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A Hydrogen Hub Blueprint for the California Supply Chain

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CSUTC California State University Transportation Consortium

CALIFORNIA STATE UNIVERSITY LONG BEACH

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16. Abstract As global climate targets tighten and state regulations accelerate, hydrogen technology presents a significant opportunity to help California supply chain and transportation stakeholders comply with state emissions mandates and global goals aimed to reduce the impacts of climate change. However, while fuel cell costs and infrastructure have received attention, workforce development remains overlooked. Hydrogen fuel cell electric vehicles (FCEVs) are especially promising for diesel-reliant sectors that are hard to decarbonize without negatively impacting operational efficiency. But scaling hydrogen vehicles and infrastructure in tandem with emerging consumer and industrial markets will not be easy. State and federal policies, often conflicting, further complicate the hydrogen rollout, which will require a workforce with the collective knowledge, skills, and abilities (KSAs) to design, develop, operate, and maintain this new system. Who will prepare that workforce? To address that question, the PIs for this report partnered with five California State University campuses (the CSU5+) to conduct the Hydrogen Workforce Peer Exchange. The research team then conducted a literature review with a focus on both U.S. federally funded workforce programs and international efforts. After conducting a comparative labor market analysis of domestic and international hydrogen production, transport, storage, and fueling systems development, researchers identified 21 key occupations active in the hydrogen supply chain today and identified Australia and Canada as leading nations in the development of the hydrogen industry. Within this broader context, the "Hydrogen Workforce Blueprint for the Southern California Supply Chain" assesses opportunities and challenges related to the hydrogen rollout in Southern California, home of the largest supply chain gateway in the nation. Preparing a skilled hydrogen workforce now means Southern California can lead the nation in building a cleaner, more resilient supply chain—one that advances climate goals and keeps goods and people moving efficiently.			
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Foreword

In the weeks leading up to the completion of this "Hydrogen Workforce Blueprint for the Southern California Supply Chain," and while attending a conference focused on freight systems, one of the PIs for this project ran into a colleague who oversees supply-chain systems for a large public agency in California. The freight leader shared candid frustrations: "All these hydrogen presentations, playbooks, and tool kits are just a bunch of ideas! I need a *blueprint* with a practical plan for how to prepare."

The PI smiled: "It just so happens that my team is in the final stages of publishing a hydrogen workforce blueprint that directly addresses your concerns." It was true. The primary objective for the Blueprint was to assess the state of preparedness in Southern California to recruit, train, and empower the emerging hydrogen workforce. If freight leaders needed a blueprint to help them develop a practical plan for how to prepare their workforces for the hydrogen transition, that's what they would get.

Both Blueprint PIs shared the same view; however, they faced a critical challenge. In the months that had passed since proposing the winning Blueprint concept to the Mineta Transportation Institute, the entire hydrogen landscape had changed. More than a billion dollars in funding to support the development of a hydrogen hub in California was now in question due to shifts in federal policy associated with a new presidential administration. Shifts in federal policy were also halting momentum associated with California's bold zero-emission vehicle (ZEV) deadlines that were pushing supply-chain stakeholders to adopt new hydrogen technologies. These federal shifts compelled the PIs to reassess every aspect of the Blueprint project only to ultimately reaffirm the value of the project.

The original Blueprint concept responded to a workforce development gap that both PIs had identified in the early rollout of the $1.2 billion U.S. Department of Energy (DOE)-funded Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES) Hydrogen Hub project. In 2023, California's ARCHES project was selected as one of seven regional locations "to accelerate the commercial-scale deployment of clean hydrogen, helping to generate clean, dispatchable power, create a new form of energy storage, and decarbonize heavy industry and transportation."[1] This was great news for California. However, as active members of the ARCHES project, both PIs noticed that very little discussion was devoted to preparing the current and future workforce for the hydrogen transition. These observations led the PIs to develop a central problem statement: workforce and learning development priorities were not aligned with the technological objectives

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1 "Regional Clean Hydrogen Hubs," United States Department of Energy, accessed June 26, 2025, https://www.energy.gov/oced/regional-clean-hydrogen-hubs-0.

in the hydrogen hub planning associated with the ARCHES project. Identifying that problem statement inspired the PIs to develop the winning proposal for this Hydrogen Workforce Blueprint for the Southern California Supply Chain.

Even if the ARCHES funding is cancelled and opposition to hydrogen is enacted by the federal government in the years ahead, there is still plenty of money and momentum for hydrogen projects and programs in California. The logic and need for the Hydrogen Workforce Blueprint remain critical for several reasons:

1. The Long Beach–Los Angeles Port Complex remains the largest freight gateway in the country, and communities adjacent to the port and near related truck and rail routes will continue to demand cleaner supply-chain systems.

2. In late December of 2024, the CEC "approved a $1.4 billion investment plan that accelerates progress on the state's electric vehicle (EV) charging and hydrogen refueling goals."[2]

3. Another highly significant, but less discussed boost for the hydrogen rollout relates to the California Public Employees' Retirement System (CalPERS), the largest public pension system in the U.S. In 2024, CalPERS announced that it would "commit at least $100 billion in climate solutions" to support the production of renewable energy sources—such as solar, wind, and hydrogen—as well as "technologies that capture and store CO_2 emissions" and waste management solutions, which include "reducing, recycling, reusing, and capturing methane from landfills."[3]

4. In addition to hydrogen funding from the State of California, there is a range of ways that municipalities and regional stakeholders can form public-private partnerships (P3s) to leverage private capital investment along with state programs and incentives to secure funding for hydrogen projects and programs.

Writ large, the global transition toward sustainable and clean energy sources has propelled the hydrogen fuel industry, and the workforce that drives it, into the spotlight. As governments, industries, and consumers alike recognize the potential of hydrogen as a clean energy carrier, the demand for skilled professionals in the hydrogen fuel sector is on the rise. Workforce development

[2] "CEC Approves $1.4 Billion Plan to Expand Zero-Emission Transportation Infrastructure," California Energy Commission (California Energy Commission, December 11, 2024), https://www.energy.ca.gov/news/2024-12/cec-approves-14-billion-plan-expand-zero-emission-transportation-infrastructure.

[3] "$100 Billion Climate Action Plan" California Public Employees' Retirement System (CalPERS), accessed July 3, 2025, https://www.calpers.ca.gov/investments/sustainable-investments-program/net-zero.

plays a pivotal role in shaping a sustainable and efficient hydrogen economy, ensuring that the industry can meet its potential while addressing the challenges associated with the energy transition. It is for these reasons that the central focus of this Blueprint remains the same: provide an evidence-based assessment to help freight leaders ensure that workforce development keeps pace with the rollout of new hydrogen technologies.

The Blueprint is intended to provide a strategic assessment of the current and future workforce needs related to implementing what will one day be a viable hydrogen market capable of consistently providing hydrogen at a price that is equal to or less than the price of diesel. When that day will come is hard to predict, and recent events have only further complicated such forecasting. However, if supply-chain leaders wait until the day that the price of hydrogen is competitive with diesel, that day will never come because ultimately it will be the workforce that will bring a future of affordable and plentiful hydrogen to fruition.

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Executive Summary

The "Hydrogen Workforce Blueprint for the Southern California Supply Chain" provides an evidence-based assessment to help freight leaders ensure that workforce development keeps pace with the rollout of new hydrogen technologies. The Blueprint identifies workforce development challenges associated with the emerging maritime, cargo-handling, rail, and trucking segments of the supply-chain that connect freight moving from the San Pedro Bay ports to destinations statewide, nationally, and internationally.

To meet workforce goals for the project, the PIs forged partnerships with faculty and leadership at five California State University (CSU) campuses based in Southern California (specifically Long Beach, Dominguez Hills, Los Angeles, Northridge, Fullerton, and Pomona). To ensure that maritime workforce planning was incorporated into the Blueprint, the PIs also partnered with leadership from Cal Maritime to participate in CSU5+ research activities.

This Blueprint is not intended to be an exhaustive technological summary nor a definitive economic analysis. It focuses on the emerging workforce development priorities for the future hydrogen workforce to help supply-chain leaders hone strategies to prepare the professionals who will design, develop, operate, and maintain the future systems that will:

1. generate hydrogen;
2. transport hydrogen to critical nodes in the Southern California supply chain; and
3. fuel ships, cargo-handling equipment, locomotives, and trucks that move freight throughout California and the nation.

To provide a workforce narrative, the Blueprint tells a story about the professionals who will lead the hydrogen transition, not the individual technologies they will operate. The central goal in developing the Blueprint is to tell a workforce story that a hydrogen industry expert could read to gain a richer sense of where the human and machine systems meet now and in the future. At the same time, the Blueprint seeks to give workforce development experts a richer sense of the knowledge, skills, and abilities (KSAs) that future professionals will need to produce, transport, and store hydrogen to fuel the ships, cargo-handling, rail, and truck systems that move goods across the global supply chain. The Blueprint includes case studies, labor market analysis, and narrative elements to make it accessible to both workforce development professionals, hydrogen experts, and a broader audience of policymakers and educators.

The comparative labor market analysis of domestic and international hydrogen production, transport, storage, and fueling systems conducted for this report provides a framework identifying 21 key occupations active in the hydrogen supply chain today. Within this broader context, the Blueprint assesses opportunities and challenges related to the hydrogen rollout in Southern California, home of the largest supply chain gateway in the nation.

The Blueprint presents a series of future scenarios to demonstrate viable paths to long-term adoption of hydrogen. Evidence and analysis in this Blueprint affirm that workforce development and upskilling is mission-critical for the hydrogen rollout in California, both nationally and internationally. If lawmakers, the regulators they direct, educators, and industry leaders do not develop accurate and compatible hydrogen KSAs, the rollout will be delayed indefinitely and at great cost. Additionally, it would be a mistake to take a *laissez-faire* approach and wait until hydrogen reaches cost competitiveness: if there is not sufficient hydrogen workforce with the requisite KSAs, hydrogen will not become competitive with the fossil fuel industry, which *already has* its own system of workforce development and a pool of workers who possess the requisite KSAs. Evidence and analysis in this report also provide a rationale for industry professionals, lawmakers, and regulators to consider the strategic value of incorporating a near-zero emissions phase into long-range hydrogen implementations. The Blueprint ends with recommended next steps to address workforce and KSA gaps, policy challenges, and ways to consider a broader definition of the emerging hydrogen workforce.

Writ large, the global transition toward sustainable and clean energy sources has propelled the hydrogen fuel industry, and the workforce that drives it, into the spotlight. As governments, industries, and consumers alike recognize the potential of hydrogen as a clean energy carrier, the demand for skilled professionals in the hydrogen fuel sector is on the rise. Workforce development plays a pivotal role in shaping a sustainable and efficient hydrogen economy, ensuring that the industry can meet its potential while addressing the challenges associated with the energy transition.

1. Introduction

1.1 Quick Start Guide

To meet the stated goals of the Hydrogen Hub Blueprint, the PIs for this project forged partnerships with faculty and leadership at five California State Universities (CSUs) based in Southern California (specifically Dominguez Hills, Los Angeles, Northridge, Fullerton, and Pomona) in addition to CSULB. Together, these universities will be referred to as the CSU5+ in this report. To ensure that maritime workforce planning was incorporated into the Blueprint, the PIs also invited leadership from Cal Maritime to participate in CSU5+ research activities.

This Blueprint is not intended to be an exhaustive technological summary nor a definitive economic analysis. It focuses on the emerging workforce development priorities for the future hydrogen workforce, providing an evidence-based assessment to help supply-chain leaders identify workforce development strategies to prepare the professionals who will design, develop, operate, and maintain the future systems that will:

1. generate hydrogen;
2. transport hydrogen to critical nodes in the Southern California supply chain; and
3. fuel ships, cargo-handling equipment, locomotives, and trucks that move freight throughout California and the nation.

To provide an accessible workforce narrative, the Blueprint tells one possible story of the professionals who will lead the hydrogen transition, not the individual technologies they will operate. The central goal in developing the Blueprint is to tell a workforce story that a hydrogen industry expert could read to gain a richer sense of where the human and machine systems meet now and in the future as the supply chains that produce hydrogen emerge, making it possible to fuel the ships, cargo-handling, rail, and truck systems that move goods across the global supply chain.

To make the workforce narrative in the report accessible to readers who are not familiar with hydrogen production, transmission, and fueling technologies, this Blueprint provides hyperlinks in a table of terms and information on relevant occupations in Appendix B. To provide a richer sense of the current and emerging professionals who will design, develop, operate, and maintain the hydrogen systems of the future, this Blueprint provides hyperlinks to tables in the Appendices that identify specific workforce development information about the critical occupations. In some cases, official Bureau of Labor Statistics job titles and associated Standard Occupational Codes (SOC) are available for hydrogen-relevant occupations. In other cases, the Blueprint forecasts the most likely new occupations with hyperlinks to associated knowledge, skills, and abilities (KSAs).

1.2 Storyline

The storyline for this Hydrogen Workforce Blueprint begins roughly 100 miles from the Port of Long Beach in Victorville, California. In this unassuming locale, Anaergia Inc.—a publicly traded company on Canada's Toronto Stock Exchange (ANRG)—operates its SoCal Biomethane facility located at the Victor Valley Wastewater Reclamation Authority. At the Anaergia facility, wastewater treatment operators and anaerobic digester operators take biosolids separated by the adjacent water treatment facilities and transfer them into anaerobic digester tanks, where microorganisms break down the biosolids into biogas. The Anaergia team works together to oversee the system, maintaining optimal temperature, flow, pH level, and microbial balance. After creating the biogas in its raw form, Anaergia gas treatment technicians initiate a process called "upgrading" to remove contaminants such as carbon dioxide and hydrogen sulfide, which can damage pipelines over time.

After the upgrading process is complete, the purified biogas, also called renewable natural gas (RNG), is injected into existing natural gas pipelines by pipeline technicians authorized by SoCalGas, who track its movement as it travels 100 miles south to the Port of Long Beach (PoLB). This technical feat is accomplished using a tracking system that ensures that the amount and quality of RNG matches what is ultimately withdrawn at the PoLB's Toyota terminal, where the Tri-Gen facility is located. This "Book-and-Claim" system allows Toyota to access RNG using existing pipeline infrastructure, which is far more affordable than building a new dedicated pipeline to the PoLB.[4]

After the pipeline technicians at the PoLB Toyota terminal access the RNG, members of the Tri-Gen team initiate the conversion process. To complete that process, the Tri-Gen team converts the RNG into hydrogen, water, and electricity using a modified version of the steam methane reformation (SMR) process. Instead of burning fossil fuels to generate the heat required to initiate the conversion process, the Tri-Gen system uses heat and steam byproducts from the generation of hydrogen fuel to achieve the elevated temperatures required. This alternate heat generation makes it possible for Tri-Gen chemical process operators to convert the RNG into Syngas, which is a mixture of hydrogen and carbon monoxide. The carbon monoxide within the Syngas is then used to extract additional hydrogen from the water. Finally, the aggregate hydrogen produced is purified to remove any excess carbon monoxide—resulting in a zero-emission fuel

[4] "Book & Claim Explained," *SkyNRG*, November 17, 2022, https://skynrg.com/book-claim-explained-what-is-book-and-claim/.

ready to power the maritime, cargo-handling, locomotive, and heavy trucking systems of the future.

From a workforce perspective, the Anaergia–PoLB–Toyota–Tri-Gen storyline holds a wide range of important insights that inform the governing logic of this report. First, the Anaergia processes and related occupations fall outside of what is considered the hydrogen workforce, yet they are directly related to very important technological processes that could generate a great deal of sustainable hydrogen. The wastewater treatment operators, for example, are performing a necessary role to ensure that their municipality has access to clean water, but by modifying the traditional process, their work now directly contributes to the production of hydrogen.

Second, the transfer of biogas from Anaergia to the Tri-Gen facility presents a valuable case study reflecting how much can be accomplished during the retrofit stage of the hydrogen rollout. A great deal of the discussion surrounding the rollout of hydrogen as a viable energy source for heavy industry relates to "new build" solutions. Anaergia and Tri-Gen reflect innovative retrofit technologies that can use existing infrastructure to generate sustainable hydrogen at this moment in time. New-build hydrogen pipelines are indeed necessary to transport hydrogen using materials that are not vulnerable to embrittlement. However, the Anaergia and Tri-Gen technologies demonstrate that it is possible to move biogas feedstock using existing pipeline infrastructure to produce hydrogen. Further, the biogas feedstock derived from wastewater facilities is a model that could be applied to wastewater facilities throughout the state and nation. There are currently two Tri-Gen facilities operating in Southern California—one at the PoLB and the second in nearby Fountain Valley, Orange County. The success of the Tri-Gen (receiving RNG from a wastewater facility) could be replicated statewide by linking other wastewater facilities to hydrogen fuel production.

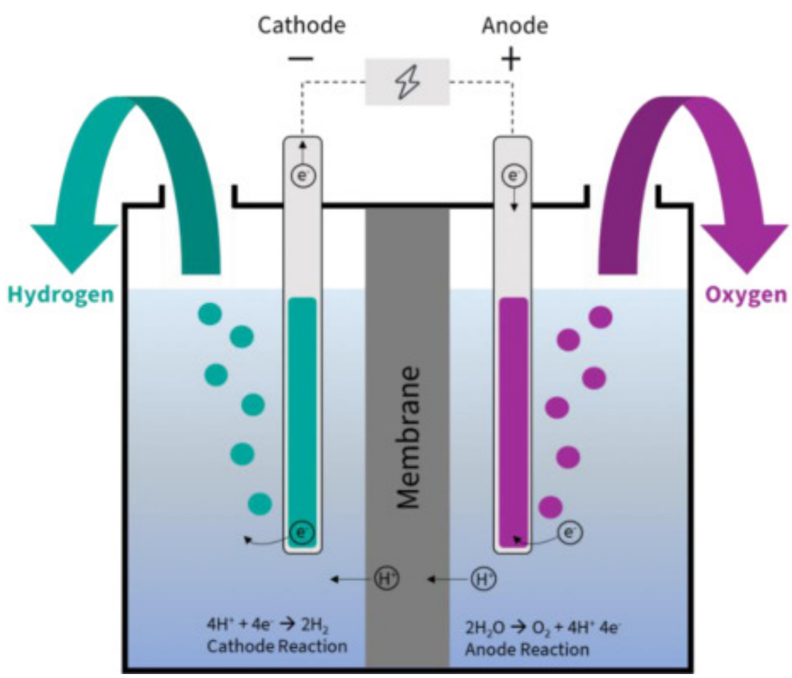
1.3 Electrolysis

Approximately 1% of hydrogen in the U.S. is produced via electrolysis. Currently, most U.S. hydrogen fuel is produced via steam methane reformation (discussed below); other methods include biomass gasification, pyrolysis, and the use of solar energy or microorganisms. Electrolysis is addressed first in this report because it is currently one of the 'greenest' forms of hydrogen fuel production . The production of hydrogen via electrolysis at a scale necessary for full commercial deployment would mark an impressive milestone for decarbonization.

At its core, electrolysis consists of splitting water into its atomic constituents, hydrogen and oxygen. The process begins at a water treatment plant, where industrial engineering technicians transfer various sources of raw water (groundwater, city water, wastewater, surface water, and seawater) into storage or feed tanks. This can be done via pumps and existing pipelines or by water delivery trucks. The feed water gets pumped through a filtration system in which water treatment specialists oversee the removal of organic matter, silica, chlorine, and salts. Once this pretreatment is complete, the purified water is pumped into a product water storage tank where it remains until the polishing step. In this second step, the purified feed water is pumped into a second filtration system in which chemical plant operators oversee the removal of a large portion of the ion load in an effort to reduce electrical conductivity and water treatment specialists remove salts (calcium, magnesium, chloride, etc.); both ions and salts are damaging for electrolysis equipment. Additionally, remaining gases are removed before the now ultrapure water is pumped into storage tanks where it can be stored or distributed. The water treatment plant is maintained by chemical technicians.

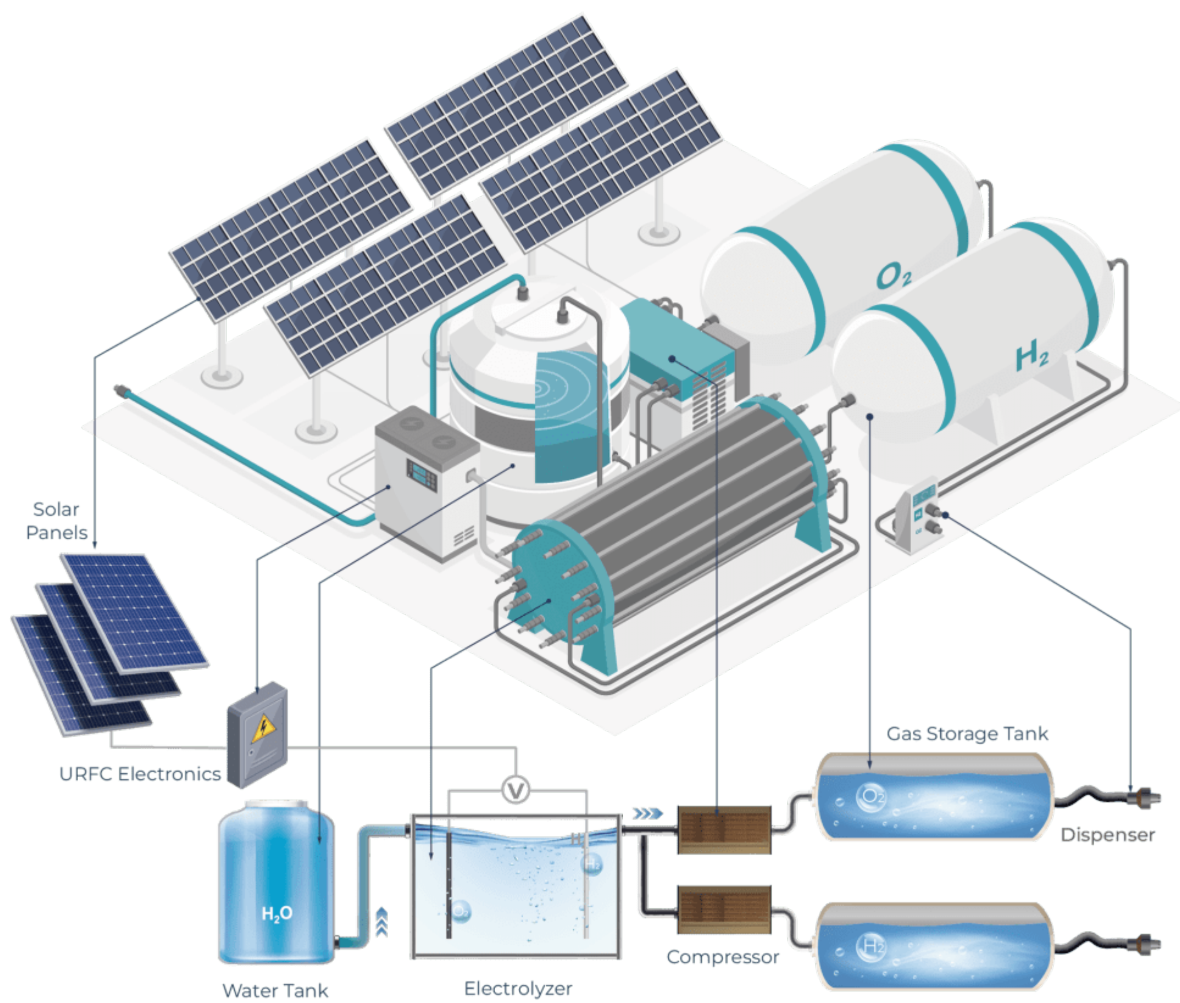
Once the ultrapure water arrives at the hydrogen plant, industrial engineering technicians transfer it into feedstock tanks. Renewable energy in the form of electricity is needed for the electrolytic process. To produce hydrogen, solar and wind energy are the most used. Hydrogen plants can pull electricity directly from the grid, since energy gained through wind or solar applications gets released into the electrical grid. In certain circumstances, mostly related to proximity of renewable energy sources, pure renewable energy can be pulled from specialized microgrids.

Figure 1. Electrolyzer Example



In the hydrogen plant, industrial engineering technicians pump the ultrapure feed water to the electrolyzer unit, where electrolyzer maintenance technicians then supply the electrolyzer cell stacks with electricity, triggering the chemical reaction to split the water into hydrogen and oxygen. An electrolyzer unit consists of an anode (positively charged), cathode (negatively charged), and electrolytes. The flow of electricity between the electrolytes splits the water into hydrogen and oxygen, which then accumulate at the cathode and anode respectively. There are currently three established forms of electrolyzer units: alkaline, polymer electrolyte membrane, and solid oxide. While the principle is the same across all types of electrolyzer units, alkaline units are the most common and ideal for industries requiring high volumes of hydrogen. Industrial engineering technicians transfer the accumulated hydrogen into storage tanks, where it can either be stored, connected to a pipeline for dispersion, or transported to end users. The accumulated oxygen can either be stored and used in other industrial settings or released into the atmosphere at no carbon cost.

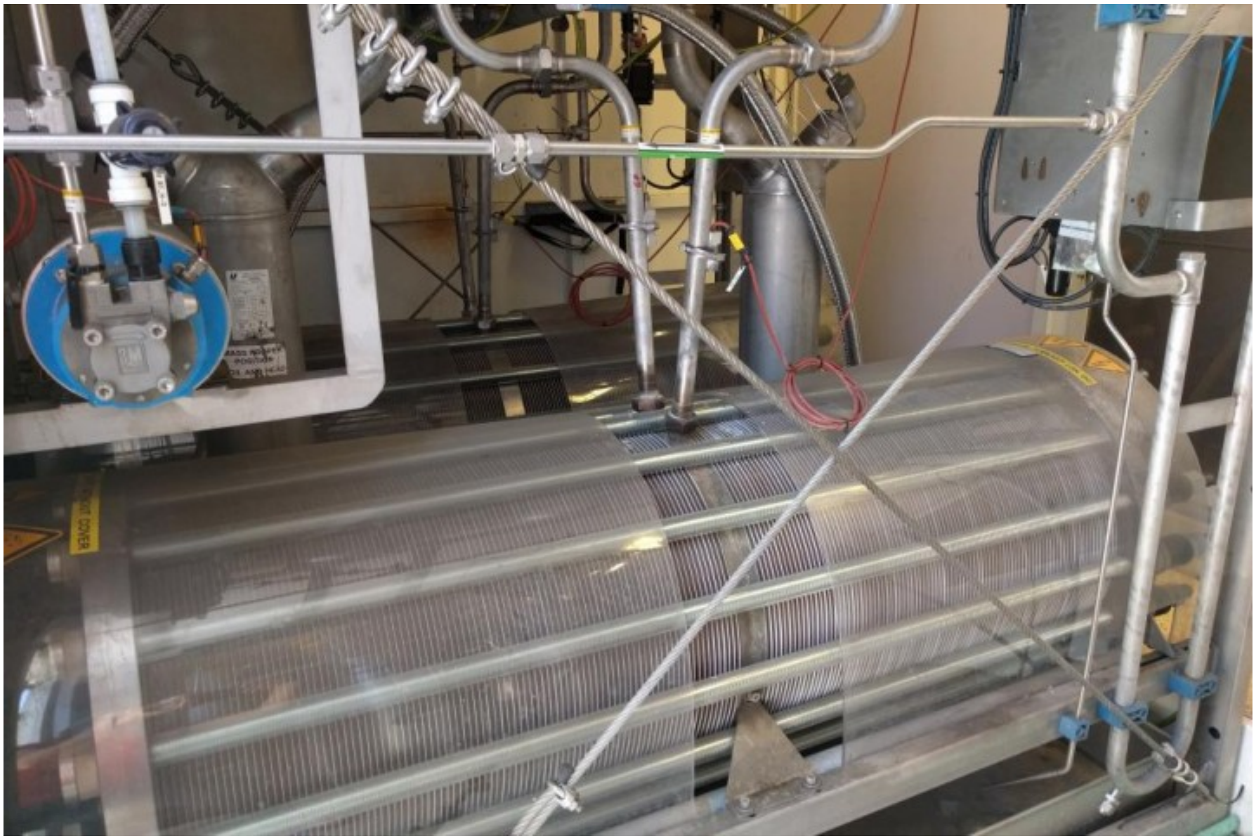
Figure 2. Hydrogen Production via Electrolysis Using Solar-Generated Electricity



Copyright © 2025 Jennings Anodes USA Inc.[6]

[6] "Hydrogen Production by Water Electrolysis," Jennings Anodes USA Inc., accessed June 26, 2025, https://jenningsanodes.com/applications/hydrogen-production-by-water-electrolysis/.

Figure 3. Hydrogenics Electrolyzer at the Cal State LA Hydrogen Station[8]



1.4 Steam Methane Reformation

Approximately 95% of all hydrogen in the U.S. is generated by Steam-Methane Reformation. The process involves mixing high-pressure steam and natural gas to form hydrogen. It begins once utility companies finish processing natural gas. Once the gas is produced, compression station operators are responsible for maintaining and operating the compressors that pressurize the gas and allow it to travel long distances via the gas grid. compression station operators are responsible for maintaining the optimal flow, temperature, and pressure needed to safely and reliably transfer gas from its origin point to its destination. Pipeline operators oversee the transportation of the now-pressurized gas and alert compression station operators of any issues.

Hydrogen production begins once natural gas is produced. To transport natural gas to a hydrogen producing facility, compression station operators activate and monitor the temperature, flow, and pressure to maintain optimal conditions. Once pressurized, pipeline technicians oversee the natural

[8] "Equipment | Cal State LA," Cal State LA Hydrogen Research and Fueling Facility, accessed June 25, 2025, https://www.calstatela.edu/ecst/h2station/equipment.

gas pipelines by using the Supervisory Control and Data Acquisition (SCADA) system, which allows them to oversee and adjust the pressure, temperature, and flow of gas moving throughout the system. Once the natural gas reaches the hydrogen plant, it must be purified to ensure that it is free from contaminants. Gas plant operators direct the gas through diffusion beds, which remove any contaminants that could damage the sensitive equipment in the facility. To initiate the steam methane reformation process responsible for producing hydrogen, the plant must produce steam to mix with natural gas. To generate that mixture, gas plant operators use heat recovery steam generators to take the excess heat from various reactions performed in the facility and generate the steam needed. If these self-generating mechanisms are not able to produce sufficient heat levels to produce steam, gas plant operators activate auxiliary boilers to generate supplemental heat and steam to ensure that they burn the minimal amount of fuel needed to keep the reaction going.

Chemical plant process operators mix the steam with natural gas by adjusting valves to regulate the flow of natural gas and steam to ensure that the correct ratio is achieved. If the mixture is unbalanced, carbon buildup will occur and damage the equipment over time, which is why the operator must carefully monitor the pressure, temperature, and flow of the gases and adjust when needed. A reformer operator oversees the 1500 ˚F reformer furnace, where the natural gas and steam mixture reacts and transforms into carbon monoxide and hydrogen. The resulting gas mixture passes through shift reactors where operators add more steam and adjust the temperature to create more hydrogen and convert carbon monoxide into carbon dioxide.

Separation technicians operate the system needed to isolate hydrogen from the other gases and remove any remaining contaminants by moving the gas through absorption beds. Instead of releasing carbon dioxide into the atmosphere, carbon capture technicians redirect the flue gas to heat exchange systems where it can be cooled for better carbon dioxide capture. The technicians then transfer the gas into an absorption column where the gas is circulated alongside a solvent to remove carbon dioxide from the flue gas. Once the process is complete, the rich solvent mixture passes through an economizer to heat up the solvent by exchanging heat with lean solvent to reduce the energy needed to remove the carbon dioxide from the rich solvent. Once the rich solvent moves to the stripper column, more heat is added to separate the carbon dioxide from the solvent. The now-lean solvent is moved back into the economizer, where it exchanges heat with the cool rich solvent, before being reused in the absorption column. The separated carbon dioxide is purified by technicians, who remove water and oxygen before compression station operators prepare the carbon dioxide for transport by compressing it to the appropriate level. Pipeline technicians direct the gas into pipelines while monitoring vital sensors to ensure a safe transfer. At the storage site, injection well technicians manage the flow of carbon dioxide into porous rock formations deep underground, where the carbon dioxide will remain long term. Thus, steam methane reformation is not a zero-emission process; however, the carbon dioxide production occurs in a controlled environment that also facilitates its capture—to make this a green-energy process.

1.5 Mobile Refueling

Figure 4. Rocketruck Mobile Fuel-Cell Generator on Display at Cal State LA

Credit: Cal State LA

The PoLB is home to hydrogen-powered rubber-tired gantry (RTG) cranes that stack and move shipping containers onto trucks. This heavy-duty equipment cannot be taken to traditional refueling stations due to its size and weight; instead, mobile refueling technicians bring the fuel to the equipment. Mobile refueling stations are truck-mounted stations equipped with storage tanks, compressors, and dispensers to provide fuel to machinery that cannot be taken to traditional refueling stations. The mobile refueling technicians inspect the tanks for any damage or potential degradation before transferring the gas from the main storage unit into the mobile tank using pressure transfer or by pumping it in. The mobile refueler is driven to the RTG crane and positioned for refueling. The technicians begin to repressurize the gas by operating the control valves installed on the truck; they then connect a hose to the tanks and to the RTG crane. During this process, the technicians ensure safe transfer by checking for leaks and monitoring the gas temperature and flow rate.

2. Methodology

2.1 Blueprint Kickoff

To meet the stated goals for this report, the Blueprint team formed partnerships with Industry Advisors (see item below) and with faculty and leadership at five other California State University (CSU) campuses based in Southern California (specifically Long Beach, Dominguez Hills, Los Angeles, Northridge, Fullerton, and Pomona), also known as the CSU5+. To ensure that maritime workforce planning was incorporated into the Blueprint, the PIs also invited leadership from Cal Maritime to participate in CSU5+ research activities. The PIs convened project kickoff meetings with the CSU5+ and Industry Advisors in June 2024 to define the scope and objectives for the Blueprint.

2.2 Industry Advisors

Cory Shumaker, Director of Market Development for the California Hydrogen Business Council, acted as this project's industry advisor. Shumaker introduced the team to companies in Southern California actively using hydrogen in their day-to-day operations, and he facilitated calls with industry contacts such as Tim McRae, the California Hydrogen Business Council Vice President of Public Affairs, and Brian Goldstein, the Executive Director of Energy Independence Now.

2.3 Literature Review

The Blueprint research team reviewed existing literature surrounding hydrogen workforce development and archived existing programs actively helping develop the future workforce. The team initially focused on federally funded programs intended to develop the workforce through higher education but later expanded their search to any certification offered by established entities such as The American Institute of Chemical Engineers. Once the team exhausted all programs based in the U.S., they expanded their search to international programs.

2.4 Labor Market Analysis

The Blueprint research team identified 21 key occupations that are active within the hydrogen supply chain today. In the literature review, the team identified Australia and Canada as leading nations in the development of the hydrogen industry. The team assigned SOC codes to the 83 unique job titles present within each country's respective reports by analyzing the duties associated with each job title and comparing them with the major SOC code categories until a specific code was found to fit best. Using the identified SOC codes as a foundation, the team conducted a labor market analysis in Southern California to determine which roles are currently relevant in the development of the industry and will likely contribute to the early development of the state's hydrogen sector.

2.5 Hydrogen Site Visits

To better understand the workforce needs of companies participating in the Southern California hydrogen supply chain, the Blueprint research team reached out to its contacts at Yusen Terminals and Toyota. Yusen Terminals, in partnership with MITSUI E&S Co., Ltd. and PACECO Corp., has had a hydrogen-powered rubber-tired gantry (RTG) crane in operation since 2014. During the tour of the facility, the team was able to ask if the crane had any significant operational differences compared to traditionally diesel-powered RTG cranes. The team learned that the crane was operating better than initially expected, but many operators requested an additional control pedal to be in parity with the diesel cranes. However, the additional pedal is not needed to operate the cranes and does not actually serve a purpose.

To ensure that both the operational side and production side of the supply chain are represented, the team leveraged its contacts with the Toyota Motor Corporation to speak with the team responsible for managing the Tri-gen facility.

2.6 CSU5+ Survey

To develop an inventory of courses and programs offered at CSU5+ campuses that will support a future Southern California hydrogen hub learning and workforce development priorities, the Blueprint research team developed nine survey questions to assist in the knowledge transfer. Apart from the basic self-identification questions, the team included questions asking each university representative to catalog what specific classes and programs they offer. The team included questions asking university representatives what section of the supply chain their programs support and questions measuring their level of awareness of other hydrogen-related workforce development programs. The final question included in the survey asked the representative to provide a brief summary of how their university is addressing the KSA gaps within the hydrogen supply chain. The team obtained an Institutional Review Board (IRB) waiver for this project as the collected responses are anonymized in subsequent discussions.

2.7 Peer Exchange

To discuss the results of the survey completed, the Blueprint research team conducted the Hydrogen Workforce Peer Exchange on June 6 virtually with representatives of the Long Beach, Los Angeles, Northridge, and Pomona California State University campuses, as well as the California Maritime Academy. Based upon findings and responses from the prior survey and research, the team developed a set of discussion points to discuss collaboration, curriculum development, industry engagement, and the creation of a Blueprint for hydrogen workforce development. The findings from the peer exchange discussion were noted by the team and compiled in a Peer Exchange Meeting Summary document.

3. Literature Review

To promote the growth of the hydrogen industry, state and federal governments have created several initiatives to reduce the cost of hydrogen and train the future workforce. At the same time, private-sector investment in hydrogen fuel-cell electric vehicles and their corresponding technologies continues. The following review of literature begins with an overview of workforce development at the state, national, and international levels.

A review of the literature reveals that the most cited concerns regarding the emergent hydrogen economy today are (1) market demand and (2) infrastructure development. It is difficult if not impossible to disentangle these two factors. Without market demand, it is hard to garner support for the development of infrastructure, but without the development of infrastructure, it is hard to grow market demand. At the same time, however, there is a *third* issue that is crucial for the development of the hydrogen economy but has not received as much attention: workforce development. This report features an overt emphasis on this third and pivotal issue.

3.1 A Brief Introduction to Hydrogen

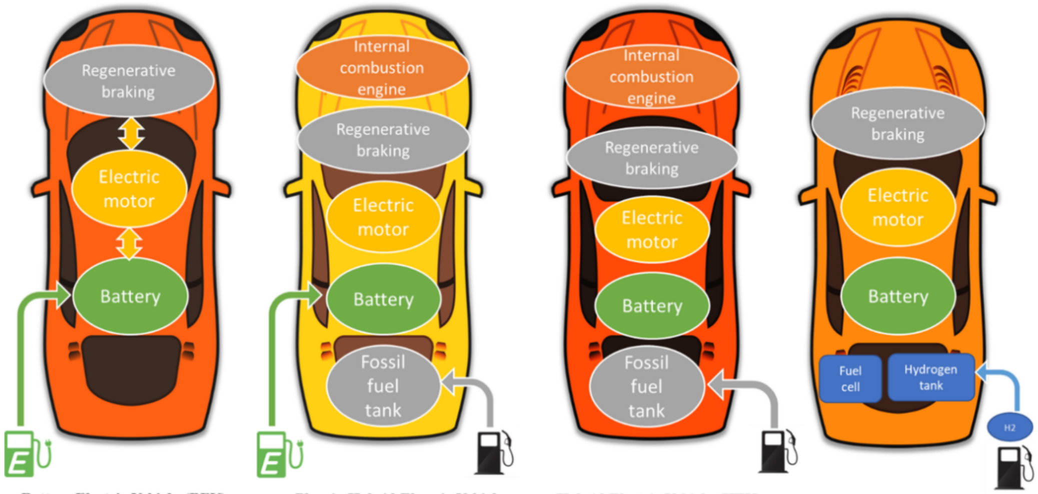
Hydrogen is an emergent alternative fuel source that is increasingly attractive to potential adopters across the logistics and supply chain industries, as well as other industries that have struggled to meet greenhouse gas (GHG) emissions reduction goals with more established approaches such as lithium-ion battery-electric vehicles. Hydrogen is used to generate electricity via fuel cells (see Figure 5 below).[10] The electricity generated is useful for a wide range of applications such as powering electric vehicles, homes, and microgrids.

In the near-term, hydrogen fuel cells are expected to become an increasingly popular alternative to fossil fuels and lithium-ion battery-electric options for medium-duty and heavy-duty vehicles, such as transit buses, Class 8 trucks, and marine port terminal equipment (such as RTG cranes). Transit agencies are among the "first movers" in the emergent hydrogen economy, and there is a range of

[10] Hydrogen Internal Combustion Engines (H2ICE) are also an emergent technology, but this technology has not yet been developed to the same extent and may not offer the same benefits as hydrogen FCEVs. See: TRC Companies, Inc., "State of Sustainable Fleets 2025 Market Brief" (Santa Monica, CA: State of Sustainable Fleets, April 2025), https://cdn.stateofsustainablefleets.com/2025/state-of-sustainable-fleets-2025-market-brief.pdf; "Hydrogen Fuel Cells and Combustion Engines," Volvo Group, 2025, https://www.volvogroup.com/en/sustainable-transportation/sustainable-solutions/hydrogen-fuel-cells.html; David Cooke, "Hydrogen Combustion Is a Dead-End Technology for Heavy-Duty Trucks," *The Equation—Union of Concerned Scientists*, December 21, 2023, https://blog.ucs.org/dave-cooke/hydrogen-combustion-is-a-dead-end-technology-for-heavy-duty-trucks/; "Cummins Launches Industry-First Hydrogen Internal Combustion Engine Turbochargers for On-Highway Applications," Cummins Inc., April 28, 2025, https://www.cummins.com/news/releases/2025/04/28/cummins-launches-industry-first-hydrogen-internal-combustion-engine.

valuable insights that supply-chain leaders can learn from the initial hydrogen fleet and fueling operations underway in transit agencies throughout California and the nation.[11]

Figure 5. Basic Comparison of the Currently Available Electric Vehicles (EVs)[12]



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[11] "ZEB Best Practices," California Transit Training Consortium (CTTC), accessed May 6, 2025, https://www.cttc.com/courses/zeb-best-practices; "Hydrogen Fuel Cell Bus Info Page: The 'Better' Electric Bus," California Hydrogen Business Council, accessed January 29, 2025, https://californiahydrogen.org/resources/hydrogen-fuel-cell-bus-info-page-the-better-electric-bus/; Leslie Eudy and Matthew B. Post, "Zero-Emission Bus Evaluation Results: Orange County Transportation Authority Fuel Cell Electric Bus," *FTA Research*, Report, No. 0134 (May 2018), https://doi.org/10.2172/1557423; Leslie Eudy, Matthew Post, Jonathan Norris, and Steve Sokolsky, "Zero-Emission Bus Evaluation Results: Stark Area Regional Transit Authority Fuel Cell Electric Buses," FTA Research, Report No. 0140 (October 2019), https://www.transit.dot.gov/about/research-innovation; "Foothill Transit Agency: Leveraging the Power of Fuel Cells," Ballard Power Systems, February 23, 2024, https://blog.ballard.com/bus/foothill-transit-agency-leveraging-power-fuel-cells; East Bay Municipal Utility District Resource Recovery Team, "Alameda-Contra Costa Transit District Fuel Cell Bus Program," https://www.ebmud.com/files/4415/5681/9632/EBMUD_FC_5-3-19-1.pdf; "OCTA to Invest $77.5 Million in New Hydrogen Fuel-Cell Electric and Battery-Electric Buses," *Mass Transit*, November 27, 2024, https://www.masstransitmag.com/bus/vehicles/hybrid-hydrogen-electric-vehicles/press-release/55246303/orange-county-transportation-authority-octa-octa-to-invest-775-million-in-new-hydrogen-fuel-cell-electric-and-battery-electric-buses; "Riverside Transit Agency - New Grant Fuels RTA's Move to Zero-Emission Buses," Riverside Transit Agency, March 6, 2024, https://www.riversidetransit.com/index.php/news-a-publications/press-releases/690-new-grant-fuels-rta-s-move-to-zero-emission-buses.

[12] Ahan Parikh, Manan Shah, and Mitul Prajapati, "Fuelling the Sustainable Future: A Comparative Analysis between Battery Electrical Vehicles (BEV) and Fuel Cell Electrical Vehicles (FCEV)," *Environmental Science and Pollution Research* 30, no. 20 (April 2023): 57236–52, https://doi.org/10.1007/s11356-023-26241-9.

FCEVs are battery-electric vehicles, just like their lithium-ion battery-electric counterparts.[14] However, instead of storing electrical energy in batteries, FCEVs generate electricity within the vehicle itself. FCEVs are equipped with hydrogen fuel-cell stacks that are responsible for converting hydrogen to usable power. Hydrogen fuel cells generate electricity via an electrochemical reaction in which hydrogen gas (H_2) is oxidized at the anode and oxygen gas (O_2) is reduced at the cathode, producing water, electricity, and heat. The ability to generate electricity allows FCEVs to operate with smaller batteries, which reduces the overall vehicle weight. Bi-fuel vehicles are also an increasingly available option. Honda recently unveiled the 2025 CR-V e:FCEV, which facilitates dual fueling/charging functionality, harnessing both BEV and FCEV technology.[15]

Neither lithium-ion battery-electric vehicles (BEVs) nor hydrogen-powered vehicles produce local GHG emissions through the operation of the vehicle, but it is important to note that overall carbon intensity (CI; a measure of how much GHG emission is produced per unit of product) depends on a multitude of factors.[16] The process of creating the requisite components (battery, fuel cell, fuel, etc.) requires materials that may have a negative environmental impact (in addition to troubling ethical concerns).[17] The source of the electricity that the battery stores originates from any source of electricity available, which could be coal-fired power plants or solar panels. The method of storage also contributes to overall CI.

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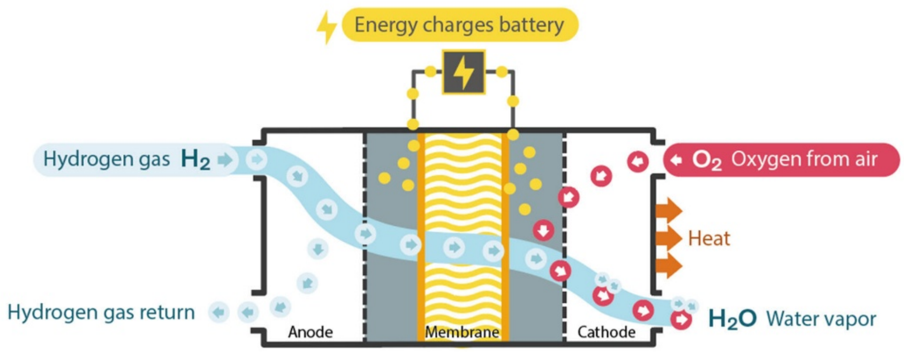
[14] For a more in-depth comparison of BEVs and FCEVs, see: "BEVs versus FCEVs" in Joshua Neutel, Andrew Robert Berson, Ethne Laude, Angela Arifi, Adam Brandt, Sarah D. Saltzer, and F.M. Orr, Jr., *Pathways to Carbon Neutrality in California: What Will It Take to Get to Net-Zero Emissions in California?* (Stanford Center for Carbon Storage and Stanford Carbon Removal Initiative, July 2024), 49–50, https://sccs.stanford.edu/california-projects/pathways-carbon-neutrality-california.

[15] "Honda Reveals 2025 Honda CR-V e:FCEV—America's First Production Plug-in Hydrogen Fuel Cell Electric Vehicle," Honda Automobiles Newsroom, February 27, 2024, http://hondanews.com/en-US/honda-automobiles/releases/honda-reveals-2025-honda-cr-v-efcev-americas-first-production-plug-in-hydrogen-fuel-cell-electric-vehicle; "2025 Honda CR-V e:FCEV | Hydrogen Fuel Cell Vehicle," Honda Automobiles, accessed June 25, 2025, https://automobiles.honda.com/cr-v-fcev.

[16] "The CI for transportation fuel is the amount of life cycle greenhouse gas emissions per unit of fuel energy, expressed in grams of carbon dioxide equivalent per megajoule (gCO_2e/MJ). CIs include the direct effects of producing and using this fuel, as well as indirect effects that may be associated with how the fuel affects other products and markets," "Apply for an LCFS Fuel Pathway," California Air Resources Board, 2025, https://ww2.arb.ca.gov/resources/documents/apply-lcfs-fuel-pathway.

[17] Terry Gross, "How 'Modern-Day Slavery' in the Congo Powers the Rechargeable Battery Economy," *NPR*, February 1, 2023, sec. Goats and Soda, https://www.npr.org/sections/goatsandsoda/2023/02/01/1152893248/red-cobalt-congo-drc-mining-siddharth-kara.

Figure 6. How Fuel Cells Generate Electricity[18]



3.2 Modes of Hydrogen Production

The most common forms of hydrogen for fuel are categorized as grey, blue, green, and bio (a form of blue hydrogen production).[20] The "color" of hydrogen is determined by the method of production. While multiple modes of hydrogen production are often touted as "clean," it is not always clear what criteria are used to make this determination. Furthermore, there is a lack of standardized methods for evaluating CI for existing modes of hydrogen production, both nationally and internationally.[21] The Infrastructure and Jobs Act of 2021 (IIJA) defines a mode of hydrogen production as clean if it produces no more than 2.0 kg of carbon dioxide equivalent per kg of hydrogen (CO_2 e/kg H2) at the site of production, while the Inflation Reduction Act of 2022 (IRA) requires less than 4.40 kg CO_2 e/kg H2.[22] California Senate Bill 1420 (2024) defines "qualified clean hydrogen" as 4.0 kg CO_2 e/kg H2 or less.[23] A given "color" of hydrogen production may or may not meet those aforementioned standards, depending on the specifics of the production process (i.e., carbon capture performance, source of electricity, and method of

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[18]"Volvo CE Takes Big Step towards a Carbon Neutral Future with Hydrogen Fuel Cell Test Lab," Volvo, May 18, 2021, https://www.volvoce.com/global/en/news-and-events/news-and-stories/2021/volvo-ce-takes-big-step-towards-a-carbon-neutral-future-with-hydrogen-fuel-cell-test-lab/.

[20] Jimena Incer-Valverde et al., "'Colors' of Hydrogen: Definitions and Carbon Intensity," Energy Conversion and Management 291 (September 2023): 117294, https://doi.org/10.1016/j.enconman.2023.117294.

[21] Fiona Mwacharo, "It Doesn't Matter What the Color of Hydrogen Is as Long as It Lowers Net Emissions," Hycamite, (March 2024), https://hycamite.com/articles/it-doesnt-matter-what-the-color-of-hydrogen-is-as-long-as-it-lowers-net-emissions/.

[22] Shree Om Bade and Olusegun Stanley Tomomewo, "A Review of Governance Strategies, Policy Measures, and Regulatory Framework for Hydrogen Energy in the United States," International Journal of Hydrogen Energy 78 (August 2024): 1363–81, https://doi.org/10.1016/j.ijhydene.2024.06.338.

[23] Anna Caballero et al., "Hydrogen Production Facilities: Certification and Environmental Review," Public Resources Code § 21189.81 and 25545 (2024), https://legiscan.com/CA/text/SB1420/id/2932700.

storage).[24] Further details on the different modes of production for hydrogen fuel can be found in Appendix A.

In the U.S., 95% of hydrogen is produced via steam methane reformation (blue or grey hydrogen), 4% by coal gasification (black hydrogen), and 1% via electrolysis (green hydrogen).[25] In California, SMR is responsible for all commercially mass-produced hydrogen, most of which is used for crude oil refining.[26] Globally, SMR makes up 76% of all produced hydrogen, coal gasification makes up 22%, and electrolysis makes up only 2%. According to the Integrated Design for Efficient Advanced Liquefaction of Hydrogen (IdealHy) project, 1 kg of hydrogen can produce 33.33 kilowatt-hours (kWh) of electricity, and the generation of 1 kg of hydrogen via SMR generates 8–12 kg of carbon dioxide emissions (see Table 1 below for a comparison of different fuels).[27]

Although green and blue hydrogen are the only existent forms of hydrogen production that can be considered carbon neutral, all forms of hydrogen production are superior to coal-fired electrification, which generates 2.31 kg of carbon dioxide per kWh. Hydrogen is also more efficient than coal: Coal-fired electricity generates 76.99 kg of carbon dioxide emissions to produce the same amount of energy as 1 kg of hydrogen. The emissions generated by coal-fired electric production are far greater than emissions-heavy forms of hydrogen production, such as coal gasification.

[24] Ryan Mills, "Hydrogen Reality Check: All 'Clean Hydrogen' Is Not Equally Clean," (October 2022), https://rmi.org/all-clean-hydrogen-is-not-equally-clean/.

[25] Ryan Lexie, "Hydrogen Production: Overview and Issues for Congress," legislation, Energy & Natural Resources (Congressional Research Service, October 3, 2024), https://www.congress.gov/crs-product/R48196.

[26] Joshua Neutel et al., Pathways to Carbon Neutrality in California: What Will It Take to Get to Net-Zero Emissions in California? (Stanford Center for Carbon Storage and Stanford Carbon Removal Initiative, 2024), https://sccs.stanford.edu/california-projects/pathways-carbon-neutrality-california.

[27] "Liquid Hydrogen Outline," Integrated Design for Efficient Advanced Liquefaction of Hydrogen, 2013, https://www.idealhy.eu/index.php?page=lh2_outline; Thomas Koch Blank and Patrick Molly, "Hydrogen's Decarbonization Impact for Industry: Insight Brief" (Rocky Mountain Institute, January 2020), https://rmi.org/wp-content/uploads/2020/01/hydrogen_insight_brief.pdf.

Table 1. Energy Output vs. CO_2 Emissions

Energy Source	Energy Output	CO_2 Emissions
Hydrogen (1 kg)	33.33 kWh	8–12 kg CO_2 (via steam methane reforming)
Natural gas	33.33 kWh	31.99 kg CO_2
Coal-fired electricity	33.33 kWh	76.99 kg CO_2
Natural gas (per kWh)	1 kWh	0.96 kg CO_2
Coal-fired (per kWh)	1 kWh	2.31 kg CO_2

3.3 From Colors to Lifecycles

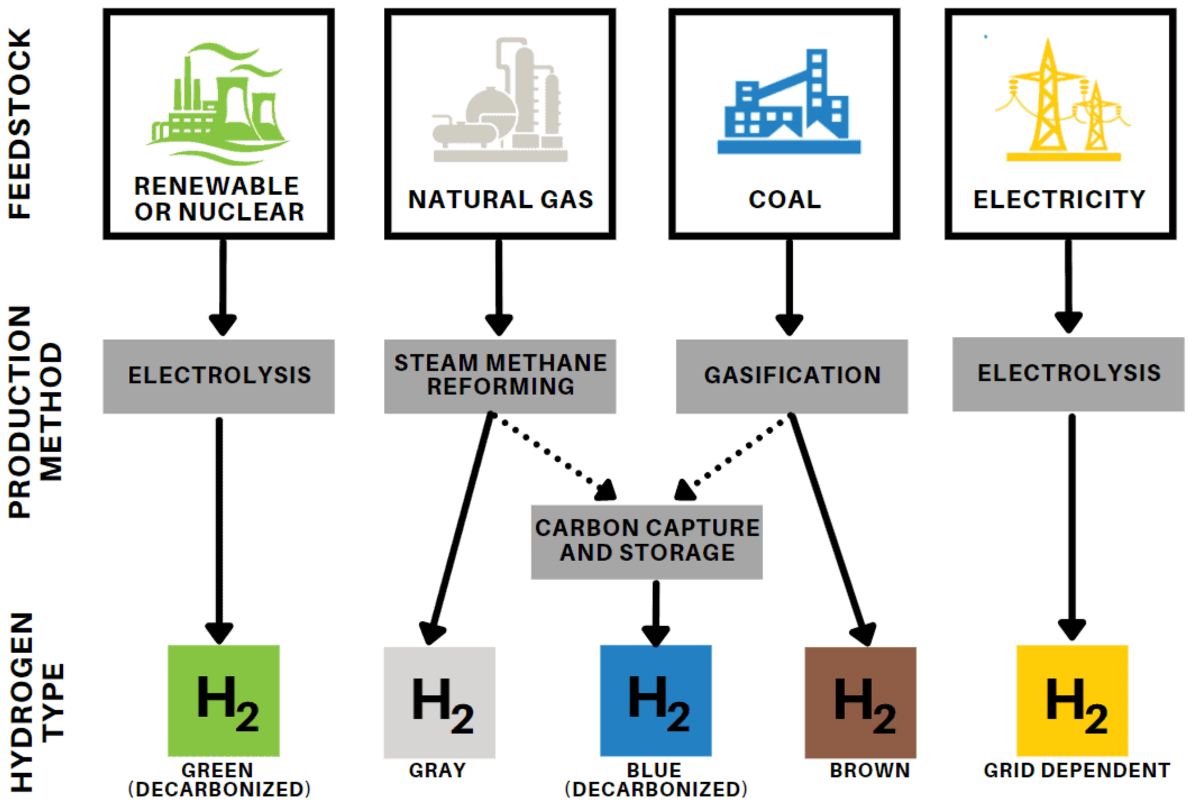
Discussions of which hydrogen production mode is "best" can often become mired in debates over a given mode's ascribed color (see Figure 8) and the emissions associated at the site of production. Hydrogen's ability to garner appeal from policymakers, stakeholders, and the general public hinges on its environmental superiority to conventional fossil fuels. Accordingly, proponents of a given mode of hydrogen production will cite its sustainability and environmental impact at the site of production, even though there is a lack of agreed-upon international standards on what exactly constitutes "sustainable" or "low-carbon" hydrogen—and sometimes it is not even clear what "color" a given mode of production falls under.[28] Increasingly, hydrogen industry professionals are moving away from colors associated with given modes of production to instead focus on lifecycle emissions as a standard for evaluating levels of decarbonization.[29] When it comes to decarbonization, it is important to consider the GHG emitted throughout the whole of the lifecycle of any alternative fuel, from raw materials, production, and storage to operations to tailpipe emissions. There are cases in which it is obvious that one "color" is cleaner than another.

[28] "Robert Wegeng, president and chief technology officer of Stars Technology Corp., said different people have different interpretations of what the colors mean, further complicating the issue." Mindy Long, "Moving Hydrogen Fuel Forward Means Looking Beyond Its Colors," Transport Topics, May 2, 2025, https://www.ttnews.com/articles/hydrogen-fuel-beyond-colors.

[29] This topic is discussed at length here: Fiona Mwacharo, "It Doesn't Matter What the Color of Hydrogen Is as Long as It Lowers Net Emissions," Hycamite (blog), March 4, 2024, https://hycamite.com/articles/it-doesnt-matter-what-the-color-of-hydrogen-is-as-long-as-it-lowers-net-emissions/. Specifically, the authors would like to call attention to this paragraph: "The International Energy Agency's (IEA) report about hydrogen definitions discusses how there's no international consensus on how to label hydrogen based on its environmental impact. Different labels use colors to indicate how hydrogen is produced, or words such as 'sustainable,' 'low-carbon' or 'clean' to differentiate it from fossil-based production without emission reduction. These labels, however, aren't clear or consistent enough to be used in standardization, or as criteria in regulations or contracts. For instance, there's no color assigned to electrolyzers using grid electricity. The labels grey and blue don't account for other factors that affect emissions, such as upstream and midstream methane emissions and carbon capture rate. It's clear there's a need for an internationally agreed-upon common language and global harmonized methodologies for calculating the CI of hydrogen." See also: Mindy Long, "Moving Hydrogen Fuel Forward Means Looking Beyond Its Colors," Transport Topics, May 2, 2025, https://www.ttnews.com/articles/hydrogen-fuel-beyond-colors.

Black hydrogen (coal gasification without carbon capture) is clearly not the desirable mode if emissions reduction is the goal. The lack of comprehensive, consistent standards across all states and the federal government also makes it difficult to assess what constitutes clean, green, low- or no-carbon hydrogen fuel. What is most important is the development of a hydrogen market that produces commercially viable energy to fuel clean energy transitions across state and national supply chains and manifests an aggregate reduction in emissions in comparison with conventional fossil fuels. For these reasons, a "tech-agnostic" approach is best suited to identifying modes of hydrogen best suited for meeting decarbonization goals.[19]

Figure 7. Hydrogen Production Methods[30]



[30] "What Hydrogen Means for the Gas Industry, Part I | Xylem Singapore," xylem, accessed June 30, 2025, https://www.xylem.com/en-sg/brands/sensus/blog/what-hydrogen-means-for-the-gas-industry-part-i/.

3.4 Domestic Workforce Development Investment Overview

While the development of hydrogen vehicles, production, and the related financial and regulatory underpinnings are all still nascent, workforce development must remain a priority for several basic reasons:

1. It will be the human systems that ultimately lead all aspects of hydrogen production and technological, infrastructure, financial, and regulatory development (an obvious but often overlooked consideration).

2. Developing a skilled and prepared workforce for an entirely new energy sector will require careful strategic workforce development planning and skills mapping to ensure that the full project lifecycle of new hydrogen production and fueling infrastructure is developed to support freight systems and supply-chain systems of the future.

3. Finally, as a cautionary notion, if the collective industry holds off on workforce priorities until production and investment push hydrogen to a point where its price is competitive with diesel, the hydrogen rollout will be delayed for years due to a lack of a skilled and prepared workforce. Said another way, workforce development efforts need to precede the investment and technological aspects of the hydrogen rollout.

3.5 Domestic Workforce Development: State and Federal

The first part of the difficulty of addressing workforce development efforts is a limited understanding of the workforce needs of the nascent hydrogen economy. Secondly, even when the education or skillset is known and identified, the level of specificity is often inadequate. Thirdly, source material sometimes conflicts in ways that, while noncontradictory, raise questions. An example of all three of these problems can be found within chemical engineering. While there are many chemical engineering degree programs in the U.S., H2EDGE found that a mere 7% of course titles contained the words/phrases "hydrogen" or "cryogenic hydrogen."[32] Yet, at the same time, the EFI Foundation Market Evaluation (2024) claims that chemical engineers with experience in the fossil fuel industry have skillsets applicable to hydrogen production, and that there are employment opportunities in the emerging hydrogen sector.[33] Thus, some of the KSAs possessed by chemical engineers presently employed in the energy sector are also relevant to

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[32] Eladio Knipping et al., "Hydrogen Education for a Decarbonized Global Economy," DOE Hydrogen Program 2022 AMR Review & PE Meeting, June 7, 2022, https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/review22/scs028_reddoch_2022_o-pdf.pdf.

[33] "Hydrogen Market Formation: An Evaluation Framework" (e EFI Foundation, January 2024), p. 24, https://efifoundation.org/wp-content/uploads/sites/3/2024/01/H2-Market-Evaluation-FINAL-with-cover.pdf

hydrogen, even if the formal education attained by these workers does not specifically pertain to hydrogen. Yet, what *are* those transferable KSAs? When it comes to workforce needs assessments for the emerging hydrogen economy, there is a need to develop a more detailed picture that can allow for more ambitious, thorough, and effective workforce development programs. These transferable KSA findings are consistent with subsequent international workforce development sections of this report.

Initially, it does make some sense to focus on workforce initiatives in states with the most hydrogen activity (such as California or Texas). However, these are not the only states where investments in the emerging hydrogen workforce are taking place. For example, in February 2025, the University of Toledo announced that it would lead "a collaborative initiative aimed at training regional workers for new and existing jobs related to hydrogen production, distribution, storage and use" in the states of Michigan and Ohio with funding provided by the DOE. The University of Toledo press release asserts that the initiative will assess "needs and opportunities for academic degree programs, courses and certifications, with plans to then develop curricula, implement programs and recruit students as early as Fall 2026."[34] As a part of its participation in this initiative, the Workforce Intelligence Network (WIN) published a Hydrogen Social Network Analysis (SNA) survey to develop a map of the hydrogen ecosystem in the American Midwest; they will administer a second survey that concerns workforce needs, job skills, and the development of relevant curricula.[23] The efforts in Michigan and Ohio reflect that hydrogen workforce initiatives are underway in regions of the U.S. beyond first movers such as California and Texas and provide valuable best practices for future implementations.

3.6 Domestic Workforce Development: California

Among all 50 states, California is a clear leader in the design and implementation of hydrogen fuel-cell technology. Additionally, educators in California are implementing related workforce programs and developing related curricula. Notable efforts taking place at California State University, Los Angeles (CSULA); Cal Poly Pomona; California State University, Long Beach; as well as University of California, Riverside (UCR); and the College of the Desert are discussed below (and as outlined in the later CSU5+ Peer Exchange section in this report).

CSULA is home to the Hydrogen Research and Fueling Facility (HRFF), which boasts numerous successes and milestones in the development of a hydrogen economy since its founding in 2011. The HRRF focuses on the production of hydrogen via electrolysis. As of today, the facility can produce 60 kg of hydrogen per day and has a storage capacity of 60 kg, meaning it and can provide

[34] Nick Gorny, "UToledo Leads $3M Initiative to Equip Workers for Emerging Hydrogen Economy | UToledo News," University of Toledo News, February 6, 2025, https://news.utoledo.edu/index.php/02_06_2025/utoledo-leads-3m-initiative-to-equip-workers-for-emerging-hydrogen-economy

fuel to 20 light-duty vehicles per day with a fueling time of 8–10 min. In the future, the facility hopes to increase production to 200 kg/day, increase storage capacity to 210 kg, and increase its fueling capacity to 50 light-duty vehicles or three heavy-duty vehicles per day, with a fueling time of 4–5 min.[35] The CSULA facility provides hands-on learning opportunities for students pursuing hydrogen-focused careers.

In late 2014, the facility became the "first in the world to sell hydrogen fuel by the kilogram directly to retail customers."[36] The CSULA Hydrogen Research and Fueling Facility has received $14.6 million in external grants as of 2024, including a $500,000 grant for workforce development related to zero-emission vehicles (ZEV) from the California Energy Commission (CEC) in 2022.[37] In November 2024, the HRRF began a partnership with SoCalGas via the Hydrogen Education for a Decarbonized Global Economy (H2EDGE) initiative to "offer development and training opportunities for the emerging and existing workforce in the hydrogen industry."[38] The HRRF claims that students who participate in the Facility's activities are trained to "perform fueling, safety inspections, operations, testing, troubleshooting, preventive maintenance, parts procurement, and more."[28]

College of the Desert in the City of Palm Desert has maintained and expanded its interest in hydrogen for more than two decades. The College offers a Hybrid, Fuel-Cell, & Electric Vehicle Certificate of Achievement, housed within the College's Automotive Technology program.[39] Additionally, faculty from College of the Desert helped develop curricula for fuel-cell electric buses (FCEBS). The College will open "a one-of-a-kind campus site focused on automotive technology

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[35] Nancy Warter-Perez and David Blekhman, "HRFFF H2 Handout" (Cal State LA, Hydrogen Research and Fueling Facility (HRFF), 2024), https://www.calstatela.edu/sites/default/files/Cal%20State%20LA%20HRFF-H2-Handout-0205-2024-rev.pdf; "Cal State LA Hydrogen Research and Fueling Facility (H2 Station) | Cal State LA," accessed April 25, 2025, https://www.calstatela.edu/ecst/h2station; "Outreach | Cal State LA Hydrogen Research and Fueling Facility (H2 Station)," California State University, Los Angeles, College of Engineering, Computer Science, and Technology, accessed May 2, 2025, https://www.calstatela.edu/ecst/h2station/outreach.

[36] "Cal State LA Hydrogen Research and Fueling Facility (H2 Station) | Cal State LA," accessed April 25, 2025, https://www.calstatela.edu/ecst/h2station.

[37] Nancy Warter-Perez and David Blekhman, "HRFFF H2 Handout" (Cal State LA, Hydrogen Research and Fueling Facility (HRFF), 2024), https://www.calstatela.edu/sites/default/files/Cal%20State%20LA%20HRFF-H2-Handout-0205-2024-rev.pdf; Margie Low, "Cal State LA Receives Grant from State's Primary Energy Agency for Workforce Development," Cal State LA Newsroom, December 3, 2022, https://news.calstatela.edu/2022/12/03/cal-state-la-receives-grant-from-states-primary-energy-agency-for-workforce-development/.

[38] Cal State LA News Service, "Cal State LA and SoCalGas to Help Develop the Emerging Hydrogen Industry Workforce in Southern California," Cal State LA Newsroom, November 7, 2024, https://news.calstatela.edu/2024/11/07/cal-state-la-and-socalgas-to-help-develop-the-emerging-hydrogen-industry-workforce-in-southern-california/.

[39] "Hybrid, Fuel-Cell, & Electric Vehicle Certificate of Achievement," College of the Desert, accessed May 6, 2025, https://catalog.collegeofthedesert.edu/programs/automotive-technology/hybrid_fuelcell_electric_certificate/.

programming, which will include emphasis areas in traditional combustion engines, electric, and hydrogen" in 2026.[40]

The University of California, Riverside (UCR) announced the formation of the Hydrogen Engine Alliance of North America (H2EA-NA) in February 2025 and held the Inaugural 2025 North American Hydrogen Engine Conference in May 2025 at the California Air Resources Board (CARB) facility.[41] UCR has also partnered with city and state agencies to launch the Riverside Clean Air Carshare (RCAC) program in May 2025, which allows participants to rent one of 13 Toyota Mirai sedans. According to a UCR press release, the program will serve as a "living laboratory" that provides "UCR engineering students with valuable training experiences." Students, alongside university researchers, will collect "anonymized trip data to analyze the program's mobility, environmental, and economic impacts."[42] Given that CARB has found that light-duty FCEV adoption has lagged behind expectations, this is a welcome and timely development.[43]

3.7 International Workforce Development Case Studies: Australia and Canada

Australia

Australia provides a valuable case study in workforce development investments and related programming. According to the IEA's 2022 World Energy Outlook, Australia is expected to become one of the largest exporters of green hydrogen by 2030.[44] Australia's natural resources provide it with an advantage in renewable energy. The Australian government claims that the global hydrogen market will reach a market cap of $1.4 trillion.

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[40] "History of the College," College of the Desert, accessed May 6, 2025, https://catalog.collegeofthedesert.edu/who/history-of-the-college/.

[41] David Danelski, "UCR and U of Michigan Launch Hydrogen-Engine Alliance | UCR News | UC Riverside," UC Riverside News, February 27, 2025, https://news.ucr.edu/articles/2025/02/27/ucr-and-u-michigan-launch-hydrogen-engine-alliance.

[42] David Danelski, "UC Riverside Joins Launch of Hydrogen Carshare Program | UCR News | UC Riverside," May 6, 2025, https://news.ucr.edu/articles/2025/05/06/uc-riverside-joins-launch-hydrogen-carshare-program.

[43] "2024 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development," Pursuant to AB 126; Reyes, Chapter 319, Statutes of 2023, Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development (Sacramento, CA: California Air Resources Board (CARB), December 2024), p. 8, https://ww2.arb.ca.gov/sites/default/files/2024-12/AB-126-Report-2024-Final.pdf.

[44] IEA, "World Energy Outlook 2022," October 2022, https://www.iea.org/reports/world-energy-outlook-2022.; "National Hydrogen Strategy 2024" (Canberra, ACT, Australia: Australian Government - Department of Climate Change, Energy, the Environment and Water, October 2024), p.5, https://www.dcceew.gov.au/sites/default/files/documents/national-hydrogen-strategy-2024.pdf.

The Australian government has identified critical occupations that will need to be developed to support its hydrogen supply chain. Of the identified occupations, the Australian government predicts an insufficient supply of electrical trade and building and engineering occupations required for the future hydrogen supply chain workforce.[45] By 2050, the country will need an additional 85,000 electricians, 2,200 civil engineering draftspersons, and 25,000 architectural, building, and surveying technicians.[46] More traditional engineering roles, such as chemical and materials engineers, are on track to meet the future demand, but it is uncertain if workers in these fields will have the skills needed to support the hydrogen industry. In the current market, employers are receiving sufficient applicants but often find that potential hires do not have the requisite experience to successfully perform the role. Jobs and Skills Australia has identified education and training priorities to support its current and future hydrogen workforce.

Over the next 30 years, the Australian government forecasts a range of education and training priorities to support the emerging hydrogen supply-chain workforce. Vocational education will provide for the necessary electricians and auto mechanics. Universities and colleges will develop specialized coursework for hydrogen-focused engineers and scientists. Additionally, industry stakeholders and trade associations will develop programs for working professionals to attain necessary KSAs through on-the-job-training.[47] These three paths—vocational, university, and on-the-job—serve to prepare the future workforce by providing broad-based qualifications, skill enhancement courses referred to as “top-ups and electives,” and new targeted qualifications. The broad-based qualifications are developed via enrollment in existing courses and programs that provide fundamental skills to work in adjacent fields. Top-ups and elective courses are for existing workers who already have the fundamental skills. These courses allow the existing workforce to obtain specialized skills required for working with hydrogen technologies.

Queensland, Australia, currently employs 31% of all fossil fuel electricity generation workers and 52% of all coal mining employment and expects to be the largest producer of hydrogen in the country by 2030. In accordance with this goal, the Queensland government has developed a “Hydrogen Industry Workforce Development Roadmap” for the years 2022–2032. The document is primarily focused on building talent pipelines, sharing knowledge to develop hydrogen training,

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[45] “The Clean Energy Generation Workforce Needs for a Net Zero Economy” (Australian Government, Jobs and Skills Australia, October 2023), https://www.jobsandskills.gov.au/download/19313/clean-energy-generation/2385/clean-energy-generation/pdf.

[46] “National Hydrogen Strategy 2024” (Canberra, ACT, Australia: Australian Government - Department of Climate Change, Energy, the Environment and Water, October 2024), p.5, https://www.dcceew.gov.au/sites/default/files/documents/national-hydrogen-strategy-2024.pdf.

[47] “National Hydrogen Strategy 2024” (Canberra, ACT, Australia: Australian Government - Department of Climate Change, Energy, the Environment and Water, October 2024), p.103, https://www.dcceew.gov.au/sites/default/files/documents/national-hydrogen-strategy-2024.pdf.

and using data insights to adapt to workforce needs over time. It outlines actions that the Queensland government will take to address workforce needs.[48]

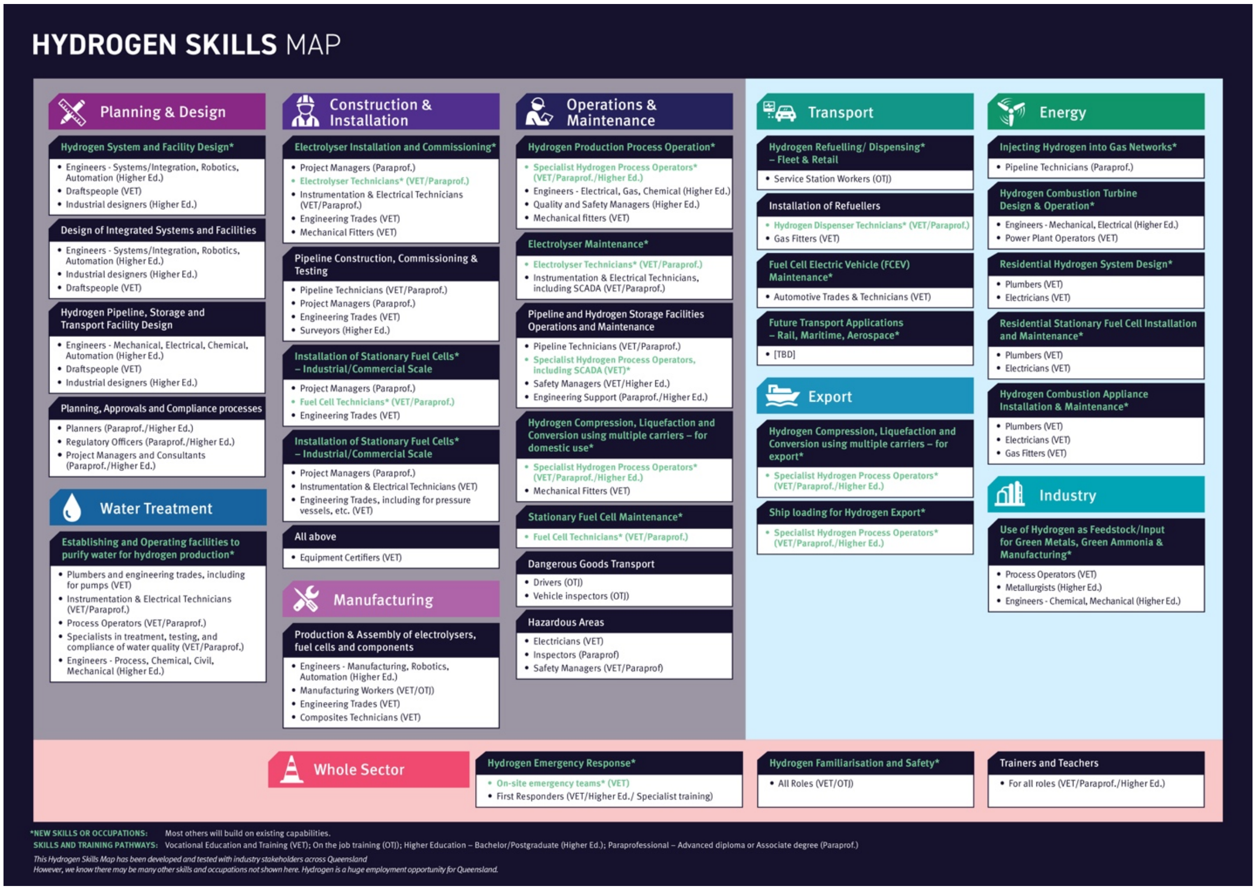
To build talent pipelines, the Queensland government will identify the skills and training needed by the hydrogen industry, pilot various training programs targeted at high school students, expand their existing Gateway to Industry Schools Program (GISP) to include hydrogen pathways, and work with industry to develop university courses that reflect the skills needed. The Queensland government plans to ultimately integrate hydrogen into its vocational education training program, but, because hydrogen energy production is still an emerging industry, it will take a considerable amount of time to develop the requisite standards. In the near term, the Queensland government will begin introducing hydrogen into public school programs to cultivate greater interest in the hydrogen technologies and related careers. To foster collaboration among key stakeholders, the Queensland government is working with original equipment manufacturers (OEMs) and major suppliers to facilitate an exchange of information. The information gathered is then provided to workforce training and educational institutions.[49]

The Queensland government is developing safety standards and protocols for facilities and occupations that work with hydrogen. The Queensland government will perform labor force and skills demand analyses every two years to gather data insights and plan for the industry's workforce.[41] The local government also plans to participate in a national skills and training research program, and the results will determine the implications for Queensland's hydrogen ambitions. As a part of the "Hydrogen Industry Workforce Development Roadmap," the Queensland government has identified the skills and roles needed for a successful deployment of hydrogen infrastructure (see Figure 8 below).

[48] Queensland Government, "Hydrogen Industry Workforce Development Roadmap 2022-2032," July 2022, https://www.publications.qld.gov.au/ckan-publications-attachments-prod/resources/5fffcbcc-7605-46ed-86b4-2c2a91e7acad/hydrogen-industry-workforce-development-roadmap.pdf?ETag=642edbb6a0b42c3acf948cfb4c695f70.

[49] Ibid, p.16.

Figure 8. Hydrogen Skills Map Australia[50]



The figure categorizes each step and sector that will be required to build and operate hydrogen infrastructure. Under each main category, the Hydrogen Skills Map details which roles will be needed for each process and the education level each role will require. Roles that currently do not exist are highlighted in green to indicate the need for proper workforce development programs for those roles.

The existing hydrogen courses and programs are largely hosted by existing universities and colleges, but there are many other programs still in development by the federal and state government in collaboration with Original Equipment Manufacturers (OEMs). Existing programs are offered by Australian National University (ANU), University of New South Wales (UNSW), and Engineering Institute of Technology (EIT). EIT's "Professional Certificate of

[50] DESBT Strategy, "Hydrogen Industry Workforce Development Roadmap 2022-2032," DESBT Strategy, July 2022, https://www.publications.qld.gov.au/ckan-publications-attachments-prod/resources/5fffcbcc-7605-46ed-86b4-2c2a91e7acad/hydrogen-industry-workforce-development-roadmap.pdf?ETag=642edbb6a0b42c3acf948cfb4c695f70.

Competency in Hydrogen Energy—Production, Delivery, Storage, and Use" is designed to teach the fundamentals of hydrogen and the components of its supply chain to both engineers and students who may not have as strong a scientific background. ANU offers its "Hydrogen Economy" course to both graduate and undergraduate students, focusing on the economic viability of the supply chain and the physics needed to understand the technical aspects of converting and storing energy via hydrogen. UNSW's course "Hydrogen Production for Electrical Engineers Part 1" is built specifically for engineers who want to develop and maintain the technology to generate hydrogen via electrolysis. The Queensland government has provided $28.9 million Australian dollars ($19.17 million USD) for the development of the Kogan Renewable Hydrogen Demonstration Plant, which once fully constructed will partner with the economic development group Toowoomba and Surat Basin Enterprise to develop a hydrogen skills mapping exercise to better target and develop the skills most in demand for the region.

Canada

Like Australia, Canada has both abundant natural resources to draw clean energy from and an interest in being a hydrogen exporter to Asia, Europe, and the U.S. The Canadian-based Transition Accelerator published a report and workforce assessment tool in 2022 titled "Assessing the Workforce Required to Advance Canada's Hydrogen Economy." According to the report, the expansion of the hydrogen supply chain will require:

- the advancement of process engineering and controls skills to include hydrogen specific safety skills and machine operations analysis;
- the selection and application of materials needed to ensure safe operations;
- the ability to service and support electrolyzers and fuel cells;
- material and equipment testing standards;
- safety courses for those handling hydrogen; and
- expanded training programs for first responders.

The report concluded that the most critical trade workers—such as electricians, instrumentation and control technicians, and industrial mechanics—are already in short supply and the development of a hydrogen supply chain will only increase the demand for these roles. Other roles that may become strained are welders, pipefitters, gasfitters, and instrumentation and control technicians. The report mentions a lack of potential specialized engineers that will be critical to hydrogen such as oil and gas engineers and electrochemical engineers.

The Canadian Hydrogen Association (CHA) assessed the state of Canada's hydrogen sector by surveying key players in the Canadian industry. The top production method is SMR without carbon capture and is mostly produced for existing industries that use hydrogen in the creation of chemical feedstocks. CHA asked respondents to identify the top barriers to investing in hydrogen. The top reported barrier in the workforce development category was a lack of skilled trade workers at 52.9% of respondents.

The Northern Alberta Institute of Technology (NAIT) developed two programs designed to upskill the current workforce with specific hydrogen competencies. The first program, "Clean Energy Professional Upskilling," specifically targets workers who have at least three years of job experience and a post-secondary certificate or degree, which makes it possible to address more specialized hydrogen learning objectives. After teaching the basics of hydrogen, the course explores real-world scenarios such as feasibility planning, operations, and maintenance of a carbon capture facility. Students are then paired with industry partners to facilitate hands-on learning experiences. NAIT also offers a diploma in "Alternative Energy Technology," which features a section on hydrogen fuel-cells.

3.8 Empowering the Hydrogen Workforce in the Golden State

At the time of writing, the U.S. has not established formal industrial and energy plans to guide the nation's hydrogen transition. However, much can be gleaned from efforts underway in California. In January 2025, the CEC published the *2024 Zero-Emission Vehicle Infrastructure Plan: Deployment Strategy 2025–2030*, which "describes California's infrastructure deployment plan to meet the goals of the light-duty passenger vehicle market and medium-duty and heavy-duty truck and bus market."[52] While it is certainly true that many of California's hydrogen infrastructure development plans were spurred by activity at the federal level during the Biden administration, the state's decarbonization goals are not derived from the prerogatives of the federal government.[53] Efforts to develop the infrastructure necessary to scale the hydrogen economy will continue. Even though the light-duty FCEV market has performed less successfully than previously expected, the

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[52] Thanh Lopez et al., "2024 Zero-Emission Vehicle Infrastructure Plan: Deployment Strategy 2025 – 2030," Staff Report (Sacramento, CA: California Energy Commission, January 2025), p. xi, https://www.energy.ca.gov/sites/default/files/2025-01/CEC-600-2025-002.pdf.

[53] Thanh Lopez et al., "2024 Zero-Emission Vehicle Infrastructure Plan: Deployment Strategy 2025 – 2030," Staff Report (Sacramento, CA: California Energy Commission, January 2025), p. 7, https://www.energy.ca.gov/sites/default/files/2025-01/CEC-600-2025-002.pdf; Hayley Smith, "BUSINESS; Lawmakers Urge Trump to Spare the State's Hydrogen Energy Project," Los Angeles Times, April 16, 2025, sec. Main News; Part A; Business Desk, https://www.proquest.com/latimes/docview/3190433847/citation/430AED1B31474220PQ/1?sourcetype=Newspapers; John Kingston, "Port of Long Beach Fully behind Push for ZEV Trucks despite ACF Failure: COO," FreightWaves, June 4, 2025, https://www.freightwaves.com/news/port-of-long-beach-fully-behind-push-for-zev-trucks-despite-acf-failure-coo

CEC projects that “hydrogen will play an important role for [medium-duty and heavy-duty vehicle] decarbonization, and as clean hydrogen is scaled for trucks and buses, the light duty market could benefit as well.”[54]

In the report, the CEC proposes three primary elements of hydrogen strategy:

1. “Continue to monitor the light-duty hydrogen FCEV market and make infrastructure investments to support current and expected future drivers.”

2. “Focus on improving the driver experience and fueling supply in California so that the existing network is more reliable and affordable.”

“Encourage development of depot and publicly accessible [medium-duty and heavy-duty vehicle] hydrogen fueling networks and [medium-duty and heavy-duty vehicle] depot refueling.”[55]

As of April 2025, California is home to fifty operational hydrogen stations, with an additional four currently under construction and eighteen in the permitting phase.[56] The Port of Oakland is home to the world’s largest public hydrogen fueling station.[57] Though these figures are impressive, CEC has noted that the “spiking prices of hydrogen and station reliability and availability that are caused by supply constraints, hydrogen supply disruptions, and equipment failures” are “barriers to FCEV market.”[58] Additionally, CARB has noted that progress in the planning and construction of fueling stations has “not kept pace with prior near-term projections.”[59] Although California’s existing fueling stations could support almost four times the number of light-duty FCEVs currently in operation, the existing network typically only operates at 60% capacity due to maintenance,

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[54] Thanh Lopez et al., “2024 Zero-Emission Vehicle Infrastructure Plan: Deployment Strategy 2025 – 2030,” Staff Report (Sacramento, CA: California Energy Commission, January 2025), p. 7, https://www.energy.ca.gov/sites/default/files/2025-01/CEC-600-2025-002.pdf.

[55] Ibid.

[56] “H2 Station List” (Hydrogen Fuel Cell Partnership (H2FCP), April 23, 2025), https://h2fcp.org/sites/default/files/h2_station_list.pdf.

[57] Thanh Lopez et al., “2024 Zero-Emission Vehicle Infrastructure Plan: Deployment Strategy 2025 – 2030,” Staff Report (Sacramento, CA: California Energy Commission, January 2025), 7, https://www.energy.ca.gov/sites/default/files/2025-01/CEC-600-2025-002.pdf

[58] Thanh Lopez, Adam Davis, Brandan Burns, and Magdulin Dwedari, “2024 Zero-Emission Vehicle Infrastructure Plan: Deployment Strategy 2025–2030,” Staff Report (Sacramento, CA: California Energy Commission, January 2025), 14, https://www.energy.ca.gov/sites/default/files/2025-01/CEC-600-2025-002.pdf.

[59] “2024 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development,” Pursuant to AB 126; Reyes, Chapter 319, Statutes of 2023, Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development (Sacramento, CA: California Air Resources Board (CARB), December 2024), p. 8, https://ww2.arb.ca.gov/sites/default/files/2024-12/AB-126-Report-2024-Final.pdf.

equipment failures, an underdeveloped supply chain, and a lack of available fuel. The agency will address these problems by "funding opportunities to support operations and maintenance of existing stations and requiring commitment to achieving 95% uptime as a condition for receiving grant funding."[60] In 2024, the CEC awarded over $17 million in grants to improve station reliability and increase the number of stations overall.[61] In 2025, the dollar amount has continued to increase, with grants awarded to Symbio North America Corporation ($9,076,445), Pilot Travel Centers LLC. ($10 million), and others.[62] AB 126 (Reyes, Chapter 319, Statutes of 2023) compels the CEC to allocate 15% or more of the budget provided by the Clean Transportation Plan (CTP) to the development of hydrogen fueling stations.[63]

Until permanent infrastructure is developed at scale, mobile fueling stations are crucial to bridging infrastructure gaps that have forestalled the large-scale deployment of FCEVs, especially in the trucking industry.[64] In February 2025, the Hydrogen Research and Fueling Facility at Cal State LA announced the reception of a $345,000 grant from the U.S. DOE Small Business Technology Transfer (STTR) program. This grant will fund the development of a portable mobile generator with RockeTruck, Inc.[65]

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[60] Thanh Lopez et al., "2024 Zero-Emission Vehicle Infrastructure Plan: Deployment Strategy 2025 – 2030," Staff Report (Sacramento, CA: California Energy Commission, January 2025), p. 14, https://www.energy.ca.gov/sites/default/files/2025-01/CEC-600-2025-002.pdf.

[61] Thanh Lopez et al., "2024 Zero-Emission Vehicle Infrastructure Plan: Deployment Strategy 2025 – 2030," Staff Report (Sacramento, CA: California Energy Commission, January 2025), p. 49-50, https://www.energy.ca.gov/sites/default/files/2025-01/CEC-600-2025-002.pdf; "GFO-23-604 - Improvements in Maintenance Processes for Reliable Operations That Are Verifiable and Effective for Hydrogen Refueling Stations (IMPROVE for H2)," California Energy Comission (California Energy Commission, current-date), https://www.energy.ca.gov/solicitations/2023-11/gfo-23-604-improvements-maintenance-processes-reliable-operations-are; "GFO-23-604 - Improvements in Maintenance Processes for Reliable Operations That Are Verifiable and Effective for Hydrogen Refueling Stations (IMPROVE for H2)," California Energy Commission (California Energy Commission, current-date), https://www.energy.ca.gov/solicitations/2023-11/gfo-23-604-improvements-maintenance-processes-reliable-operations-are.

[62] "GFO-21-605 - Zero-Emission Transportation Manufacturing," California Energy Commission (California Energy Commission, 2025), https://www.energy.ca.gov/solicitations/2022-03/gfo-21-605-zero-emission-transportation-manufacturing;

[63] "2024 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development," Pursuant to AB 126; Reyes, Chapter 319, Statutes of 2023, Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development (Sacramento, CA: California Air Resources Board (CARB), December 2024), p. 9, https://ww2.arb.ca.gov/sites/default/files/2024-12/AB-126-Report-2024-Final.pdf.

[64] Hydrogen Market Formation: An Evaluation Framework" (EFI Foundation, January 2024), pp. 11, 82-83, https://efifoundation.org/wp-content/uploads/sites/3/2024/01/H2-Market-Evaluation-FINAL-with-cover.pdf.

[65] "Cal State LA Receives $345,000 Grant to Develop a Portable Mobile Fuel Cell Generator with RockeTruck, Inc.," Cal State LA Newsroom, February 5, 2025, https://news.calstatela.edu/2025/02/05/cal-state-la-receives-345000-grant-to-develop-a-portable-mobile-fuel-cell-generator-with-rocketruck-inc/.

Figure 9. Rendering of a Linde Hydrogen Mobile Fueling Station

Copyright © Linde PLC 2018–2025[67]

[67] "Think Hydrogen. Think Linde.," accessed October 30, 2025, https://www.lindeus.com/industries/decarbonization-for-industries/hydrogen-mobility/mobile-fueling.

Figure 10. Mobile Refueling Station for SunLine Transit FCEBs in Indio, CA, 2022

A mobile refueling station is a hydrogen refueling station installed inside of the trailer box of a truck that can travel to the location of end-users. Early developments of the concept began in earnest in 2021, with the support of the CEC.[68] Nikola's HYLA system is also an early demonstration of the concept.[69]

Just as with hydrogen fuel-cell buses, a key marketing component for hydrogen fuel-cell cargo-handling equipment, drayage trucks, and other important terminal equipment is the operational similarity to conventional diesel.[70] Pilot testing for other hydrogen fuel-cell vehicles has been ongoing, and more will take place in the future. Toyota's "Uno" (a hydrogen-powered

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[68] Ted Barnes and Gas Technology Institute, "Mobile Hydrogen Refueler," Final Project Report, California Energy Commission Clean Transportation Program (Sacramento, CA: California Energy Commission, April 2021), https://www.energy.ca.gov/sites/default/files/2021-04/CEC-600-2021-006.pdf.

[69] "HYLA Mobile Fuelers Brochure" (Nikola Motor, February 2, 2023), https://nikolamotor.com/wp-content/uploads/2023/04/HYL007_HYLA-Mobile-Fuelers-Brochure-02.02.23-1.pdf.

[70] H2-ZE RTG Crane – PACECO CORP.," PACECO Corporation, 2025, https://pacecocorp.com/h2-ze-rtg-crane/.

fuel-cell-electric utility tractor rig) was piloted at the at Fenix Marine Services Terminal at the Port of Los Angeles in 2019 with notable success.[71]

Rail operations are also a site of early hydrogen adoption, often referred to by the contraction "hydrail." The CEC and California State Transportation Agency (CALSTA) have supported the development of hydrail, including an effort by Sierra Northern Railway involving short line locomotives.[72] The Zero Emission Multiple Unit (ZEMU) is planned to go into service this year in San Bernadino, CA, with similar developments taking place in Germany, the United Kingdom, China, and France.[73] In 2024, the Federal Railroad Administration (FRA) awarded Colorado State University, Pueblo, $11.7 million to "pioneer research in hydrogen and natural gas-powered rail technologies."[74] However, in many other cases regarding hydrogen-powered machines and technologies, federal standards lag behind.[75] It is claimed that hydrail has advantages over more traditional electric rail systems (such as lower refueling times and lower capital costs for infrastructure), but it remains to be seen whether this will be the case in practice.[76] Furthermore, the development of hydrail faces the same hurdles as other emerging hydrogen markets (namely, fuel cost and infrastructure).[77]

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[71] Danielle Hannon, "'Uno' Looks to Provide Toyota with More Ways to Fight Carbon," Toyota USA Newsroom, April 13, 2023, https://pressroom.toyota.com/uno-looks-to-provide-toyota-with-more-ways-to-fight-carbon/.

[72] Stuart Chirls, "Short Line Eyes Cali Market, Buys Hydrogen Locomotive Builder," FreightWaves, February 11, 2025, https://www.freightwaves.com/news/short-line-eyes-cali-market-buys-hydrogen-locomotive-builder.

[73] Simon Torkington, "This Is How Hydrogen Trains Could Transform Transport," World Economic Forum (blog), September 23, 2024, https://www.weforum.org/agenda/2024/09/hydrogen-trains-sustainable-transport/; "California Continues to Expand Hydrogen-Powered Passenger Rail Fleet: Latest Order Pushes Number of Zero-Emission Intercity Trainsets to 10," California Department of Transportation (Caltrans), February 14, 2024, https://dot.ca.gov/news-releases/news-release-2024-007. For more information, seek: Stephen Kent et al., "Low- or Zero-Emission Multiple-Unit Feasibility Study," Feasibility Report (Eli Broad College of Business, Michigan State University: Center for Railway Research and Education, December 30, 2019), https://www.gosbcta.com/wp-content/uploads/2019/09/20191231_RPT_SBCTA_2019_Low_or_Zero_Emission_Multiple_Unit_Feasibility_Study.pdf; Marie Boran, "China Unveils 'Groundbreaking' Hydrogen High Speed Train," Newsweek, September 27, 2024, https://www.newsweek.com/china-unveils-groundbreaking-hydrogen-high-speed-train-1960349.

[74] Gene Alfonso, "CSU Pueblo & the Southern Colorado Institute on Transportation Technology (SCITT) Awarded $11.7M to Lead Next Generation of Rail Technology Research and Innovation Hub | 2024 | CSU Pueblo," Colorado State University Pueblo, October 29, 2024, https://www.csupueblo.edu/news/2024/10-29-csu-pueblo-and-the-southern-colorado-institute-on-transportation-technolgy-scitt-awarded-11-point-7-million-to-lead-next-generation-of-rail-technology-research-and-innovation-hub.html; Noël Fletcher, "FRA Awards $96.5M to Hydrogen Rail Projects in Three States," Transport Topics, November 8, 2024, https://www.ttnews.com/articles/fra-awards-hydrogen-rail.

[75] Stuart Chirls, "Short Line Eyes Cali Market, Buys Hydrogen Locomotive Builder," FreightWaves, February 11, 2025, https://www.freightwaves.com/news/short-line-eyes-cali-market-buys-hydrogen-locomotive-builder.

[76] Daniel Ding and Xiao-Yu Wu, "Hydrogen Fuel Cell Electric Trains: Technologies, Current Status, and Future," Applications in Energy and Combustion Science 17 (March 2024): 100255, https://doi.org/10.1016/j.jaecs.2024.100255.

[77] Keith Fender, "German Hydrogen Trains Experience Problems," Trains.Com, February 5, 2025, https://www.trains.com/trn/news-reviews/news-wire/german-hydrogen-trains-experience-problems/;

3.9 Without ARCHES, Still Plenty of Momentum for Hydrogen in California

In 2023, the State of California was awarded $1.2 billion by the U.S. DOE to fund its proposed ARCHES Hydrogen Hub project. The ARCHES project was selected as one of seven regional locations to "to accelerate the commercial-scale deployment of clean hydrogen, helping to generate clean, dispatchable power, create a new form of energy storage, and decarbonize heavy industry and transportation."[78] This was great news for California until federal policy shifts associated with the priorities of the Trump administration halted the funding indefinitely and perhaps permanently. This federal shift, while unexpected for many in hydrogen and supply-chain workforce circles, does not change the central problem statement that this report addresses: Workforce and learning development priorities are not strategically aligned with the technological objectives related to implementing a hydrogen hub in California.

Additionally, the underlying logic that ARCHES funding would support the development of a hydrogen hub in California to "decarbonize energy-intensive heavy industry and support heavy-duty transportation" remains the same. Ground zero for hydrogen hub development in California—with or without ARCHES funding—continues to be the Long Beach–Los Angeles Port Complex and its link to the ships, cargo-handling equipment, trains, and trucks that move freight through the Southern California supply chain.[79] As such, workforce development planning for the Blueprint will continue to tell the story of the current and future professionals who will lead the production, storage, delivery, and end-use of hydrogen in freight systems.

Even if the ARCHES funding is ultimately cancelled and more opposition to hydrogen is enacted by the federal government in the years ahead, the logic and need for the hydrogen workforce Blueprint remains critical. Atop the list of reasons why strategic workforce development planning remains critical for the hydrogen rollout in California is the Long Beach-Los Angeles Port Complex. Collectively, the San Pedro Bay ports represent the largest freight gateway in the U.S. and communities adjacent to the port and located near major truck and rail routes will continue to demand cleaner supply-chain systems. Terminal operators at both ports are moving ahead with innovative technology demonstrations involving hydrogen-powered maritime, cargo-handling, locomotive, and heavy trucking technologies.

To gain a richer sense of the hydrogen technology demonstrations underway at the San Pedro Bay ports, the Blueprint research team toured Yusen Terminals (see Figure 11) at the Port of Los Angeles to observe the deployment of a technology demonstration of hydrogen rubber-tired gantry cranes manufactured by Toyota Tsusho. This exhibition was conducted in collaboration with the International Longshore and Warehouse Union (ILWU) workers operating the new equipment.

[78] "Regional Clean Hydrogen Hubs."
[79] Ibid.

The field research revealed an important insight: Workforce development researchers can mine hydrogen technology demonstrations to rapidly identify new KSAs requiring responsive training and upskilling to prepare future professionals. In this instance, the original equipment manufacturer, Toyota Tsusho, provides an opportunity for the operator, Yusen Terminals, to deploy new hydrogen equipment to assess how to prepare its ILWU workforce. This format of working in concert with OEMs, operators, and front-line workers can be applied to planned hydrogen technology demonstrations at the San Pedro Bay ports related to maritime, cargo-handling, locomotive, and trucking technologies and related fueling systems in the years ahead.

Figure 11. Hydrogen-Powered Rubber-Tired Gantry Crane at Yusen Terminals, Port of Los Angeles

Courtesy of Fran Ohlheiser, Director of Communications for Yusen Terminals

Similar workforce development insights can be gleaned from early hydrogen deployments such as the Tri-Gen facility in operation at the Toyota terminal at the PoLB, which is converting renewable natural gas into hydrogen and electricity as outlined in the Introduction of this report (see Figure 12).

Figure 12. Aerial Photo of the Tri-Gen Facility at the Port of Long Beach, May 2024

Toyota Motor North America and FuelCell Energy collaborated to develop the facility, which uses biogas to produce renewable electricity, renewable hydrogen, and usable water. Copyright © 2025 Port of Long Beach[81]

Although federal funding for hydrogen could be reduced or eliminated over the next few years, California represents the fourth largest economy in the world with a $4.1 trillion gross domestic product and has a proven track record of funding ZEV priorities for the state.[83] In late December

[81] "Renewable Energy Project Powers Port with Hydrogen," Port of Long Beach, May 2, 2024, https://polb.com/port-info/news-and-press/renewable-energy-project-powers-port-with-hydrogen-05-02-2024/.

[83] Governor of California, "California Is Now the 4th Largest Economy in the World," State of California, April 24, 2025, https://www.gov.ca.gov/2025/04/23/california-is-now-the-4th-largest-economy-in-the-world/.

of 2024, the CEC "approved a $1.4 billion investment plan that accelerates progress on the state's electric vehicle (EV) charging and hydrogen refueling goals."[84]

In addition to hydrogen funding from the State of California, there is a range of ways that municipalities and regional stakeholders can form public-private partnerships (P3) to leverage private capital investment and state programs and incentives to secure funding for hydrogen projects and programs. The State of California operates a range of financial tools and programs, including Climate Resiliency Districts (CRD), Tax Increment Financing Districts (TIF), P3 Financing Solutions, and Credit Enhancements with the State of California Infrastructure Bank (IBank), and other credit sponsors, to leverage credit enhancements, loan guarantees, and other financial products to reduce risk and attract more cost-effective private investment in hydrogen infrastructure and systems.

The abovementioned reasons demonstrate that there is still plenty of money and momentum for hydrogen projects and programs in California. The literature review featured in this report builds on that California-based rationale and also documents the implementation of hydrogen systems and construction of related infrastructure that is progressing in other countries around the world. Those domestic and international findings underscore the importance of developing workforce and learning development plans and priorities that align with the technological implementations of hydrogen systems and infrastructure throughout California.

3.10 Navigating Political Uncertainty

Political uncertainty is another challenge that many leaders in supply chain and energy industry circles are increasingly citing as a significant challenge in developing and implementing long-range hydrogen industrial and workforce plans. A very recent example of competing views and legislative agendas between the State of California and the federal government took place in the weeks leading up to the publication of this report. In May 2025, the U.S. Congress "passed a Congressional Review Act measure to block California from implementing the Advanced Clean Cars II regulation, Advanced Clean Trucks regulation, and the Heavy-Duty Low-NOx Omnibus rule."[85] Two years earlier, in April 2023, the CARB "voted to ban the sale of new diesel big rigs by

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[84] "CEC Approves $1.4 Billion Plan to Expand Zero-Emission Transportation Infrastructure," California Energy Commission, December 11, 2024, https://www.energy.ca.gov/news/2024-12/cec-approves-14-billion-plan-expand-zero-emission-transportation-infrastructure.

[85] Tony Briscoe, "STATE RULE ON GAS-ONLY CARS IS REVOKED: The Senate Voted to Nullify California's Plan to Ban the Sale of New Vehicles That Run Only on Fossil Fuels," *Los Angeles Times*, May 23, 2025, https://www.proquest.com/latimes/docview/3206726850/citation/FF97E19CA3964410PQ/1?sourcetype=Newspapers.

2036 and require all trucks to be zero-emissions by 2042."[86] One month after the passage of the Congressional Review Act, U.S. President Donald Trump, on June 12, 2025, signed the resolutions, revoking U.S. Environmental Protection Agency waivers for the three California vehicle emissions rules.[87] The same day, California Gov. Gavin Newsom signed an executive order challenging federal legislation and announcing that he and California Attorney General Rob Bonta would "challenge the order in court."[88]

The above-mentioned political battles and shifts in federal and state policy require a reevaluation of hydrogen workforce strategic planning. Removing ZEV deadlines does slow the State of California's regulatory urgency to drive supply-chain industry leaders to transition to zero-emission hydrogen and battery-electric vehicles. And while Gov. Newsom's executive order and related legal challenge signal a commitment to supporting the previous ZEV mandates, court challenges move slowly and provide no near-term regulatory certainty for supply-chain leaders to develop a hydrogen workforce strategy. The surer bet for supply-chain leaders is to base their hydrogen workforce and industry strategies on existing California legislation that is not in question. Assembly Bill 126, for example, mandates that at least $15 million annually is dedicated through 2030 for hydrogen fueling station development. Similarly, the Clean Hydrogen Hub Fund,

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[86] Emma Newburger, "California Bans the Sale of New Diesel Trucks by 2036," *CNBC*, April 28, 2023, https://www.cnbc.com/2023/04/28/california-bans-the-sale-of-new-diesel-trucks-by-2036.html.

[87] Congress.gov, "Text - H.J.Res.87 - 119th Congress (2025-2026): Providing congressional disapproval under chapter 8 of title 5, United States Code, of the rule submitted by the Environmental Protection Agency relating to 'California State Motor Vehicle and Engine Pollution Control Standards; Heavy-Duty Vehicle and Engine Emission Warranty and Maintenance Provisions; Advanced Clean Trucks; Zero Emission Airport Shuttle; Zero-Emission Power Train Certification; Waiver of Preemption; Notice of Decision'," June 12, 2025. https://www.congress.gov/bill/119th-congress/house-joint-resolution/87/text; Tony Briscoe, "BUSINESS: Trump Signs Law to Kill State Auto Emission Rules: President Seeks to Cancel Regulations. California's Attorney General Files a Lawsuit," *Los Angeles Times*, June 13, 2025, https://www.proquest.com/latimes/docview/3218322650/citation/59C3A4B078254F6DPQ/1?sourcetype=Newspapers.

[88] Imam Palm, "Newsom Signs Executive Order Advancing California's Clean Car Goals amid Pushback from the Trump Administration | KTLA," *KTLA*, June 12, 2025, https://ktla.com/news/california/newsom-signs-executive-order-advancing-californias-clean-car-goals-amid-pushback-from-the-trump-administration/; Briscoe, "STATE RULE ON GAS-ONLY CARS IS REVOKED."

established by Senate Bill 1075 and administered by the California Infrastructure and Economic Development Bank, subsidizes green hydrogen projects.[89]

Another highly significant but less discussed policy shift relates to the California Public Employees' Retirement System (CalPERS). In 2024, the largest public pension system in the U.S. announced that it would "commit at least $100 billion in climate solutions" to support the production of renewable energy sources—such as solar, wind, and hydrogen—as well as "technologies that capture and store CO_2 emissions" and waste management solutions, which include "reducing, recycling, reusing, and capturing methane from landfills."[90] The CalPERS commitment serves as yet another example that, in the face of shifting political winds and the inevitable policy shifts that occur from one gubernatorial or presidential administration to the next, the development and implementation of hydrogen technologies are moving forward in California. It is also important to note that many of the CO_2 and methane capture and storage technologies supported by the CalPERS climate initiative relate to hydrogen production technologies and related workforce initiatives that are addressed in this report.

Writ large, the global transition toward sustainable and clean energy sources has propelled the hydrogen fuel industry—and the workforce that drives it—into the spotlight. As governments, industries, and consumers alike recognize the potential of hydrogen as a clean energy carrier, the demand for skilled professionals in the hydrogen fuel sector is on the rise. Workforce development plays a pivotal role in shaping a sustainable and efficient hydrogen economy, ensuring that the industry can meet its potential while addressing the challenges associated with the energy transition. This Blueprint assesses current and future workforce needs related to implementing what will one day be a viable hydrogen market capable of consistently providing hydrogen at a price that is equal to or less than the price of diesel. When that day will come is hard to predict, and recent events have made predicting that day all that much more difficult. However, if supply-chain leaders wait until the day that the price of hydrogen is competitive with diesel, that day will never come, because ultimately it will be the workforce that will bring a future of affordable and plentiful hydrogen to fruition.

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[89] Eloise Reyes, "AB-126 Vehicular Air Pollution: Clean Transportation Program: Vehicle Registration and Identification Plate Service Fees: Smog Abatement Fee: Extension," Pub. L. No. Assembly Bill 126 (2023), https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202320240AB126; Nancy Skinner, "An Act to Add Section 38561.8 to the Health and Safety Code, to Add and Repeal Section 25307 of the Public Resources Code, and to Amend Section 400.3 of the Public Utilities Code, Relating to Energy," Pub. L. No. SB 1075 (2022), https://leginfo.legislature.ca.gov/faces/billStatusClient.xhtml?bill_id=202120220SB1075. See also: California Air Resources Board (CARB), "Senate Bill 1075: Hydrogen Development, Deployment, and Use," Harbor City Community Meeting, Harbor Gateway Branch Library, Los Angeles, June 12, 2025, https://ww2.arb.ca.gov/sites/default/files/classic/SB%201075%20Harbor%20City%20Presentationnoqr.pdf.

[90] "$100 Billion Climate Action Plan."

4. Labor Market Analysis

Using a combination of the U.S. Bureau of Labor Statistics (BLS) data and existing research from Canada and Australia, the Blueprint research team identified 21 occupations and skills currently in demand by the California hydrogen market. Canada and Australia are first movers in the emerging hydrogen market and have each developed a workforce development roadmap detailing which occupations are needed to support the future hydrogen supply chain. Using the labor market data and analytics tool Lightcast©, the team examined over 1,000 job postings related to hydrogen and found 21 occupations that overlapped with the workforce development roadmaps.

Australia identified 76 occupations critical to their future hydrogen supply chain and Canada identified 102. The Blueprint research team found that of the 178 total occupations, 83 were unique roles. To facilitate a relevant comparison to the Lightcast© data, the team assigned each occupation the closest SOC code available within the BLS database based on the duties associated with each role. Emerging occupations such as fuel cell engineers and fuel cell technicians do not have a dedicated SOC code but may have an O*NET code in which case the occupation was placed under its parent SOC code (e.g., Fuel Cell Engineers 17-2141.01 placed under 17-2141 Mechanical Engineers). The team then found the top technical skills for the 56 remaining SOC codes and the projected job growth.

Table 2. Hydrogen SOC Codes

Hydrogen Supplier Codes							
SOC Code	**Occupation Title**	**Top Technical Skills**	**Average Wage**	**Education Level**	**2023 Employees**	**Projected Employment change in 2033**	**%change**
17-2041	Chemical Engineers	MATLAB, AutoCAD, Aspen HYSYS, ChemCAD	$121,860	Bachelor's degree	336,600	40,900	12%
17-2051	Civil Engineers	AutoCAD, Structural Analysis, Building Information Modeling	$99,590	Bachelor's degree	291,900	32,100	11%
17-2141	Mechanical Engineers	AutoCAD, Finite Element Analysis (FEA), Computational Fluid Dynamics (CFD)	$102,320	Bachelor's degree	291,900	32,100	11%
17-2071	Electrical Engineers	AutoCAD, MATLAB, LabVIEW	$111,910	Bachelor's degree	21,400	2100	10%

A functioning supply chain requires both higher education roles and technical roles to ensure smooth, efficient operation. To ensure that the entirety of the supply chain is represented within the Lightcast© data, the team preformed two Lightcast© job market analyses targeting hydrogen job postings in California. The first analysis required each job posting to include at least a bachelor's degree and the second required each job posting to have an education level below a bachelor's degree. The two analyses ensured that roles that require higher education and roles that may only require certifications or technical training are included in the data.

By cross-examining California job posting data with the existing SOC codes found within the Australian and Canadian workforce development roadmaps, the team identified the overlaps between the theoretical roles and the roles in demand by the market. The most valuable SOC codes come from the overlap between the previously identified SOC codes and the SOC codes found in the California Job Market. The overlap between these categories suggests that these jobs have the foundational skills needed to develop hydrogen systems and will remain important as the industry evolves and begins to demand a more specialized skill set.

Table 3. Labor Market and Literature Review SOC Code Overlap

SOC Code	Occupation Title
11-3051	Industrial Production Managers
17-2141	Mechanical Engineers
17-2041	Chemical Engineers
49-9041	Industrial Machinery Mechanics
19-5011	Occupational Health and Safety Specialists
47-2111	Electricians
17-2051	Civil Engineers
17-2071	Electrical Engineers
17-2112	Industrial Engineers
11-9041	Architectural and Engineering Managers
19-4031	Chemical Technicians
43-5061	Production, Planning, and Expediting Clerks
17-3029	Engineering Technologists and Technicians, Except Drafters, All Other
13-1081	Logisticians
49-3042	Mobile Heavy Equipment Mechanics, Except Engines
49-9071	Maintenance and Repair Workers, General
53-3032	Heavy and Tractor-Trailer Truck Drivers
49-1011	First-Line Supervisors of Mechanics, Installers, and Repairers
17-3023	Electrical and Electronic Engineering Technologists and Technicians
49-3023	Automotive Service Technicians and Mechanics
53-6031	Automotive and Watercraft Service Attendants

The 21 identified Job Titles and related SOC codes reflect hydrogen-related occupations in the current workforce landscape, but there are many other current and future related occupations to consider. There is a wide array of occupations that will be essential to the development of the hydrogen sector. Pipeline technicians, truck drivers, and water treatment specialists are contributing to the production and transport of hydrogen today. These hydrogen-adjacent occupations should be factored into strategic workforce development and planning moving forward.

5. Survey and Peer Exchange Summary

The CSU5+ Hydrogen Workforce Peer Exchange convened representatives from the Long Beach, Los Angeles, and Northridge California State University campuses, as well as California Polytechnic University Pomona and the California Maritime Academy. The peer exchange provided a forum to discuss hydrogen workforce development and curriculum alignment across the five institutions. Participants completed a survey prior to the peer exchange to document existing course and certificate offerings and curricula in development. Each of the CSU representatives also serve as primary investigators leading hydrogen-related research and workforce development programs and projects at their campuses.

Six representatives from the five participating campuses participated in the survey and subsequent peer exchange. Four of the five participating campuses have established hydrogen-related coursework, while only one campus offers a related program concentration. One campus did not have any hydrogen-related coursework but was open to and interested in adopting an academic approach. During the peer exchange, participants emphasized the importance of developing a cohesive approach to address hydrogen workforce development. Key themes included sharing resources, organizing additional peer exchanges, and increased cross-campus collaboration.

In terms of curricular development, the participants in the peer exchange identified the integration of emerging hydrogen topics into existing curricular offerings as a primary challenge. The survey showed that four campuses had integrated hydrogen topics into general education (GE) as well as graduate-level courses. Entire program focuses remain scarce while options for certificate programs are explored increasingly. Where hydrogen topics are included in existing curricula, additional components such as case studies and student research projects were often incorporated. Targeted workforce development activities included internship and work-study opportunities.

Table 4. CSU5+ Available Hydrogen Courses and Programs

Campus	Classes	Program	Department/ College	Type	Degree Level
CSU Long Beach	Energy and Environment, Sustainability (ENGR 302), Electromechanical Sciences, Thermodynamics	Mechanical Engineering	Engineering	Coursework/For credit	Undergraduate/TBD
CSU Los Angeles	Sustainable Energy and Transportation (ETEC 3700), Electric and Hybrid Vehicles (ETEC 4700), Engine Design and Performance (ETEC 4710), Photovoltaic Applications (ETEC 4720), Fuel Cell Applications (ETEC 4740), Measurement, Instrumentation and Control (ETEC 4760)	Engineering Technology	Engineering Technology	Concentration/For credit	Undergraduate
Cal Poly Pomona	Alternative Energy Systems (ME 3070), Electrochemistry Engineering (ME 4990), Fuel Cell Fundamentals (ME5990), Hydrogen Fundamentals (6990)	Mechanical Engineering	Engineering	Coursework/For credit	Undergraduate
CSU Northridge	Fundamentals of Alternative Energy and Fuel Cell Technology (ME482)	Mechanical Engineering	Mechanical and Computer Science	Coursework/For credit	Undergraduate
Cal Maritime	N/A	N/A	N/A	N/A	N/A

In addition to curricular development, participants in the peer exchange emphasized the importance of industry and research engagement. These relationships are fundamental in connecting the developing workforce and students to real-world hydrogen applications and supplementing academic knowledge with internships, guest lectures, and site visits. Currently, only one campus offers an internship as part of its Sustainable Energy and Transportation-focused program. In this informal, part-time work-study internship, approximately four to six students work in the campus' Hydrogen Research and Fueling Facility annually. These positions are open to students across the College of Engineering, Computer Science, and Technology. At the time of the peer exchange, more than 30 students had completed the internship, of which roughly 50% now work in the hydrogen industry. The campus, in collaboration with a community college, also uses its research facility to offer a Hydrogen Technology and Infrastructure teaching externship aimed at providing foundational training on hydrogen technologies and initiating discussions for future collaboration in integrating hydrogen-related curricula into community college settings (see Figure 13 below).

Figure 13. Hydrogen-Related Workshop

Courtesy of David Blekhman, CSULA

Most participants across the represented campuses were aware of ongoing hydrogen-related workforce development efforts such as the ARCHES project, as well as efforts by the U.S. Department of Energy. Across the represented campuses, several hydrogen-related research efforts are ongoing, including topics such as the storage of pressurized liquid hydrogen in collaboration with the National Aeronautics and Space Administration (NASA), work surrounding experimental test stands and theoretical fuel cell models, and fluid dynamic dispersion simulations. Two campuses are currently participating in grant-funded research on hydrogen storage. Additionally, one campus is collaborating with two major hydrogen workforce development initiatives, the H2Skills program, and the H2EDGE initiative.

The peer exchange participants identified five core recommendations to address challenges and support the development of the growing hydrogen workforce:

- increased cross-campus collaboration;
- increased coordination;
- increased resource sharing;
- development of research competitions; and

strengthening of industry partnerships.

Cross-campus collaboration, coordination, and resource sharing should be increased by developing articulation agreements that support a common hydrogen curriculum across community college, 4-year, and graduate programs. Additionally, peer exchange participants supported the development of hydrogen-related research competitions across the CSU campuses to foster student engagement and innovation.

To bridge in-class and applied experiential learning, peer exchange participants noted the importance of recruiting industry champions and expert practitioners, citing site visits and cooperation with mobile hydrogen labs as two examples. Providing students with hands-on experience and supporting them in establishing connections would facilitate a smoother, less intimidating transition into the workforce through internships or job placements. Peer exchange participants emphasized that this type of collaboration could be a resource in establishing a variety of educational pathways into the hydrogen industry as the efforts mentioned above can be combined with curricular learning and integrated into stackable credentials and certificate programs. The peer exchange participants surmised that such differentiated pathways into the hydrogen industry could be helpful for campuses such as the California Maritime Academy, which does not currently offer any hydrogen-related coursework but is interested in and making efforts to explore the use of hydrogen in the maritime industry. This is a nascent discipline that could greatly benefit from a cohesive learning approach to the hydrogen economy. The CSU5+ Hydrogen Workforce Peer Exchange found that in addition to efforts in curriculum integration and industry partnerships, a key next step is for campuses, researchers, and partners to seek and apply for funding to support hydrogen workforce development initiatives across the CSU system.

6. Conclusion and Recommendations

Workforce development is a cornerstone for the successful implementation of hydrogen production, transport, storage, and fueling systems required to power the California supply chain. As the world accelerates its transition to clean energy, investing in education, training, and research initiatives will not only meet the current demand for skilled workers but also ensure the industry's resilience and adaptability in the face of evolving challenges. By nurturing a skilled and diverse workforce, the hydrogen specialists—who produce hydrogen and transport it to power the Southern California supply chain of boats, cargo-handling, locomotive, and trucking technologies—will play a pivotal role in achieving decarbonization goals for the Golden State.

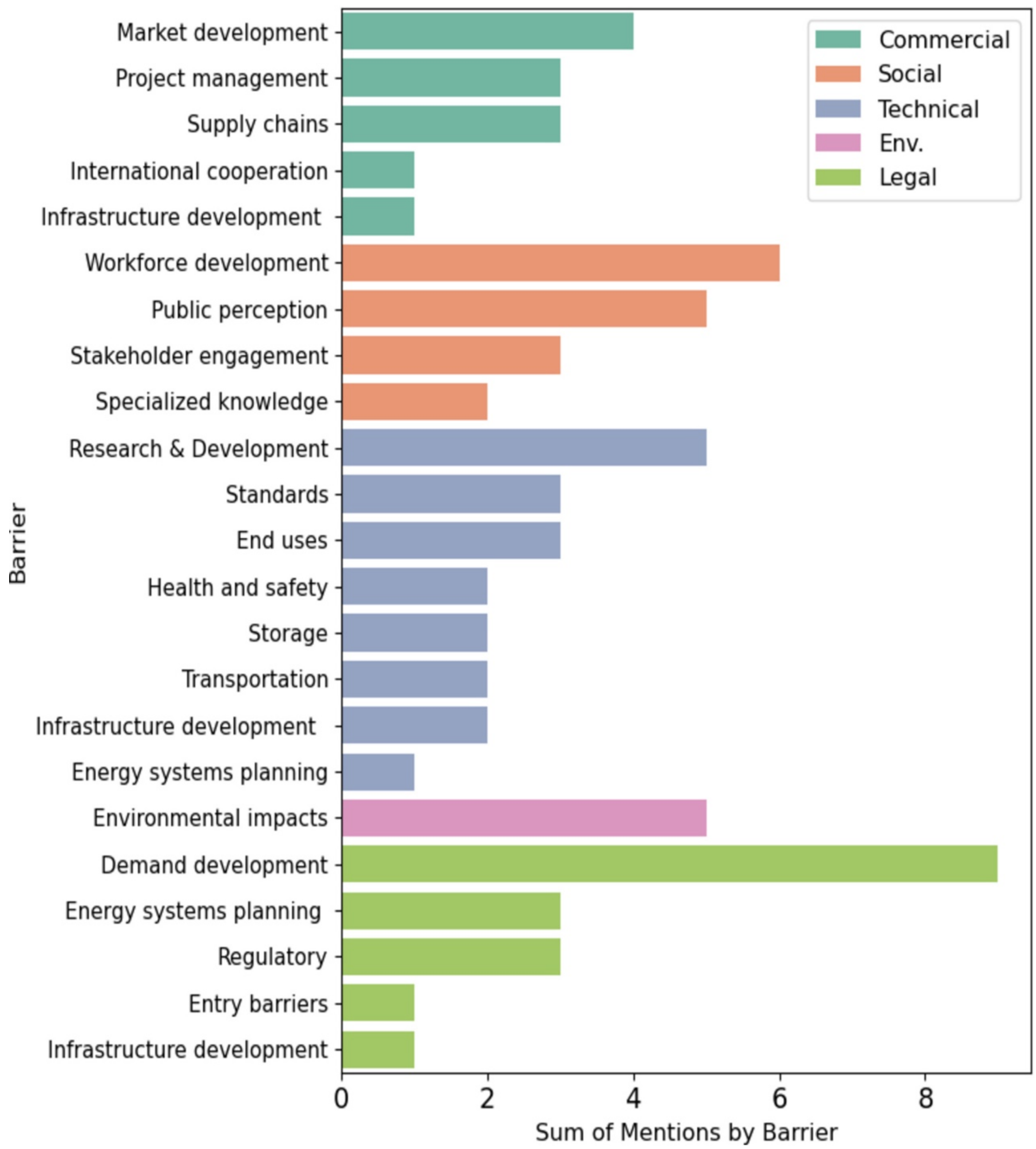
The trade and transportation sector faces a current and projected shortage of labor, and failure to properly prepare for the introduction of an increasing number of hydrogen production, transport, storage, and fueling professionals in the years ahead will only further complicate trade, transportation, and commerce challenges for the state and nation. As outlined in this report, hydrogen can be produced through various methods, such as electrolysis, natural gas reforming, and biomass gasification, among other methods. Once produced, hydrogen requires a robust infrastructure for storage, transportation, and distribution before being utilized in fuel cells for electricity generation, as a combustible fuel or as a feedstock in a range of industrial processes. The importance of hydrogen in achieving a low-carbon future cannot be overstated. It is a versatile energy carrier that can be produced from diverse sources, offering a viable solution to decarbonizing sectors such as transportation, manufacturing, and power generation. Thus, meeting the workforce needs of the trade and transportation workforce and meeting the industry's decarbonization goals are tasks that go hand in hand.

A recent analysis of 56 national hydrogen roadmaps and stakeholder interviews with domestic hydrogen professionals found that workforce development was the second most cited barrier to creating a market for hydrogen only behind demand development (see Figure 14).[91] The analysis, published in March 2025 in the peer-reviewed journal *Energy Research & Social Science*, provides solid footing to support an earlier finding in this Blueprint: that workforce and demand development efforts should be carried out simultaneously to ensure the highest probability of building a successful hydrogen market statewide and nationally. As previously stated in this report, if the collective industry holds off on workforce priorities until demand development efforts push hydrogen to a point where its price is competitive with diesel, the hydrogen rollout will be delayed

[91] Ioana Iacob, M. Granger Morgan, and Sabrina Curtis, "Barriers to Creating a Market for Hydrogen: Insights from Global Roadmaps and Stakeholders in the United States," *Energy Research & Social Science* 121 (March 2025): 103947, https://doi.org/10.1016/j.erss.2025.103947.

for years due to a lack of a skilled and prepared workforce. Accordingly, workforce development is an essential factor in determining a successful hydrogen rollout.

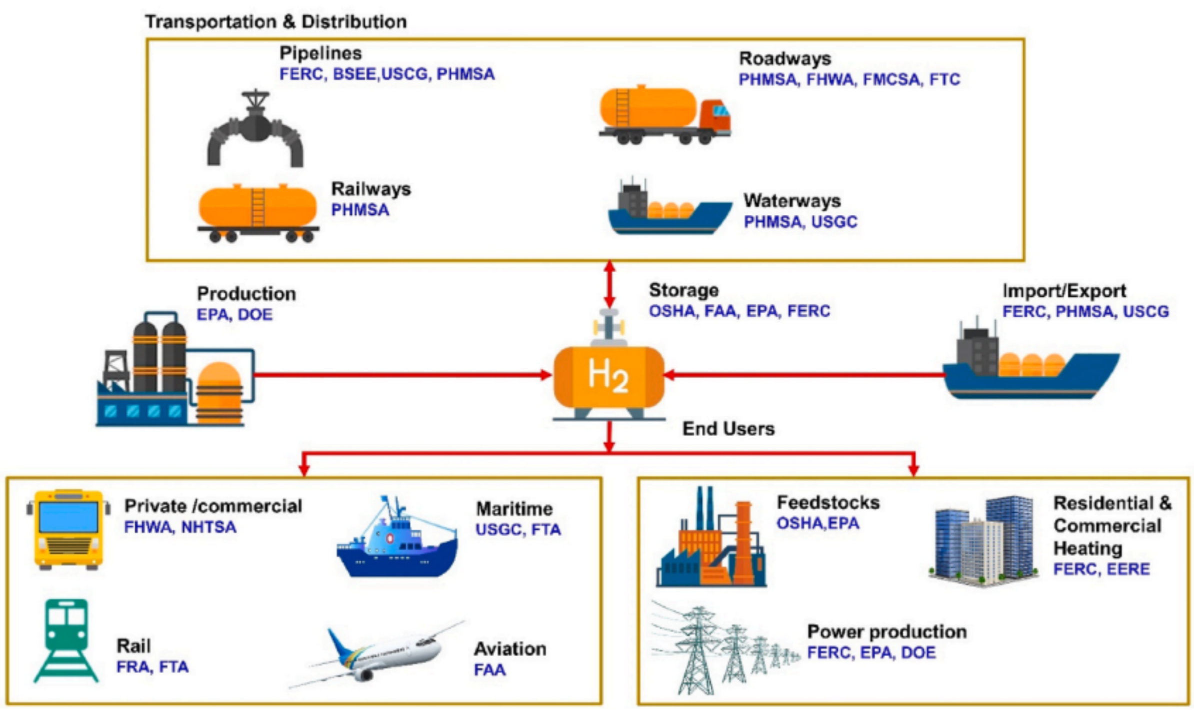
Figure 14. Barriers Identified in Recent Analysis of 56 National Hydrogen Roadmaps[92]



[92] Iacob, Granger Morgan, and Curtis, "Barriers to Creating a Market for Hydrogen," 103947.

The workforce development documentation and analysis in this Blueprint make clear that, beyond narrowly focused hydrogen-related occupations and hydrogen-adjacent occupations, it will be federal and state lawmakers and regulators who will serve as the gatekeepers for the production, transport, and end-use of hydrogen across the state and national supply chains. Figure 15 and the corresponding Table 5 present visual and textual documentation of the federal agencies that play a role in regulating production, transport, and end-user access to hydrogen. In California, the CEC and CARB play similar gatekeeper roles. This regulatory reality makes it a top workforce development priority for leaders in industry and education to partner with legislators and regulators to develop hydrogen energy and industrial plans that are informed by confirmed scientific evidence and strategic economic viability.

Figure 15. Illustration of the Agencies that Oversee the Hydrogen Supply Chain in the United States[94]



[94] Shree Om Bade and Olusegun Stanley Tomomewo, "A Review of Governance Strategies, Policy Measures, and Regulatory Framework for Hydrogen Energy in the United States," *International Journal of Hydrogen Energy* 78 (August 12, 2024): 1363–81, https://doi.org/10.1016/j.ijhydene.2024.06.338.

Table 5. Regulating Bodies of The Hydrogen Supply Chain

Transportation & Distribution; Pipelines:	Production:	Storage:	Import/Export:
FERC – Federal Energy Regulatory Commission	EPA – Environmental Protection Agency	OSHA – Occupational Safety and Health Administration	FERC – Federal Energy Regulatory Commission
BSEE – Bureau of Safety and Environmental Enforcement	DOE – U.S Department of Energy	FAA – Federal Aviation Administration	PHMSA – Pipeline and Hazardous Materials Safety Administration
USCG – U.S. Coast Guard		EPA – Environmental Protection Agency	USCG – U.S. Coast Guard
PHMSA – Pipeline and Hazardous Materials Safety Administration		FERC – Federal Energy Regulatory Commission	
Transportation & Distribution; Roadways:			
PHMSA – Pipeline and Hazardous Materials Safety Administration			
FHWA – Federal Highway Administration			
FMCSA – Federal Motor Carrier Safety Administration			
FTC – Federal Trade Commission			
End Users; Private/Commercial:	End Users; Rail:	End Users; Maritime:	End Users; Aviation:
FHWA – Federal Highway Administration	FRA – Federal Railroad Administration	USCG – U.S. Coast Guard	FAA – Federal Aviation Administration
NHTSA – National Highway Traffic Safety Administration	FTA – Federal Transit Administration	FTA – Federal Transit Administration	
End Users; Feedstock	End Users; Power production	End Users; Residential & Commercial Heating	
EPA – Environmental Protection Agency	FERC – Federal Energy Regulatory Commission	FERC – Federal Energy Regulatory Commission	
OSHA – Occupational Safety and Health Administration	EPA – Environmental Protection Agency	EERE – Office of Efficiency and Renewable Energy (DOE)	

Public-private partnerships will drive the hydrogen rollout

The opening storyline in the Introduction of this Blueprint concludes with a bold possibility:

"Imagine if every wastewater facility in California was transferring RNG to a Tri-Gen facility."

To recap, Anaergia, the previously mentioned Canadian-based company, was named Net Zero Carbon Champion at the 2023 Global Water Awards. The same year, Anaergia's subsidiary, SoCal Biomethane, was named Wastewater Project of the Year for its P3 with the Victor Valley Wastewater Reclamation Authority. SoCal Biomethane "converts 235,000 tons a year of waste and biosolids into 320,000Mmbtu of biomethane" and is the largest privately financed "co-digestion-to-biomethane project for pipeline injection at a wastewater treatment plant" in North America.[96]

The RNG produced at the SoCal Biomethane facility is injected into California's existing natural gas pipeline infrastructure and sent 100 miles south to the PoLB Toyota Terminal where the Tri-Gen facility is operated. In May 2025, the U.S. DOE awarded FuelCell Energy, Inc. and Toyota Motor North America with the 2025 Better Project Award for their joint development of the Tri-Gen facility: "Commissioned by Toyota and owned and operated by FuelCell Energy, Tri-Gen produces three products for port vehicle processing operations at Toyota Logistics Services: renewable electricity, renewable hydrogen and usable water." To accomplish this innovative energy conversion, the Tri-Gen technology takes RNG—converted from feedstock at wastewater treatment facilities or landfills—to generate on a daily basis "up to 2.3 megawatts of renewable electricity…1,200 kilograms of hydrogen…[and] about 1,400 gallons of water daily."[97]

In response to the success of Tri-Gen technology, Shell Exploration & Production Company/Equilon Enterprises LLC., "developed, designed, built, and currently operates three refueling stations for heavy-duty hydrogen fuel-cell electric trucks…that connect the Ports of Los Angeles and Long Beach with major warehouse complexes inland."[98]

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[96] Anaergia Team, "Anaergia Wins 'Net Zero Carbon Champion of the Year' at 2023 Global Water Awards," Anaergia, May 10, 2023, https://www.anaergia.com/about-us/media-center/anaergia-continues-expansion-of-biomethane-production-in-europe-with-commissioning-of-new-facility-in-northern-italy-2-4/.

[97] "Tri-Gen Receives U.S. Department of Energy 2025 Better Project Award - Fuelcellsworks," Fuel Cell Works, May 2, 2025, https://fuelcellsworks.com/2025/05/02/clean-energy/tri-gen-receives-u-s-department-of-energy-2025-better-project-award.

[98] "Tri-Generation System Blueprints the Possible | About Us," Shell, accessed July 8, 2025, https://www.shell.us/about-us/news-and-insights/everybody-forward-stories/tri-generation-system-blueprints-the-possible.html.

The Anaergia-PoLB-Toyota-Tri-Gen-Shell storyline holds a wide range of important insights:

1. A vast majority of the professionals who operate each stage in the wastewater-to-hydrogen production system fall outside of what is considered the hydrogen workforce, yet each professional contributes directly to technological processes that could generate significant volumes of sustainable hydrogen for the state and nation (see Figure 16 and Tables 6 and 7 below).

2. The transfer of biogas from Anaergia to the Tri-Gen facility presents a valuable case study reflecting how much can be accomplished during the retrofit stage of the hydrogen rollout. A great deal of the discussion surrounding the rollout of hydrogen as a viable energy source for heavy industry relates to "new build" solutions. Anaergia and Tri-Gen reflect innovative retrofit technologies that can use existing infrastructure to generate sustainable hydrogen at this moment in time. New-build hydrogen pipelines are indeed necessary to transport hydrogen using materials that are not vulnerable to embrittlement. However, Anaergia and Tri-Gen technologies demonstrate that it is possible to move biogas feedstock using existing pipeline infrastructure to produce hydrogen today.

3. Further, the biogas feedstock derived from wastewater facilities is a model that could be applied to wastewater facilities throughout the state (Figure 16) and later scaled throughout the nation. There are currently two Tri-Gen facilities operating in Southern California, one at the PoLB and the second in nearby Fountain Valley, Orange County. Innovative P3s leveraging private capital investment, state CRD and TIF programs, and IBank credit enhancements and loan guarantees could be used to scale Anaergia, Tri-Gen, and similarly innovative technologies throughout California.

Figure 16. Wastewater Treatment Plants and Natural Gas Pipeline Infrastructure in California

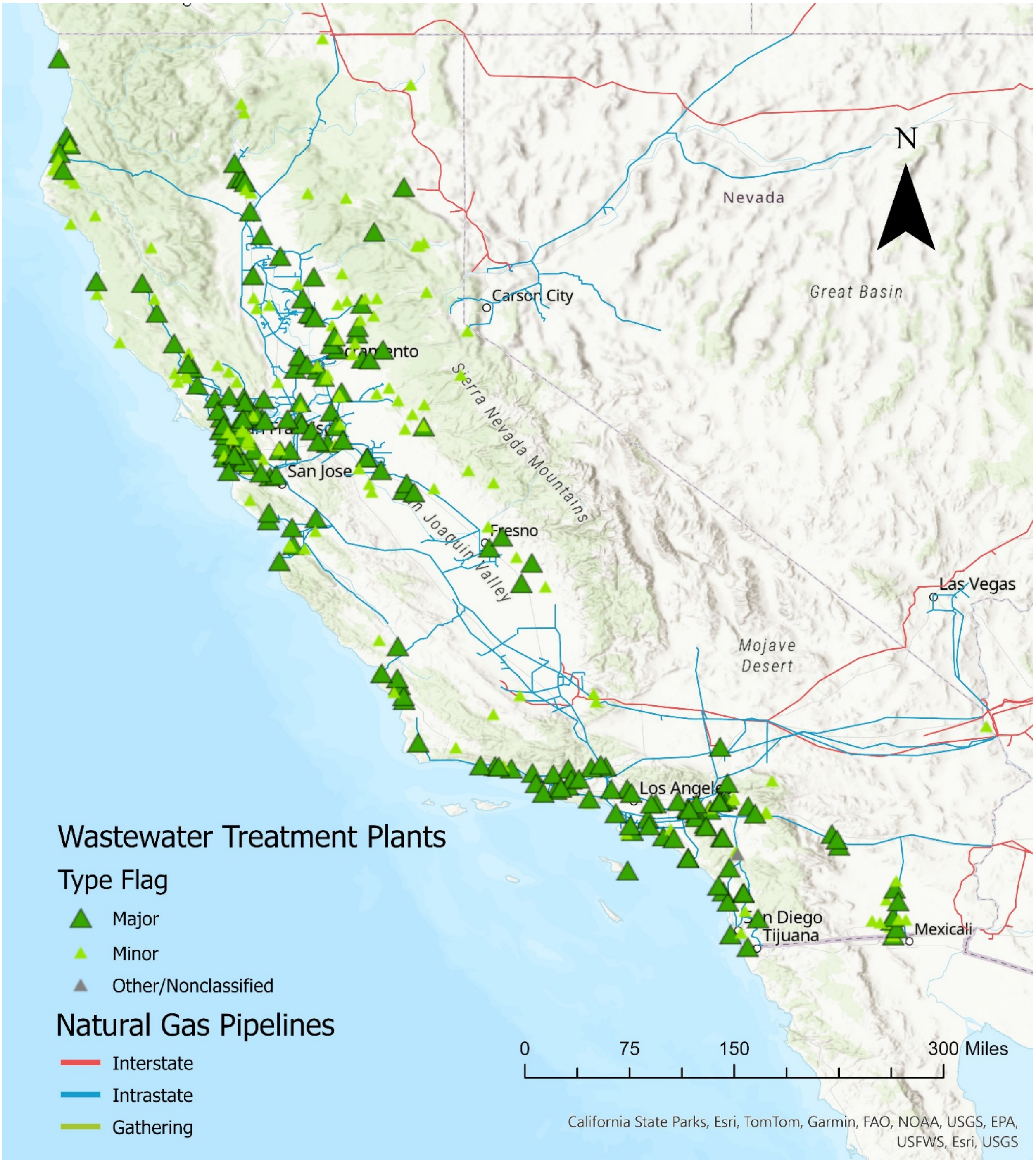

Table 6. Potential Outputs from Californian Wastewater Treatment Plants[99]

Wastewater treatment plants	331
Hydrogen (kg)	397,200
Electricity (MW)	761.3
Water (gallons)	46,340

Table 7. Potential outputs from Californian landfills[100]

Operational landfills	53
Hydrogen (kg)	63,600
Electricity (MW)	121.8
Water (gallons)	74,200

To generate a strategic future scenario, it is instructive to take the reported daily production rates of the Tri-Gen facility operating at the PoLB and extrapolate those numbers to consider how much hydrogen, electricity, and water could be generated if P3s similar to the Anaergia-PoLB-Toyota-Tri-Gen-Shell model were developed for the 331 water sanitation facilities and 53 landfills currently operating in California as documented in Tables 6 and 7. Collectively, 384 Anaergia-like facilities—using anaerobic digestion technologies to convert water-sanitation and landfill waste to RNG that is then transported using existing natural gas pipeline infrastructure to corresponding trigeneration facilities—could produce up to 460,800 kg of hydrogen, 883.2 MW, and 537,600 gallons of water daily.[101] In this future scenario, the hydrogen produced would power boats, cargo-handling equipment, locomotives, and heavy trucks moving freight across state, national, and global supply chains. The electricity generated could be transferred to microgrids or sent back to local utilities, and the water could be used for a range of important industrial purposes. These calculations are, of course, estimates that do not account for higher and lower volumes generated at each facility, but they do provide a baseline to conceptualize the highly significant short- and long-term energy challenges for California. The big short-term takeaway is that, before

[99] U.S. EPA Office of Environmental Information, "EPA Facility Registry Service - Integrated Compliance Information System (ICIS) Wastewater Treatment Plants - Overview," accessed July 8, 2025, https://www.arcgis.com/home/item.html?id=0895b107f9184e7cb31707767b506a64.

[100] United States Environmental Protection Agency, "Landfill and Landfill Gas Energy Database (LMOP Database)," Overviews and Factsheets, January 4, 2017, https://www.epa.gov/lmop/project-and-landfill-data-state.

[101] To calculate the potential of the Toyota-Tri-Gen-Shell model production, the Blueprint team multiplied the capacity of one Tri-Gen facility (2.3MW, 1,200kg of hydrogen and, 1,400kg of water) with the number of available water sanitation facilities and landfills (384).

new-build hydrogen infrastructure projects are scaled throughout California, retrofit innovations leveraging existing infrastructure will play a foundational role in the larger rollout. The long-term takeaway is that the larger, new-build rollout will require strategic civic-market coordination between industry leaders, educators, legislators, and regulators.

However, even in speculative future scenarios, economic and workforce realities are determined by what the numbers mean in the broader context. In a future scenario where 331 water sanitation facilities and 53 landfills in California were equipped with systems similar to the Anaergia-PoLB-Toyota-Tri-Gen-Shell model, the estimated 460,800 kg of hydrogen produced daily would provide enough volume to fuel approximately 5,760 Class 8 fuel cell electric trucks (FCETs),[102] and the estimated 883.2 MW would charge approximately 588 Class 8 battery electric trucks (BETs).[103] The combined FCET and BET Class 8 trucks powered in this future scenario total 6,348, which would be a significant first step in decarbonizing the California supply chain. According to CARB estimates, approximately 34,400 drayage trucks serviced California seaports and intermodal railyards in 2024.[104] A recent LA Business Council report estimates that the number could increase to a fleet of approximately 50,249 zero-emission drayage trucks by 2035.[105] The drayage fleet does not include the nearly one million medium-duty trucks or the more than 500,000 long-haul Class 8 trucks moving goods throughout the state and nation. It also does not include the boats, cargo-handling, and locomotives that drive California supply chains. Hitting that high-water mark will require P3s supported by industry leaders, educators, legislators, and regulators who agree on common energy, industrial, and workforce plans. Such plans require that all parties involved commit to what the Stanford Social Innovation Review describes as the *five conditions of collective impact*:[106]

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[102] To calculate the future scenario of FCETs in operation, the Blueprint team used the higher end of fueling estimates in an NREL report (80 kg per truck) divided by the estimated Toyota-Tri-Gen-Shell model production (460,800 kg).

[103] Wayne Hicks, "NREL Research into Fueling Big Rigs Could Help More Hydrogen Vehicles Hit the Road | NREL," National Renewable Energy Laboratory (Unted States Department of Energy Office of Energy Efficiency and Renewable Energy), May 1, 2020, https://www.nrel.gov/news/detail/features/2020/nrel-research-fueling-big-rigs-help-hydrogen-vehicles-hit-road.

[104] Steven S. Cliff to Liane M. Randolph and Honorable Board Members, "Advanced Clean Fleets Regulation High Priority Fleet Size Analysis," memorandum, February 10, 2023, https://ww2.arb.ca.gov/sites/default/files/2023-02/HPF%20Fleet%20Size%20Board%20Memo_ADA.pdf.

[105] Marlon G. Boarnet, Genevieve Giuliano, Clemens Pilgram, Ruoyu Chen, and Qifan Shao, "LABC Institute: Navigating California's Transition to Zero-Emission Drayage Trucks" (University of Southern California: METRANS Transportation Consortium and Los Angeles Business Council Institute, September 6, 2024), https://labusinesscouncil.org/wp-content/uploads/2024/09/LABC-ACF-Report-Full-Report-5.pdf.

[106] John Kania and Mark Kramer, "Collective Impact," *Stanford Social Innovation Review* 9, no. 1 (2011), https://doi.org/10.48558/5900-KN19.

1. A common agenda;
2. Shared measurement;
3. Mutually reinforcing activities;
4. Continuous communication; and
5. Backbone support.

It will take an A-list team of public- and private-sector leaders to assemble P3s to finance, design, develop, operate, and maintain robust hydrogen systems of the future. These teams of P3 A-listers will also need to use commonly agreed upon scientific principles to challenge previous assumptions and confirm the most strategic path forward for hydrogen demand and workforce development efforts in the years ahead. A good example of challenging previous assumptions involves reconsidering the near- and long-term role of traditional oil and gas companies in the development of hydrogen infrastructure.

Figure 17. Merchant and Oil Refinery Hydrogen Production Plants in California 2021

In 2021, California produced "1.83 million metric tonnes of hydrogen" annually at 20 SMR facilities concentrated in the San Francisco Bay Area and Los Angeles (Figure 17):[107] "Ten of these facilities are located within the gate of refineries and the other ten are merchant facilities, many located next to oil refineries and selling hydrogen directly to the California refineries."[42] The aggregate hydrogen produced in those 20 SMR facilities (Table 8) totals 5,031,105 kilograms per day of what is defined as grey hydrogen, which emits about 12 kilograms of CO_2 "into the atmosphere per kilogram of hydrogen produced,"[108] according to Emre Gençer, a principal research scientist at the MIT Energy Initiative. As noted in this report, modern CCS technologies now make it possible to capture up to 90% of the carbon released in grey hydrogen production to instead produce blue hydrogen, which is a lower carbon alternative.[109] New innovations in Autothermal Reforming (ATR) and other synergistic technologies have demonstrated in a range of industrial applications that as much as 98% of carbon emissions can be captured in blue hydrogen production.[110] In 2023, ExxonMobil added new carbon capture technologies to its Baytown Complex in Texas, enabling it to "produce approximately one billion cubic feet of low-carbon hydrogen per day and capture more than 98%, or around 7 million metric tons per year of the associated CO_2 emissions, making it the largest project of its kind in the world."[111]

Current CCS and related synergistic reforming technologies now make it possible to capture 90–98% of carbon emissions compared to traditional grey hydrogen production. If those technologies were integrated into the 20 SMR facilities currently producing 5 million kilograms of hydrogen per day, the state could reduce hydrogen-related carbon emissions by 90–98%. In a future scenario

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[107] Neutel, Berson, Laude, Arifi, Brandt, Saltzer, and Orr, Jr., Pathways to Carbon Neutrality in California."

[108] "How Clean Is Green Hydrogen? | MIT Climate Portal," MIT, accessed July 17, 2025. https://climate.mit.edu/ask-mit/how-clean-green-hydrogen.

[109] Daniel Davids, Neil Grant, Shivika Mittal, Adam Hawkes, and Gbemi Oluleye, "Impact of Methane Leakage Rate and Carbon Capture Rate on Blue Hydrogen Sustainability Using Combined Warming Index," *Applied Energy* 394 (September 15, 2025): 125888, https://doi.org/10.1016/j.apenergy.2025.125888; Christian Bauer, Karin Treyer, Cristina Antonini, Joule Bergerson, Matteo Gazzani, Emre Gencer, Jon Gibbins, Marco Mazzotti, Sean T. McCoy, Russell McKenna, Robert Pietzcker, Arvind P. Ravikumar, Matteo C. Romano, Falko Ueckerdt, Jaap Vente, Mijndert van der Spek, "On the Climate Impacts of Blue Hydrogen Production," *Sustainable Energy & Fuels* 6, no. 1 (2022): 66–75, https://doi.org/10.1039/d1se01508g; Matia Riemer and Vicki Duscha, "Carbon Capture in Hydrogen Production - Review of Modelling Assumptions," Applied Energy Innovation Institute (AEii), November 6, 2022, https://doi.org/10.46855/energy-proceedings-10204. Note: The exact figure is not agreed upon at this time, and further research must be conducted. Furthermore, the authors of this report consider lifecycle emissions to be key. For a discussion of lifecycle emissions and hydrogen production, see: Mwacharo, "It Doesn't Matter What the Color of Hydrogen Is."

[110] Wonjun Noh and Inkyu Lee, "Synergizing Autothermal Reforming Hydrogen Production and Carbon Dioxide Electrolysis: Enhancing the Competitiveness of Blue Hydrogen in Sustainable Energy Systems," *Chemical Engineering Journal* 499 (November 2024): 156688, https://doi.org/10.1016/j.cej.2024.156688.

[111] "Technip Energies Awarded Contract for FEED of World's Largest Low-Carbon Hydrogen Project at ExxonMobil's Baytown, Texas Facility," Nasdaq, accessed July 17, 2025. https://www.nasdaq.com/press-release/technip-energies-awarded-contract-for-feed-of-worlds-largest-low-carbon-hydrogen.

where public- and private-sector leaders secured the funding and cleared the necessary regulatory hurdles to double hydrogen production with modern CCS technologies, enough hydrogen would be generated to fuel 62,888 Class-8 FCETs—enough for current and future drayage fleet forecasts and an additional 12,000 long-haul FCETs moving goods throughout California and across state lines. Such an accomplishment would legitimize hydrogen as a viable fuel source for the California supply chain and pave the way for additional new-build solutions to fuel maritime, cargo-handling, and locomotive supply-chain systems.

Table 8. Hydrogen Production Capacity from Hydrogen Production Plants in California 2021[42]

Producer	City	Facility Type	Capacity (kg/day)
Air Liquide	El Segundo	Merchant	207,240
Air Liquide	Rodeo	Merchant	289,172
Air Products	Sacramento	Merchant	5,542
Air Products	Carson	Merchant	240,976
Air Products	Martinez	Merchant	212,059
Air Products	Martinez	Merchant	84,342
Air Products	Wilmington	Merchant	385,562
Praxair	Ontario	Merchant	20,483
Praxair	Ontario	Merchant	28,917
Praxair	Richmond	Merchant	626,539
Chevron USA Inc.	Richmond	Oil Refinery	795,222
Chevron USA Inc.	El Segundo	Oil Refinery	178,323
Marathon Petroleum Co.	Martinez	Oil Refinery	209,649
Marathon Petroleum Co.	Carson	Oil Refinery	289,172
PBF Energy Inc.	Martinez	Oil Refinery	465,084
Phillips 66 Company	Rodeo	Oil Refinery	53,015
Phillips 66 Company	Wilmington	Oil Refinery	253,025
San Joaquin Refining Co. Inc.	Bakersfield	Oil Refinery	9,639
Torrance Refining Co. LLC	Torrance	Oil Refinery	351,826
Valero Refining Co. California	Benicia	Oil Refinery	325,318

Recommendations

For more than 100 years, supply-chain systems around the world have relied on fossil fuels to power ships, cargo-handling equipment, locomotives, and trucks that move freight from origin to destination. Developing a skilled and prepared workforce for an entirely new energy sector will require careful strategic workforce development planning and skills mapping to ensure that the full project lifecycle of new hydrogen production and fueling infrastructure is developed to support supply-chain systems of the future. As the recent political and legislative shifts documented in this Blueprint suggest, funding and building hydrogen infrastructure and launching related consumer and industrial marketplaces will be an iterative process with many fits and starts. Navigating those fits and starts will require long-range strategic planning, unprecedented P3 innovation, and a willingness for all parties involved to leave their egos at the door and challenge assumptions when evidence-based research supports such reconsideration.

It is in that spirit that the Blueprint authors provide the following recommendations:

1. Mine hydrogen technology demonstrations and early implementations to identify new KSA gaps and related workforce development needs. Then develop responsive certificate training. Curriculum is updated in real-time due to technology-transfer P3s. To address rapid rates of change in the hydrogen sector, leaders in Professional and Continuing Education (PaCE) units on college campuses throughout California can partner with industry leaders in hydrogen production, transport, storage, and fueling systems to develop certificate training programs that respond to the KSA gaps identified by feedback from frontline workers, managers, and original equipment manufacturers as part of interview-based assessments and brief surveys about challenges associated with designing, developing, operating, and maintaining specific hydrogen infrastructure systems and vehicles. Project life-cycle compliance issues would also be addressed in this process. The hydrogen rollout is part of the ongoing Fourth Industrial Revolution (4IR)—an era of dramatic rates of technological change.[112] One potential accelerant that educators and trainers can leverage to keep pace with 4IR rates of change is to research and facilitate learning and workforce

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[112] Tyler Reeb, Chris Swarat, and Barbara Taylor, "Talent Pipelines for the Fourth Industrial Revolution: How California PaCE Units Can Bridge Critical KSA Gaps," UC Berkeley: Center for Studies in Higher Education, Research and Occasional Papers Series, no. Special Issue: Opportunities and Challenges for California Higher Education (June 7, 2024), https://escholarship.org/uc/item/5hh3904k. See also: Klaus Schwab, "The Fourth Industrial Revolution: What It Means and How to Respond," World Economic Forum, January 14, 2016, https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/; Klaus Schwab, *The Fourth Industrial Revolution* (New York: Crown, 2017).

development in the trenches and develop portable "quick-strike"[113] curricula and training. Insights into trigeneration and deployments of hydrogen powered rubber-tired gantry cranes provided in this Blueprint were made possible due to field research and expert interviews facilitated by industry champions, Yusen Terminals, FuelCell Energy, and Toyota Motor North America.

2. **Launch a CSU5+ Lecture Series to Incubate P3 Innovations and Generate Awareness for Hydrogen Pilot Certification.** The ARCHES funding from DOE might never materialize, but there is a veritable hydrogen brain trust within the CSU5+ network. This network of researchers has strong working relationships with hydrogen and supply-chain industry experts. Embracing the quick-strike mantra described in Recommendation 1 above, the PIs recommend that the CSU5+ team led by CSULB's CITT and the Institute of Innovation and Entrepreneurship should host a series of guest lectures addressing mission-critical hydrogen issues. The format for each lecture and subsequent pilot curriculum would use the five principles of collective impact previously mentioned in this Blueprint along with five principles for practicing futures thinking identified by the Institute for The Future (IFTF):

- Forget about predictions;[114]
- Focus on signals;[115]
- Look back to see forward;[116]

[113] Thomas O'Brien, Tyler Reeb, Deanna Mastumoto, Diana Sanchez, "Critical Issues in Trucking Workforce Development" (San José State University: Mineta Transportation Institute, April 2020), https://transweb.sjsu.edu/sites/default/files/1941-O%27Brien-Critical-Issues-Trucking-Workforce-Development.pdf; Deanna Matsumoto, Caitlin Mace, Tyler Reeb, and Thomas O'Briend, "Environmental Plans and Freight Movement at the San Pedro Bay Ports: A Quick Strike Analysis," White Paper (UC Davis, March 1, 2022), https://escholarship.org/content/qt5jb232mt/qt5jb232mt.pdf?t=r9tr8g.

[114] The first principle for practicing futures thinking identified by the IFTF states that accurate and precise predictions of long-term overarching change are impossible. Forecasting tools help analysist predict particular events or points but larger transformations that reshape the economy, jobs, and technology are too complex. Futures thinking allows people to explore future scenarios without the limitations of today's environment.

[115] The IFTF states that forecasting tools are limited to historical data and planning for the same trajectory can work well when things are stable. When change hits an inflection point, traditional methods are no longer adequate. IFTF states that they focus on signals that indicate future changes such as the success of eBay being a signal for the proliferation of an online reputation system that will eventually enable companies for Uber and Lyft to exist.

[116] Historical data can reveal patterns of human behavior and concerns that may be applicable to today's issues.

- Uncover patterns;[117] and
- Create a community.[118]

The lecture series would engage CSU5+ faculty to partner with hydrogen and supply chain industry experts to develop guest lectures that will later be developed into a pilot curriculum for a certificate training offered by CITT. The pilot program—working title, "Zero-Emission Vehicle & Infrastructure (ZEVI)"—would feature dynamic and interactive knowledge transfer, technology transfer, and applied skills development for not only front-line technicians and operators, but also legislators, regulators, and industry stakeholders. At the time of writing, the PIs for this report were pitching hydrogen industry leaders on the idea of forming a P3 to build a pilot hydrogen test lab on CSU-owned land adjacent to the CSU Desert Studies Center, in Zzyzx, California.[120] A ZEVI training in Zzyzx has a compelling ring to it!

A Case for Near-Zero to Get to Zero Quicker

A challenge associated with investments in hydrogen and the corresponding workforce is that the most commercially viable means of producing hydrogen at this time, are not the greenest modes of production. While this report (1) adopts a tech-agnostic viewpoint and (2) advocates for investments in all modes of hydrogen production, it is likely that a market for blue hydrogen (steam methane reformation with carbon capture/sequestration) will be much easier and quicker to grow to scale than green hydrogen (electrolysis). However, for moral[121] and strategic purposes, consider the possibility that California can go from near-zero to zero faster than it can with its current regulatory framework. Findings in this report support the conclusion that "there is no single technology or resource that would allow California to reach net-zero emissions by 2045," but rather an aggregation "of efficiency improvements, renewable electricity generation, carbon capture &

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[117] IFTF introduces the use of what they call the Two-Curve Framework. They show a descending curve labelled "today's way of doing things" and a second rising curve labelled "Tomorrow's way of doing things;" they argue that the first curve shows todays norms and procedures but at some unknown angle those procedures are being used less. At the same time, the second curve is slowly gaining traction as the first curve declines. IFTF argues that to move from the first curve to the second, stakeholders need to be open to doing things in a new way and potentially starting from zero for procedures that they already have.

[118] Ted Mitchell, "Changing Demographics and Digital Transformation," *Educause* 54, no. 1 (2019). IFTF argues that in order to create a robust forecast based on signals, entities require a diverse set of ideas that may find different signals and interpret those signals in different ways.

[120] "CSU Desert Studies Center, Zzyzx – OBFS," Organization of Biological Field Stations, accessed July 10, 2025, https://obfs.org/field-station/csu-desert-studies-center-zzyzx/.

[121] The authors of this report believe that, as a society, we have an obligation to improve air quality and mitigate climate change. The argument for this obligation is beyond the scope of the present paper. The authors believe that we will be better positioned to meet these moral obligations with a "near-zero to zero faster" regulatory framework, as opposed to a "zero-emission or bust" approach.

storage (CCS), electrification, biofuels, hydrogen, low global warming potential (GWP) refrigerants and carbon dioxide removal (CDR) is needed."[122] If the State of California resists any attempts to revise its industrial and energy policies and regulations pertaining to decarbonizing transportation, trade, energy production, and manufacturing industries in the years ahead, its clean energy goals could generate a range of unintended consequences, moral concerns, and strategic setbacks.

If regulators continue to push ahead with a *zero-emission or bust* approach, families living adjacent to the San Pedro Bay ports and near major truck and rail routes could be exposed to a decade or more of diesel particulate. The reason? If the FCETs and BETs that form the drayage fleets of the future cannot access sufficient hydrogen fueling and electric charging infrastructure at a competitive cost, diesel trucks will be the default. At the same time, current state policies and regulations are creating increasingly likely scenarios where oil and gas production reaches dangerously low levels at a time when alternative hydrogen and electric energy production transport, storage, and fueling/charging systems are not yet viable alternatives.[123] Researchers and industry leaders are raising a growing chorus of concerns about the current and future fate of California's zero-emissions goals—valid concerns that should be addressed. In a future scenario where Californians are paying soaring utility bills and high prices at the pump, environmentally

[122] Neutel, Berson, Laude, Arifi, Brandt, Saltzer, and Orr, Jr., "Pathways to Carbon Neutrality in California."

[123] Jesse H.F. Hammerling and Virginia Parks, "In Its Rush to Shutter Oil and Gas Refineries, California Risks Abandoning Workers and Local Communities," *San Francisco Chronicle*, July 2, 2025, https://www.sfchronicle.com/opinion/openforum/article/valero-refinery-benicia-california-20401030.php; Dan Walters, "Can California Manage the Switch to Electric Vehicles and a Carbon-Free Future?," CalMatters, April 23, 2025, http://calmatters.org/commentary/2025/04/california-carbon-free-transition/; Martha McHardy, "California Gas Prices Could Skyrocket 75%, Newsom Warned," *Newsweek*, May 7, 2025, https://www.newsweek.com/california-gas-prices-brian-jones-2069113; Shariq Khan and Nicole Jao, "California Fuel Imports Hit 4-Year High amid Refinery Outages," *Reuters*, June 9, 2025, https://www.reuters.com/business/energy/california-fuel-imports-hit-4-year-high-amid-refinery-outages-2025-06-09/.

favorable sentiments in the Golden State could wane, and political overcorrections could occur at all levels of government.[124]

What is the alternative? To borrow IFTF Principles 3 and 5, public- and private-sector leaders in California should "look back to go forward" and "create a community." Looking back, history provides reminders that the 1973 and 1979 U.S. oil shortages wreaked havoc on the economy and enraged citizens.[125] Looking forward, if California regulations force closures of refineries without viable alternative energy sources, the state's dependency on foreign oil will increase and access to the hydrogen produced at those facilities will cease. Herein lies the value of IFTF Principle 5: create a community of all energy stakeholders to drive clean energy transitions.

Revising California's cap-and-trade program provides a great starting point to improve the strategic probability of successfully transitioning to a future where hydrogen powers the state's supply chain systems. For background, cap-and-trade is California's "leading climate program—proposed by Republican Governor Arnold Schwarzenegger and adopted under a law he signed in 2006—that holds carbon polluters accountable by charging them for emitting more carbon pollution than allowed."[126]

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[124] Claims about gas prices can be found here: Brian W. Jones to Gavin Newsom, "RE: Refinery Closures and California's Fuel Supply," May 6, 2025, https://files.constantcontact.com/6ddc9aab901/80a46fa4-e4a0-4b29-94c8-0bfb0a47724f.pdf; Michael A. Mische, "A Study of California Gasoline Prices March 2025" (University of Southern California, Marshall School of Business: USC Business of Energy Transition Initiative, March 16, 2025), https://www.scribd.com/document/845315706/A-Study-of-Califiornia-Gasoline-Prices-March-2025?v=0.998. Response to the claims about gas prices can be found here: Governor of California, "Fact Check: Claims Swirling on California Gas Prices," State of California, June 26, 2025, https://www.gov.ca.gov/2025/06/25/fact-check-claims-swirling-on-california-gas-prices/. See also: Abby Smith, "California Forced to Defend Green Goals amid Blackouts," *Washington Examiner*, August 21, 2020, https://www.proquest.com/docview/2437665167/citation/221B8741FE544B1APQ/27; Sammy Roth, "California's Blackouts Could Make Fighting Climate Change Even Harder," *Los Angeles Times*, October 29, 2019, https://www.proquest.com/latimes/docview/2413634098/citation/4271E32D08284F70PQ/4?sourcetype=Blogs,%20Podcasts,%20&%20Websites.

[125] Clyde H. Farnsworth, "GROWING DEFICITS EXPECTED IN WAKE OF OIL-PRICE RISE: Recessionary Trend Likely to Worsen Worldwide, According to Experts UNEMPLOYMENT IS SEEN Common Market Estimates a Prolonged Crisis Could Double Joblessness Immediate Problem Growing Deficits, Recessionary Push And Cost Gains Seen in Oil-Price Rise Higher Living Costs Hard Times in India," *New York Times*, December 25, 1973, https://www.proquest.com/docview/119735497/abstract/F830D9AC66754100PQ/6; Thomas O'Toole, "Oil Crisis Laid to Nixon, Industry," *Los Angeles Times*, November 11, 1973, https://www.proquest.com/docview/157296720/F6E803E50AA64BA3PQ/6?accountid=10351&sourcetype=Newspapers; Norman Kempster, "NO EASY WAY: Oil Decontrol: A Nightmare for President," *Los Angeles Times*, March 31, 1979, https://www.proquest.com/docview/158826015/abstract/F98D266D7AEC44BCPQ/1.

[126] Governor of California, "Governor Newsom, Legislature Double down on State's Critical Cap-and-Trade Program in Face of Federal Threats," State of California, April 15, 2025, https://www.gov.ca.gov/2025/04/15/governor-newsom-legislature-double-down-on-states-critical-cap-and-trade-program-in-face-of-federal-threats/.

In a future scenario where California lawmakers worked with oil and gas industry stakeholders to revise California's cap-and-trade program to extend incentives rather than penalties, the likelihood that those companies operating refineries and factories would invest in CCS technologies to generate blue hydrogen would increase significantly. In economic parlance, in the current political climate, it will be carrots rather than sticks that will inspire the formation of P3s that will lead to a new era of sustainable clean energy for supply chain stakeholders and communities throughout the state. Rather than "double down" on the same policies, it is incumbent upon lawmakers and the regulators that they direct to consider the value of transitioning first to near-zero regulations to get to zero faster.[127]

As documented in this Blueprint, traditional refineries produce more than 5 million kilograms of hydrogen each day. If California lawmakers revised current state regulations to support near-zero goals that lead to zero-emission goals, the likelihood of enlisting traditional energy companies to invest in CCS and blue hydrogen production technologies would increase significantly. This report also outlines the possibility that water sanitation facilities and landfills operating throughout the state could provide RNG feedstock for a substantial amount of hydrogen, electricity, and water production in the future. It is worth noting that RNG and CNG, though sourced differently, are both C4, which means that the above-mentioned infrastructure could be used to turn both RNG and CNG into hydrogen, electricity, and water.

The CalPERS "$100 Billion Climate Action Plan," mentioned in this report, signals that California leaders are already moving in this direction with a broad slate of new incentives to support a "low-carbon" economy. The CalPERS plan continues to support the production of renewable energy sources—such as solar, wind, and hydrogen—but also "technologies that capture and store CO_2 emissions" and waste management solutions, which include "reducing, recycling, reusing, and capturing methane from landfills" and retrofitting refineries.[128] The CalPERS plan identifies three core investment areas—Mitigation, Adaptation, and Transition—with each signaling a revised state approach to incentivizing traditional energy partners to transition the state to a low-carbon economy on the path to a carbon-neutral economy.

For many ardent supporters of current zero-emissions policies in California, it is understandable that parting ways with the current regulatory framework is not an easy choice. Considered in this way, the future of hydrogen in California will be determined by legislative and regulatory workforces as much as by industrial and technological innovations.

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[127] State of California, "Governor Newsom."

[128] "$100 Billion Climate Action Plan."

Glossary

Please note the following glossary definitions were sourced from several peer reviewed and government sources including the California Energy Commission's Energy Glossary.[129]

(U.S.) DEPARTMENT OF ENERGY (US DOE) – The federal department established by the Department of Energy Organization Act to consolidate the major federal energy functions into one cabinet-level department that would formulate a comprehensive, balanced national energy policy. DOE's main headquarters are in Washington, D.C.

ABSORPTION BEDS – Systems filled with material that captures specific substances from a gas or liquid stream. As the stream flows through, certain components are pulled in and held by the material, often to clean or separate the stream. See also: PRESSURE SWING ADSORPTION (PSA).

ALL-ELECTRIC VEHICLES (AEV) – EVs use a battery to store the electric energy that powers the motor. EV batteries are charged by plugging the vehicle in to an electric power source.

ALTERNATIVE ENERGY SOURCES – See RENEWABLE ENERGY.

ANODE – A positive electrode.

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[129] "Hydrogen Production by Water Electrolysis;" Piyush Choudhary, "Carbon Capture and Storage Program (CCSP) Final Report 1.1.2011–31.10.2016," Technical Report, Carbon Capture and Storage Program (CCSP), (CLIC Innovation Oy, 2018), https://www.researchgate.net/publication/328352287_Carbon_Capture_and_Storage_ProgramCCSP_Final_rep …; Michael E. Mann, *Dire Predictions: Understanding Climate Change* (Pearson, 2016); Muhammad Ikhsan Taipabu, Karthickeyan Viswanathan, Wei Wu, Nikmans Hattu, and A.E. Atabani, "A Critical Review of the Hydrogen Production from Biomass-Based Feedstocks: Challenge, Solution, and Future Prospect," *Process Safety and Environmental Protection* 164 (August 2022): 384–407, https://doi.org/10.1016/j.psep.2022.06.006; California Energy Commission, "Energy Glossary," California Energy Commission, accessed June 26, 2025, https://www.energy.ca.gov/resources/energy-glossary; Jonathan Law and Richard Rennie, eds., *A Dictionary of Chemistry* (Oxford University Press, 2020), https://www.oxfordreference.com/display/10.1093/acref/9780198841227.001.0001/acref-9780198841227; James G. Speight, "Synthesis Gas and the Fischer–Tropsch Process," in ed. James G. Speight, *The Refinery of the Future* (Elsevier, 2020), 427–468, https://doi.org/10.1016/B978-0-12-816994-0.00012-9; Hussam Jouhara, Navid Khordehgah, Sulaiman Almahmoud, Bertrand Delpech, Amisha Chauhan, and Savvas A. Tassou, "Waste Heat Recovery Technologies and Applications," *Thermal Science and Engineering Progress* 6 (June 2018): 268–89, https://doi.org/10.1016/j.tsep.2018.04.017; Kubilay Bayramoğlu, Semih Yilmaz, and Tolga Bayramoğlu, "Effect of SMR and Hydrogen-Enriched Methane Combustion on Emissions and Performance," *International Journal of Hydrogen Energy* 142 (June 2025): 1054–66, https://doi.org/10.1016/j.ijhydene.2025.05.045.

ANAEROBIC DIGESTER TANKS – Sealed containers where microorganisms break down organic waste without oxygen. This process produces biogas, which can be cleaned and used to help produce hydrogen or generate energy.

AUTOTHERMAL REFORMING – The combination of the steam reformation reaction and the partial oxidation reaction resulting in a net reaction enthalpy of zero.

AUXILIARY BOILERS – Small boilers that produce steam when the main steam methane reforming system can't meet demand. This steam is crucial because it supports the chemical reactions needed to produce hydrogen consistently and safely during startup or low operation times.

BATTERY ELECTRIC VEHICLE (BEV) – Also known as an "All-electric" vehicle (AEV), BEVs utilize energy that is stored in rechargeable battery packs. BEVs sustain their power through the batteries and therefore must be plugged into an external electricity source to recharge.

BI-FUEL VEHICLE – A vehicle with two separate fuel systems designed to run on either fuel, using only one fuel at a time. These systems are advantageous for drivers who do not always have access to an alternative fuel refueling station. Bi-fuel systems are usually used in light-duty vehicles. One of the two fuels is typically an alternative fuel.

BIODIESEL – A biodegradable transportation fuel for use in diesel engines that is produced through the transesterification of organically-derived oils or fats. It may be used either as a replacement for or as a component of diesel fuel.

BIOFUEL – Fuel produced from renewable biomass material, commonly used as an alternative, cleaner fuel source.

BIOGAS – A process that converts organic materials, like wood chips or agricultural waste, into a gas mixture using heat and limited oxygen. This gas, which includes hydrogen and carbon monoxide, can be used to produce hydrogen or generate energy.

BIOMASS GASIFICATION – The mixture of methane, carbon dioxide, and other minor gases formed from the decomposition of organic materials.

BIOSOLIDS – Nutrient-rich solids left over after wastewater treatment. They can be used as fertilizer or processed further for energy recovery, including as a feedstock in hydrogen production through thermal or biological conversion methods.

BITUMINOUS COAL – Soft coal containing large amounts of carbon. It has a luminous flame and produces a great deal of smoke.

CALIFORNIA AIR RESOURCES BOARD (CARB) – The "clean air agency" in the government of California, whose main goals include attaining and maintaining healthy air quality; protecting the public from exposure to toxic air contaminants; and providing innovative approaches for complying with air pollution.

CALIFORNIA DEPARTMENT OF TRANSPORTATION (Caltrans) – The Agency responsible for the design, construction, maintenance, and operation of the California State Highway System, as well as that portion of the Interstate Highway System within the state's boundaries.

CALIFORNIA ENERGY COMMISSION – The state's primary energy policy and planning agency. The agency was established by the California Legislature through the Warren-Alquist Act in 1974. It has seven core responsibilities: developing renewable energy; transforming transportation; increasing energy efficiency; investing in energy innovation; advancing state energy policy; certifying thermal power plants; and preparing for energy emergencies.

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY (CAL/EPA) – A state government agency established in 1991 for unifying environmental activities related to public health protection in the State of California. There are six boards, departments, and offices under the organization of Cal/EPA, including the California Air Resources Board (ARB), the State Water Resources Control Board (SWRCB) and its nine Regional Water Quality Control Boards (RWQCB), the Department of Pesticide Regulation (DPR), the Department of Toxic Substances Control (DTSC), the Department of Resources Recycling and Recovery (CalRecycle), and the Office of Environmental Health Hazard Assessment (OEHHA). The Cal/EPA boards, departments, and offices are directly responsible for implementing California environmental laws, playing a cooperative role with other regulatory agencies at regional, local, state, and federal levels.

CALIFORNIA ENVIRONMENTAL QUALITY ACT (CEQA—pronounced See' quah) – A law enacted in 1970 and amended through 1983, established state policy to maintain a high-quality environment in California and set up regulations to inhibit degradation of the environment.

CALIFORNIA FUEL CELL PARTNERSHIP (CaFCP) – The California Fuel Cell Partnership is an industry/government collaboration aimed at expanding the market for fuel cell electric vehicles powered by hydrogen to help create a cleaner, more energy-diverse future with no compromises to zero-emission vehicles.

CALIFORNIA HYDROGEN HIGHWAY NETWORK (CAH2NET) – An initiative to add hydrogen fueling infrastructure in California to meet the demands of hydrogen vehicles deployed in the state.

CARBON CAPTURE AND SEQUESTRATION (CCS) – The process of capturing CO_2 from a stationary source, followed by compressing, transporting, and injecting it into a suitable geologic formation where it will be sequestered.

CARBON COST – The value assigned to carbon released into the atmosphere as a polluting factor.

CARBON DIOXIDE (CO_2) – A colorless, odorless, non-poisonous gas that is a normal part of the air. Carbon dioxide is exhaled by humans and animals and is absorbed by green growing things and by the sea. CO_2 is the greenhouse gas whose concentration is being most affected directly by human activities. CO_2 also serves as the reference to compare all other greenhouse gases (see carbon dioxide equivalent). The major source of CO_2 emissions is fossil fuel combustion. CO_2 emissions are also a product of forest clearing, biomass burning, and non-energy production processes such as cement production. Atmospheric concentrations of CO_2 have been increasing at a rate of about 0.5% per year and are now about 30% above preindustrial levels.

CARBON INTENSITY (CI) – The amount of carbon by weight emitted per unit of energy consumed. A common measure of carbon intensity is weight of carbon per British thermal unit (Btu) of energy. When there is only one fossil fuel under consideration, the carbon intensity and the emissions coefficient are identical. When there are several fuels, carbon intensity is based on their combined emissions coefficients weighted by their energy consumption levels.

CARBON SEQUESTRATION – The uptake and storage of carbon. Trees and plants, for example, absorb carbon dioxide, release the oxygen, and store the carbon. Fossil fuels were at one time biomass and continue to store the carbon until burned.

CATALYST – A substance that can increase or decrease the rate of a chemical reaction between the other chemical species without being consumed in the process.

CATHODE – A negative electrode.

CHEMICAL ABSORPTION COLUMNS – Vertical tanks where gas flows through a liquid that chemically reacts to remove impurities. In steam methane reforming, these columns capture gases such as carbon dioxide to purify hydrogen, making it clean and ready for use.

CLEAN FUEL VEHICLE – This term is frequently incorrectly used interchangeably with "alternative fuel vehicle." Under the California Public Resources Code, a "clean fuel vehicle" is one certified to meet the clean-fuel vehicle standards for its model year, and "clean fuels" are those alternative fuels—including methanol, ethanol (at least 85 percent content), reformulated gasoline, natural gas, hydrogen, and electricity—used in vehicles that comply with such standards.

CLIMATE CHANGE – Also referred to as "global climate change." The term "climate change" is sometimes used to refer to all forms of climatic inconsistency, but because the Earth's climate is never static, the term is more properly used to imply a significant change from one climatic condition to another. In some cases, "climate change" has been used synonymously with the term "global warming"; however, scientists tend to use the term in the wider sense to also include natural changes in climate. The preceding explanation is the official definition of the California Energy Commission and is the broadest, most neutral definition. However, in the context of this report, climate change is understood to refer specifically to anthropogenic climate change – climate change that is a result of human action and industrial activity (i.e., the transportation of goods and people, the generation of electricity, etc.). See also Enhanced Greenhouse Effect.

COAL – Black or brown rock, formed under pressure from organic fossils in prehistoric times, that is mined and burned to produce heat energy.

COAL CONVERSION – The process of changing coal into synthetic gas or liquid fuels. See GASIFICATION.

COKE – A porous solid left over after the incomplete burning of coal or crude oil.

COMBUSTION BURNING – Rapid oxidation, with the release of energy in the form of heat and light.

COMPRESSED NATURAL GAS (CNG) – Natural gas that has been compressed under high pressure, typically between 2,000 and 3,600 pounds per square inch, held in a container. The gas expands when released for use as a fuel.

CRUDE OIL – Petroleum as found in the earth, before it is refined into oil products. Also called CRUDE.

CRYOGENIC HYDROGEN – Hydrogen that has been cooled to extremely low temperatures until it becomes a liquid. This form takes up much less space, making it easier to store and transport, especially in large-scale hydrogen supply chains.

DIFFUSION BEDS – Layers of material designed to help gases mix or separate by letting molecules spread out naturally. In steam methane reforming, diffusion beds can improve how gases flow and react, making hydrogen production more efficient and consistent.

ECONOMIES OF SCALE – The concept that as production increases, the cost per unit decreases.

ECONOMIZERS – Devices that capture leftover heat from hot gases, such as flue gas, and use it to preheat water or feed into steam systems. This saves energy by recycling heat that would otherwise be wasted.

ELECTRICAL GRID – An interconnected network of power stations, substations, and transmission lines to deliver electricity.

ELECTROLYSIS – The process of breaking a chemical compound down into its elements by passing a direct current through it. Electrolysis of water, for example, produces hydrogen and oxygen.

ELECTROLYZER, SOLID OXIDE – An electrolyzer unit using a solid ceramic material as the electrolyte.

ELECTROLYZER CELL STACK – A stack of electrolyzer units.

ELECTROLYZER UNIT – A modular electrolysis processing unit consisting of two electrodes and an electrolyte.

ELECTROLYZER, ALKALINE – An electrolyzer unit using alkaline solution as the electrolyte.

ELECTROLYZER, POLYMER ELECTROLYTE MEMBRANE (PEM) – An electrolyzer unit using a solid polymer as the electrolyte.

EMBRITTLEMENT – The weakening of a material, usually a metal becomes brittle and weak, often due to exposure to certain gases or chemicals such as hydrogen. In hydrogen systems, embrittlement can cause cracks or failure in pipes and equipment, making it a key safety concern.

EMISSION FACTOR – For stationary sources, the relationship between the amount of pollution produced and the amount of raw material processed or burned. For mobile sources, the relationship between the amount of pollution produced and the number of vehicle miles traveled. By using the emission factor of a pollutant and specific data regarding quantities of materials used by a given source, it is possible to compute emissions for the source. This approach is used in preparing an emissions inventory.

EMISSION RATE – The weight of a pollutant emitted per unit of time (e.g., tons/year).

EMISSIONS – Released or discharged air contaminants in the ambient air from any source.

ENERGY EFFICIENCY – the measure of how well a system uses energy to perform its task compared to how much energy is wasted.

ENVIRONMENTAL PROTECTION AGENCY (EPA) – A federal agency created in 1970 to permit coordinated governmental action for protection of the environment by systematic abatement and control of pollution through integration or research, monitoring, standards-setting, and enforcement activities.

ETHANOL (also know as Ethyl Alcohol or Grain Alcohol, CH3CH2OH) – A liquid that is produced chemically from ethylene or biologically from the fermentation of various sugars from carbohydrates found in agricultural crops and cellulosic residues from crops or wood. Used in the U.S. as a gasoline octane enhancer and oxygenate, it increases octane 2.5 to 3.0 numbers at 10 percent concentration. Ethanol can also be used in higher concentration (E85) in vehicles optimized for its use.

EV (ELECTRIC VEHICLE) – A vehicle powered by electricity, which is usually provided by batteries but may also be provided by photovoltaic (solar) cells or a fuel cell.

FEDERAL CLEAN AIR ACT (FCAA) – A federal law passed in 1970 and amended in 1974, 1977, and 1990 that forms the basis for the national air pollution control effort. Basic elements of the act include national ambient air quality standards for major air pollutants, mobile and stationary control measures, air toxics standards, acid rain control measures, and enforcement provisions.

FEDERAL ENERGY REGULATORY COMMISSION (FERC) – U.S. government agency that regulates the interstate transmission of electricity, natural gas, and oil. It oversees energy markets, approves major energy projects like pipelines and liquefied natural gas terminals, and ensures reliable, fair, and safe operation of the nation's energy infrastructure.

FEDERAL HIGHWAY ADMINISTRATION (FHWA) – A division of the U.S. Department of Transportation. The FHWA is a cabinet-level organization of the Executive Branch of the U.S. Government. The FHWA specializes in highway transportation. The FHWA ensures that the U.S. highways and public roads are in good shape and technologically up to date for traveling.

FEEDSTOCK – A feedstock is the source of raw material required for an industrial process.

FLUE GAS – Hot gas released from burning fuel, usually containing carbon dioxide, water vapor, and other pollutants. In hydrogen production, flue gas is the waste gas from furnaces or boilers that must be managed or treated before release.

FOSSIL FUEL – Oil, coal, natural gas, or their by-products. Fuel that was formed in the earth in prehistoric times from remains of living-cell organisms.

FUEL CELL – A device or an electrochemical engine with no moving parts that converts the chemical energy of a fuel, such as hydrogen, and an oxidant, such as oxygen, directly into electricity. The principal components of a fuel cell are catalytically activated electrodes for the fuel (anode) and the oxidant (cathode) and an electrolyte to conduct ions between the two electrodes, thus producing electricity.

FUEL CELL ELECTRIC VEHICLE (FCEV) – A zero-emission vehicle that runs on compressed hydrogen fed into a fuel cell "stack" that produces electricity to power the vehicle.

GAS GRID – A network of pipelines transporting natural gas from producers to businesses and consumers.

GASIFICATION – The process where biomass fuel is reacted with sub-stoichiometric quantities of air and oxygen, usually under high pressure and temperature, along with moisture to produce gas which contains hydrogen, methane, carbon monoxide, nitrogen, water, and carbon dioxide. The gas can be burned directly in a boiler, or scrubbed and combusted in an engine-generator to produce electricity. The three types of gasification technologies available for biomass fuels are the fixed bed updraft, fixed bed downdraft, and fluidized bed gasifiers. Gasification is also the production of synthetic gas from coal.

GLOBAL WARMING – An increase in the temperature of the Earth's troposphere. Global warming has occurred in the past as a result of natural influences, but the term is most often used to refer to the warming predicted by computer models to occur as a result of increased emissions of greenhouse gases.

GOODS MOVEMENT – The processes and activities involved in the pickup, movement, and delivery of goods (agricultural, consumer, industrial products, and raw materials) from producers/points of origin to consumers/point of use or delivery. “Goods movement” relies on a series of transportation, financial, and information systems for this to occur, which involves international, national, state, regional, and local networks of producers and suppliers, carriers, and representative agents from the private sector, the public sector (federal, state, regional, and local governmental agencies), and the general public.

GOVERNOR’S OFFICE OF BUSINESS AND ECONOMIC DEVELOPMENT (GO-Biz) – The Governor’s Office of Business and Economic Development (GO-Biz) serves as the State of California’s leader for job growth and economic development efforts. They offer a range of services to business owners, including attraction, retention and expansion services, site selection, permit assistance, regulatory guidance, small business assistance, international trade development, and assistance with state government.

GREENHOUSE GAS – Any gas that absorbs infra-red radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halogenated fluorocarbons (HCFCs), ozone (O_3), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs).

HEAT RECOVERY STEAM GENERATOR – Devices that capture leftover heat from hot gases and use it to produce steam. In steam methane reforming, they recycle heat from the process to make steam, improving energy efficiency and supporting hydrogen production without wasting fuel.

HYBRID ELECTRIC VEHICLE (HEV) – A vehicle that combines an internal combustion engine with a battery and electric motor. This combination offers the range and refueling capabilities of a conventional vehicle, while providing improved fuel economy and lower emissions.

HYBRID VEHICLE – Usually a hybrid EV, a vehicle that employs a combustion engine system together with an electric propulsion system. Hybrid technologies expand the usable range of EVs beyond what an all-electric-vehicle can achieve with batteries only.

HYDROCARBONS – Compounds containing various combinations of hydrogen and carbon atoms. They may be emitted into the air by natural sources (e.g., trees) and as a result of fossil and vegetative fuel combustion, fuel volatilization, and solvent use. Hydrocarbons are a major contributor to smog.

HYDROFLUOROCARBONS (HFCs) – Compounds containing only hydrogen, fluorine, and carbon atoms. They were introduced as alternatives to ozone depleting substances in serving many industrial, commercial, and personal needs. HFCs are emitted as by-products of industrial processes and are also used in manufacturing. They do not deplete the stratospheric ozone layer, but they are greenhouse gases.

HYDROGEN (H2) – A colorless, odorless, highly flammable gas; the chemical element of atomic number 1.

HYGAS – A process that uses water to help produce pipeline-quality gas from coal.

INFRASTRUCTURE – Generally refers to the recharging and refueling network necessary to successful development, production, commercialization, and operation of alternative fuel vehicles, including fuel supply, public and private recharging and refueling facilities, standard specifications for refueling outlets, customer service, education and training, and building code regulations.

INTERNAL COMBUSTION ENGINE – An engine in which fuel is burned inside the engine. A car's gasoline engine or rotary engine is an example of an internal combustion engine. It differs from engines having an external furnace, such as a steam engine.

JOULE – A unit of work or energy equal to the amount of work done when the point of application of force of 1 newton is displaced 1 meter in the direction of the force. It takes 1,055 joules to equal a British thermal unit. It takes about 1 million joules to make a pot of coffee.

KILOGRAM (kg) – The base unit of mass in the International System of Units that is equal to the mass of a prototype agreed upon by international convention and that is nearly equal to the mass of 1000 cubic centimeters of water at the temperature of its maximum density.

KILOVOLT (kv) – One-thousand volts (1,000). Distribution lines in residential areas usually are 12 kv (12,000 volts).

KILOWATT (kW) – One thousand (1,000) watts. A unit of measure of the amount of electricity needed to operate given equipment. On a hot summer afternoon, a typical home, with central air conditioning and other equipment in use, might have a demand of four kW each hour.

KILOWATT-HOUR (kWh) – The most commonly-used unit of measure telling the amount of electricity consumed over time. It means one kilowatt of electricity supplied for one hour. In 1989, a typical California household consumes 534 kWh in an average month.

LIGHT-DUTY VEHICLE (LDV) – Any motor vehicle with a gross vehicle weight of 6,000 pounds or less.

LIQUEFACTION – The process of making synthetic liquid fuel from coal. The term also is used to mean a method for making large amounts of gasoline and heating oil from petroleum.

LIQUEFIED GASES – Gases that have been or can be changed into liquid form. These include butane, butylene, ethane, ethylene, propane, and propylene.

LITHIUM-ION (Li-Ion) BATTERY – A type of rechargeable battery. In the batteries, lithium ions move from the negative electrode to the positive electrode during discharge and back when charging.

LNG (LIQUEFIED NATURAL GAS) – Natural gas that has been condensed to a liquid, typically by cryogenically cooling the gas to minus 260 degrees Fahrenheit (below zero).

LOW CARBON FUEL STANDARD (LCFS) – A set of standards designed to encourage the use of cleaner low-carbon fuels in California, encourage the production of those fuels, and reduce greenhouse gas (GHG) emissions. The LCFS standards are expressed in terms of the "carbon intensity" (CI) of gasoline and diesel fuel and their respective substitutes. The LCFS is a key part of a comprehensive set of programs in California to cut greenhouse gas emission and other smog-forming and toxic air pollutants by improving vehicle technology, reducing fuel consumption, and increasing transportation mobility options.

LOW EMISSION VEHICLE (LEV) – A vehicle certified by the California Air Resources Board to meet strict exhaust standards, which require that emissions from zero to 50,000 miles do not exceed 0.075 grams per mile of non-methane organic gases, 3.4 grams per mile of carbon monoxide, and 0.2 grams per mile of nitrogen oxides, with slightly higher limits allowed between 50,000 and 100,000 miles.

MEGAJOULE (MJ) – A joule is a unit of work or energy equal to the amount of work done when the point of application of force of 1 newton is displaced 1 meter in the direction of the force. It takes 1,055 joules to equal a British thermal unit. It takes about 1 million joules to make a pot of coffee. A megajoule itself totals 1 million Joules.

MEGAWATT (MW) – One thousand kilowatts (1,000 kW) or one million (1,000,000) watts. One megawatt is enough electrical capacity to power 1,000 average California homes (assuming a loading factor of 0.5 and an average California home having a 2-kilowatt peak capacity).

MEGAWATT HOUR (MWh) – One thousand kilowatt-hours, or an amount of electrical energy that would supply 1,370 typical homes in the Western U.S. for one month. (This is a rounding up to 8,760 kWh/year per home based on an average of 8,549 kWh used per household per year [U.S. DOE EIA, 1997 annual per capita electricity consumption figures].)

MERCHANT HYDROGEN PLANTS – Facilities that produce hydrogen specifically for sale to external customers. Unlike plants that make hydrogen for their own use, these facilities deliver hydrogen to various industries by pipeline, truck, or in liquid form, depending on the need.

METHANOL (also known as Methyl Alcohol, Wood Alcohol, or CH3OH) – A liquid formed by catalytically combining carbon monoxide (CO) with hydrogen (H2) in a 1:2 ratio, under high temperature and pressure. Commercially, it is typically made by steam reforming natural gas. Also formed in the destructive distillation of wood.

MICROORGANISMS – Tiny living organisms, such as bacteria and archaea, that can break down organic material. In hydrogen production, they are used in processes like anaerobic digestion to produce biogas, which can then be upgraded into renewable natural gas or hydrogen.

MICROGRID – A combination of localized electricity generation sources, energy storage devices, and multiple loads that acts as a small electric grid with respect to the main electric grid. The microgrid can operate interconnected or isolated from the main electric grid.

NATURAL GAS – Hydrocarbon gas found in the earth, composed of methane, ethane, butane, propane, and other gases.

NET-ZERO ENERGY – Producing as much energy on an annual basis as one consumes on site, usually with renewable energy sources such as photovoltaics or small-scale wind turbines.

OIL REFINERY HYDROGEN PLANTS – Facilities that produce hydrogen for use within the refinery itself. This hydrogen is essential for processes such as removing sulfur from fuels and breaking down heavy hydrocarbons into lighter, more valuable products such as gasoline and diesel.

PIPELINE – A line of pipe with pumping machinery and apparatus (including valves, compressor units, metering stations, regulator stations, etc.) for conveying a liquid or gas.

PLUG-IN ELECTRIC VEHICLE (PEV) – A general term for any car that runs at least partially on battery power and is recharged from the electricity grid. There are two different types of PEVs: pure battery electric and plug-in hybrid vehicles.

PLUG-IN HYBRID ELECTRIC VEHICLE (PHEV) – PHEVs are powered by an internal combustion engine and an electric motor that uses energy stored in a battery. The vehicle can be plugged in to an electric power source to charge the battery. Some can travel nearly 100 miles on electricity alone, and all can operate solely on gasoline (similar to a conventional hybrid).

POLISHING – Water polishing refers to the process of purifying water by removing organic water and pollutants.

POWER PLANT – A central station generating facility that produces energy.

PRESSURE SWING ADSORPTION (PSA) – A process by which carbon dioxide and other impurities are removed from a gas mixture in order to isolate hydrogen.

PYROLYSIS – The breaking apart of complex molecules by heating in the absence of oxygen, producing solid, liquid, and gaseous fuels.

REFORMER FURNACE – Large heaters that provide the high temperatures needed to trigger chemical reactions in steam methane reforming. They heat the natural gas and steam mixture so it can break down and form hydrogen efficiently.

RENEWABLE ENERGY – Resources that constantly renew themselves or that are regarded as practically inexhaustible. These include solar, wind, geothermal, hydro, and wood. Although particular geothermal formations can be depleted, the natural heat in the earth is a virtually inexhaustible reserve of potential energy. Renewable resources also include some experimental or less-developed sources such as tidal power, sea currents, and ocean thermal gradients.

RENEWABLE NATURAL GAS – A methane gas produced from organic waste such as food scraps, sewage, or agricultural leftovers. It can be cleaned and used like regular natural gas to generate energy or serve as a feedstock for producing hydrogen.

RENEWABLE RESOURCES – Renewable energy resources are naturally replenishable, but flow-limited. They are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time. Some (such as geothermal and biomass) may be stock-limited in that stocks are depleted by use, but on a time scale of decades, or perhaps centuries, they can probably be replenished. Renewable energy resources include biomass, hydro, geothermal, solar, and wind. In the future they could also include the use of ocean thermal, wave, and tidal action technologies. Utility renewable resource applications include bulk electricity generation, on-site electricity generation, distributed electricity generation, non-grid-connected generation, and demand-reduction (energy efficiency) technologies.

RETROFIT – Upgrading or adding new equipment to an existing system to improve its performance or meet new requirements.

SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA) – A computer system that monitors and controls industrial processes, such as hydrogen production, by collecting real-time data and allowing operators to manage equipment remotely and safely.

SHIFT REACTORS – Chambers where a chemical reaction called the "water-gas shift" takes place. This reaction converts carbon monoxide and steam into carbon dioxide and more hydrogen, increasing hydrogen production during steam methane reforming.

SOLAR ENERGY – Heat and light radiated from the sun.

STEAM-METHANE REFORMATION – A catalytic process that involves a reaction between natural gas or other low-boiling hydrocarbon derivatives and steam.

STRIPPER COLUMNS – Tall tanks where unwanted gases or liquids are separated from a mixture by using heat or a stripping agent. In hydrogen production, they help remove impurities to purify the hydrogen stream.

SUSTAINABILITY – Preserving and enhancing California's people, environment, and prosperity by meeting current needs and improving quality of life without compromising future generations' abilities to meet their needs.

SYNFUEL – Synthetic gas or synthetic oil. Fuel that is artificially made as contrasted to that which is found in nature. Synthetic gas made from coal is considered to be more economical and easier to produce than synthetic oil. When natural gas supplies in the earth are being depleted, it is expected that synthetic gas will be able to be used widely as a substitute fuel.

TAX CREDITS – Credits established by the federal and state government to assist the development of the alternative energy industry. Beginning in 1976, California had a solar tax credit. From 1978 to 1985, both California and the federal government offered tax credits for alternative energy equipment. The state provided a 55 percent tax credit on solar, wind, geothermal, and biomass for residential applications. However, the residential tax credits were reduced by applicable federal credits. State commercial tax credits for alternative energy systems in commercial and industrial sectors ranged from 10–15 percent. During this same time, the federal government offered a 40 percent tax credit on residential applications and a 10–15 percent credit on commercial and industrial applications. California in 1990 instituted a new 10 percent tax credit for commercial solar systems in excess of 30 watts of electricity per device. This credit expired on December 31, 1993.

TRIGENERTAION – A system that produces electricity, heat, and hydrogen fuel from a single energy source.

SYNGAS – A synthetic mixture of hydrogen, carbon monoxide, and some carbon dioxide. It is produced by breaking down natural gas or other fuels and is a key intermediate step in making hydrogen through processes like steam methane reforming.

ULTRAPURE WATER – Water that has been purified to remove almost all impurities, including minerals, bacteria, and chemicals. It is essential in hydrogen production because even tiny contaminants can damage equipment or interfere with chemical reactions.

UNITED STATES DEPARTMENT OF ENERGY (U.S. DOE) – The federal department established by the Department of Energy Organization Act to consolidate the major federal energy functions into one cabinet-level department that would formulate a comprehensive, balanced national energy policy. DOE's main headquarters are in Washington, D.C.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (U.S. EPA) – A federal agency created in 1970 to permit coordinated governmental action for protection of the environment by systematic abatement and control of pollution through integration or research, monitoring, standards-setting, and enforcement activities.

VOLT – A unit of electromotive force. It is the amount of force required to drive a steady current of one ampere through a resistance of one ohm. Electrical systems of most homes and offices have 120 volts.

VOLTAGE OF A CIRCUIT (Electric utility) – The electric pressure of a circuit, measured in volts. Usually a nominal rating, based on the maximum normal effective difference of potential between any two conductors of the circuit.

ZERO EMISSION (ZE) – An engine, motor, process, or other energy source that emits no waste products that pollute the environment or disrupt the climate.

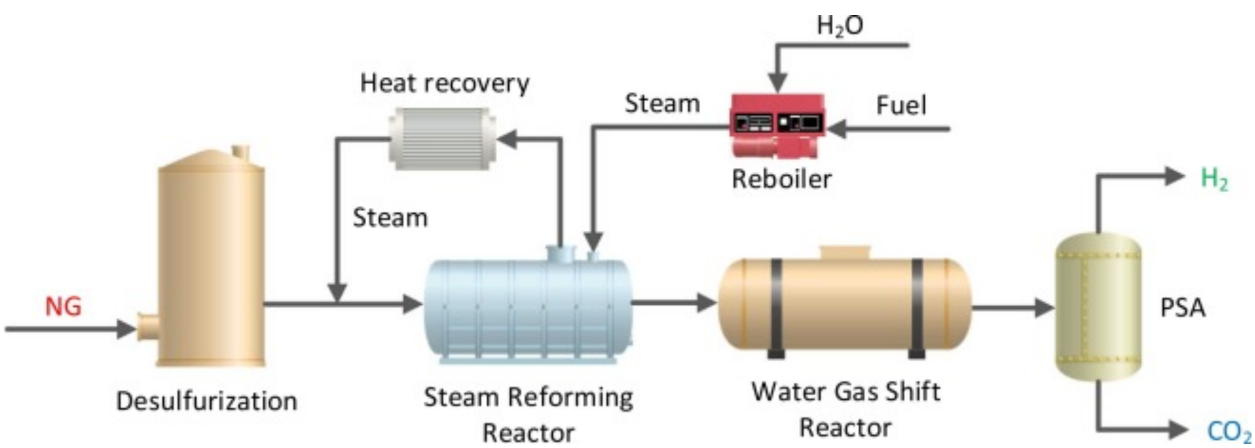
ZERO-EMISSION VEHICLE (ZEV) – Vehicles which produce no emissions from the on-board source of power (e.g., an electric vehicle).

Appendix A: Modes of Hydrogen Production

Steam Methane Reformation: Blue and Grey Hydrogen

Blue and grey hydrogen both make use of a process known as steam methane reformation (SMR). In SMR, high-temperature steam reacts with methane at 3–25 bar in the presence of a noble metal catalyst such as nickel or platinum. The result is the production of hydrogen, carbon monoxide, and carbon dioxide. Hydrogen is separated from carbon monoxide and carbon dioxide. Carbon monoxide is then used for further hydrogen production via the water-gas shift reaction, released into the atmosphere, or captured using Carbon Capture and Sequestration (CCS) technology.[130]

Figure 18. A Graphic Depiction of Steam Methane Reformation Using Natural Gas (NG)



A process known as pressure swing adsorption (PSA) separates H_2 and CO_2[132]

If the carbon gas is captured, then the produced hydrogen is referred to as blue hydrogen. If carbon is released into the atmosphere, then it is referred to as grey hydrogen. The most common form of hydrogen production in the U.S. is grey hydrogen. Grey hydrogen production does not involve the capture of any resulting GHG emissions, making it one of the cheapest forms of production.[134] Accordingly, grey hydrogen is among the least environmentally sustainable forms of hydrogen production.

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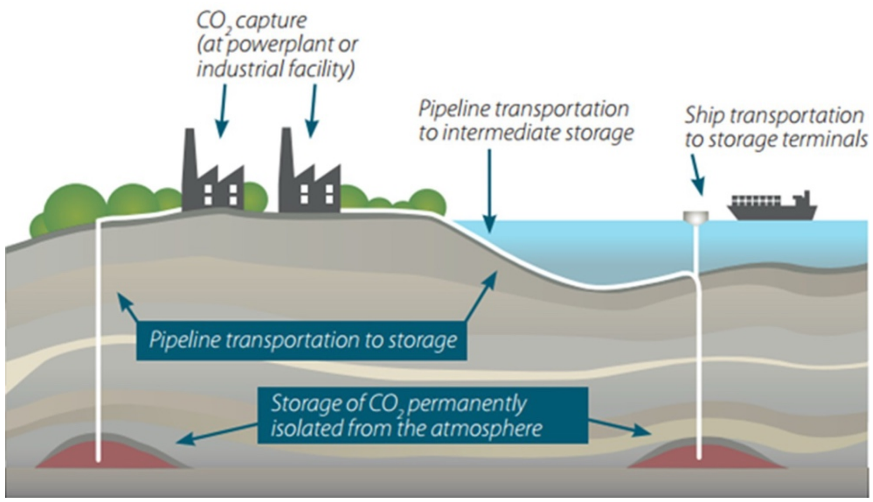
[130] United States Department of Energy, "Hydrogen Production: Natural Gas Reforming," Energy.gov, accessed April 15, 2025, https://www.energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming.

[132] Ikhsan Taipabu, Viswanathan, Wu, Hattu, and Atabani, "A Critical Review of the Hydrogen Production from Biomass-Based Feedstocks."

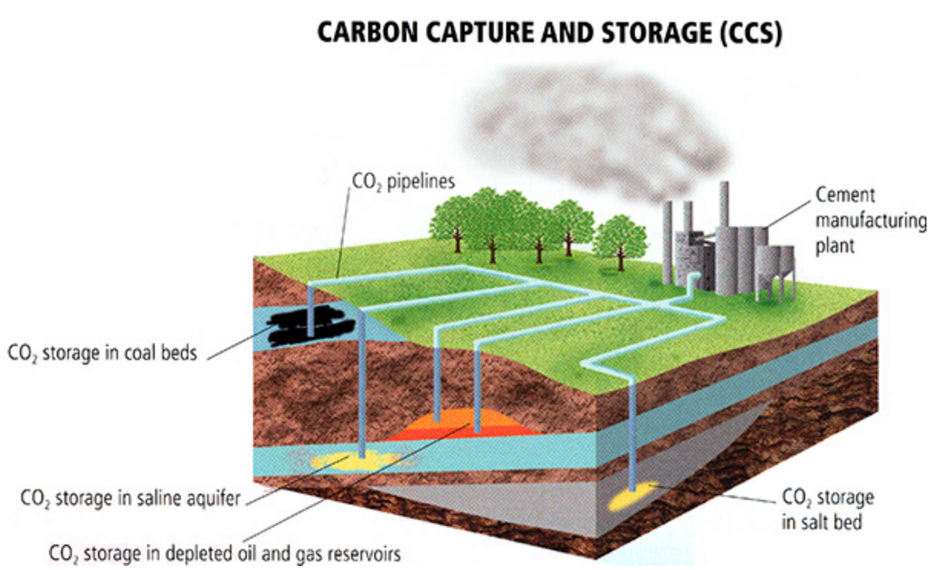
[134] United States Department of Energy, "Hydrogen Production: Natural Gas Reforming."

Figure 19. The Basic Principle for Carbon Capture and Storage (CCS)



Blue hydrogen is differentiated from grey hydrogen by the use of CCS methods[136]

Figure 20. Diagram of Carbon Capture and Storage (CCS) Techniques for a Cement Manufacturing Plant



[136] Choudhary, "Carbon Capture and Storage Program (CCSP) Final Report 1.1.2011–31.10.2016."

[140] Mann, Dire Predictions.

CCS and sequestration involve the process of capturing the carbon dioxide generated by the production of hydrogen from traditional manufacturing processes. CCS systems use pipeline transportation to move CO_2 to intermediate storage and permanent storage isolated from the atmosphere, as depicted in Figure 19.[141]

The final destination for the resultant carbon can be a coal bed, a saline aquifer, a depleted oil and gas reservoir, or a salt bed.

Gasification: Black and Biomass Hydrogen

Hydrogen can also be produced through gasification. Coal can be transformed into a synthetic gas through the gasification process. The gas is a combination of carbon monoxide, carbon dioxide, and hydrogen. Once the gas has cooled, any impurities in the gas are discarded and the gas is transferred to a shift reactor where the carbon monoxide is converted into carbon dioxide. The mixture of carbon dioxide and hydrogen is then separated into two streams of gas. The stream of carbon dioxide can be captured using CCS or, more commonly, released into the atmosphere. Coal gasification is referred to as black hydrogen and has the most detrimental environmental impact among all the modes of hydrogen production. The production of black hydrogen emits 18–20 kg of carbon dioxide—up to two times as much carbon dioxide as grey hydrogen produced by SMR (8–12 kg).[142]

Biomass gasification is a more environmentally sound practice than coal gasification or SMR. Biomass gasification converts unused biomass such as wheat straw, animal waste, and organic municipal solid waste into gas by exposing it to high temperatures under controlled oxygen levels. Biomass gasification forms hydrocarbon compounds, which are reformed into a synthetic gas made of carbon dioxide, carbon monoxide, and hydrogen. This makes biomass gasification less efficient than coal gasification—it simply takes longer and is more complex. Just as in the coal gasification process, the resultant synthetic gas is processed, separated, and stored for later use. Unlike coal gasification, however, biomass gasification can be a carbon neutral process—if it recycles the carbon emissions that it generates. Plants absorb carbon dioxide as they grow, and if the carbon released during the bio gasification process is equal to the carbon absorbed by the plant, then the process is considered carbon neutral.[143] However, this depends on the source of biomass used in

[141] Carbon Capture and Storage (CCS) and sequestration are similar but different concepts, though they are sometimes used interchangeably. Sequestration generally refers to deep, underground storage of captured carbon. Because sequestration is a common form of CCS, authors sometimes use CCS instead of sequestration.

[142] Aman Verma and Amit Kumar, "Life Cycle Assessment of Hydrogen Production from Underground Coal Gasification," *Applied Energy* 147 (June 1, 2015): 556–68, https://doi.org/10.1016/j.apenergy.2015.03.009.

[143] "Hydrogen Production: Biomass Gasification," Energy.gov, accessed May 1, 2025, https://www.energy.gov/eere/fuelcells/hydrogen-production-biomass-gasification.

the production of hydrogen. There are no biomass gasification facilities presently in operation, because it is an emergent form of hydrogen production. However, since 2023, Toyota Motor Corporation has been exploring the production of hydrogen from biomass, using local chicken manure from a poultry farm in Thailand.[144] Further research and development may lower capital costs, which would make biomass gasification a more commercially viable form of hydrogen production.

Electrolysis: Green Hydrogen

In the production of green hydrogen, water is converted into hydrogen using electricity generated from green sources such as wind, solar, nuclear, and hydroelectric. Green hydrogen is primarily produced by splitting water into its constitutive elements (hydrogen and oxygen) via a process known as electrolysis. According to the Office of Energy Efficiency & Renewable Energy, "Like fuel cells, electrolyzers consist of an anode and a cathode separated by an electrolyte. Different electrolyzers function in different ways, mainly due to the different types of electrolyte material involved and the ionic species it conducts."[145] Electrolyzers can drastically vary in size and the type of electrolyte material used, but all produce hydrogen gas. Since electrolysis uses green energy to convert water into hydrogen, all excess energy can be used to convert water into hydrogen gas which can be stored and used to supply power at a later date. Less common forms of green hydrogen are produced by photo-electrochemical or solar thermochemical reactions. In the U.S., electrolysis is the most popular form of green hydrogen production, because of its potential for very effective decarbonization at scale. However, electrolysis is responsible for just 1% of the total hydrogen produced in the U.S. because of the expense associated with this method. Transportation and storage costs are a barrier for large-scale commercial deployment of hydrogen, and this is especially true for green hydrogen.[146] While the DOE Hydrogen Program found that there have been advancements in the technology as of 2024, the current price of electrolysis $5–7/kg.[147]

Hydrogen Fuel Cell Technology Overview

[144] David Crouch, "Toyota Unveils New Technology That Will Change the Future of Cars," Toyota, June 13, 2023, https://media.toyota.co.uk/toyota-unveils-new-technology-that-will-change-the-future-of-cars/; Mindy Long, "Manufacturers Strive to Strengthen Hydrogen Fuel Cell Tech," *Transport Topics*, May 2, 2025, https://www.ttnews.com/articles/oems-hydrogen-fuel-cells.

[145] United States Department of Energy, "Hydrogen Production: Electrolysis," Energy.gov, accessed April 15, 2025, https://www.energy.gov/eere/fuelcells/hydrogen-production-electrolysis.

[146] TRC Companies, Inc., "State of Sustainable Fleets 2025 Market Brief."

[147] Mckenzie Hubert, "24005-Clean-Hydrogen-Production-Cost-Pem-Electrolyzer," United States Department of Energy, May 2024, https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/24005-clean-hydrogen-production-cost-pem-electrolyzer.pdf.

Fuel cells are housed within what is traditionally identified as the engine block, enabling it to consume oxygen and initiate the chemical process necessary to generate electricity from hydrogen. This process is what gives FCEVs their name, vehicles powered by electricity produced from fuel cells.

In every FCEV, electricity generated by the fuel cell then passes through a boost converter, a device that converts low-voltage systems into high-voltage systems by storing energy and subsequently releasing it when enough energy has been amassed.[148] The low-voltage to high-voltage conversion powers the electric motor, with any excess energy stored in a lower voltage auxiliary battery that powers the vehicle's electrical system (such as headlights, entertainment system, etc.).

Hydrogen can be stored in either a gaseous or liquid form. Liquid hydrogen has greater energy by volume than gaseous hydrogen, which means that it contains considerably more energy than gaseous hydrogen within the same-sized space. While this makes liquid hydrogen more attractive than gaseous hydrogen for fuel-cell applications, there are complications. Liquid hydrogen requires cryogenic storage, with some hydrogen inevitably lost due to evaporation. The energy density by weight, in either form, is far greater than lithium-ion batteries—and even gasoline or diesel. The comparison with diesel is especially important, as hydrogen fuel cell electric vehicles (FCEVs) are often a desirable replacement for diesel-fueled vehicles.[149] Diesel has an energy density by weight of 44 MJ/kg, while hydrogen has an energy density by weight of 120 MJ/kg. While the energy density of lithium-ion batteries has increased from about 0.5 MJ/kg in 2008 to 0.95–1.01 MJ/kg in recent years, it has not yet reached the levels of fossil fuel alternatives. By contrast, hydrogen is almost four times as energy-dense as diesel by mass, but only about a fifth as energy-dense by volume. By volume, diesel holds more potential energy than gaseous hydrogen (5.6 MJ/L) or liquid hydrogen (8 MJ/L). Liquid hydrogen is more energy dense by volume than gaseous hydrogen, but it is not as widely available.[150]

Figure 21. Energy Comparison Chart

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[148] Boost convertors are discussed in greater detail here: "Boost Converters (Step-Up Converter)," Monolithic Power Systems, Inc., 2025, https://www.monolithicpower.com/en/learning/mpscholar/power-electronics/dc-dc-converters/boost-converters?srsltid=AfmBOorcGoRXcI8l3bTkaPco07_GgnFf7ZbH8V0n3NZs7PeqPFL6LvXn.

[149] For example, see: "Foothill Transit Agency."

[150] F.M. Nizam Uddin Khan, Mohammad G. Rasul, A.S.M. Sayem, and Nirmal Mandal, "Maximizing Energy Density of Lithium-Ion Batteries for Electric Vehicles: A Critical Review," *Energy Reports, Proceedings of 2022 7th International Conference on Renewable Energy and Conservation*, 9 (October 1, 2023): 11–21, https://doi.org/10.1016/j.egyr.2023.08.069; "Energy Future: Think Efficiency—How America Can Look Within to Achieve Energy Security and Reduce Global Warming" (American Physical Society, September 2008), https://rael.berkeley.edu/old_drupal/sites/default/files/Kammen%202008-%20energy%20future,%20think%20efficiency.pdf; Chester Simpson, "Characteristics of Rechargeable Batteries," Texas Instruments, 2011, https://www.ti.com/lit/an/snva533/snva533.pdf.

ATTRIBUTE	HYDROGEN	DIESEL	GASOLINE	LITHIUM-ION
ENERGY DENSITY	>120 MJ/KG	= 45 MJ/KG	= 46 MJ/KG	= 1 MJ/KG
EMISSIONS	WATER VAPOR	CO2, NITROGEN OXIDES, PM	CO2, NITROGEN OXIDES	NONE
APPLICATIONS	FUEL CELLS	VEHICLES, MACHINERY	VEHICLES, MACHINERY	ELECTRONICS, EVS

FCEVs are battery-electric vehicles, just like their lithium-ion battery-electric counterparts. However, instead of storing electrical energy in batteries, FCEVs generate electricity within the vehicle itself. FCEVs are equipped with hydrogen fuel-cell stacks that are responsible for converting hydrogen to usable power. Hydrogen fuel cells produce electricity via the reaction between hydrogen and oxygen atoms. The reaction produces electricity, water, and some residual heat. The ability to generate electricity allows FCEVs to operate with smaller batteries, which reduces the overall vehicle weight.

Appendix B: Hydrogen Workforce SOC Code Tables

Table 9. Hydrogen Supplier SOC Codes

Hydrogen Supplier Codes							
SOC Code	Occupation	Top Technical Skills	Average Wage ($)	Education Level	# of Employees	Projected change in 2033	% Change
11-3051	Industrial Production Managers	Lean manufacturing, Six Sigma, SAP ERP	121,440	BA/BS	230,100	6,500	3%
17-2141	Mechanical Engineers	AutoCAD, Finite Element Analysis (FEA), Computational Fluid Dynamics (CFD), Design fluid systems	102,320	BA/BS	291,900	32,100	11%
17-2041	Chemical Engineers	MATLAB, AutoCAD, Aspen HYSYS. ChemCAD, NFPA 2, Hydrogen Technologies Code	121,860	BA/BS	336,600	40,900	12%
49-9041	Industrial Machinery Mechanics	PLC programming, CMMS software, HVAC systems	63,760	High school diploma / Eq.	429,500	73,800	17%
19-5011	Occupational Health and Safety Specialists	OSHA Compliance, Risk assessment, ISO 14001	83,910	BA/BS	125,900	18,800	14.90%

Hydrogen Supplier Codes							
47-2111	Electricians	Circuit analysis, PLC Programming, AutoCAD Electrical	62,350	High school diploma / Eq.	779,800	84,300	11%
17-2051	Civil Engineers	AutoCAD, Structural Analysis, Building Information Modelling	99,590	BA/BS	291,900	32,100	11%
17-2071	Electrical Engineers	AutoCAD, MATLAB, LabVIEW	111,910	BA/BS	21,400	2,100	10%
17-2112	Industrial Engineers	AutoCAD, SolidWorks, Six Sigma	101,140	BA/BS	287,800	26,200	9%
11-9041	Architectural and Engineering Managers	Software development, Architectural review, Cloud computing	167,740	BA/BS	210,200	11,600	5.50%
19-4031	Chemical Technicians	Chromatography (HPLC), Spectroscopy (FTIR), Mass Spectrometry (GC-MS)	57,790	Associate's degree	58,300	3,200	5%
43-5061	Production, Planning, and Expediting Clerks	ERP Systems, SAP, Material Requirements Planning (MRP)	57,770	High school diploma / Eq.	399,200	19,500	4.90%

Hydrogen Supplier Codes							
17-3029	Engineering Technologists and Technicians, Except Drafters, All Other	AutoCAD, MATLAB, SolidWorks	77,390	Associate's degree	69,500	3,100	4.40%
53-7071	Compression Station Operators	Equipment Maintenance, UP Testing, PLC Programming	71,510	High school diploma / Eq.	4,500	100	1.20%
51-8093	Pipeline Technicians	SCADA, PIG Launching, HAZOP Analysis	97,540	High school diploma / Eq.	33,600	-800	-2.30%
51-8092	Gas Plant Operators	SCADA, PLC Programming, HAZOP Analysis	83,400	High school diploma / Eq.	16,100	-160	-9.80%
51-9012	Separation Technician	Equipment Maintenance, Data Analysis, Process Control	49,500	High school diploma / Eq.	53,400	900	1.70%
19-4042	Carbon Capture Technicians	Systems Analysis, Process Control, Equipment Maintenance	49,490	Associate's degree	33,900	2,400	7%
17-3026	Industrial Engineering Technicians	CAD, Process Improvement, Circuit Analysis	64,790	Associate's degree	74,500	3,000	4.10%

Hydrogen Supplier Codes							
19-4031	Chemical Technicians	Chromatography (HPLC), Spectroscopy (FTIR), Mass Spectrometry (GC-MS)	57,790	Associate's degree	58,300	3,200	5%
51-8031	Water Treatment Specialists	SCADA, Reverse Osmosis, Membrane Filtration	58,260	High school diploma / Eq.	124,700	-7,500	-6%
51-8091	Chemical Plant Operators	HAZOP Analysis, SCADA, Process Control	73,540	High school diploma / Eq.	18,400	-100	-0.80%
49-3023	Automotive Service Technicians and Mechanics	High-Pressure Gas Handling, DOT & HazMat Compliance, Safety Protocols, and Emergency Response	49,670	Postsecondary nondegree award	815,900	21,200	2.70%
47-5013	Service Unit Operators, Oil and Gas	Process Control, Operations Monitoring, Safety Protocols, and Emergency Response	57,980	No formal educational credential	48,700	1,000	2.10%
No existing SOC	Electrolyzer Maintenance Technician						

Table 10. Hydrogen User SOC Codes

Hydrogen User SOC Codes							
SOC Code	**Occupation**	**Top Technical Skills**	**Average Wage ($)**	**Education Level**	**# of Employees**	**Projected change in 2033**	**% Change**
13-1081	Logistician	SAP, Oracle, Inventory management	80,880	BA/BS	237,100	45,800	19.30%
49-3042	Mobile Heavy Equipment Mechanics, Except Engines	Hydraulics, Pneumatics, Diagnostic software	63,980	High school diploma/Eq	191,100	16,200	8.50%
49-9071	Maintenance and Repair Workers, General	Hydraulic pumps and cylinders, cranes, calipers	48,620	High school diploma/Eq	1,616,500	81,800	5.10%
53-3032	Heavy and Tractor-Trailer Truck Drivers	CDL, Safety and compliance, TWIC card	57,440	Postsecondary nondegree award	2,211,300	102,000	4.60%
49-1011	First-Line Supervisors of Mechanics, Installers, and Repairers	regulatory intelligence, GMP Compliance, Risk management	78,300	High school diploma/Eq	604,300	21,900	3.60%
17-3023	Electrical and Electronic Engineering Technologists and Technicians	Programmable Logic Controller (PLC), SCADA, HART Communication	77,180	Associate's degree	99,600	3,000	3%
53-6031	Automotive and Watercraft Service Attendants	Safety compliance, fuel systems, CDL	34,850	No formal educational credential	94,600	-100	-0.10%

Appendix C: CSU5+ Survey Questionnaire

Q1 Please provide your name and email address.

◯ Name: (1) ____

◯ Email Address: (2) ____

Q2 Which member of the CSU5+ do you represent?

◯ California State Polytechnic University, Pomona (1)

◯ California State University, Long Beach (2)

◯ California State University, Los Angeles (3)

◯ California State University, Northridge (4)

◯ California State University, Dominguez Hills (5)

◯ California State University, Fullerton (6)

◯ California State University Maritime Academy (7)

Q3 How many hydrogen-related programs do you offer at your institution?

◯ 0 (1)

◯ 1-2 (2)

◯ 3-4 (3)

◯ 5+ (4)

Q4 Regarding the hydrogen economy, do you have any of the following developed? Select all that apply.

- [ ] Badges (1)
- [ ] Microcertificates and/or Microcredentials (2)
- [ ] Certificate programs (3)
- [ ] Degrees or concentrations (4)
- [ ] Individual classes not linked to any one program (5)
- [ ] Other (please describe) (6) ____

Q5 What are the names of the programs indicated in the previous question?

____

____

____

____

____

Q6 How do these programs relate to current hydrogen supply chain needs?

- [ ] Production (Steam Methane Reformation, Electrolysis, Biomass Gasification, etc.) (1)
- [ ] Transportation and Delivery (pipeline, trucking developments, mobile fueling stations) (2)
- [ ] End-Use (3)
- [ ] Awareness and Public Engagement (4)
- [ ] Other (please describe) (5) ____

Q7 Are you aware of any other hydrogen-related workforce development programs that are: (a) partnerships with other universities, government agencies? (b) programs taking place in the State of California?

- ○ Yes (1)
- ○ No (2)

Display this question: If Q7 = Yes

Q8 Are you aware of any other hydrogen-related workforce development programs that are: (a) partnerships with other universities, government agencies? (b) programs taking place in the State of California?

____

____

____

____

____

Q9 Please provide a 300-word summary of your university's approach to addressing hydrogen knowledge, skills, and abilities (KSAs) gaps. References or links to official websites or reports is appreciated.

____

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End of Block: Default Question Block

Appendix D: CSU5+ Meeting Summary

Date: June 6, 2025

Time: 5:01 PM

Participants:

- Tyler Reeb (Moderator, CSULB)
- Steven Browne (CSU Maritime)
- David Blekhman (CSU LA)
- Barbara Taylor (CSULB)
- Devin Martinez-Flores (CSULB)
- James Reuter (CSULB)
- Ehsan Madadi (CSULB)
- Vinicius Sauer (CSU Northridge)
- Hadi Tavassol (CSULB)
- Alejandra Hormaza (Cal Poly Pomona)

Meeting Overview

The CSU5+ Peer Exchange meeting held on June 6, 2025, focused on hydrogen workforce development and curriculum alignment across CSU campuses. The meeting brought together key stakeholders from various CSU campuses to discuss collaboration, curriculum development, industry engagement, and the creation of a blueprint for hydrogen workforce development.

Key Themes

#1. CSU5+ Collaboration

The participants emphasized the importance of collaboration among CSU campuses to develop a cohesive approach to hydrogen workforce development. The discussion highlighted the need for shared resources, peer exchange, and cross-campus collaboration to achieve common goals.

#2. Curriculum Development

One of the primary challenges discussed was the integration of hydrogen topics into existing courses. The participants explored opportunities for incorporating hydrogen education into general education (GE) courses, graduate-level special topics, and certificate programs. Faculty turnover and administrative hurdles, such as academic senate approval, were identified as major barriers to curriculum development.

#3. Industry and Research Engagement

The meeting underscored the significance of partnerships with industry and research institutions. Examples of industry partners included Yusen Terminals, Toyota, and SoCalGas. The participants discussed the importance of real-world applications, internships, and technology demonstrations to enhance student learning and engagement.

#4. Blueprint/Roadmap Development

The development of a forward-looking document to guide hydrogen workforce development was a key topic of discussion. The blueprint is intended to include case studies, labor market analysis, and visual storytelling to make it accessible to both workforce professionals and hydrogen experts.

Challenges Discussed

- **Integration into Existing Courses:** The participants acknowledged the difficulty of integrating hydrogen topics into existing courses due to faculty turnover and administrative hurdles.

- **Industry Engagement:** Establishing and maintaining partnerships with industry was identified as a challenge, particularly in terms of securing internships and real-world applications for students.

- **Resource Allocation:** The need for shared resources and funding to support hydrogen workforce development initiatives was highlighted as a significant challenge.

Coordination: Participants recognized need to establish a coordinated effort that involves contributions from people with different roles (university faculty, university administrators, industry leaders, etc.).

Recommendations

- **Stackable Credentials and Certificates:** Develop stackable credentials and certificates to provide students with flexible learning pathways in hydrogen education.

- **CSU-Wide Competitions:** Create CSU-wide hydrogen competitions to foster student engagement and innovation.

- **Mobile Hydrogen Labs:** Leverage mobile hydrogen labs to provide hands-on learning experiences for students across different campuses.

- **Industry Champions:** Engage industry champions to validate the curriculum and provide internships and real-world applications for students.

Articulation Agreements: Explore articulation agreements and cross-campus course sharing to enhance collaboration and resource utilization.

Next Steps

- **Blueprint Development:** Continue working on the development of the hydrogen workforce development blueprint, incorporating feedback from industry partners and stakeholders.

- **Curriculum Integration:** Focus on integrating hydrogen topics into existing courses and developing new courses and certificate programs.

- **Industry Partnerships:** Strengthen partnerships with industry and research institutions to provide students with real-world learning opportunities. Similar to Barbara and Tyler's previous talent pipeline efforts, industry partners can sometimes help get certificates/credentials/workshops off the ground when working within traditional academic frameworks proves to be cumbersome and slow.

- **Resource Allocation:** Seek funding and resources to support hydrogen workforce development initiatives across CSU campuses.

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