Supercharging ELECTROLYZERS

Boosting Zero-Emission Hydrogen Production and Deployment in California

DECEMBER 2022
Policy Report

Climate Change
and Business
Research Initiative

Berkeley Law | Center for Law, Energy, & the Environment

UCLA School of Law Emmett Institute on Climate Change & the Environment

BANK OF AMERICA

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ABOUT THIS REPORT

This policy report is part of a series on how specific sectors of the business community can drive key climate change solutions and how policymakers can facilitate those solutions. Each report results from workshop convenings that include expert representatives from the business, academic, policy, and environmental sectors. The convenings and resulting policy reports are sponsored by Bank of America and produced by a partnership of UC Berkeley School of Law's Center for Law, Energy & the Environment (CLEE) and UCLA School of Law's Emmett Institute on Climate Change and the Environment.

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I. INTRODUCTION & EXECUTIVE SUMMARY

As California seeks to decarbonize its electricity grid and achieve carbon neutrality by 2045, hydrogen produced from zero-emission sources could play a critical role. The gas can generate electricity when solar or wind energy is unavailable, as well as power fuel-cell electric vehicles.

Developers can harness surplus renewable energy to create it, resulting in zero-emission (sometimes referred to as "green") hydrogen. Zero-emission hydrogen refers to the production and creation of hydrogen using only renewable energy resources. Electrolyzers, which separate water into oxygen and hydrogen, are critical to mass production of zero-emission hydrogen. As a result, zero-emission hydrogen depends on reducing the cost of electrolyzers, as well as ensuring access to low-cost renewable energy. California could be well positioned to leverage its renewable energy deployment and cleantech industry expertise to decrease these costs and create a sustainable industry of electrolysis-based zero-emission hydrogen.

Hydrogen is on pace for significant growth in the world energy marketplace. In 2020, global hydrogen demand reached 90 million tons.[1] By 2050, forecasts indicate that demand for renewable or low-carbon hydrogen could reach 660 million tons, or 22% of total energy demand worldwide.[2] In the U.S., the Infrastructure Investment and Jobs Act of 2021 and the Inflation Reduction Act of 2022 have spurred significant interest in hydrogen at all levels of government.[3] With hydrogen likely to play a role in the ongoing economy-wide decarbonization process, California can help ensure that the future of this gas is truly zero-emission through state policies promulgated this decade.

Zero-emission electrolytic hydrogen has the potential to replace fossil gas in a myriad of applications, including hard-to-decarbonize industrial uses such as metals processing, cement production, and glass manufacturing, as well as a transportation fuel for heavy-duty goods

DEFINING ZERO-EMISSION HYDROGEN

This report focuses on boosting the production of zero-emission electrolytic hydrogen, defined by a production process involving renewable or zero-carbon energy that powers an electrolyzer to create hydrogen. Beyond production, once the hydrogen is created, it has a variety of end uses. Some of these end uses cause air pollution and emissions that contribute to climate change. While this report discusses the need to reduce those emissions to mitigate those impacts, the end uses of hydrogen are largely beyond the scope of this report.

movement (trucks, rail, and ships). The produced hydrogen can be distributed in pipelines or by truck, ship, or other means for immediate use. Hydrogen may also be stored in large quantities using natural underground caverns or massive tanks, to be utilized or converted back into electricity when needed. In this way, hydrogen could serve as long-term seasonal energy storage to help California's electricity grid decarbonize by providing dispatchable, zero-emission power when the sun and wind are absent. Grid operators and project developers could utilize surplus renewable power (solar or wind) to create the hydrogen, helping to solve the issue of having to dump or "curtail" excess solar or wind energy produced during times of low demand.[4]

Yet major hurdles remain to deployment. Most prominently, producing zero-emission hydrogen currently costs somewhere between two to three times more compared with hydrogen created from fossil-fuels.[5] While analysts expect prices for electrolyzers to decrease this decade, zero-emission hydrogen will not achieve cost parity with fossil-based hydrogen absent significant market scale and policy support.[6] Electrolyzers also have additional capital and operating costs, including water, reliance on intermittent power generation, and requirements for new storage infrastructure and distribution systems.[7]

To address these challenges and opportunities, UC Berkeley School of Law's Center for Law, Energy and the Environment (CLEE) and UCLA School of Law's Emmett Institute on Climate Change and the Environment convened leaders from state and local government, electric utilities, and environmental organizations in Spring 2022 to examine opportunities to optimize deployment of zero-emission hydrogen electrolyzers to meet California's climate goals.

TOP BARRIERS AND RECOMMENDATIONS

Barrier 1: A lack of consistent state policy on zero emission electrolyzers, including legal and regulatory requirements and long-term planning processes.

- The governor could craft an executive order to align agency priorities and establish a zero-emission hydrogen roadmap to support the U.S. Department of Energy Hydrogen Hub grant application.
- The legislature could mandate that all hydrogen production be zero emission or require average 'well-to-gate' greenhouse gas emissions for hydrogen production to be magnitudes cleaner than fossil-based hydrogen production.
- The California Air Resources Board could utilize a lifecycle approach to define carbon intensity and create an intensity scoring methodology for all hydrogen production pathways and applications, like it already does for hydrogen use in the transportation sector.
- The California Air Resources Board and/or regional air districts could set nitrogen oxide emission limits on hydrogen combustion.

- The legislature, California Workforce Development Board, and community-based organizations could work together to establish statewide “High Road” job standards to support a just transition for the fossil fuel workforce.
- The legislature could dedicate funding to support zero-emission electrolyzer projects, rather than relying primarily on ratepayer funds.

Barrier 2: High upfront and operational costs prevent electrolyzer projects from attracting private investment.

- The legislature, California Independent System Operator, and California Public Utilities Commission could develop a “direct-tie” or direct access program to support zero-emission hydrogen production from surplus renewable energy.
- The Governor’s Office of Business and Economic Development Climate Catalyst fund could provide financial backstops or guarantees to attract private investment.
- The California Energy Commission could assist regional and local governments to develop Zero-Emission Hydrogen Master Plans.
- The legislature, California Energy Commission, California Natural Resources Agency, and local utilities could establish a “zero-water-waste” statewide initiative to invest in research advancing the use of reclaimed, brackish, or non-potable wastewater in electrolyzers.

Barrier 3: Zero-emission hydrogen lacks targeted support to fuel difficult-to-decarbonize activities.

- The California Air Resources Board could require heavy industrial sources to decarbonize through regulations on thermal emissions.
- The California Energy Commission could assess the current hydrogen offtake market and provide producers with a market viability analysis to entice investment in zero-carbon hydrogen production.


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II. OVERVIEW

Hydrogen's versatility can help address energy challenges and reduce reliance on fossil fuels like coal and fossil gas. Hydrogen will play a critical role in a comprehensive energy portfolio for California.

THE POTENTIAL OF ZERO-EMISSION HYDROGEN

Developing zero-emission hydrogen resources will enhance the state's energy resilience. Today, hydrogen made from fossil fuels is largely used for oil refining, chemical production, or heavy industrial uses. There are significant carbon dioxide emissions associated with current fossil hydrogen usage. According to the International Energy Agency, in 2021, developers produced 99.6% of global hydrogen using fossil fuels, typically natural gas or coal.[8] As a result, in 2021 hydrogen production emitted 900 megatons of greenhouse gas emissions.[9]

Industry created color codes to describe the carbon intensity of hydrogen.[10] Fossil hydrogen, known as either "gray" or "blue" hydrogen, converts either coal or natural gas to hydrogen and carbon dioxide through processes such as steam methane reform (SMR).[11] Color codes have been created by industry to describe the carbon intensity of hydrogen. "Gray" hydrogen process vents the carbon dioxide into the atmosphere, whereas "blue" hydrogen incorporates carbon capture technologies.[12]

However, there is strong global interest in instead utilizing hydrogen made from renewable resources for energy storage, transportation, and cleaner manufacturing. Zero-emission (or "green") hydrogen, uses solar or wind energy that powers an electrolyzer. Electrolysis is a century-old electrochemical production process that produces hydrogen using energy from an electric current to split water (H_2O) into oxygen (O_2) and hydrogen (H_2).[13]

Biomass gasification represents yet another method of hydrogen production, which developers can pair with carbon capture to achieve net-negative greenhouse gas emissions. In this process, biomass such as waste wood or crops is precisely heated to release the gasses.[14] Developers then collect the hydrogen and capture and sequester the accompanying carbon.

Zero-emission hydrogen has numerous priority end-uses. As a flexible resource, it can be applied to many sectors, including power generation or for an industrial heat source. Some priority end-uses include:

- industries that rely on hydrogen as a chemical feedstock
- real-time dispatchable electricity production for firm power generation
- storing renewable and zero-carbon electricity for long-duration storage
- transportation fuel cell vehicles, especially valuable for heavy-duty/long-haul trucks and ocean-going vessels
- ammonia and fertilizer production
- difficult-to-electrify industrial applications and appliances (e.g., high-heat industrial, food processing, cement, plastics, computer chip fabrication, displacing coking coal in steel production and recycling, etc.)

Yet while the hydrogen used in these end uses may be zero-emission in origin, these various uses of hydrogen result in different emission impacts. On one hand, hydrogen fuel cells produce electricity without any direct emissions (a fuel cell simply converts hydrogen to electricity without combustion, producing only water vapor and avoiding carbon dioxide or other harmful emissions). On the other hand, combusting hydrogen produces harmful emissions, including oxides of nitrogen (NOx), which are precursors to ozone pollution and represent a public health concern.[15] Many industries are exploring hydrogen combustion as a replacement for fossil fuels, given that burning or combusting hydrogen may be the only way to reduce fossil fuels from specific heavy-duty and high-heat industrial end uses, such as at refineries, in food processing facilities, and semiconductor manufacturing.

Additionally, utilities and powerplants are assessing the use of hydrogen both for combustion in existing turbines as well as in fuel cell generators. Because of the potential for localized air pollution impacts in California's environmental justice communities, policymakers may seek to focus the use of zero-emission hydrogen away from combustion and toward fuel-cell applications. In addition, policymakers will need additional research on a host of emission control options around combustion to mitigate these impacts.[16]

ZERO-EMISSION HYDROGEN COULD OFFSET FOSSIL FUEL USAGE

Electric Sector: Zero-emission hydrogen has the potential to play a key role in grid stabilization, providing important benefits as California works to integrate greater amounts of renewable energy to phase out high-polluting fossil gas peaker plants. In California, gas power plants currently provide about 75 percent of the flexible capacity.[17] The variability and intermittency of solar and wind energy resources has led to unprecedented investments in energy storage technologies. Zero-emission hydrogen produced from renewable resources can be a low-carbon fuel for existing combustion turbines or fuel cells, and provide energy storage for later combustion or fuel cell application.[18] In addition to utilizing hydrogen in some of the same combustion equipment and infrastructure currently in operation today, fuel cell stack technology could provide similar power without combustion emissions. Fuel cells could also support distributed or back-up generation, power microgrids, and grid services.[19]

While still in the early stages, long-term, seasonal storage of hydrogen for readily dispatchable power has substantial potential. Grid operators could use zero-emission hydrogen as a way to store large quantities of excess, carbon-free solar or wind energy for extended periods of time. Today, producers most commonly store gaseous or liquid hydrogen in tanks. While storage tanks are not economically feasible because they are limited in size, efforts are underway to study and utilize vast geological resources (e.g., salt caverns) to provide a cost-effective option for bulk, long-term hydrogen storage. The Los Angeles Department of Water and Power is planning to store hydrogen in a salt cavern as part of the Intermountain Power Project in Delta, Utah, the United States' largest zero-emission hydrogen project.[20] Just recently, the U.S. Department of Energy (DOE) offered a conditional commitment for a $504.4M loan guarantee to the project, aiming to fund the first grid-scale, seasonal hydrogen storage effort of its size.[21] As part of the project, Mitsubishi Power is procuring 220 megawatts of electrolyzers that will use renewable electricity to produce up to 100 metric tons of hydrogen per day.[22] By hollowing out the salt domes with water, the partners plan to create two underground repositories, each large enough to store 150 gigawatt-hours of energy.

Transportation: Zero-emission hydrogen may be most valuable in the heavy-duty transportation sector, where hydrogen fuel cell trucks could replace diesel powered trucks along with providing solutions in the shipping and aviation sectors. Heavy-duty diesel trucks represent an outsized emissions impact: while they constitute only 2% of vehicles on California roads, they generate more than 9% of California's greenhouse gas emissions and 32% of its NOx emissions.[23] Fuel cell medium- and heavy-duty vehicles have some advantages over battery electric vehicles, including longer driving range, faster refueling, and near-conventional payload capacity.[24] However, fuel-cell trucks and their refueling infrastructure are more expensive than battery electric trucks, and with only a handful of small heavy-duty fuel cell truck demonstration projects underway, fuel cell trucks are still far from achieving market availability.[25]

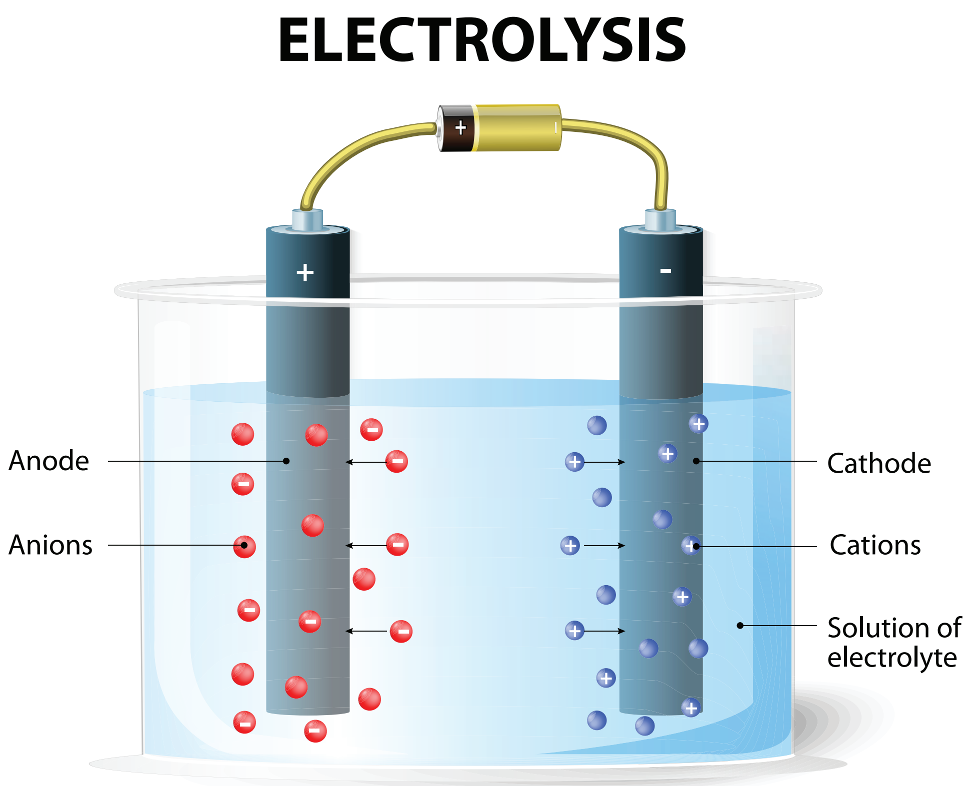
Industrial: Zero-emission hydrogen could displace fossil fuel-based hydrogen used in industrial processes, including supporting domestic hydrogen-based cement and steel production.[26] Simply decarbonizing the hydrogen used at oil refineries by replacing fossil hydrogen with zero-emission hydrogen would have significant climate impacts, especially as refineries look to transition to sustainable biodiesel and other lower-carbon fuels. Using zero-emission hydrogen for steel making could result in multiple levels of decarbonization because the hydrogen is not only used for heat but as a catalyst, replacing coal in the current process.[27] The production of cement is another carbon-intensive process requiring high temperature furnaces currently fueled by coal, which could employ hydrogen instead as a zero-emission alternative.[28]

ADVANCEMENTS IN ELECTROLYSIS AND ELECTROLYZER TECHNOLOGY CREATE NEW OPPORTUNITIES

In its most basic form, an electrolyzer contains a cathode (negative charge), an anode (positive charge), and a membrane. Applying electricity, the electrolyzer can then split water into hydrogen and oxygen. Electrolyzers range in size from small-scale, appliance-sized devices to large-scale equipment that operators can directly connect to utility-scale electricity generation sources. An electrolyzer apparatus includes myriad critical minerals, such as platinum, iridium, scandium, titanium, and yttrium that support the cathode and anode.[29] The entire electrolyzer system also contains pumps, vents, storage tanks, and the power supply creating the electricity.

The electrolysis process that splits water into hydrogen takes place within what is referred to as the "cell." The cell consists of the anode, cathode and membrane. They are typically assembled in series in a "cell stack" that produces more hydrogen and oxygen as the number of cells increases. Developers can stack the largest electrolysis cells and use them for commercial zero-emission hydrogen production when connected to wind farms, solar plants, or other renewable electricity sources. Electrolyzer systems can also be modular, with the ability to add additional cells over time.

In the long term, electrolyzers have the potential to decrease significantly in both capital and operating costs, as research continues to advance deployment and commercialization of the technology. According to the Hydrogen Council, innovation and a scaled zero-emission hydrogen industry could reduce the cost of the critical minerals that comprise electrolyzers by 60% to 80% within a decade.[30]



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TYPES OF ELECTROLYSIS

The different types of electrolysis include the following:

- Alkaline electrolysis is the most common type of process.[31] It uses a cell with a cathode, an anode, and an electrolyte solution. When the operators apply voltage, water decomposes in the alkaline solution. Hydrogen is formed at the cathode and oxygen at the anode. The electrolyte is liquid, which means that the alkaline electrolyzer requires more peripheral equipment, such as pumps for the electrolyte, solution washing, and preparation. Although alkaline is currently the cheapest of all electrolysis processes to purchase, it has relatively high maintenance costs.
- Proton exchange membrane (PEM) is a process that presses water through a stack of two electrodes and a polymer membrane to split the hydrogen.[32] PEM requires no liquid electrolyte but does require a rare metal to serve as the cell's catalyst. Operators can arrange cells in stacks to optimize performance.
- Anion exchange membrane (AEM) electrolysis is similar to PEM because operators split water into hydrogen and oxygen via the application of an electric current.[33] AEM avoids the use of the costly precious metals required as catalysts in PEM electrolysis by replacing the conventional noble metal electrocatalysts with low-cost catalysts. The process is effective at a smaller scale, making it suitable for decentralized applications.
- High-temperature (solid oxide) electrolysis separates oxygen and hydrogen using extreme temperatures (600 to 800 degrees Celsius).[34] Since heat already provides most of the energy required for this process, the electrical energy requirement is lower. When operators use industrial waste heat or steam, which costs little or nothing, this method can be efficient. Measured in terms of the electrical input, its efficiency is higher than with other methods. Bloom Energy recently released a solid oxide electrolyzer and stated the technology could better optimize intermittent renewable energy.[35]
- Photoelectrochemical water splitting produces hydrogen from water using sunlight and specialized semiconductors called photoelectrochemical materials, which use light energy to directly dissociate water molecules into hydrogen and oxygen.[36] The emerging technology has durability challenges, but it offers the potential for high efficiency at low operating temperatures using thin-film and particle semiconductor materials.
- Other emerging methods include photon-based, salt water, and non-water electrolyte technologies.[37] For example, Australian start-up Hysata has made progress on capillary-fed electrolysis cell technology. Capillary-fed electrolysis produces hydrogen from water at 98% cell energy efficiency by eliminating bubbles, one of the biggest remaining drags on efficiency.[38]

FEDERAL & STATE ACTIONS SPUR HYDROGEN GROWTH

The federal government has recently significantly increased investment in hydrogen. As part of the Infrastructure Investment and Jobs Act of 2021, the U.S. Department of Energy is investing in the following, either via competitive grants or tax credits:

- $8 billion for Regional Clean Hydrogen Hubs to create jobs to expand use of clean hydrogen in the industrial sector and beyond[39]
- $1 billion for a Clean Hydrogen Electrolysis Program to reduce costs of hydrogen produced from clean electricity.
- $500 million for Clean Hydrogen Manufacturing and Recycling Initiatives to support equipment manufacturing and strong domestic supply chains.[40]

Additionally, the Inflation Reduction Act of 2022 provides an important clean hydrogen production tax credit of up to $3 per kilogram, on top of continued investment tax credits for renewable energy resources.[41] The new law provides the largest hydrogen subsidies in the world and allows zero-emission electrolytic hydrogen to better compete against incumbent fossil hydrogen. In total, the Inflation Reduction Act's $369 billion in energy and climate spending will bolster the development of zero-emission hydrogen.

The U.S. DOE's "Earthshots Initiative" also supports hydrogen as part of its aim to accelerate breakthroughs of more abundant, affordable, and reliable clean energy solutions within the decade.[42] The 2021 Hydrogen Energy Earthshot seeks to reduce the cost of clean hydrogen by 80% to $1 per 1 kilogram in 1 decade, from its current costs of roughly $5 per kilogram.[43] In addition, the U.S. DOE is working with stakeholders to design and implement a national clean hydrogen roadmap and strategy that could accelerate progress, reduce technology costs, and ramp up the use of hydrogen.[44] However, the U.S. DOE hydrogen roadmap does not solely focus on zero-emission technologies, instead including fossil fuel technologies as well.[45]

Defining "clean hydrogen" at the federal level will have significant implications for electrolyzers. The DOE is currently developing guidance on what qualifies as clean hydrogen via the Clean Hydrogen Production Standard Draft Guidance, using the Inflation Reduction Act's lifecycle greenhouse gas emissions target for clean hydrogen production and the statutory factors included in the Infrastructure Investment and Jobs Act.[46] The DOE's proposed standard 4.0 $kgCO_2e/kgH_2$ would allow fossil fuel systems that employ high rates of carbon capture to qualify for the standard in addition to electrolysis and certain biomass-based systems.[47] To the extent this definition promotes fossil fuel-based hydrogen production as "clean hydrogen" qualifying for federal incentives or investment, it may undercut or dilute efforts to develop zero-emission, non-fossil fuel-based hydrogen production.

In California, state leaders have a history of incentivizing hydrogen innovation that spans more than two decades, as part of the zero-emission vehicles goals and low-carbon fuel standard program. In 2006, Senate Bill 1505 (Lowenthal, Chapter 877, Statutes of 2006) aimed to set a clean hydrogen framework for the original "Hydrogen Highway." Then-Governor Arnold Schwarzenegger proposed the highway as a way to bolster hydrogen for light-duty vehicles. The highway never came to fruition, however, and the state is now trying to reach a new goal of 200 hydrogen fueling stations by 2025.[48] In the last decade, Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) provided financial resources to support building hydrogen infrastructure for transportation fueling.[49]

California now has an opportunity to spearhead deployment of zero-emission hydrogen through the Regional Clean Hydrogen Hubs program, funded through the Infrastructure Investment and Jobs Act. State leaders have launched the Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES), LLC, which will serve as a governance body to support California's application to the Regional Clean Hydrogen Hub program.[50] Participants in ARCHES include the University of California, the Governor's Office of Business and Economic Development, non-profit organizations, labor partners, and renewable energy organizations.[51]

Existing hydrogen fuel cell transportation policies in the state have begun to support the zero-emission hydrogen economy. Specifically, the California Air Resources Board's Low Carbon Fuel Standard (LCFS) provides some foundational support to electrolyzer projects.[52] The LCFS is a market-based system administered by the California Air Resources Board that requires vehicle fuel providers to reduce the carbon content of their fuels over time. Low carbon-intensity transportation fuels generate LCFS credits, while fossil fuels used in transportation—such as gasoline and diesel fuel—generate deficits, for which those fuel providers have to purchase or generate credits in an equal amount. Zero or low-carbon fuels thus generate LCFS credits that can be sold to fossil fuel providers, creating an incentive to produce and commercialize low-carbon fuels.[53] CARB provides pathways for electrolysis to receive financial incentives under the LCFS for projects that use renewable energy.[54] LCFS credits are also available for renewable hydrogen used in the production of a transportation fuel, such as hydrogen used at a petroleum refinery. Hydrogen used in fuel cell electric vehicles and the hydrogen refueling infrastructure are eligible for LCFS credits.[55]

Hydrogen refueling stations for fuel cell vehicles have also been supported by targeted grants. In addition to Assembly Bill 8, the California Energy Commission has launched the EnergIIZE Commercial Vehicles Project to support the transition to zero-emission medium- and heavy-duty vehicles and away from polluting diesel vehicles.[56] Funded by the California Energy Commission, hydrogen refueling infrastructure and related technologies are eligible for grants and financing. EnergIIZE is available to fund electrolyzers, hydrogen storage, piping and pipelines, point-of-sale systems, and hydrogen dispensers such as hoses and nozzles. The program is technology-neutral, funding both battery electric and fuel cell infrastructure.

Most recently, in September 2022, Governor Newsom signed Senate Bill 1075 (Skinner, Chapter 363, Statutes of 2022) into law, which requires the California Air Resources Board, California Energy Commission, and the California Public Utilities Commission, in consultation with the California Workforce Development Board and labor and workforce organizations, to identify the role of hydrogen (particularly "green" hydrogen) in helping to achieve the state's climate goals.[57] The legislation delineated tasks to various agencies, with dates to report back to the Legislature. The legislature previously defined green electrolytic hydrogen in Senate Bill 1369 (Skinner, Chapter 567, Statutes of 2018) as hydrogen gas "produced through electrolysis and does not include hydrogen gas manufactured using steam reforming or any other conversion technology that produces hydrogen from a fossil fuel feedstock."[58] SB 1369 codified electrolytic hydrogen as a form of energy storage.[59] Also in September 2022, Governor Newsom signed a state budget that allocated $100 million for hydrogen projects and provided financial incentives for in-state hydrogen projects as a part of the overall energy and climate change package.[60]

Going forward in 2023, the California Energy Commission will award funding to complete an assessment of hydrogen production from renewable electricity and hydrogen's role in decarbonizing California's electric system.[61] As a part of the Commission's Electric Program Investment Charge research, the solicitation aims to provide recommendations for California's electric system operators that accelerate cost and performance improvements of key hydrogen technologies, equipment, and subcomponents, based on the production of hydrogen from renewable electricity.[62] The research will also examine specific end-use applications in the electric sector, such as firm and dispatchable zero-carbon generation. The Energy Commission intends for the solicitation to support the state's ARCHES Hydrogen Hub activities.


TRUE ZERO
FLAMMABLE GAS
Sale $
Kilograms
Price per kg
H70
STOP
H2
FIRE
EXTINGUISHER

III. VISION FOR ZERO-EMISSION HYDROGEN PRODUCTION IN CALIFORNIA

To address the challenges of reducing the cost of zero-emission hydrogen, participants at the March 2022 convening first outlined a vision for producing this hydrogen in California. The hydrogen production would support a low-carbon, resilient grid of the future, industrial activities that are difficult to electrify, and transportation solutions.

Core elements of the zero-emission hydrogen vision included:

- Establishing a state-level regulatory structure that supports balanced, bottom-up solutions and enhanced coordination among state and local leaders, including long-term resource planning to promote electrolyzers as a distributed energy resource that can boost energy storage capability and provide firm electricity generation
- Making electrolyzers cost competitive with other renewable sources through access to fuels and resources needed to solidify zero-emission hydrogen within the state's energy portfolio
- Utilizing zero-emission hydrogen to enhance reliability and affordability for both electricity generation and transportation fuels
- Supporting zero-emission hydrogen for hard-to-decarbonize industrial and transportation needs (e.g., cement and steel production, aviation, and heavy-duty transport)
- Crafting rate structures and electricity generation policies that support electrolyzers using surplus energy from intermittent renewable energy resources
- Creating a skilled and trained workforce ready for the zero-emission hydrogen economy within a clean industrial sector
- Eliminating air pollution risks from hydrogen production and reducing pollution from combustion, especially in disadvantaged and historic environmental justice communities
- Providing flexibility for innovation to allow many potential bridges to zero-emission hydrogen bankability and scale

IV. BARRIERS AND PRIORITY POLICY SOLUTIONS

Convening participants identified a range of barriers to achieving their vision of reducing the cost of electrolyzer deployment. This section describes those barriers and details the top-priority policy solutions participants identified to overcome them.

The barriers centered on three themes:

- A lack of consistent state policy on zero-emission electrolyzers, including legal and regulatory requirements and long-term planning processes.
- High upfront and operational costs prevent electrolyzer project deployment from attracting private investment.
- A lack of targeted support for zero-emission hydrogen applications in difficult-to-decarbonize activities, such as refining, cement and steel production, shipping, aviation, food processing, and other industrial sectors.

This section describes those barriers in detail and highlights the top-priority policy solutions participants identified to overcome them.

A. BARRIER: A LACK OF CONSISTENT STATE POLICY ON ZERO EMISSION ELECTROLYZERS, INCLUDING LEGAL AND REGULATORY REQUIREMENTS AND LONG-TERM PLANNING PROCESSES.

While California has taken initial steps to support hydrogen, the state still has a patchwork of regulations, laws, and agency actions that govern the sector. In building a hydrogen economy, the legislature has tasked multiple agencies with implementation responsibilities. The California Air Resources Board, California Energy Commission, California Public Utilities Commission, Governor’s Office of Business and Economic Development, and other agencies all have roles in advancing zero-emission hydrogen. As California progresses towards its 2045 carbon neutrality goal, agencies will need a coordinated strategy to ensure project developers and local governments can navigate the necessary steps for deploying renewable energy-powered electrolyzers.[63] Ultimately, a clear and supportive governance structure can improve outcomes for electrolyzers and a zero-emission hydrogen economy.

Solution: The governor could craft an executive order to align agency priorities and establish a zero-emission hydrogen roadmap to support the U.S. Department of Energy Hydrogen Hub grant application.

Participants recommended an executive order that would direct one regulatory agency to serve as the central authority or facilitator to govern and support implementation of zero-emission hydrogen projects in the state. While the Governor's Office of Business and Economic Development is helping to lead the Hydrogen Hub application efforts, other agencies may serve a similar role. Some participants recommended California Air Resources Board as a natural home to be a central coordinator, given the agency's experience implementing the Low Carbon Fuel Standard and regulating emissions from electricity and power-generating equipment. Others recommended the California Energy Commission, given the Commission's support for hydrogen fuel cell vehicle infrastructure and work within its research and development division. The Energy Commission is currently undertaking some of this key coordination work in awarding a contract to establish a Green Hydrogen Roadmap and Strategic Plan, which would develop a research, development, and demonstration framework to advance the production, delivery, storage, and use of green hydrogen for targeted use cases. Alternatively, as discussed earlier, ARCHES is serving as the statewide public-private partnership that is shepherding the Hydrogen Hub application and could potentially serve as the governance body for the state's hydrogen ecosystem.

An executive order or gubernatorial roadmap could rely on existing legislative authority related to electrolytic hydrogen. For example, Senate Bill 1075 directed the Air Resources Board, Energy Commission, and Public Utilities Commission to provide recommendations on clean hydrogen production pathways, infrastructure, electrical usage, cost benefit analysis, and workforce development, which could form the basis for recommending an agency to coordinate these actions.[64] SB 1075 also tapped the California Workforce Development Board and labor and workforce organizations to identify the role of hydrogen, and particularly the role of "green hydrogen," in helping achieve the state's existing climate goals.[65] Furthermore, Assembly Bill 157 (Chapter 570, Statutes of 2022) provided governance structure for a California Clean Hydrogen Hub Fund.[66] Numerous agencies have significant roles in permitting and supporting zero-emission hydrogen projects. While AB 157 supports coordination among these agencies, the governor's office or future legislation could clarify which agencies will be ultimately responsible for helping electrolyzer projects become operational as the state competes for the U.S. DOE Hydrogen Hub funding.

Solution: The legislature could mandate that all hydrogen production be zero-emissions or require average 'well-to-gate' greenhouse gas emissions for hydrogen production to be magnitudes cleaner than fossil-based hydrogen production

The legislature could require all future hydrogen projects to be zero-emissions or create a market-based system that sets production standards for a company's hydrogen production portfolio to be near-zero emissions. A variety of options exist to achieve that goal. Legislation could set a zero-emissions standard for all new hydrogen projects. Alternatively, the legislature could revisit or build upon previous hydrogen-related legislation to refine and clarify support for electrolytic hydrogen pathways. Senate Bill 1505, which requires 33.3 percent of the hydrogen produced for (or dispensed by) fueling stations that receive state funds be made from eligible renewable energy resources.[67] The legislation, passed in 2006, was never fully implemented due largely to the lack of electrolytic hydrogen supplies in California. Working in coordination with the California Air Resources Board, the legislature could revisit the language from SB 1505 and reinforce the need to reduce hydrogen production emissions.

The legislature could collaborate with the California Air Resources Board, California Public Utilities Commission, and the California Energy Commission to revisit the SB 1505 requirements and see if a program similar to the Renewable Portfolio Standard might best support zero-emission electrolytic hydrogen. Legislation could establish that zero-emission electrolytic hydrogen provides a fixed percentage of the state's hydrogen mix by a date certain. Alternatively, the legislature could mandate zero-emission equipment in sectors with potential hydrogen demand: vessels, locomotives, planes, trucking, agricultural equipment, and back-up generators.

At present, a large quantity of the "renewable hydrogen" in California's marketplace is produced from fossil-based SMR and coupled with the purchase of biogas credits.[68] The legislature could work with the California Air Resources Board to eliminate opportunities to define fossil-based hydrogen as "renewable" through the purchasing of credits in the Low Carbon Fuel Standard (LCFS) market. Some participants argued that the current regulatory framework of the LCFS program does not encourage electrolytic hydrogen. Environmental groups have advocated for eliminating the process known as "book-and-claim accounting" and fully incorporating the value of avoided methane costs within the LCFS program.[69] Book-and-claim accounting means that a fossil-based hydrogen project can buy renewable power or environmental credits generated outside of California (such as a dairy manure biogas project) and still attain a zero-carbon intensity score under the LCFS program.[70] Additionally, fully accounting for impact of methane emissions within LCFS will further support electrolytic pathways and move away from dairy digester credits. The LCFS program is scheduled to be revisited in 2023, providing an opportunity

FRAMEWORK CRITERIA FOR DEVELOPING ZERO-EMISSION HYDROGEN HUB PROJECTS

As part of a state-led Zero Emission Hydrogen Hub, the administering agency would need to develop methodology for supporting and funding proposed projects. Participants developed some potential criteria for the Hub to apply to proposed projects:

1. Does the proposed project rely on zero-emission hydrogen? If so, is it exclusively considering zero-emission hydrogen, or is it considering an eventual switch to 100% zero-emission hydrogen?
2. How costly will producing zero-emission hydrogen from renewable resources be, and what resources are needed to get adequate interconnection infrastructure in place?
3. Is the electrolyzer producing hydrogen that is addressing a difficult-to-decarbonize end-use?
4. Does the hydrogen use intend to replace or compete in a market where there are already, or likely to be, lower-cost and low-emissions technologies deployed and commercialized?
5. Is the zero-emission hydrogen being produced onsite? Is there appropriate infrastructure for transporting and storing the fuel that will not create environmental justice concerns?

to eliminate labeling hydrogen as renewable whenever it is derived from fossil fuels, landfill, or dairy biomethane.

Alternative to a mandate, the legislature could require a specific “well-to-gate” emissions level for all hydrogen production. Well-to-gate is an industry term that describes the full lifecycle analysis of hydrogen from creation to the factory gate.[71] In practice, a well-to-gate approach could account for up-stream combustion, process, and fugitive emissions, in order to ensure that the “zero-emission” classification accounts for all emissions in the production of hydrogen. This term does not consider the end-use of hydrogen, because customers could use the electrolytic hydrogen for a variety of purposes, including electricity generation, transportation fuel, or industrial combustion. Ultimately, the state could establish that zero-emission electrolytic hydrogen is preferred over a well-to-gate approach and best for California’s future.

Solution: The California Air Resources Board could utilize a lifecycle approach to define carbon intensity and create an intensity scoring methodology for all hydrogen production pathways.

The California Air Resources Board could enhance its emissions accounting system to ensure that the hydrogen source is indeed zero-emission. By applying a lifecycle carbon intensity methodology to all hydrogen projects, the Air Resources Board would better understand how electrolyzers can drive down emissions. California already has established similar lifecycle-emission based accounting as part of the Low Carbon Fuel Standard, in which zero-emission electricity generation and hydrogen production for low-carbon transportation fuel are credit-generating activities.[72] The agency could base a similar methodology applied to all types of hydrogen production on its existing CA-GREET3.0 model (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation), which assesses lifecycle greenhouse gas emissions.[73]

As discussed previously, the hydrogen color code system inadequately distinguishes fossil-based hydrogen (gray or blue) from zero-emission hydrogen (green). Since many project developers are taking an all-of-the-above approach to producing hydrogen in a way that may use both fossil and renewable resources, utilizing a lifecycle carbon intensity methodology will allow for greater transparency and accountability. Defining hydrogen based on a carbon intensity framework would allow purchasers and regulators to determine what resources produced the fuel.

The Air Resources Board could apply CA-GREET3.0 to all hydrogen projects, even outside the Low Carbon Fuel Standard program. This application would be a new use of an existing methodology and could provide the basis for a certification process or baseline threshold to account for greenhouse gas emissions arising from upstream processes. It could support electrolyzers that generate hydrogen from any renewable energy resource. It could also be technology-neutral and updated over time to reflect changes in innovation. The Air Resources Board, in coordination with the Public Utilities Commission and Energy Commission, could then apply the lifecycle carbon intensity of various hydrogen production pathways to the various state programs.

Solution: The California Air Resources Board and/or regional air districts could establish air emission limits for hydrogen combustion to reduce nitrogen oxide impacts, especially in environmental justice communities.

Even where hydrogen is created from zero-emissions electrolysis, end uses of hydrogen vary in their environmental impacts. Participants noted the need to avoid and reduce emissions from combustion of hydrogen in order to protect air quality and advance environmental justice priorities. Some end uses of hydrogen rely on combustion, including turbines at power plants and boilers that provide high heat for industrial processes. Many industrial facilities that either combust hydrogen today or could combust hydrogen as a replacement for fossil fuels are located in or near California's environmental justice communities. Furthermore, proposals to combust hydrogen with gas in power plants raise questions about the scale, scope, and environmental impact of such projects.[74]

In response to these impacts, the California Air Resources Board and regional districts could implement enhanced air emissions limits for all hydrogen combustion facilities. Specifically, regulatory agencies could set standards for nitrogen oxide (NOx) emissions on hydrogen combustion. Best Available Retrofit Control Technology (BARCT), established as part of Assembly Bill 617 (C. Garcia, Chapter 136, Statutes of 2017) to address the disproportionate impacts of air pollution in disadvantaged communities, applies to existing stationary sources of emissions and could ensure the maximum degree of reduction achievable from hydrogen combustion, taking into account environmental, energy, and economic impacts by each class or category of source.[75] The California Air Resources Board could work with California's 35 local air districts to expand regulations on hydrogen combustion using the BARCT framework. While air districts already engage in permitting and regulating NOx emissions, an organized effort between state and regional air leaders could lead to optimal criteria pollutant reductions while supporting the growth of zero-emission hydrogen.

Expanding AB 617's BARCT and community outreach model to cover all hydrogen combustion facilities could reduce combustion emissions, spur research to further control NOx, and help build trust with the fenceline communities who live along these industrial facilities. For example, in the South Coast Air Quality Management District, the BARCT requirement was recently applied to a regulation that aimed to address refinery pollution. The NOx reduction regulation on all refinery combustion equipment also covered hydrogen facilities and followed the BARCT standards by going piece-by-piece to cover all equipment, requiring approximately 220 pieces of equipment to be retrofitted with pollution control.[76]

Solution: The legislature, California Workforce Development Board, and community-based organizations could work together to establish statewide "High Road" job standards to support a just transition for the fossil fuel workforce.

By 2030, the hydrogen economy in the US could generate an estimated $140 billion per year in revenue and support 700,000 total jobs, according to one industry estimate.[77] The same industry report estimated that by 2050, hydrogen could support a cumulative 3.4 million jobs. However, analysts have rarely focused on evaluating the corresponding education, skills, and training required and the likely earnings that workers can expect.[78] Overall, zero-emission hydrogen could provide a transition to a clean energy economy for workers in sectors that currently utilize fossil fuels and cannot be electrified.

The California Workforce Development Board could work with labor unions, apprenticeship programs, and electrolyzer project developers to promote local hire in disadvantaged communities. The Workforce Development Board has developed a High Road Clean Energy Jobs Action Plan to develop a pipeline for training California's future clean energy workforce.[79] A High Road job can be described as family-supporting jobs that optimize climate policy outcomes.[80] As the term is used here, the High Road economy supports businesses that compete on the basis of the quality of their products and services by investing in their workforces; these businesses pay the wages and benefits necessary to attract and retain skilled workers, who in turn perform high-quality work.

Thus far, the High Road Training Partnership projects have focused on specific climate topics like building decarbonization[81] and energy storage.[82] Policymakers could take a number of steps to enhance clean energy job training for electrolytic hydrogen production. First, the legislature could direct funds from either the General Fund or California Climate Investments toward training a hydrogen workforce to accelerate potential federal Hydrogen Hub grant awards. Next, the California Workforce Development Board could develop a Training Partnership, focusing on areas where electrolyzer projects might be installed first. For example, the Inland Empire, Riverside County, and the Central Valley provide relatively inexpensive land for solar arrays and a potential for large hydrogen demand from future fuel cell trucks. Due to the high volume of both renewable and fossil infrastructure in the Inland Empire and Central Valley, electricians and renewable energy installers—along with natural gas and other fossil fuel industry workers—could receive training from hydrogen professionals to prepare for these electrolyzer opportunities. In developing the Training Partnership for zero-emission hydrogen, the Workforce Development Board could include community-based organizations and trusted partners to help build trust with impacted communities. State leaders could fund community-based organizations through small grants to conduct outreach and education on behalf of the Workforce Development Board.

Furthermore, the legislature and the Workforce Development Board could design zero-emission hydrogen labor standards and training pathways for Californians located in disadvantaged communities. As several national hydrogen strategies highlight, job training is an essential driver of hydrogen development. It can also retrain the existing fossil fuel workforce as part of ensuring a just transition to the zero-emission economy.[83] As part of this retraining, the state could continue to work with the State Building & Construction Trades Council to set standards for hydrogen storage, transportation, and distribution through safe and high-quality pipeline systems.

Local government and labor unions can also support workforce development. For example, Community Workforce Agreements among local governments, labor unions, and project developers can include strong pre-apprenticeship programs that work closely with the building trades unions and ensure inclusion of historically marginalized workers. Both the International Brotherhood of Electrical Workers and the State Building & Construction Trades Council have formally joined the ARCHES entity.[84] State leaders could continue to work with the International Brotherhood of Electrical Workers to set standards installing electrolyzers, completing the renewable energy interconnection, and handling grid management.

Solution: The legislature, the California Air Resources Board, local governments, and community-based organizations could establish equity principles for hydrogen and comprehensively integrate the principles into land use decisions.

At the baseline level, the state, via the legislature, the California Air Resources Board, and the new ARCHES entity, must support environmental justice groups involvement in the local permitting processes related to hydrogen infrastructure projects. Given that projects will be permitted and approved at the local level, the state must work collaboratively with local governments to increase the workforce capacity necessary to adequately address community concerns. Agencies and local governments could establish best practices for incorporating community concerns and formalize mechanisms for receiving input from unbiased commissions such as the California Public Utilities Commission or California Energy Commission.

Equity considerations can be grouped as (1) Distributional: the equitable and fair distribution of environmental burdens and benefits; (2) Procedural: meaningful public engagement that is accessible, transparent, and inclusive; and (3) Structural: recognition of past harms and underlying structural and institutional systems that are the root causes of such harms.[85]

To ensure distributional equity, state regulators and local government officials need to address the fact that existing industrial facilities are disproportionately located in low-income communities and communities of color, resulting in cumulative impacts on these communities that are grossly disproportionate to those in other communities.[86] For example, the San Pedro Port Complex hosts many existing hydrogen facilities, creating additional concerns for nearby environmental justice communities such as Long Beach and Wilmington.

Planning and regulatory work could protect those communities from bearing additional burdens from new facilities. The California Air Resources Board and regional air districts could utilize the state's CalEnviroScreen 4.0 screening model to assess cumulative impacts and risks to disadvantaged communities.

These air agencies could collaborate to update and enhance the California Environmental Quality Act (CEQA) Air Quality Analysis Guidance documents for assessing cumulative impacts on communities.[87] Focusing resources on areas experiencing regular levels of extreme air pollution (such as the South Coast Air Basin and San Joaquin Valley Air District), these agencies could establish more aggressive mitigation measures to reduce cumulative air toxics impacts. The agencies could incorporate criteria pollutants in addition to air toxics, which would capture the NOx impacts from hydrogen combustion. Additionally, the agencies could better protect communities from seeing high concentrations of hydrogen combustion projects by applying cumulative impacts analysis in permitting decisions. The air agencies could be more aggressive in commenting on hydrogen projects that local governments approve through the land use permitting process. Both the Air Resources Board and the districts could deploy staff to ensure projects benefit disadvantaged communities overburdened with air pollution and not just the region as a whole. Both entities could also help educate local cities about the benefits of new electrolytic hydrogen facilities in reducing pollution from diesel trucks and goods movement.

As a part of the ARCHES Hydrogen Hub governance model, the governor's office and legislature could also collaborate to set aside future funding for community-based organizations to have an outreach and education role in incorporating environmental justice principles into policies.[88] This model has proven successful in the Solar on Multifamily Affordable Housing (SOMAH) Program, which partners with and provides resources to community-based organizations to help communicate program benefits to tenants and communities.[89] Assembly Bill 693 (Eggman, Chapter 582, 2015) created SOMAH to provide financial incentives for the installation of solar on multifamily affordable housing properties, directing the California Public Utilities Commission on program administration. The legislature could create a SOMAH-style community outreach program that provides resources to organizations as part of the state's ARCHES hydrogen governance efforts. Providing funding to community groups to participate in electrolyzers and zero-emission hydrogen outreach and education could be essential to creating the capacity and knowledge necessary for local residents to equitably engage in project development and decisions that impact their communities.

To further address procedural equity, local governments and permitting agencies could utilize the model of AB 617 or the state law that requires environmental justice to be addressed in local government planning. Senate Bill 1000 (Leyva, Chapter 587, Statutes of 2016) requires local general plans to incorporate an environmental justice element or integrate environmental justice goals or policies in other general plan elements.[90] Local governments, especially in areas that could reasonably foresee significant hydrogen project development, could set proactive health standards and best practices within their environmental justice plans. These jurisdictions could also establish public engagement strategies to educate and include residents in the development of new hydrogen facilities or even create an oversight council with certain authority to reject or modify projects.

Stakeholder processes developed by the state and localities must be accessible, inclusive, and transparent community engagement that aims to meaningfully incorporate community concerns into decision-making. Local governments and permitting agencies need to prioritize the incorporation of community concerns into project processes if they are to build trust with and help mitigate past harms in disadvantaged communities.

To address structural equity, some convening participants noted that hydrogen has historically been used in areas around refineries, heavy industry, industrial processing, and goods movement hubs like ports and railyards. Many California environmental justice communities share a historical distrust of industry leaders who have made promises to reduce emissions that local leaders feel were not kept.[91] As state and local governments look to win the federal Hydrogen Hub grant award, communities may be more open to hydrogen projects decision makers embed structural equity in implementation plans. For example, prioritizing funding for fuel cell technology and zero-emission electrolyzer hydrogen projects that can displace polluting industrial and transportation sources and generate cleaner, good-paying local jobs could help redress past harms. Input from community-based organizations on how this type of targeting or other mechanisms can do the most to help address historical discrimination in environmental justice communities will be essential to ensuring that the holistic hydrogen ecosystem can be part of improving environmental equity in California. Policymakers will need to develop accountability mechanisms to ensure disadvantaged communities can meaningfully participate in hydrogen land use, permitting, and workforce decisions.

Solution: The legislature could dedicate funding to support zero-emission electrolyzer projects, instead of primarily relying on electric utility ratepayers.

Zero-emission hydrogen will require multiple levels of financial support to become cost-competitive with fossil fuel alternatives. Investor-owned electric utility ratepayers have paid for many of the state's climate programs through higher electricity rates, which is a largely regressive structure.[92] Instead, the state legislature could direct existing money from the general fund for investments in electrolyzer projects.

The state could build on funding allocated in 2022, through Assembly Bill 209 (Committee on Budget, Chapter 251, 2022), the energy trailer bill, which dedicated $100 million in 2022-2023 General Fund surplus funds for 10 to 15 commercial demonstration zero-emission hydrogen projects.[93] Approximately two-thirds of the funding focuses on lowering the cost of electrolyzers and remaining funding could demonstrate the use of electrolytic hydrogen for industrial activities, power plants, and energy storage. State leaders could consider allocating more General Fund money to similar projects in future years, based on budgetary availability.

B. BARRIER: HIGH UPFRONT AND OPERATIONAL COSTS PREVENT ELECTROLYZER PROJECT DEPLOYMENT FROM ATTRACTING PRIVATE INVESTMENT.

The current market for zero-emission hydrogen is still pre-commercial due to high costs.[94] Industry leaders categorize the cost of hydrogen from electrolysis into the price of electricity, the capital cost, and the system efficiency or operating costs of electrolyzers. The capital costs of electrolyzers include actual electrolyzer technology (often including expensive minerals), and the hydrogen storage infrastructure or pipelines. Operating costs can include the price of water treatment, water processing, electricity inputs, cooling, purifiers, and thermal management, which all consume power in order to operate.[95] The solar and wind energy resources can be considered part of the capital cost of hydrogen production in general, not electrolyzers.

Participants noted that while reducing upfront capital costs to make projects more appealing to investors will be important, developers and financiers would benefit the most from reduced operating costs. While reducing hardware costs will allow investors to build electrolyzers for less initial money, reducing operating costs will allow projects to make better returns on the produced hydrogen. This problem is known to project developers as long-term *bankability*. Financing electrolyzers will be difficult if: (1) the regulatory structure does not support renewable energy integration, (2) government agencies cannot provide financial backstops to reduce investor risks, (3) state and local governments fail to plan for electrolyzer permitting and approvals, or (4) both public and private sector leaders fail to reduce costs from electrolyzer water usage. While federal and state research continues to highlight ways to increase system efficiency, state policymakers and utility managers have tools at their disposal to help reduce costs and boost financial incentives.

Solution: The state legislature, California Independent System Operator, and California Public Utilities Commission could develop a behind-the-meter "direct-tie" program or direct access program to support zero-emission hydrogen production through surplus renewable energy.

Investor interest in a hydrogen project will be limited if it produces hydrogen only when the sun is shining, or the wind is blowing. In order for developers of solar- or wind-powered electrolyzers to make money, they need to be able to pair surplus renewable energy with battery storage or affordable electricity from the grid to allow the electrolyzer to run full-time on non-fossil sources. Furthermore, from a technical perspective, shutdown cycles accelerate electrolytic cell degradation.[96]

Policymakers could address the challenge of reliable renewable electricity by developing a new utility rate model for electrolyzers. Participants described the need for zero-emission electrolyzer projects to benefit from the cheap renewable energy produced by co-located solar panels or wind turbines, rather than having to purchase it from the existing party in charge of delivering electricity (normally an electrical utility). Since there is energy loss during the electrolysis process, reducing the cost of the input energy will make projects more viable. Matching solar or wind energy with energy storage can help maximize the renewable energy, but all projects will also likely need to be able to access bulk electricity from the electrical grid to support full-time electrolysis. The California Public Utilities Commission would have to create and approve a new rate structure or model that could match this arrangement.

Participants called this concept “direct-tie,” which could allow an electrolyzer to both utilize their own renewable energy and bypass traditional metering (and retail prices) to participate in the wholesale market. By participating in the wholesale market, the electrolyzer operators could access the additional revenue opportunities of ancillary services and resource adequacy capacity when generation exceeds demand. The goal is to craft a program that would maximize flexibility compared to traditional “grid-tied” solar projects, which dump excess solar into the grid. Participants used the term “direct-tie” because the renewable energy generation would be prioritized for electrolyzers over the grid. The renewable energy facilities could have the flexibility to be backup grid resources, but without having to be beholden to grid operators or limitations. Direct-tie could also help boost offshore wind deployment goals, as these wind resources could tie with electrolyzers to create firm, dispatchable energy.

As the state’s primary energy policy and planning agency, the Energy Commission could assist the Public Utilities Commission in conducting technical and economic analyses on optimal rate structures for electrolyzers. This research could be focused on enhancing California’s energy reliability and long-durational storage needs and helping the state transition away from fossil fuels. The Public Utilities Commission could then consider authorizing a “direct-tie” rate structure that makes it more flexible and cost-effective for customers to purchase surplus renewable energy resources if they use the power for electrolyzers.

Alternative to the “direct-tie” proposal, electrolyzer owners could be eligible to participate as part of the state’s existing Direct Access program. Direct Access is retail electric service where customers purchase electricity from a bulk electric service provider, instead of from a regulated electric utility.[97] The state’s Direct Access program is currently at capacity, because demand for service exceeds the load permitted under the adopted utility service area caps.[98] Regulators could expand the program to include zero-emission hydrogen electrolyzers in order to create an additional pathway for renewable procurement.

Overall, to implement either solution, grid operators and regulators will need to develop criteria for (1) tracking zero-emission electrolytic hydrogen production, (2) identifying pathways for connection of hydrogen systems and wholesale rates, and (3) determining whether “direct-tie” or some other rate structure could give electrolyzer operators the optimal opportunity to recoup investments.

Solution: The Governor's Office of Business and Economic Development (GO-Biz) Climate Catalyst fund could de-risk projects by providing financial backstops or guarantees to attract private investment.

As with all large infrastructure projects, hydrogen investors are seeking long-term guarantee of product demand and price, creditworthy offtakers, and, where appropriate, financial assurances to mitigate outsized risks. One mechanism that could provide a financial backstop for zero-emission hydrogen projects is the state Climate Catalyst fund, housed within the California Infrastructure and Economic Development Bank (IBank) and connected to the Governor's Office of Business and Economic Development (GO-Biz).[99] The IBank has broad statutory authority to issue bonds, incur debts, and to provide guarantees and other credit enhancements for a wide variety of projects.[100]

In 2020, California established the Climate Catalyst Revolving Loan Fund to provide low-cost, low-interest finance to support eligible low carbon technology and infrastructure projects and attract private capital.[101] Climate Catalyst projects are defined as "any building, structure, equipment, infrastructure, or other improvement" or "financing the general...operations or activities" within the state to further California's climate goals, reduce climate risk, or implement low-carbon technology and infrastructure.[102]

As of this report's publication, the fund has just begun to disburse the first dollars for climate-smart agriculture and forest biomass management. However, the state may look to create a zero-emission hydrogen program to support the state's climate greenhouse gas mitigation and energy resilience efforts. As part of the ARCHES Hydrogen Hub governance model, GO-Biz and the IBank could leverage a new hydrogen program within the Climate Catalyst Fund to reduce risks for private or institutional investors in the nascent electrolyzer industry.

A hydrogen program within the Climate Catalyst fund could offer credit enhancement or loan guarantees to electrolyzer project financiers and developers. The fund administrators could use available monies to reduce risks in the nascent electrolyzer industry and offer hydrogen project financiers guarantees to attract more private sector investment returns. By covering the borrower's debt obligations to private sector investors, private sector financiers will be more willing to take risks on electrolyzer projects.

Furthermore, maintaining the IBank's "rolling" basis for applications will support electrolyzer developers by allowing them to apply for Catalyst funds at any time. Generally, government funding opportunities have limited windows and timeframes. Allowing for rolling applications will allow projects to apply as soon as they have received permits from local authorities or finalized site acquisition. Since the fund requires that all permits be in place before financing can be provided, the rolling application process will supercharge opportunities that are closest to impacting California's zero-emission hydrogen economy.[103]

The state of California could also support electrolyzer investors by establishing a Community Development Block Grant for zero-emission hydrogen production. A Community Development Block Grant (CDBG) program has largely supported housing developments administered by the U.S. Department of Housing and Urban Development.[104] However, the Infrastructure Investment and Jobs Act established the Energy Efficiency and Conservation Block Grant Program to reduce fossil fuel emissions and enhance efficiency.[105] The IBank could administer a state-operated block grant using these federal funds to support the development, permitting, and construction of electrolytic hydrogen projects, ensuring they meet established zero-emission criteria.

Solution: The California Energy Commission could assist regional and local governments to develop Zero-Emission Hydrogen Master Plans.

The role of state and local government coordination and collaboration in accelerating electrolyzer approval is critical, as a lack of local support can kill even well-funded projects. With local governments controlling land use and zoning decisions, undertaking a jurisdiction-wide Master Plan effort may accelerate electrolyzer projects and reduce costs. Projects will require the approval of local planning commissions and city councils or county boards of supervisors. The bulk of electrolyzer projects that incorporate large-scale solar or wind will be in smaller or medium-sized rural cities or unincorporated towns with more available land. Yet few resources are available for local governments and relevant agencies to plan for and permit zero-emission hydrogen facilities. Most small and medium-sized cities, counties, and utilities need capacity and technical assistance to develop a plan and ensure benefits from the zero-emission hydrogen transition.

The California Energy Commission could work with cities and counties to develop master plans that incorporate best practices and local strategies for supporting electrolyzers. Recently, the Energy Commission and local air pollution control districts completed a Tri-Counties Hydrogen Readiness Plan for the counties of Ventura, Santa Barbara, and San Luis Obispo.[106] In addition to preparing communities for the safe use of hydrogen, the plan provided input on how to best target early users of electrolytic hydrogen (e.g., industrial customers, refineries, and heavy-duty transportation such as trucks). Separate from agencies involved in electrolyzer permitting, the Energy Commission could convene state agencies involved in hydrogen transportation and end-use, including the State Fire Marshal and local fire departments (safety approvals and training guidelines), and the California Department of Food and Agriculture Division of Measurement Standards (setting standards for certifying hydrogen dispensers for transportation).[107]

LANCASTER - CALIFORNIA'S FIRST HYDROGEN CITY

In 2020, City of Lancaster officials announced that they were becoming the first American hydrogen city. Aiming to build several hydrogen production plants, Lancaster's leaders offered a testing ground for different hydrogen feedstocks including organic trash, recycled mixed paper and solar power electrolysis.[108] City officials have taken steps to prepare a comprehensive hydrogen uptake plan and conduct a review of the city's gas and electricity load, delineating any renewable energy assets.[109] Their municipal leaders continue to work on attracting investors, building hydrogen facilities, and supporting hydrogen companies with advanced permitting, city procurement, infrastructure support, fleet building, and consumer education.[110]

In a hydrogen master plan, utilities or local governments could identify environmental and community issues, infrastructure planning, as well as work on permit streamlining. Utilities could help local electrolyzer project developers find existing industrial customers currently purchasing hydrogen. The Energy Commission could enhance its existing funded research to identify technology needs and solutions that could build drought resilience, support electric reliability, and reduce greenhouse gas emissions in many small- and medium-sized cities and counties.[111] The Commission could undertake similar efforts to assist local governments with anticipating implementation barriers, determining technology readiness, and assisting with predevelopment tasks to better fast-track electrolyzer buildout. As one potential model, the Energy Commission's Alternative and Renewable Fuels and Vehicle Technology Program has already focused funding and resources on smaller cities.[112] The Energy Commission also supported smaller cities in the February 2022 renewable hydrogen grant awards, providing $9 million to expand production capacity for hydrogen, largely benefiting smaller cities like Lancaster and Moreno Valley (a community in the Inland Empire).[113]

Solution: The legislature, California Energy Commission, California Natural Resources Agency, and local utilities could establish a "zero-water-waste" initiative to invest in research advancing the use of reclaimed, brackish, or non-potable wastewater in electrolyzers.

Electrolytic hydrogen projects require substantial water supply to provide the feedstock for hydrogen production, adding significant costs. Electrolyzers consume about 9 kilograms of water per every 1 kilogram of hydrogen produced, as well as the additional water needed for plant operations such as cooling towers.[114] The facilities typically purify the water and send it to an electrolyzer, which produces hydrogen and oxygen. The hydrogen is then purified, compressed, and stored in a tank.[115]

While zero-emission electrolysis requires only half as much water as producing hydrogen through steam methane reforming (SMR) of fossil gas, new electrolyzer projects will still need to further reduce water usage.[116] If solar and wind energy powers electrolyzers, project locations will likely be in areas suffering from limited water accessibility. For example, large solar arrays or wind farms have become commonplace in the Central Valley and Inland Empire, where land is more affordable but water more scarce. As one expert described, "the affordability and accessibility of freshwater is one side of the coin, and the proximity of these two supplies" is the other.[117] Policy makers need a statewide strategy to ensure California electrolyzer projects use water responsibly.

The California Energy Commission, in coordination with the Natural Resources Agency, could spearhead a statewide initiative to assist electrolyzer project developers in utilizing reclaimed municipal wastewater and impaired groundwater. With limited freshwater resources in communities most likely to see electrolyzer projects, opportunities exist for innovation in reusing and recycling wastewater and brackish water in hydrogen production. However, electrolyzers need high-quality water which requires water treatment. Low-quality water can lead to faster degradation of equipment. Water impurities such as iron, chromium, or copper can adversely affect the catalysts for alkaline electrolyzers or the membrane for PEM electrolyzers.[118] Because high filtration costs and ecosystem impacts make desalinated seawater unlikely for electrolysis, reclaimed wastewater may provide an opportunity instead.[119]

Both water quality and hydrogen industry experts can determine the level of treatment required for utilizing freshwater, treated wastewater, or brackish water. Determining the acceptable level of trace contaminants for PEM, alkaline, and solid oxide electrolyzers without experiencing degradation will allow the state to set water treatment standards and promote the use of these alternative waters. The legislature could work in coordination with agencies and local utilities to provide additional funding for electrolyzers that minimize water consumption, including by reducing the water consumption of cooling towers and investigating dry cooling technologies, which is a more costly and energy-intensive approach to large-scale cooling that does not use water.[120] The Energy Commission's Electric Program Investment Charge research and development program previously funded dry cooling technologies to reduce water usage in industrial facilities.[121] The Energy Commission could enlist local water and power utilities to study dry cooling techniques and other best practices for reducing water usage.

C. BARRER: ZERO-EMISSION HYDROGEN LACKS TARGETED SUPPORT TO FUEL DIFFICULT-TO-DECARBONIZE INDUSTRIES.

Experts typically describe industrial activities as "difficult-to-decarbonize" when no easy technological solution exists to reduce or eliminate their carbon emissions. Examples include cement and steel production, semiconductor chip manufacturing, food processing, and other industrial processes that are difficult to electrify. These processes require extreme temperatures, and fossil-based fuels have served exclusively, or almost exclusively, as the heat source.

Industrial emissions represent a critical sector to tackle. Scientists estimate that the global industrial sector releases about 20% of overall carbon dioxide and 12.5% of greenhouse gas pollution in the United States.[122] Industrial emissions comprise 24% of the 2010-2019 greenhouse gases in California, as determined by the latest Air Resources Board emissions inventory.[123]

Hydrogen provides an opportunity to power some of the needs of these complex industries instead of fossil fuels. Hydrogen and industrial developers will need greater policy and financial tools to achieve these reductions in difficult-to-decarbonize industrial activities in California.

Solution: The California Air Resources Board could require heavy industrial sources to decarbonize through regulations on thermal emissions.

Two pathways exist to expedite deployment of zero-emission hydrogen as a solution for difficult-to-decarbonize industrial activities. First, the California Air Resources Board could require heavy industrial facilities to reduce emissions by transitioning to zero-emission energy sources and feedstocks. For facilities that lack decarbonization pathways through direct electrification, zero-emission hydrogen could allow for continued operation of most industrial facilities due to the similarities between fossil fuels and hydrogen. In actuality, industrial heating and processing may likely be met by a combination of direct electrification and zero-emission hydrogen, a potential least-cost decarbonization pathway.

Second, the Air Resources Board could expand the Low Carbon Fuel Standard to the industrial sector or adopt an analogous program for industrial facilities that use fossil fuels and fossil-based hydrogen. Some participants recommended a performance-based regulation for industrial facilities that could build on the state's existing Cap-and-Trade program. A technology-neutral performance standard for high heat industrial activities could support the use of zero-emission hydrogen without directly setting mandates. The California Air Resources Board could adopt or extend a regulation like the Low Carbon Fuel Standard to the industrial sector, setting a standard of zero-emission fuel sources for facilities to meet and providing credits for facilities that incorporate more zero-emission fuel sources. Such a performance-based standard could reduce emissions from the most intensive facilities. The Air Resources Board could collaborate with the U.S. Environmental Protection Agency and local air districts to establish New Source Performance Standards (NSPS) for any modified or reconstructed industrial facility to control excess emissions that come from hydrogen. A performance-based regulation would likely lead to increased demand for zero-emission hydrogen in refineries, steel, and other heavy industry workplaces that would otherwise struggle with electrification.

Other jurisdictions have explored hydrogen markets for industrial sectors. In Germany, the government is exploring demand-side measures like quotas for low-carbon steel, pairing regulations with hydrogen roadmaps for individual subsectors and subsidies for using hydrogen as an industrial feedstock.[124]

Solution: The California Energy Commission could assess the current hydrogen offtake market and provide producers with a market viability evaluation to entice investment in zero-carbon hydrogen production.

Hydrogen project developers will need to show financiers that they have a willing buyer or user of the zero-emission hydrogen. Offtake agreements are the "commercial heart" of any hydrogen project because they guarantee the revenue source.[125] Any offtake or purchase agreement is crucial to obtain financing at an early stage and decisive for bankability in the longer run.[126] As investment volumes grow, the challenge of securing offtake agreements will intensify.[127] While some industrial customers already use fossil-based hydrogen in large volumes, they offer relatively fixed demand. Most hydrogen production directly feeds an industrial process without a third-party commercial agreement or price and is created on-site using existing pipelines and infrastructure. Growing the market for zero-emission industrial hydrogen will therefore require innovations in distribution and reducing combustion emissions, as well as an accurate assessment of the current offtake market.

The Energy Commission could conduct a statewide offtake market analysis to help technology developers and suppliers find matches and optimize investments. The Energy Commission could include this analysis as part of its SB 1075-mandated study to model potential growth for hydrogen and its role in decarbonizing the electrical and transportation sectors in the 2023 and 2025 Integrated Energy Policy Reports.[128]

A statewide analysis or modeling process could include online resources that assist hydrogen suppliers and users with self-identifying collaborators and opportunities to expand development toward realizing regional hydrogen hubs. For example, the U.S. Department of Energy has launched H2 Matchmaker to help support national hydrogen investment efforts.[129] The Matchmaker provides hydrogen supply and demand maps for current and planned projects to facilitate regional business development opportunities. A statewide offtake assessment could improve the Matchmaker tool and help project developers secure contracts to purchase their electrolytic hydrogen supplies.

An Energy Commission model could go beyond the H2 Matchmaker platform to provide insights into both technical factors, such as hydrogen volume, price, quality, and project credit risk, and state policy factors such as the opportunity to leverage other transportation decarbonization efforts. For example, federal, state, and regional agencies are focused on reducing diesel emissions from trucks along the California Interstate 710 freeway between Downtown Los Angeles and the San Pedro Bay Port Complex. The Energy Commission could work with other agencies such as the California Transportation Commission, California State Transportation Agency, California Department of Transportation, and Metro Los Angeles to undertake an offtake assessment and market study for potential zero-emission hydrogen demand in the 710 freeway corridor. The targeted offtake analysis could help expedite projects that reduce diesel and pollution burdens from the environmental justice communities neighboring the freeway.


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VI. CONCLUSION

To reduce the price of zero-emission hydrogen electrolyzers, policymakers could adopt a suite of approaches to provide both market certainty and increased private investment in innovative technologies. Paired with federal and state investments, additional legislation and regulatory decisions could supercharge project developers to build zero-emission hydrogen projects at scale and help California meet decarbonization goals.

Ultimately, zero-emission hydrogen will only fulfill its potential with sustained investment, continued policy support, and clear market signals that end the use of fossil-based hydrogen and fossil fuels generally. State leaders can accelerate electrolyzer investment by clarifying state goals for zero-emission hydrogen production types and tightening market-based approaches. These policies could then spur greater investment from refineries, heavy industrial companies, vehicle manufacturers, shipping and goods movement conglomerates, and energy companies. Additional research to determine priority market sectors and methods to reduce combustion emissions from hydrogen end-use could address difficult-to-decarbonize activities, support workforce development goals, and protect public health in environmental justice communities.

California is once again on the front lines of launching a new clean technology. By successfully deploying a portfolio of electrolyzer projects throughout the state, California could demonstrate how to incorporate this zero-carbon fuel into the energy mix, enhance resiliency, reduce harmful diesel and fossil fuel pollution, and bring down the costs of zero-emission hydrogen technologies. If done right, state support of zero-emission hydrogen could also support a just transition by boosting local economies that might otherwise suffer from decreased reliance on fossil fuels or that currently bear the brunt of environmental and health impacts of fossil fuels. Support for electrolyzers can therefore result in a cleaner, fossil-free economy with a more resilient electricity grid, strong base of well-paying jobs, and a pathway to leading the transition to a decarbonized world.


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