UCLA Luskin Center for Innovation

Informing effective and equitable
environmental policy

Exploring the Water Footprint of "Green" Hydrogen for Power Generation in California

EQUITY IMPLICATIONS, PITFALLS, AND OPEN QUESTIONS

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CONTENTS

EXECUTIVE SUMMARY

Many in the energy sector have recently hailed hydrogen gas as a versatile fuel that can store energy and replace fossil fuels for several hard-to-decarbonize uses. Hydrogen is an attractive alternative, as the fuel can be produced and used carbon-free if renewable electricity is used to split water into hydrogen and oxygen. This process results in so-called "green" hydrogen. Yet hydrogen has never been implemented as a large-scale energy resource, and there is substantial uncertainty about how expanding its role in the energy system will affect the climate, resource and infrastructure use, communities, and associated public health outcomes.

Despite the unproven nature of this technology in the field, until 2025, the federal and California governments had made substantial commitments to hydrogen as a linchpin of the transition to carbon-free energy. The pending federal investment includes the Biden Administration-era $7 billion "hydrogen hub" initiative — $1.2 billion of which has been promised to California. The California hydrogen hub is led by a coalition of public and private stakeholders that make up the Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES). While the federal energy investment landscape is now in flux in the early months of the Trump administration, massive investments in hydrogen are still anticipated.

One concern raised by environmental justice advocates, academics, and other stakeholders is that producing green hydrogen requires water — a scarce resource in a drought-prone state such as California. The quantity and quality of water required depends on the hydrogen production and usage processes, the energy needed, the technologies employed, and other factors — and many (if not all) of these factors are not publicly known with respect to proposed projects. However, it is important to consider the amount of water that will be needed, where it will come from, and what it will cost, as these factors could have major implications for water use and access across the state.

There remain many unanswered questions about hydrogen's water impact in California. Given green hydrogen's seemingly imminent rollout, this brief sets out to review key questions, begin to answer some of them, and catalog many more. We examine the context of hydrogen production throughout California, with a focus on hydrogen combustion for power generation in the Los Angeles area. This analysis allows us to discuss potential water-related pitfalls, challenges, and open questions surrounding green hydrogen in California.

What did we find? Our examination of existing information left us with more questions than answers. Thus, in many places, the analysis is more conceptual than empirical, with many assumptions required. This is, in part, due to the untested nature of many aspects of the technology, as well as the uncertainty faced by those without access to the proprietary information protected by ARCHES's nondisclosure agreements. However, the centrality of hydrogen to energy transition plans in LA and the state overall makes it essential for researchers to begin to address these questions, even with high degrees of uncertainty.

With limited public information, we use simple calculations to sketch the potential water footprint of green hydrogen production under different demand scenarios and assumptions. We calculate scenario-based estimates to show how much water may be needed, depending on the details of the plans. According to water requirements published in the reviewed literature and ARCHES's projections for hydrogen demand, we conservatively estimate that hydrogen production in 2045 will require between 230,000 and 390,000 acre-feet of water annually. While this represents a modest impact on statewide water demand, it could have significant effects at the local level. Understanding the exact locations, the amount of water sourced, and the water requirements for each production site is, thus, crucial to further assessing the on-the-ground impacts.

Hydrogen production's reliance on ultrapure water also imposes significant quality demands with high per-unit costs, introducing questions of feasibility. This coincides with concerns by environmental justice organizations of the risks hydrogen management from production to end use poses to local drinking supplies, and underscores that green hydrogen's water demands and impacts should not take precedence over achieving the Human Right to Water.

These factors underscore hydrogen's potential complications within California's renewable energy future and its alignment with broader environmental justice principles. Despite enthusiasm from many energy stakeholders, our review of public information on hydrogen reveals significant uncertainties and potential pitfalls that could exacerbate environmental justice issues in California. More publicly available information and analysis are necessary to prove that green hydrogen can be implemented without mismanaging public resources and deepening environmental injustice, with the burden of proof resting on proponents despite the climate urgency. It is imperative that local and state leaders proceed with caution and commit to protect against these potential negative outcomes.

1. INTRODUCTION

The global fight to prevent the worst effects of climate change has driven governments and parts of industry across the world to reduce planet-warming greenhouse gas emissions. For almost 200 years, fossil fuels (coal, oil, and methane gas[1]) have been both the dominant energy source in the world and one of the main drivers of climate change. Among the different approaches to phase out fossil fuels, the energy sector has looked toward technological innovation to find alternative sources of energy that can support our society's needs without contributing additional climate-warming greenhouse gases to the atmosphere.

One solution that is being heavily promoted worldwide is the use of hydrogen gas. The use of hydrogen as an alternative to fossil fuel-based energy sources is expected to grow as hydrogen technologies advance and costs eventually decrease (Muhammed et al., 2023). Hydrogen is a versatile energy resource that can store energy for future use, then produce heat or electricity through combustion or chemical reactions, without producing CO2. It is also energy dense, able to store nearly three times as much energy per kilogram of fuel as methane gas (AFDC, 2024). And while hydrogen has historically been produced as a byproduct of fossil fuel production, it can be a carbon-free fuel when produced by using renewable electricity to split water into hydrogen and oxygen, resulting in so-called "green" hydrogen.[2] This process is slated to be used in California.

While the federal energy investment landscape is now in flux in the early months of the Trump administration, there is still an expectation that massive investments are underway to expand hydrogen's role throughout the U.S. economy. The pending federal investment includes funding from the Biden Administration's Bipartisan Infrastructure Law, which included a $7 billion initiative to establish "hydrogen hubs" across the nation to accelerate clean energy efforts and climate goals.[3] A hydrogen hub is meant to create networks of hydrogen producers and consumers, and provide local connective infrastructure[4] required for the widespread use of hydrogen as an energy source (OCED, 2024). In July 2024, the U.S. Department of Energy (DOE) and Alliance for Renewable Clean Hydrogen Systems (ARCHES) officially announced the signing of an agreement that would allocate $1.2 billion in federal funding, with an additional

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[1] We use the term "methane gas" instead of the typical "natural gas," a phrase that has been used to minimize the negative impacts of this fossil fuel in the public's eye (Lacroix et al., 2021). This fuel is predominantly methane, though it also includes other hydrocarbons that contribute to climate change

[2] There is not yet a widely agreed upon definition of what exactly constitutes "green" hydrogen, in terms of the fuels that can count as renewable. California advocates, legislators, and other stakeholders are engaged in ongoing legislative and regulatory processes to define what will qualify. We refer to "green" hydrogen throughout this document with this ambiguity in mind, acknowledging it may or may not be a legitimate term depending on the definition.

[3] It is not yet clear how federal support for hydrogen will fare under the Trump administration (as reported by Reuters, for example). This variable could have substantial ramifications for the speed, cost, and other implications of California's hydrogen push.

[4] ARCHES Technical Volume Submission: "The required distribution infrastructure will initially include pipelines and trucking and storage of gaseous and liquid hydrogen to the deployment locations as appropriate."

$11.4 billion in public and private matching funds, for the development and expansion of hydrogen infrastructure in California. The California hydrogen hub includes projects that power public transportation, port operations, and heavy-duty transport — sectors that significantly contribute to greenhouse gas emissions and air pollution (“California’s Renewable Hydrogen Hub Officially Launches,” 2024).

While hydrogen is a versatile fuel that can theoretically replace several uses of fossil fuels, thus reducing greenhouse gas emissions, it has never been produced and used as an energy resource on a large scale, and many challenges are associated with doing so. One of the concerns that has been raised, including by California environmental justice advocates, is the water use associated with producing green hydrogen, which, by definition, requires water as an input to the production process. The lack of clarity on how much water will be required to meet hydrogen-driven demand is especially concerning to some, given the state’s dry, drought-prone climate and the implications for water conservation and equitable drinking water access across the state. Environmental justice advocates have thus raised questions about the potential water impacts, concerned that producing green hydrogen could have a major impact on scarce and quality-impaired water resources.

According to ARCHES resources, at least seven hydrogen production sites and at least 20 offtake sites will be in Southern California (OCED, 2024). Furthermore, the Los Angeles region is set to become a focal point for the hub’s activity in Southern California. Several hydrogen projects are already moving forward, such as the modernization of the Scattergood Power Generation Station, which this brief discusses further, and the incorporation of hydrogen to reduce emissions of cargo-handling trucks and ships at both the Los Angeles and Long Beach ports (Smith, 2023; OCED, 2024). Other known hydrogen projects in the Los Angeles region include Southern California Gas’ Angeles Link, the Lancaster Clean Energy Center, and the SGH2 Lancaster Project.

This brief focuses on the production of hydrogen for power generation within the broader context of California, with a sub-focus on the Los Angeles area. Taking both contexts into consideration, we aim to discuss the potential water-related pitfalls, challenges, and open questions surrounding green hydrogen. We empirically examine the potential water footprint of green hydrogen production under different scenarios and assumptions, as well as conceptually discuss how projected water use may affect California and the Los Angeles region. Notably, the majority of this brief was written in 2024 and may not reflect implications of the Trump administration’s 2025 actions.

Initially, we sought information from parties and resources directly associated with the ARCHES project, a statewide initiative to implement hydrogen as a major energy resource and achieve state climate goals. However, due to a lack of public engagement and transparency from

ARCHES[5], as well as ARCHES sources showing that no hydrogen production is slated to occur within the Los Angeles region,[6] we shifted our focus to reviewing publicly available information and literature that would help us answer key questions about hydrogen's likely water usage, supply requirements, and potential water sources in California broadly, and Los Angeles specifically.

As we note throughout the brief, our examination of existing information left us with as many — or more — questions than answers. Thus, in many places, the analysis is more conceptual than empirical, with many assumptions required. This is, in part, due to the untested nature of many parts of the technology, as well as the uncertainty faced by those without access to the proprietary information protected by the ARCHES nondisclosure agreements. Given the proposed reliance on green hydrogen as a strategy to transition to renewable energy, both in Los Angeles and more broadly in California, we nevertheless proceeded with the goal of informing greater public knowledge and discussion of the issues.

What do we find? In short, despite enthusiasm from hydrogen proponents to adopt hydrogen as a "silver bullet" for the final portion of clean energy needed to help abate the climate crisis[7], our review of publicly available information reveals significant uncertainties and potential pitfalls that could exacerbate environmental justice issues in the Los Angeles region and California more broadly, such as drinking water insecurity in communities that have not yet achieved the Human Right to Water. Until more information and data become publicly available, proving that green hydrogen can be implemented without mismanaging public resources and deepening environmental injustice, it is imperative that local and state leaders proceed with caution.

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[5] We identified one technical document which lays out the goals and logistics of the ARCHES project. However, this document manually redacted key information on items including: how and where hydrogen will be produced; how much will be produced, both in state and out of state; how much will be used in each year; and associated costs of each stage of the hydrogen life cycle ("ARCHES Technical Submission," 2024).

[6] ARCHES "H2 Hubs Fact Sheet," 2024; Rincon Consultants, Inc., & Jacobs Engineering Group (2024, July).

[7] Recent Los Angeles Department of Water and Power General Manager Martin Adams is among those who have recently referred to hydrogen as a "silver bullet" for clean energy ("LADWP's Marty Adams on Sustainability Goals...," 2023).

2. THE HYDROGEN LIFE CYCLE: OVERVIEW AND WATER IMPACTS

First, we provide a brief overview of the stages of the hydrogen life cycle — production, transportation and storage, and use — and introduce associated water impacts.

2.1. Production of Hydrogen Gas

The United States produces about 10 million metric tons of hydrogen gas per year, of which California currently produces nearly 70% ("ARCHES Technical Submission," 2024). Expected growth in production is massive.[8] According to the Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES), as of 2023, the state is producing 6.8 million metric tons per year (MTPY) of hydrogen. By 2030–2032, however, the state is projected to produce 190,000 MTPY and 17 million MTPY by 2045 (OCED, 2023).

There are multiple methods for producing hydrogen, each of which is typically referred to by a specific color. Several of the main hydrogen types are shown below in Table 1. For this brief, our analysis, calculations, and findings will pertain to "green" hydrogen production, specifically. As described above, this refers to hydrogen produced through water electrolysis (which uses an electrical current to separate water into hydrogen and oxygen gases), using electricity from renewable energy sources in a zero-carbon process (Arcos & Santos, 2023). Green hydrogen, which accounted for only 2% of global hydrogen production in 2023 (Martinez Lopez, 2023), is now the only form of hydrogen approved for production under California's hydrogen hub.

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[8] For context, around 100 million metric tons per year (MTPY) of hydrogen is currently produced globally, underlining the magnitude of expected growth of hydrogen within California alone (Greenwald et al., 2024).

TABLE 1

Hydrogen Production Classifications by Color

Hydrogen Color	Description
Green	Often referred to as “clean hydrogen,” “renewable hydrogen,” or “low carbon hydrogen.” Hydrogen produced with water electrolysis using electricity from renewable energy sources. By using renewable energy, green hydrogen production does not generate carbon dioxide emissions at any point.
Grey	Hydrogen produced from steam methane reforming (SMR), partial oxidation, or autothermal reforming. Most of the produced hydrogen globally corresponds to grey hydrogen. 40% of grey hydrogen is a byproduct of other chemical processes. Around 6% of the worldwide extracted natural gas and 2% of coal are used to produce grey hydrogen. Grey hydrogen is related to the high CO2 emissions during hydrogen production.
Blue	Hydrogen produced from fossil fuels, but with a carbon capture, utilization, and storage system (CCUS). As no CO2 is to be emitted, blue hydrogen production is categorized to be carbon neutral. Different methods can be used to produce blue hydrogen, some of which are conventional ones to produce grey, brown, or black hydrogen.
Aqua	This technology extracts hydrogen from oil sands and conventional oil fields. The aqua hydrogen technology involves placing oxygen into a sealed fuel deposit between grains of rock, using unswept petroleum as the fuel and the ground as the reactor vessel. By separating atmospheric air into nitrogen and oxygen, the oxygen is injected into an underground reservoir, where the temperature is increased, creating a water-gas shift, hot gasification, and aqua thermolysis reactions within the fuel reservoir, generating syngas. The hydrogen is then extracted using membranes in the production wells. The membranes keep carbon oxides in the ground, and hydrogen reacts with the membrane, allowing only hydrogen to come to the surface.
Black and Brown	Considering production from coal, the brown and black hydrogen colors refer to the type of lignite (brown) and bituminous (black) coal. It is considered to be the lead environmentally friendly hydrogen production method, creating as much CO2 as burning the source file would have in the first place. Around 20 kilograms of CO2 is released for every kilogram of brown/black hydrogen produced. Although some researchers claim that hydrogen from biomass should be seen as green, assuming the whole lifecycle of the biomass is carbon-neutral, the high CO2 emissions of the process cause it to be considered brown hydrogen.
Yellow	Hydrogen produced with electrolysis using electricity from the energy grid. Carbon emissions vary significantly in time, depending on the grid’s energy sources.
Turquoise	Hydrogen produced by using methane as a feedstock, but is produced via methane pyrolysis. Contrary to SMR, the hydrogen byproduct is solid carbon appearing as filamentous carbon (or carbon nanotubes). This type of byproduct can be further used and is easier to store, thus can have a lower carbon footprint. So far, pyrolysis has never been commercialized as a hydrogen production method.
Purple, Pink, and Red	Hydrogen produced through the use of nuclear power. Purple hydrogen is produced by using nuclear power and heat through combined electrolysis and thermochemical water splitting. Pink hydrogen is produced with water electrolysis using electricity from a nuclear power plant. Red hydrogen is produced through the high temperature catalytic splitting of water using nuclear thermal power as the energy source.
White	White hydrogen refers to naturally occurring hydrogen, which is found in nature as a free gas in layers of the Earth’s crust, volcanic gases, geysers, and hydrothermal systems. White hydrogen appears to be carbon free, and abundant sources require minimal infrastructure for its exploitation. However, only low-level research on the topic exists.

Large-scale hydrogen production poses significant challenges, particularly in California. A critical consideration in this transition is the water footprint associated with hydrogen production. Green hydrogen relies on water as a feedstock, and the amount necessary to produce a given amount of fuel varies. Several factors, which we discuss below, influence the amount of water required to produce hydrogen: the electrolyzer type used, the source of the electricity for electrolysis, and the purity of the water source.

2.1.1. Electrolyzer Type

A commonly cited conversion factor suggests that 9 liters (9 kilograms) of water are required to produce 1 kilogram of hydrogen. This figure is a minimum and assumes ideal conditions. Most commercial electrolyzers demand 10 to 17 liters of “ultrapure water” to ensure efficiency (Saulnier et al., 2020; Newborough & Cooley, 2021).[9] There are four main types of electrolyzers being considered for large-scale hydrogen production: Anion-Exchange Membrane (AEM), Alkaline Water Electrolysis (AWE), Polymer Electrolyte Membrane (PEM), and Solid Oxide Electrolysis Cells (SOECs).

ADDITIONAL ELECTROLYZER TYPE CONCERNS

Each electrolyzer type has its own **requirements for efficient hydrogen production**, and each poses different challenges to produce hydrogen in the long run.[10] For example, SOECs, which use steam rather than liquid water, provide thermodynamic benefits but require coupling with high-temperature heat sources, raising questions about their carbon neutrality (Min et al., 2022). On the other hand, electrolyzers like AWEs are sensitive to lower-quality water, shortening their operational lifespan and lowering hydrogen production efficiency.

The **energy requirement** to power an electrolyzer will depend primarily on the type of electrolyzer technology used. Based on publicly available information on commercial electrolyzers for large-scale production, the average electricity needed to produce hydrogen varies from about 50 to 65 kWh per kilogram of hydrogen.[11] However, because several electrolyzers are still in the research and development stage, there is potential for energy demand to go down.

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[9] “Ultrapure water” refers to water that contains no other dissolved salts or minerals present within the water; in other words, pure H_2O.

[10] For an in-depth overview of electrolyzer requirements, see Lopez et al., 2023; Miller et al., 2023; Min et al., 2022.

[11] AEMs require 53.73 kWh, AWEs need 63.09 kWh, PEMs use 55.62 kWh, and SOECs need about 49.5 kWh. It’s important to note, however, that SOECs might require additional energy for steam generation unless paired with a heat producing facility.

The **lifespan** of electrolyzers is a crucial factor in their economic viability and large-scale application. AWEs generally last between 60,000 to 90,000 hours, while PEMs have a shorter lifespan of 20,000 to 60,000 hours (Martinez Lopez, 2023). The longevity of these systems is heavily influenced by factors such as water quality and operating conditions. High voltages and temperatures can accelerate the degradation of electrolyzers, leading to issues such as corrosion, electrode damage, and even gas crossover, which could result in dangerous situations (Angulo et al., 2020).

The **materials** used in electrolyzers, particularly the minerals required for their construction, also play a significant role in determining their overall impact on water resources and the environment (Greenwald, 2024). The need for specific minerals, such as nickel, zirconium, platinum, and iridium, complicates the scaling of hydrogen production due to their scarcity and the water-intensive processes required for their extraction. For instance, producing 1 kilogram of platinum-group metals (PGMs) in South Africa demands approximately 743 cubic meters of water, equivalent to about 196,000 gallons (Haggard et al., 2015). Water shortages in countries from which PGM is extracted could or should pose challenges to global PGM production, emphasizing the delicate balance required to scale hydrogen production sustainably. This issue is particularly pressing given that the United States produces only 4% of the world's PGMs, and further highlights the resource-intensive nature of expanding hydrogen infrastructure, among other types of clean energy infrastructure.

2.1.2. Energy Source and Water Impacts

The energy source for electrolysis also affects the water footprint of green hydrogen. Aside from water required for electrolysis, green hydrogen will require sufficient renewable electricity to power the electrolyzers, potentially at terawatt quantities by 2045.[12] If the state doesn't expand or match renewable electricity supply enough to meet this demand, especially as the state transitions away from nuclear power, the void in electricity supply may need to be filled by carbon-emitting sources, undermining California's climate objectives and complicating efforts to produce green hydrogen.[13]

Different energy sources require different amounts of water for power generation, whether as part of the cooling system or in the form of steam that turns turbines. Therefore, the water cost of electricity generation used for electrolysis should be considered alongside the water quantity directly required for the electrolysis process.[14] Renewable energy sources like wind and solar have lower water footprints than fossil fuels, biofuels, nuclear energy, and the overall electric

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[12] Applying a Low Energy Requirement for Electrolysis (50 kwh/kgH_2) to ARCHES' Hydrogen production 2045 hydrogen production goal of 17 million MTPY.

[13] See Briscoe, 2023, for details on the status of nuclear power in California.

[14] See Table "Water Consumption by Energy Source for Electrolysis."

grid (see Table 2 below). Because the definition of green hydrogen has not been universally accepted, including what constitutes "renewable energy sources," this leaves an opening for water-intensive energy generation practices to fill in the energy supply void. For example, if biofuels are considered an acceptable renewable energy source for green hydrogen, then producing the gas would have a higher water footprint.[15]

TABLE 2

Water Footprint by Hydrogen Production Energy Source

Water Consumption by Energy Source for Electrolysis		
Energy Source	**Estimated Water Consumption ($L\ H_2O$ / kg hydrogen)**	**Reference**
Gas	95	Newborough & Cooley, 2021
Nuclear	51.1 – 127.2	Newborough & Cooley, 2021 Makhijani & Hersbach, 2024 Olaitan et al., 2024
Electricity Grid	46.9	Makhijani & Hersbach, 2024
Biofuels (ethanol)	10,000	Newborough & Cooley, 2021
Biofuels (biodiesel)	70,000	Newborough & Cooley, 2021
Coal	50 – 100	Olaitan et al., 2024 Newborough & Cooley, 2021
Solar	3.8 – 20	Makhijani & Hersbach, 2024 Olaitan et al., 2024
Wind	0 – 0.2	Makhijani & Hersbach, 2024 Olaitan et al., 2024
Biomass (wood chips)	7,450	Olaitan et al., 2024

2.2. Transportation and Storage of Hydrogen Gas

Once hydrogen is produced, it must be transported to the location where it will be used. Hydrogen transportation requires specialized pipelines and storage facilities, as the small size of hydrogen molecules allows the gas to easily leak from standard pipelines and tanks. While some delivery infrastructure exists today, growing demand will necessitate both infrastructure expansion and the development of new technologies to ensure safety and maintain hydrogen purity. An effective transportation infrastructure must also include viable storage facilities to house hydrogen when it is not in use or demand. At this time, the infrastructure necessary for large-scale hydrogen transportation is still under development and would require significant investment to scale up existing methods.

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[15] Grid electricity in the U.S., which includes a mix of renewable and nonrenewable sources, consumes about 46.9 liters of water per kilogram of hydrogen produced (Makhijani & Hersbach, 2024). Water consumption escalates with sources like coal and biofuels, in which biofuels potentially consume tens of thousands of liters per kilogram of hydrogen produced, depending on the crop and region (Newborough & Cooley, 2021).

Challenges associated with storing hydrogen: Hydrogen storage is a challenge because hydrogen has a low energy density, so a large volume of gas must be stored relative to the amount of energy it will ultimately produce. If stored improperly in underground tanks, hydrogen can contaminate underground water resources or alter geologic formations that can disrupt local water supplies (Martin et al., 2024). This raises concerns for environmental justice advocates, as groundwater often serves as a primary source of local drinking water, and groundwater quality issues resulting from industrial toxic legacies are common across California communities. Existing methane storage facilities will not be sufficient for the hydrogen hub's storage needs. Investments in new storage facilities and retrofits to existing facilities will almost certainly be necessary.

2.3. End Use: Combustion of Hydrogen Gas for Power Generation

2.3.1. Scattergood Power Plant's Transition to Hydrogen

California plans to use hydrogen across the transportation, industrial, and power sectors to achieve the state's zero-emissions goals. For example, hydrogen fuel cells will be used to power medium- and heavy-duty vehicles, such as trucks and buses in communities and at the Los Angeles and Long Beach ports. In the power sector, hydrogen will be used as a fuel in compatible turbines to replace fossil fuel power plants. The appeal of burning hydrogen to produce electricity is that it does not directly emit CO2, as opposed to burning methane, and therefore, it is seen as a climate-friendly alternative. However, the process of burning hydrogen for thermoelectric generation has several potential pitfalls, which may exacerbate environmental justice and broader concerns.

The transition toward hydrogen power is still in its early stages, as no power plant currently operates on 100% hydrogen fuel. For example, the Hillabee Generating Station in Alabama recently set an industry record in 2023 after testing a 38% hydrogen blend in its gas turbine system (Constellation, 2023). Simultaneously, the Los Angeles Department of Water and Power (LADWP) has been moving forward to retrofit the Scattergood Generating Station from gas to an eventual 100% hydrogen fuel-burning power plant.

Originally built in the late 1950s, Scattergood's partial conversion to burn hydrogen is part of Los Angeles' strategy for carbon neutrality. A portion of the federal funding allocated to the California Hydrogen Hub will be used to convert two of Scattergood's methane units into a 346 MW combined-cycle system capable of burning both hydrogen and methane. Initially, the system is expected to use a 70% methane and 30% hydrogen blend, with plans to transition to 100% hydrogen by 2035, operating during peak hours to support Los Angeles' climate goals.

2.3.2. NOx Control System

As mentioned above, burning hydrogen does not emit CO2, but it does release nitrogen oxides (NOx), which raises questions about the potential air quality impact, especially in communities where air quality burden may be high. Why might this matter for understanding the potential water footprint attributed to burning hydrogen, especially at Scattergood?

A typical method to control NOx emissions involves injecting water or steam into the combustion chamber. This initiates a cooling effect, thereby reducing the thermal formation of NOx (Chiesa et al., 2005; Sargent & Lundy, 2022). It is not clear, however, how much water would be required to control for NOx when burning hydrogen. Some cooling technologies can condense steam back into water for potential reuse, but there will always be some water loss (Mohammed Ali et al., 2020).

Reducing the water footprint could also be achieved by avoiding technologies like water injection, but would come at the cost of effective air pollution control, requiring investment in alternative NOx control strategies. Here, however, we will briefly discuss the water/steam injection method, as other NOx control strategies do not have a direct relationship with water use.[16] If water injection is necessary, it could be costly. While there is information on NOx control system costs for gas turbines, information on hydrogen NOx control systems is limited. For example, a 2022 white paper on NOx control technologies for combustion turbines, conducted by Sargent & Lundy and funded by the U.S. Environmental Protection Agency, estimates that a water injection system project for a 50 MW simple-cycle combustion turbine could cost nearly $5 million, with an estimated $100,000 in annual operation and maintenance costs. The paper also estimates that a steam injection system project for a natural gas combined-cycle system could cost $6.2 million with an estimated $300,000 in annual operation and maintenance costs. In the end, how much water would be required for steam or water injection will depend on the turbine design and capacity. Furthermore, other technical questions must be considered, such as how the stoichiometry of burning hydrogen affects NOx production, and whether the higher heat output of hydrogen also affects the water demand for NOx control.

2.3.3. Keeping Hydrogen Power Cool

Additionally, there is the question of how hydrogen's heat output, compared to natural gas, will impact the amount of water needed for cooling. Hydrogen combustion generates higher temperatures and flame velocities than methane, increasing thermal stress on turbine components. This requires enhanced cooling systems and durable materials to manage the heat effectively (Topolski et al., 2022; Muhammed et al., 2023). Public data-supported estimates on water use for cooling systems in hydrogen-fueled turbines are currently unavailable. However, data on water use in methane turbines provides useful context, suggesting that water withdrawals for hydrogen-fueled turbines will likely exceed current levels.

For example, the U.S. Energy Information Administration (2023) reports that the average water withdrawal intensity for a methane combined-cycle turbine unit is 2,803 gallons per megawatt-hour, including cooling water. Applying this figure to publicly available details on Scattergood's retrofit from LADWP's 2023 CEQA Initial Study, the plant could require approximately 1 billion gallons of water per year for hydrogen use.[17] Water withdrawals may increase further due to hydrogen's higher heat output. However, the plant's retrofit also includes converting the existing once-through cooling system to an air-cooled condenser, which could reduce water consumption (Guerras & Martin, 2020). Given the early stage of the project and limited data, uncertainty remains regarding the exact water footprint of burning hydrogen. Further research and additional information are needed to produce precise estimates.

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[16] Literature we reviewed (Pandey et al., 2023; Asghar et al., 2021) shows NOx control methods for point sources are usually a blend of fuel control components and post-combustion technologies; however, most are not directly dependent on water use.

[17] The initial study details the construction of the 346 megawatt combined-cycle generation system unit, which will operate during peak hours (which LADWP says is 50 hours per week).

3. ESTIMATING SCENARIOS OF THE GROSS AND NET WATER FOOTPRINT OF FUTURE STATEWIDE HYDROGEN PRODUCTION

3.1. What Has Been Projected So Far — Angeles Link

The original primary goal of this analysis was to estimate the potential water footprint of producing hydrogen in California. The amount of water required depends on the amount of hydrogen produced, how the hydrogen is produced, and how the water is treated to be pure enough for electrolysis. We begin by noting estimates of water footprint from other studies, then introduce our own sketch of potential water requirements based on simple calculations.

Broadly speaking, the literature we reviewed supports the claim that hydrogen has a smaller water footprint than fossil fuels, with green hydrogen being the most water-efficient production method compared to traditional methods, such as steam methane reformation.[18] As we have stated, access to technical details of water use in ongoing hydrogen projects in California has been a challenge, as most of those details have been concealed, if not kept totally secret. As a result, we had insufficient information to make precise projections for this brief.

That being said, we did identify one of the only in-depth water use reports that provided estimates and other information on the potential water footprint of hydrogen production. The December 2024 report, "Angeles Link Phase 1: Water Resources Evaluation," was commissioned by Southern California Gas Company (SoCalGas, 2024). It focused on the feasibility of water availability and water quality for supporting green hydrogen production that serves the Southern California region. SoCalGas plans to build the Angeles Link pipeline to transport hydrogen to Southern California; therefore, the company wants to know if there will be reliable water sources to support the production of hydrogen, whether in California or elsewhere. The report estimated that producing hydrogen for SoCalGas' service area would require between 21,000 and 65,000 acre-feet per year. It also identifies potential water resources to be used, cost considerations associated with water use for hydrogen production, and challenges that must be overcome.

The SoCalGas report's analysis differs from our calculations below in multiple ways, making it difficult to compare results. First, it focuses on a narrower segment of the state — the utility's service area — while we estimate demand for the whole state. Second, their report does not account for the water consumed by the energy source powering the hydrogen production process, which can significantly affect the water footprint, as illustrated below.

3.2. Illustrating Green Hydrogen's Potential Water Footprint by Scenario

We calculated scenario-based estimates using water requirements from the literature and public plans for hydrogen in California. These calculations only represent water used in hydrogen production and do not include water impacts of water transportation, storage, or

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[18] Arcos & Santos, 2023; Saulner et al., 2020; Shiva Kumar & Lim, 2022; Fairly, 2023; Newborough & Cooley, 2021; Simoes et al., 2021.

end use. Research on hydrogen technologies, process stages, and water sourcing is still emerging, with most studies being theoretical or, at best, lab-tested rather than field-evaluated. Consequently, it is safe to assume that current resource use estimates represent a lower bound, and thus our estimates are quite conservative.

The estimates are based on the following scenarios and assumptions. The gross and net water footprint estimates in Table 3 present options for the assumptions about the amount of water used to produce hydrogen. The estimates vary depending on what electrolyzers are used and the source of electricity for electrolysis.

TABLE 3

Estimated Gross Water Footprint of Green Hydrogen Production

	Low Estimate	Moderate Estimate	High Estimate
Water required for electrolysis[19] (1.89 kg "very clean" water required per kg[20] ultrapure water[21])	9 kg UPW 17 kg clean water	11 kg UPW 21 kg clean water	15 kg UPW 28 kg clean water
Water footprint of renewable electricity (see Table 2)[22]	0 kg water (minimum value for wind)	10 kg water (midpoint)	20 kg water (maximum value for solar)

Figure 1 shows the range of estimated annual water consumption for different annual hydrogen production levels, without including additional water use from the energy source. ARCHES projects California's hydrogen capacity will be approximately 17 million metric tons per year in 2045; as the chart shows, this correlates to a range of 230,000 to 390,000 acre-feet of "very clean" water per year as a feedstock for electrolysis, depending on the electrolyzer used.

Figure 2 adds another dimension: water from energy production for electrolysis. It compares the lowest water-use energy source (wind, which could use little enough water to round down to zero) to higher water-use energy sources like solar (at different water use levels).

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[19] This range was selected based on published ranges for commercially available electrolyzers, with the goal of presenting a range from the absolute minimum consumption to a higher, but still reasonable, level (Saulnier et al., 2020; Newborough & Cooley, 2021). Some electrolyzers use more water than 15 kg UPW per kg hydrogen, so our high estimate could be exceeded.

[20] This is an average of the water demand to produce 1 kg of ultrapure water based on the requirements mentioned in the following source: Vishnu et al., 2024, Simoes et al., 2021., and Dohkani et al., 2023.

[21] Very clean" water represents water, such as tap water or certain freshwater sources, where it either has undergone a pretreatment process or contains relatively less dissolved minerals or other contaminants compared to other water sources such as seawater or raw river water.

[22] ARCHES is planning to use some hydrogen produced from biomass. Because of several points of uncertainty (what type of biomass would be used, where it would come from, and more), it is not clear exactly how this will impact the water footprint of hydrogen. The literature suggests that the water use for biomass is hundreds of times greater than for solar or wind, but there are many factors that influence this number. For our purposes, we only considered wind and solar energy sources, which may lead to underestimate of water use.

FIGURE 1

Estimated Electrolysis Water Consumption vs. Hydrogen Production Level

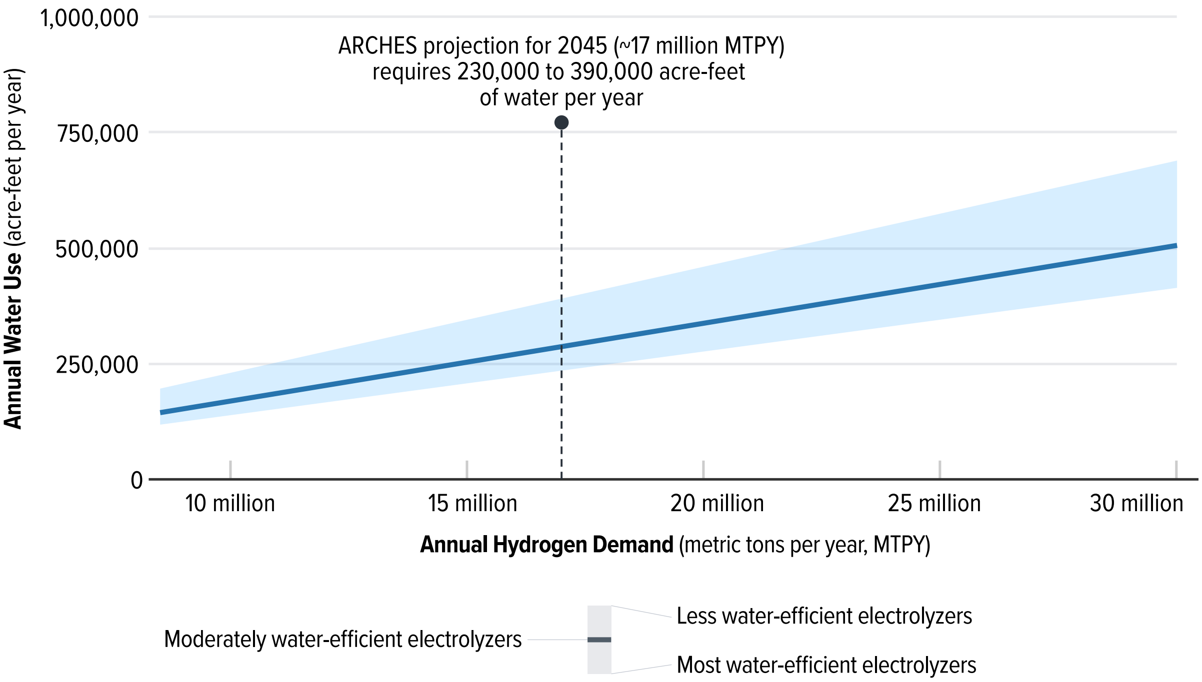
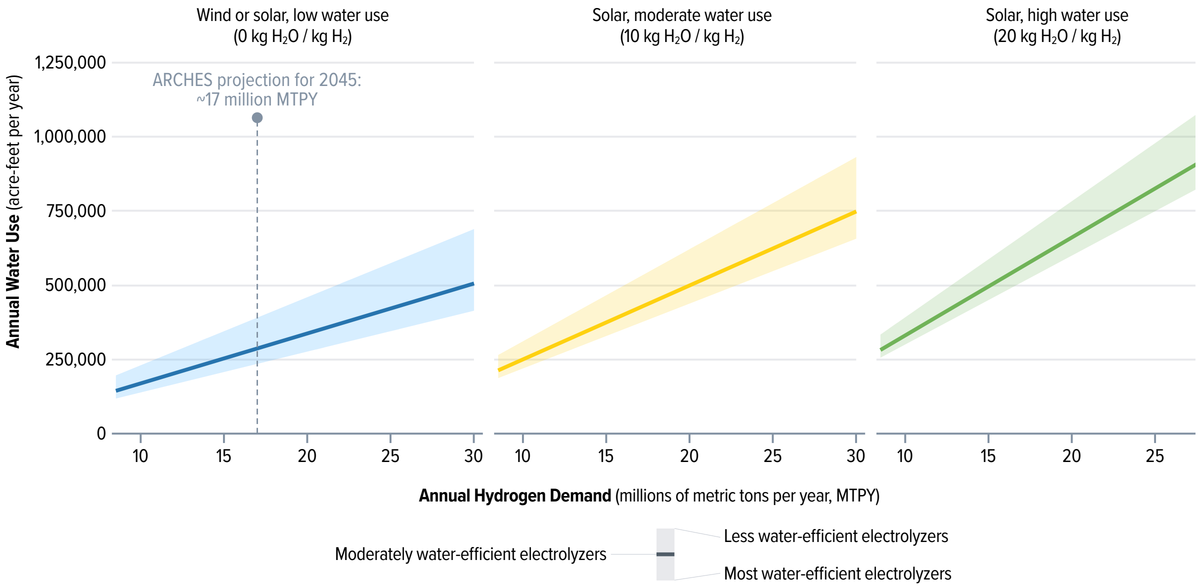


FIGURE 2

Estimated Electrolysis and Energy Water Consumption vs. Hydrogen Production Level



These charts suggest that the energy source for electrolysis will play as critical a role in the water footprint as the electrolyzer technology. However, these results do not show net impacts of hydrogen on water consumption. Green hydrogen production uses less water than many other energy generation processes; if hydrogen replaces several types of oil and gas production, which are both water intensive and degrade water quality, thus limiting supply, it may have less detrimental impacts on water supply.[23]

In the long run, substituting green hydrogen for fossil-fuel energy generation is likely to decrease water use. However, it is uncertain whether and when hydrogen will actually substitute, rather than augment, existing energy supplies. The task of removing fossil fuels from the energy system remains much harder than adding renewable generation (Davidson, 2019). The overall water impacts of hydrogen production (as well as transportation, storage, and use) will be heavily dependent on many other energy system changes.

To contextualize the results above, the statewide average annual water consumption between 1998 and 2015 was 39 million acre-feet, excluding environmental uses (Mount and Hanak, 2019). Based on these numbers and the ARCHES projection of hydrogen demand, hydrogen production would account for 0.59% to 1% of water demand in 2045.

With little clarity on the planned production locations and methods that are withheld under the ARCHES nondisclosure agreements, we cannot say whether the projected hydrogen generation will occur in state or out of state. Thus, it is difficult to say what the quantitative distribution of these impacts are for local water supply sources across California. Depending on the actual production amounts and locations, the resulting water footprint and supply impacts will vary. Nonetheless, we discuss potential implications and considerations for local water impacts below.

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[23] Olaitan et al., 2024; Fairley, P., 2023; Saulnier, R., Minnich, K., Sturgess, P.K., 2020; and Makhijani & Hersbach, 2024.

4. LOCAL WATER FOOTPRINT CONSIDERATIONS

While the estimated state water footprint of hydrogen could be considered low compared to the state's water consumption, this is, in part, because much of hydrogen production for California will not take place in the state. Regardless, local water quantity considerations in hydrogen production and use may be considerable and have not yet been incorporated in local water system planning, as this type of planning is not coordinated statewide, whether in California or any other state in the U.S. Also, the state does not have a plan for or the authority to centralize and distribute "new water" supply for any end-use purpose, much less the emerging hydrogen industry. The production and distribution of new supply relies on local water systems, which are sometimes aligned in regional coalitions.

As things stand in California, unmet water demands in one locality are not easily remedied by supply from another, except through carefully negotiated regional partnerships and in residential supply emergencies. Thus, local water supply systems — "community water systems" (CWS) in the regulatory language of the Safe Drinking Water Act — are largely on their own in terms of water sourcing, including for new or emerging demands from hydrogen processes. CWSes are the fundamental building blocks of California's water supply network. While they perform essential roles in providing drinking water supplies and adapting to drought and climate change, they also face challenges from underinvestment, aging infrastructure, and increasingly stringent regulatory standards.

The task of sufficient water supply sourcing for CWS is only going to get harder in California, and throughout the South and Intermountain West where hydrogen is expected to be produced (Nazzal, 2024). Proposals that involve drawing from water supplies for hydrogen uses outside the purview of CWS in the West, such as the Cadiz groundwater project, are at least as problematic in terms of sustainable water management (Roth, 2024). The local water demands of hydrogen production outside California for its use are just as important as those within the state. However, this simple reality has largely been glossed over in discussions of water use for hydrogen use in California. Arguably, local water systems in many other Western states are less prepared than those in California to face the unclear demands of the burgeoning hydrogen industry.

It is also important to note that CWSes are quite fragmented compared to other utility sectors, whether in Los Angeles, California, or nationwide (Pierce, Lai and DeShazo, 2019). Even in urban areas such as Los Angeles County, there are 200 local water systems, which come in all shapes and sizes. While we expect water demands for hydrogen to occur in large urban areas served by larger, more source-diversified and managerially capable water systems (such as LADWP for the City of Los Angeles' Scattergood plant), this will not be universally true. Even if it is true, systems such as the Los Angeles Department of Water and Power (LADWP) have committed to continued conservation and growing shares of local water source reliance, but have not projected hydrogen industry demands, at least as far as public information suggests.

While the total water demand for hydrogen production and use in California may be lower than that of methane gas at the state level, there is no guarantee of this locally, either within or outside California, nor is there any empirical basis for confidence in such an assumption. This case could be more compelling if information on specific locations for hydrogen infrastructure was released or if proponents can show that there will be minimal water supply impacts where they actually matter, which is locally. Since not enough information has been released on exact hydrogen production and use locations, it is also not possible to project the local water supply impacts, much less net impacts, when considering the location of existing energy generation likely to be retired.[24]

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[24] There is no reason to think that the local concentration of energy generation is likely to be retired and will be similar in local geography to the local areas where green hydrogen will demand the most water.

5. WATER QUALITY AND COST CONSIDERATIONS

5.1. Costs of Producing Ultrapure Water

Water supply is only part of the water impact question. Whatever and wherever the water demands of hydrogen production may be, it is also necessary to consider the required water quality for hydrogen, the treatment technologies needed to achieve it, and their related costs. Above, we noted potential impacts of hydrogen transportation on groundwater quality, which should be minimal if transportation is well-constructed and maintained. As of now, this represents some level of risk, simply because hydrogen transportation infrastructure has not been field tested in the long term, much less under disaster-event scenarios such as earthquakes, which threaten the stability and safety of other infrastructure transmission networks in California (Martin., 2024).

Here, however, we focus on the highly treated water (known as "ultrapure" water) required for hydrogen use.[25] This water contains no dissolved salts or minerals — much more pure than what is required for drinking water (Santana et al., 2024; Woods et al., 2022). Most, if not all, electrolyzers advertise a "ultrapure" or "deionized" water requirement to guarantee electrolyzer efficiency (Saulnier et al., 2020; Lampert et al., 2015). This level of water quality is achievable with existing treatment techniques, including reverse osmosis, ion exchange technologies, or desalination (Saulnier et al., 2020), but the cost of purification will vary dramatically based on the treatment method, water source, and energy requirement.

Desalination costs for hydrogen production are primarily driven by energy consumption, infrastructure, and operational expenses, with demineralized water contributing less than 1% to total hydrogen production costs (Dokhani et al., 2023; Kumar et al., 2024). Reverse osmosis, a common water treatment technology, incurs costs between $0.50 and $1.50 per cubic meter, depending on electricity prices, while optimized systems using low-salinity feedwater can range from $0.53 to $2.50 per cubic meter, translating to approximately $0.02 – $0.05 per kilogram of hydrogen (Woods et al., 2022; Beswick et al., 2021; Dokhani et al., 2023). Additional expenses stem from maintenance, brine disposal, and ion exchange post-treatment, with capital costs reaching $180,000 and annual operation costs around $13,000, contributing $0.10 – $0.50 per kilogram of hydrogen produced (Dokhani et al., 2023; Kumar et al., 2024). To reduce costs, emerging technologies, such as ones that leverage waste heat, offer potential cost reductions, especially in water-scarce regions where competition for resources and infrastructure needs drive costs higher (Kumar et al., 2024; Woods et al., 2022). Though, if the waste heat source comes from fossil fuel-based facilities like refineries, it could undermine climate goals.

5.2. Costs of Water Abstraction

Local water availability and quality will further influence water treatment costs, affecting the feasibility of green hydrogen in regions where water resources are constrained (Santana et al., 2024; Woods et al., 2022; Barghash et al., 2022). For long-term hydrogen sustainability, effective water management and treatment strategies are essential to avoid additional stress

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[25] Lampert et al., 2015; Simoes et al., 2021; Shiva Kumar & Lim, 2022; Kumar et al., 2024; Lindquist et al., 2020; Miller et al., 2020; Newborough, M. & Cooley, G., 2021; Saulnier, 2020; Woods et al., 2022.

on local water supplies. In regions experiencing water scarcity, producing ultrapure water could drive up costs and potentially compete with other water-dependent sectors (Saulnier et al., 2020). For instance, Santana et al. (2024) assess the economic impact of different water sources in Brazil for hydrogen production. They find that water-related expenses for abstraction, transport, treatment, and storage typically constitute less than 2% of the levelized cost of hydrogen (LCOH). However, transport costs over long distances can push water-related expenses above 10% of LCOH, particularly in large-scale plants. Of particular interest, given the plans for Scattergood in Los Angeles, is that using treated wastewater can be cost-feasible, but is capital-intensive.[26]

The quality of local source water is also influenced by economic factors, historical trends, and the compounding impacts of climate change. Poorer-quality water sources will be more expensive to treat to potable standards, let alone to the "ultrapure" water required for hydrogen production. Globally and domestically, water resource quality faces critical challenges. Since the 1990s, industrialization, population growth, and climate change have significantly worsened water quality, straining human health, biodiversity, and ecosystems (Damania et al., 2019). In the Western United States, altered weather patterns, aging infrastructure, and uneven enforcement of regulations threaten water safety. The Fifth National Climate Assessment projects significant changes to the U.S. water cycle due to climate change. In the Southwest, reduced future precipitation is expected to strain water availability in regions reliant on snow and groundwater resources, with prolonged droughts likely to worsen. Considering these factors, water resources will diminish, and water quality will likely degrade in the near future.

Therefore, the costs of treating and securing safe water resources will likely be passed on to local water system customers, increasing affordability concerns. As further discussed below from an equity perspective, the cost burden to provide clean water for hydrogen cannot fall onto the customers who are not responsible for the industrial practices that place new demands on their local water supplies. Given this, and relating to both local quantity and quality considerations, it is not immediately clear why using recycled water produced at the Hyperion Wastewater Treatment Plant (located adjacent to the planned hydrogen use at Scattergood Power Plant in the City of Los Angeles) is assumed in planning for the conversion (LADWP, 2023). Obviously, "new" water is planned to be produced there to meet the city's local water targets enshrined in the Green New Deal, but this water is already projected to be absorbed by existing demands and conservation mandates of the city.

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[26] The feasibility study at the Al Ansab sewage treatment plant in Muscat's Bousher region showed annual revenue of 7.02 million Omani rial (OMR) for conventional operations. Sustainable hydrogen production using a PEM electrolyzer could yield 8.30 million OMR/year for a 1,500 kg H_2/day capacity and 49.73 million OMR/year for a 50,000 kg H_2/day capacity.

6. BROADER EQUITY IMPLICATIONS AND PRINCIPLES FOR HYDROGEN'S WATER IMPACT IN CALIFORNIA

Holistic water equity needs to be considered in the hydrogen planning discussion. Around 1 million Californians do not have access to safe, clean, or affordable drinking water. Thus, we ask the question: Should the state be investing significant financial and water resources to provide the ultrapure water required for the hydrogen industry when California residents (and out-of-state residents) are not seeing the same urgency to provide them water that meets the Human Right to Water, including some in Los Angeles (Becker, 2024; Pierce and Gmoser-Daskalakis, 2020)? To meet its minimum environmental justice commitments, the state must be able to ensure and guarantee that current local drinking water provision will not be affected by the development of the hydrogen hub, and it should reflect on whether the allocation of financial resources represents a tradeoff with realizing the Human Right to Water for all California residents.

Over the past several years, California environmental justice (EJ) advocates have been raising concerns about the legitimacy and safety of a California hydrogen hub. Here, we summarize these concerns as expressed in multiple letters to decision makers overseeing the roll out of the hydrogen hub.

EJ advocates have articulated deep concerns about hydrogen development in California, emphasizing its potential to exacerbate existing environmental and social inequities, thus disproportionately impacting environmental justice communities. They argue that current hydrogen initiatives have lacked meaningful community input, transparency, and accountability, potentially perpetuating harmful legacies in vulnerable communities. As stated in one letter, "environmental justice organizers have been fighting these hubs since they were announced, and it's time for the DOE to listen" ("Don't believe the 'hydrogen hype,'" 2023). Hydrogen's water demands are one of the primary concerns — EJ groups have stressed that hydrogen projects must not divert water from communities already struggling to meet clean drinking water needs. In their words, "projects must not negatively impact California's already stretched water supply" ("Equity Principles for Hydrogen," 2023). This highlights a broader problem: "All types of hydrogen production use vast quantities of water, which is unsustainable in drought-stricken states" ("Reject Western Interstate Hydrogen Hub," 2023).

Advocates also emphasize the risks posed by hydrogen infrastructure, particularly to low-income communities of color, noting that hydrogen's flammability and potential for leaks could lead to health and safety hazards, disproportionately impacting already overburdened neighborhoods. They state that "hydrogen pipelines will increase this burden…the slightest rupture can cause an explosion" ("Don't believe the 'hydrogen hype,'" 2023). Additionally, the emissions from hydrogen combustion, such as NOx, are described as a significant threat to public health: "Hydrogen burns at a higher flame temperature, [creating] more NOx than burning methane" ("Equity Principles for Hydrogen," 2023).

Despite these warnings, EJ advocates argue that their voices are being ignored. They criticize hydrogen hub proponents for failing to meaningfully include EJ groups in decision-making processes. One letter criticizes the process as excluding vital community perspectives, while another adds that “communities cannot meaningfully engage in determining their energy future when critical information about these proposals is withheld” (“Don’t believe the ‘hydrogen hype,’” 2023).

Frustrated by the process, several California-based EJ organizations representing heavily polluted communities across the state outlined a call for a stringent and community-centered approach to hydrogen production and utilization in California. The report, titled “Equity Principles for Hydrogen: Environmental Justice Position on Green Hydrogen in California,” emphasizes acceptance of green hydrogen that is produced, transported, and used in accordance with these principles. However, the organizations prioritize electrification whenever possible and argue that green hydrogen should only be used when electrification is not feasible. With respect to water, the principles include stipulations that hydrogen should be produced through electrolysis only when there is a surplus renewable electricity and water supply, and where water is not being diverted from communities lacking clean drinking water. In addition to production, the principles address the transport, storage, and delivery of hydrogen. They call for hydrogen pipelines and storage infrastructure to meet stringent safety and leak prevention standards.

In conclusion, EJ advocates are calling for stringent standards, greater transparency, and true community engagement to ensure hydrogen development does not exacerbate existing inequities. Though they support solely green hydrogen as a potential method to produce hydrogen, they demand that hydrogen be limited to specific, necessary uses and paired with investments in renewable energy like wind and solar, stating, “we should be building toward a truly just and equitable transition…that reduces consumption and exploitation” (“Don’t believe the ‘hydrogen hype,’” 2023).

The concerns EJ advocates have raised can be addressed in various ways during hydrogen planning and implementation. An immediate example is the current Los Angeles Department of Water and Power Environmental Impact Report for the Scattergood Modernization Project, which suggests various strategies to address NOx during combustion and presents an opportunity to adhere and adapt strategies to address community concerns. Ultimately, it falls on hydrogen proponents and decision makers to work with communities to make projects work for them, whether it comes to community engagement, transparency, or accessible information best practices. Without engagement and support of the communities where these projects will occur, there is no guarantee hydrogen won’t exacerbate environmental justice issues.

7. CONCLUSION

California's green hydrogen train seems to have left the station, with new power generation projects in LA and beyond already in progress and more slated to break ground in the coming years. For example, the Los Angeles Department of Water and Power is "modernizing" the Scattergood Generating Station to generate power with increasing proportions of hydrogen and is poised to complete the environmental review process for the modernization in summer 2025 (LADWP, 2024). Throughout California, other projects are planned or in progress. However, it is impossible for the public to know what these plans entail due to a lack of public transparency, as the majority of specific plans are held under a nondisclosure agreement. This lack of transparency makes research difficult and is widely criticized by advocates and stakeholders as stifling community engagement (for example, see a 2023 letter to the Office of Clean Energy Demonstrations from the California Environmental Justice Alliance) (CEJA, 2023).

Beyond the opaque details of hydrogen plans, there are many unknowns and potential pitfalls accompanying the resource along its life cycle. Even beyond the many uncertainties and challenges we address here, there are further knowledge gaps and impediments to equitable, affordable hydrogen implementation in California. It is crucial to thoroughly explore these barriers — if not before hydrogen projects are begun, then in parallel to implementation and before locking in an unknown future. While finding immediate certainty will be impossible on many fronts, we encourage leadership on hydrogen to make efforts to provide more transparency and assurances wherever possible.

In this brief, we aimed to estimate the impact that hydrogen production and use will have on water resources in the state. However, the aforementioned secrecy surrounding the Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES) and the planned hydrogen resources, as well as a broader lack of long-term field testing, made this difficult, if not impossible. We instead provided an empirical sketch of possible water impacts under different hydrogen scenarios. The implications will depend heavily on details that are not publicly known at this time. The burden of proof that hydrogen can be a sustainable energy resource (in terms of its water footprint and other impacts) is on the industry and decision makers. To reduce doubts, fears, and opposition, in-the-know leaders must provide such proof and commitments to sustainable implementation — blanket assurances that hydrogen is the best or only option are insufficient.

While we cannot confirm or demonstrate that there is no concern in terms of hydrogen's water footprint, the simple calculations in this brief illustrate that the aggregate impacts on water quantity in the state will likely be fairly minimal, if we take for granted the assertion that much of the hydrogen will be produced outside the state. Additionally, some or all of the water use may be offset by reduction of fossil fuel demand and use. Although our initial analyses suggest that aggregate water quantity impacts might be relatively minimal in the context of statewide water consumption, local effects, both within California and in other areas where hydrogen is being produced, could be substantial, as there could be the potential for increased competition of local water resources. It will be necessary to know exactly where and how much water will be required to understand these local impacts. Depending on these specifics, we may find that hydrogen has substantial negative water impacts.

Hydrogen production's reliance on ultrapure water also introduces high costs and significant quality demands, making options like recycled water or desalinated water less feasible and locally unsustainable. The quality and associated cost impacts of this purification are considerable and cannot be locally borne. The negative impacts hydrogen might have on local water supply are crucial to address. Taking into account broader environmental justice principles, hydrogen's water needs cannot be prioritized over achieving the Human Right to Water in the state, which remains a challenge. Environmental justice considerations highlight the complications of hydrogen's role in California's renewable energy future. Environmental justice organizations have raised concerns, specifically regarding the impact of hydrogen on local drinking water sources, emphasizing that hydrogen's water demands should not take precedence.

Given the track record of ARCHES, there is reason to be concerned whether these considerations will be fully addressed. Therefore, the hydrogen industry bears the burden of proof to ensure transparency and accountability. Moving forward, meaningful changes in industry practices will be essential to address community concerns, uphold environmental justice principles, and ensure hydrogen is well understood before doubling down on it as a climate — much less a climate equity — solution.

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