Stations	2030 Total Capital Cost	2035 # Stations	2035 Total Capital Cost	Assumed Capacity
Light-Duty Vehicles: Urban	$1.9M	0	0	1	$2M	33	$63M	1,500kg
Light-Duty Vehicles: Corridor	$1.9M	6	$11M	7	$13M	14	$27M	1,500kg
Total Light-Duty Vehicles		*6*	*$11M*	*8*	*$15M*	*47*	*$90M*	
Medium-Duty Vehicles	$7.5M	0	0	1	$7.5M	8	$60M	5,000kg
Heavy-Duty Vehicles	$7.5M	0	0	1	$7.5M	6	$45M	5,000kg
Transit Buses	$7.5M	0	0	1	$7.5M	5	$37.5M	5,000kg
Total Medium-and Heavy-Duty Vehicles		*0*	*0*	*3*	*$22.5M*	*19*	*$142.5M*	
Capital Costs Total			**$11M**		**$37.5M**		**$232.5M**	

Note: The hydrogen fueling needs presented in this study are the result of a capacity analysis that estimated the number of stations required to serve an assumed number of FCEVs. It is not a projection of what is likely to happen or a recommendation of what should happen. As such, the timeline presented in this Study could be quite different than what occurs.

Hydrogen Fueling Station Cost Reductions

Hydrogen station costs – specifically those supporting light-duty vehicles – have been decreasing relatively quickly over the past decade. This is attributed to the increasing size and fueling capacity of individual stations as well as the reduced cost of fueling components (storage, compression, dispensing), all of which drive down the cost to build and operate hydrogen stations. In other words, hydrogen fueling stations are benefiting from improved economies of scale. According to a DOE study (United States Department of Energy, 2020), the normalized cost of stations per dispenser has decreased between 77%–88% since 2012. Similarly, a recent CARB report on the economic self-sufficiency of public LDV hydrogen stations ran 840 individual cost, capacity and revenue scenarios and found that, in most cases, the hydrogen fueling network could be built in California without further public financial support beyond planned AB 8 funding, reaching self-sufficiency within the decade (California Air Resources Board, 2020). Industry stakeholders expect that fueling stations for MDVs and HDVs will follow a similar cost-reduction path: stations will move from one-off pilot projects to projects involving several stations and, from these learnings, will be able to benefit from the economies of scale that LDV stations are currently experiencing.

Section 5: Special Considerations for Oregon

Five key themes arose in this study that were particularly important to stakeholders in Oregon:

- Fuel Cell Electric Vehicle Market Growth: LDV vs MDV/HDV
- Transit Bus Fuel Cell Electric Vehicles
- West Coast Hydrogen Corridor
- Hydrogen and the Grid
- Low or Net-Zero Carbon Hydrogen Production

Fuel Cell Electric Vehicle Market Growth: Light-Duty vs. Medium- and Heavy-Duty

While FCEV technology in the U.S. has rolled out first in the light-duty vehicle sector – Honda, Hyundai, and Toyota have all offered commercial fuel cell vehicles in California – hydrogen fuel cell electric vehicles could ultimately play an even greater role in the medium- and heavy-duty truck and transit bus sectors, as these use cases may be harder to fully electrify with current battery technology. In these more challenging use cases, fuel cells may be cost-competitive sooner than batteries due to the larger batteries otherwise required to deliver the range necessary for these heavier, longer-distance vehicle segments. The increased scale of hydrogen production and large capacity refueling stations required for these larger vehicles will also work to drive down the cost of producing and supplying hydrogen regionally to all vehicles. In particular, captive medium- and heavy-duty fleets with return-to-base vehicles are in a unique position to directly evaluate the opportunity to meet their objectives with fuel cells or batteries, where a single hydrogen fueling station located at (or near) the depot may be sufficient to meet all fueling needs. A few captive fleets moving forward with hydrogen fuel cell vehicles could alter the economics of hydrogen in the region and accelerate the market for other medium- and heavy-duty vehicles, as well as the light-duty sector.

Transit Bus Fuel Cell Electric Vehicles

Transit agency greenhouse gas targets could speed adoption of FCEVs. TriMet, Portland's transit bus agency and the largest transit agency in Oregon, is committed to having a 100 percent zero emission fleet by 2040. Currently, given route distance, route topography and cold weather in Oregon, TriMet believes it can serve only about half of its bus fleet with battery electric technology and is considering alternative technologies for the other half. In particular, TriMet recently completed a hydrogen bus feasibility study, as described in Section 4 (Hydrogen Fueling Needs Assessment & Costs), to study the potential for FCEVs to serve the roughly 40% of its bus fleet that travels more than 150 miles per weekday. Other transit agencies across the state, as well as other major medium- and heavy-duty fleets operating within Oregon, might be encouraged in the near-term to assess their fleets for hydrogen FCEV suitability, feasibility, and affordability. This is particularly pressing for fleets like TriMet that have strong internal zero emission vehicle or greenhouse gas (GHG) reduction targets, or those operating within cities or counties with such targets.

West Coast Hydrogen Corridor

Similar to the West Coast Electric Highway (a battery electric vehicle fast charging network from California to British Columbia), a network of hydrogen stations along I-5 and other major trucking corridors could serve not only Class 8 long-haul hydrogen FCEV trucks but local commercial and private LDVs as well. There are no active plans in place today to build such a hydrogen corridor network, although CaFCP lays out a vision as described in Section 4 (Hydrogen Fueling Needs Assessment & Costs). However, 30% of long-haul trucking VMT in Oregon comes from out-of-state. Thus, if interest in the use of hydrogen for long-haul trucking continues to grow in California, a coordinated multi-state approach to develop such a hydrogen fueling corridor might be pursued. Such an approach would create a backbone of large-capacity commercial stations that would mitigate concerns by fleets about whether there will be places to refuel if they are to adopt fuel cell electric trucks. These larger-capacity heavy-duty stations also create predictable demand for hydrogen production, which can be leveraged and ramped up to also supply second-generation light-duty vehicle stations.

Hydrogen and the Grid

If full decarbonization of the economy is required, hydrogen will almost certainly play an important role given its broad availability, transportability, long-duration energy storage capability, and its various production pathways, many of which result in low or zero emissions. This is especially true as calls increase for a net-zero grid, driving the use of intermittent renewables (e.g., wind and solar) that will require multi-day and seasonal storage to ensure a reliable supply of power and a resilient grid. Any large-scale production of hydrogen serving the grid will drive economies of scale that will benefit the economics of operating hydrogen FCEVs. In Oregon, as discussed in Section 1 (Hydrogen Activity Landscape), the Eugene Water & Electric Board is partnering with Northwest Natural and the Bonneville Environmental Foundation to explore the development of a large, 2-10 MW renewable hydrogen production facility that will support the decarbonization of the region's space heating. Projects such as these are likely to also benefit the transportation sector.

Low or Net-Zero Carbon Hydrogen Production

Low carbon intensity hydrogen production is critical. As electrolyzer costs continue to decline, zero-carbon hydrogen production costs could fall below the critical $2 per kilogram target before 2030, according to a recent RMI analysis (RMI, 2021). The U.S. DOE is targeting even more aggressive cost reductions in its ***Hydrogen Energy Earthshot*** program (United States Department of Energy, 2021), which aims to reduce the cost of clean hydrogen (using net-zero carbon production pathways) to achieve $1 per 1 kilogram in 1 decade ("1 1 1"). With the passage of HB 2021 in Oregon in June 2021, retail electricity providers (Portland General Electric, Pacific Power) are required to reduce greenhouse gas emissions associated with electricity sold to consumers to 80 percent below baseline emissions levels by 2030, 90 percent below baseline emissions levels by 2035 and 100 percent below baseline emissions levels by 2040. The bill also bans expansion or new construction of power plants that burn natural gas or other fossil fuels. Oregon may find value in reviewing these targets with stakeholders across the state and considering the adoption of equivalent low-carbon targets for hydrogen production, especially considering that any new hydrogen production assets built today will likely be operating for decades. Importantly, there is broad stakeholder support in Oregon for the use of renewables to produce hydrogen. As noted in Section 1 (Hydrogen Activity Landscape), there are multiple ongoing efforts to study, pursue and develop renewable hydrogen in Oregon (ODOE, EWEB/NW Natural/Bonneville Environmental Foundation, Avangrid, and Poet/NW Natural). As of this writing, the authors are not aware of any efforts in Oregon to develop or expand hydrogen production using conventional fossil fuel pathways, with or without carbon sequestration.[7]

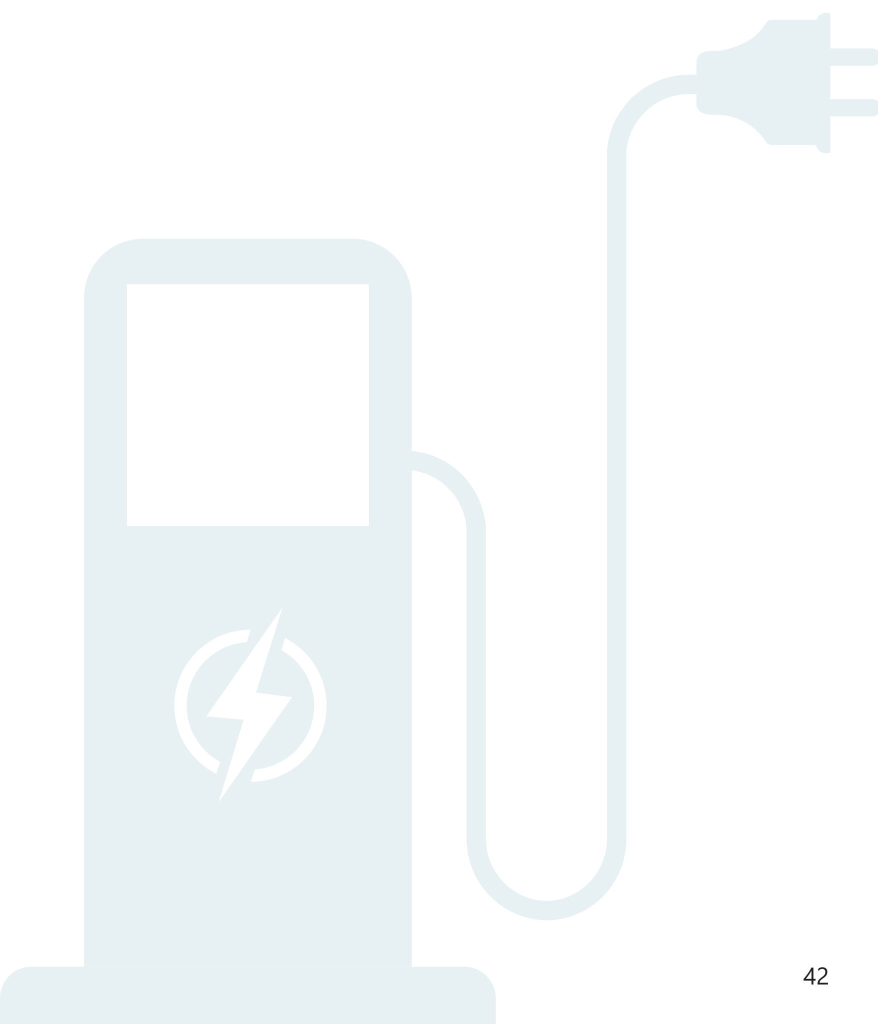
7 For more information about the carbon emissions associated with the production of hydrogen, refer to the ongoing work of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), which aims to "facilitate the market valuation and international trade in 'clean' hydrogen by outlining a common approach established through collaborative work by several countries" (International Partnership for Hydrogen and Fuel Cells in the Economy, 2021).

Section 6: Recommendations

Existing battery electric vehicle technology can tackle the operational needs of most on-road transportation, enabling significant progress toward zero-emission climate goals. But to achieve 100% zero-emissions across all vehicle sectors, particularly in the most challenging on-road use cases, hydrogen and fuel cells offer key operational advantages, including a longer driving range, shorter refueling times (on par with gasoline), several low and no-carbon production pathways and extended storage capabilities. (Fuel Cell & Hydrogen Energy Associates, Undated). These attributes may also result in hydrogen addressing electricity sector challenges, which can be a catalyst for the use of hydrogen in transportation.

It is currently unclear how quickly a hydrogen market for transportation will develop in Oregon. However, recognizing the critical role hydrogen may play in fully decarbonizing the transportation sector, there are many steps Oregon can take to develop the market for hydrogen and FCEVs. Of critical importance is engagement in the broader hydrogen community, not only to stay abreast of developments but also to ensure a thriving, cost-competitive hydrogen market. These efforts will enable Oregon to better prepare for FCEVs and more accurately anticipate the support the industry will need.

A phased approach of strategic actions over the near-, mid- and long-term is recommended to prepare for the arrival of hydrogen-fueled electric vehicles in Oregon. The phased recommendations can be accelerated to better serve the state's interests or to address market needs. To keep pace with progress in the market, it is critical to watch for leading indicators that help inform decision-makers about whether the market is developing more or less quickly than anticipated. The following section describes both the recommended next steps and the leading indicators that warrant regular monitoring.



Click on any of the text below to go to that section or simply scroll through the following pages.

Near-Term (2022-2023)

Near-Term Recommendations

Near-Term Leading Indicators

Mid-Term (2024-2027)

Mid-Term Recommendations

Mid-Term Leading Indicators

Long-Term (2028-2035)

Long-Term Recommendations

Long-Term Leading Indicators

Near-Term (2022-2023)

Near-Term Recommendations

1 **Assess hydrogen market regularly and coordinate hydrogen interests** – As hydrogen interests and deployments grow both globally and in California, assess the state of the market in Oregon and evaluate the leading indicators at no more than 2-year intervals. A periodic analysis of the progress and projected future development of hydrogen use across the light-duty, trucking, and transit sectors will ensure Oregon keeps pace with the potentially fast-evolving fuel cell vehicle market. In addition, track public and private fleets and use cases in Oregon that may increasingly seek hydrogen fuel cell solutions (e.g., 24/7 out-and-back trucking delivery services, long-haul trucking, and transit fleets with longer-range bus routes). To better understand and coordinate hydrogen interests, the Oregon Department of Transportation may consider soliciting industry inputs through a Request for Information (RFI) and/or through convening industry stakeholders to identify potential hydrogen market participants and needs. This includes an increased understanding of projected FCEV volumes, timelines, targeted sectors, fleet commitments, public vs. private fueling needs, station network plans, and regional hydrogen production capacity development efforts.

2 **Engage with regional stakeholders** – participate in hydrogen discussions with regional stakeholders, such as those in California, Washington, and British Columbia, to better plan and anticipate how regional activities may impact Oregon. Important groups include the California Air Resources Board, the California Energy Commission, the Washington Department of Transportation, the California Fuel Cell Partnership, Hydrogen BC, the Western States Hydrogen Alliance, and the Renewable Hydrogen Alliance, among others.

3 **Support industry-led technology demonstrations and pilot projects** – Some examples include:

- **FCEV and hydrogen fueling demonstrations** – support and encourage in-state actors developing demonstration projects. This might include the ongoing interests and efforts of TriMet. Look for demonstrations that reflect the entirety of the hydrogen ecosystem, from hydrogen production to delivery, storage and dispensing at public or private hydrogen stations and fleet utilization ranging from ports to commercial trucks, buses and private vehicles.
- **Hydrogen production** – support and encourage pilot projects that demonstrate low and zero-emission hydrogen production pathways, particularly those focused on improving the economics. This includes the efforts of EWEB, Northwest Natural, POET, Avangrid, and others who have formed collaborative teams to pursue renewable hydrogen production projects.

4 **Support policies enabling FCEVs and local, low or zero-carbon hydrogen production** – continue to ensure that hydrogen fuel cell vehicles are eligible in all zero-emission technology related legislation (e.g., goals and fleet acquisition requirements). Policies might also target low or zero-carbon hydrogen locally produced, as long-distance transport adds inefficiencies and cost.

5 **Ensure statewide regulations and processes enable FCEVs and hydrogen fueling infrastructure siting** – Some examples might include:

- Confirmation that hydrogen can be used as a transportation fuel in Oregon, without any restrictions relative to transport through tunnels, bridges, or ferries
- Verification that there is a transparent and streamlined permitting process for hydrogen fueling stations as well as for fuel cell vehicle maintenance bay conversions
- Confirmation that existing MDV/HDV length or weight restrictions do not preclude or hamper hydrogen FCEV adoption

Near-Term Leading Indicators

Oregon should regularly evaluate market indicators to determine if the FCEV industry is evolving more quickly or slowly than anticipated.

- **Commercial fleet activity** – look for increasing hydrogen interest, particularly across fleet operators in the transit bus and the medium- and heavy-duty sectors, including captive fleets with return-to-depot logistics and long-haul trucking fleets. TriMet has signaled interest by completing a hydrogen feasibility study for its fleet. In addition, watch major national fleets operating long-haul trucks such as Amazon, FedEx and Pepsico.

- **Original Equipment Manufacturer (OEM) activity** – look for auto and truck makers to signal interest in expanding FCEV production capacity, combined with an interest in offering these vehicles to markets outside California. Pay special attention to OEM manufacturers Cummins, Daimler, Hyundai, Hyzon, Kenworth, Nikola, and Toyota.

- **Federal policy** – look for major DOE or DOT funding commitments or opportunities targeting hydrogen fueling station investments outside California, including funding to build out the designated FHWA Alternative Fuels Corridors in Oregon. It is noteworthy that the U.S. DOE awarded $110 million through the Supertruck 3 program to four truck manufacturers for the development of Class 4-8 FCEV trucks. Also look for any indication of strict net-zero or heavy-duty emission standards.

- **California** – watch for investment commitments for highway corridor fueling stations, including investments for the heavy-duty long-haul trucking sector that would enable cross-state travel and might encourage interstate travel. As mentioned in Section 5 (Special Considerations for Oregon), 30% of Oregon's long-haul trucking highway vehicle miles traveled (VMT) originates out of state.

Mid-Term (2024-2027)

Mid-Term Recommendations

1 **Establish a statewide hydrogen planning effort** – Based on the statewide market assessment and regional stakeholder engagement during the previous phase, consider establishing a more formal hydrogen planning group that includes stakeholders across the state. The CaFCP has organized such an organization that includes key public and private actors across the hydrogen landscape. A meaningful first step might be to align Oregon's interests with this large and existing stakeholder group.

2 **Fleet coordination** – coordinate with Oregon's public and private fleets to understand battery vehicle technology and fuel cell vehicle technology needs and challenges to achieve a 100% zero-emission fleet. Regional corridor coordination - discuss opportunities with California, Washington, and British Columbia stakeholders to collaborate on one or more regional hydrogen fueling corridors to support light-, medium- and heavy-duty vehicle interstate travel and fueling.

3 **Develop and invest in pilot projects** – encourage low and zero-emission hydrogen production projects, fueling station deployments, and fleet demonstrations. Ensure the investment in fueling infrastructure is tightly connected to FCEV demand. Focus on projects that encourage large-scale hydrogen production and high station utilization to drive economies of scale. Consider the following vehicle and fueling pilot examples:

- **Light-duty Vehicles** – provided OEMs have signaled the availability of FCEVs, develop a market-centric pilot project with stations concentrated in a few urban areas and a large-capacity highway corridor station enabling intercity travel between several urban markets. (Note: this market-oriented approach, as deployed in California and discussed earlier, results in a different investment strategy than the state target-driven modeling conducted in this study where highway corridor stations precede urban stations.)

- **Medium and heavy-duty Trucking** – a project could be developed combining OEMs, fleet operators, and station providers in an ecosystem that enables goods movement throughout a select region, leveraging the fleets as anchor tenants for the fueling station(s). For example, one such project might involve the Port of Portland (PDX) and manufacturing or warehousing centers.

- **Heavy-duty Long-haul Trucking** – Consider a highway corridor project that introduces fueling stations and select fleets delivering goods along a major highway corridor, ideally coordinated with California.

- **Transit** – Consider a project to demonstrate the feasibility of transitioning transit buses with longer travel routes to hydrogen FCEVs and build the supporting depot fueling station(s).

4 **Target-setting** – coordinate with stakeholders across the state and consider establishing targets that would drive confidence in both the supply and demand for low and zero-emission hydrogen production, vehicle availability, and vehicle fleet acquisition.

5 **Electrofuel tariff** – review Tacoma Power's unique electrofuel tariff pilot and consider implementing a similar pilot of this rate design across select Oregon utilities where it is determined to be feasible (Tacoma Public Utilities, 2021). Recognizing that some of the rationale for regulator approval of this rate may be due to unique characteristics of Tacoma Power (generation sources, economic development justification), it is worth understanding this rate design for applicability elsewhere.

6 **Pursue federal funding opportunities for hydrogen infrastructure** – building on the work completed in previous years, consider submitting a funding proposal to the U.S. DOE or DOT (e.g. under the IIJA's competitive grant program) for hydrogen fueling infrastructure. Consider developing a project concept, building support (including regional support) and identifying partners for a project that might propose the buildout of one to five hydrogen fueling stations on I-5 in Oregon, which is a designated hydrogen corridor under the FHWA's Alternative Fuel Program.

Mid-Term Leading Indicators

Oregon should regularly evaluate market indicators to determine if the FCEV industry is evolving more quickly or slowly than anticipated.

- **Commercial fleet activity** – look for either hydrogen FCEV purchase announcements or commitments across major fleet operators or partnering announcements with fueling providers (e.g., FirstElement Fuel). These signals can communicate a growing confidence in hydrogen FCEV technology (and demand certainty for OEMs) and the associated need to secure fueling solutions.

- **OEM activity** – continue to look for automakers and truck makers to signal their intent to expand FCEV production and to offer these vehicles to markets outside California.

- **Federal policy** – continue to look for any major DOE or DOT funding commitments or opportunities targeting hydrogen fueling station investments outside California. Also look for any indication of strict net-zero or heavy-duty emission standards.

- **California** – look for the development of a hydrogen highway fueling corridor for long-haul trucking that could relatively quickly result in increased demand for hydrogen fueling across Oregon's connecting highway corridors (e.g., I-5).

- **Hydrogen production** – look for signs that hydrogen production is ramping up, particularly low and zero-emission hydrogen. Look also for utility engagement and any indication that utilities are planning to use hydrogen as a grid storage solution. As a significant portion of the economics of operating hydrogen FCEVs depends on the cost of hydrogen production, track any achievements or announcements relative to these evolving economics.

Long-Term (2028-2035)

Long-Term Recommendations

1. **Statewide hydrogen planning effort** – continue to leverage this coalition to track hydrogen plans and needs across fleets, vehicle manufacturers, station providers and hydrogen producers.

2. **Regional coordination** – continue to work with California, Washington, and British Columbia stakeholders to build the requisite West Coast hydrogen fueling corridors that support the needs of the statewide hydrogen planning effort and allow regional interstate travel.

3. **Transition from pilot projects to scale** – based on the mid-term outcomes and those mobility sectors moving most quickly to hydrogen FCEV solutions, establish phased plans to invest public/private funds in large-scale solutions that deliver low and zero-emission hydrogen production, high-capacity fueling station deployments and large FCEV fleet deployments. Ensure the investment in fueling infrastructure is tightly connected to FCEV demand. Use a whole-system approach that considers multi-modal fueling (public LDV, local/commercial MDV goods movement, long-haul HDV) and high station utilization to help drive economies of scale and future-proofing to ensure reliability.

4. **Consumer and fleet awareness** – depending on the leading light-, medium- and heavy-duty vehicle indicators observed in the previous phase, consider establishing an education and outreach program to increase consumer and fleet operator awareness of hydrogen as a transportation fuel.

Long-Term Leading Indicators

Oregon should regularly evaluate market indicators to determine if the FCEV industry is evolving more quickly or slowly than anticipated.

- **Commercial fleet activity** – look for scale in fleet announcements. Determine if a pattern is developing for the use of hydrogen FCEVs across different sectors (e.g. LDVs, ports, food & beverage, long-haul trucking, transit). Discern whether these transitions are occurring only in California or whether fleets plan to adopt FCEVs in all geographies. Look for patterns in the use of private depot vs. public fueling stations.

- **Fueling providers** – look for major fueling station network announcements and investments. Determine whether these investments are growing outside California. Determine if major fueling/fleet/OEM partnerships are evolving.

- **OEM activity** – continue to look for automakers across the LDV sector and truck makers across the MDV and HDV sectors to signal their intent to expand FCEV production and to offer these vehicles to markets outside California.

- **Federal policy** – Look for signs that the federal government is showing increasing leadership in supporting the development of a hydrogen economy, including investments beyond research, a national hydrogen fueling station network, support for FCEVs in transit, renewable hydrogen production and grid storage, or FCEV procurements by the GSA, including the military.

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