# THE SOUTHERN CALIFORNIA GREEN HYDROGEN CLUSTER


CA H2 HUB
SoCal Cluster

## Acknowledgements

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We would also like to thank 7th Generation Advisors, Accenture, Energy Independence Now, and Momentum, whose staff provided valuable research, analysis, and editorial guidance throughout the development of this report.

Ultimately, we are working together toward the common goal of jumpstarting an economically self-sustaining, multi-sector renewable hydrogen market across the state's ten southernmost counties. We believe that this effort will drive emissions reductions, economic growth, and environmental justice, particularly for those in disadvantaged and low-income communities who have been disproportionately burdened by the negative impacts associated with conventional transportation fuels.

AltaSea at the Port of Los Angeles is solely responsible for the conclusions and recommendations in this report.





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"Governments need to take rapid actions to lower the barriers that are holding low-carbon hydrogen back from faster growth, which will be important if the world is to have a chance of reaching net zero emissions by 2050." [2]

— Fatih Birol
Executive Director
International Energy Agency

"We are on the precipice of huge growth in the production, distribution, and use of green hydrogen to enable high renewable use and zero emissions in all sectors of the economy." [3]

— Jack Brouwer
Director the National
Fuel Cell Research Center at
the University of California, Irvine




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With the vast majority of hydrogen refueling stations in the United States,[4] 71% of total number of hydrogen fuel cell electric vehicles (FCEVs) in the United States (10,127/14,225),[5,6] and an abundance of hard-to-electrify sectors, California is exceptionally well situated to jumpstart an economically self-sustaining green hydrogen economy.[7]

These strengths are backed by one of the globe's strongest economies. In 2021, California's gross domestic product (GDP) was $3.36 trillion, representing 14.6% of the total U.S. economy.[8] If it were a country, California would have the fifth largest economy in the world.[9] Southern California alone—an area encompassing the state's ten southernmost counties[10]—had a GDP of $1.6 trillion in 2021, which would make it the 13th largest economy in the world, between Brazil and Australia.[11] California is also home to almost 40 million people.[12]

**Both California as a whole and the Southern California region in particular are leading efforts to decarbonize the state's modern economy, while creating new jobs, advancing equity, and tackling some of the state's most pressing environmental challenges, including drought, wildfires, extreme heat, poor air quality, and pollution.**

Green hydrogen can play an essential role to play in this process, presenting major opportunities in a variety of sectors, including transportation, goods movement, grid stabilization, industrial decarbonization, and energy storage. Most commonly referring to hydrogen that is produced via water electrolysis powered by renewable electricity, green hydrogen has a safer risk profile than many conventional fuels, is non-toxic, and has three times the energy content of gasoline by mass.[13] It can be stored for long durations, transported via pipelines at high energy-density, and used in a variety of ways—from power generation and transportation fuel to the decarbonization of hard-to-electrify sectors such as cement production and steel manufacturing.

PERCENTAGE OF U.S. ECONOMY

**14.6**

2021 GDP

**$3.36 TRILLION**

POPULATION

**39.2M**

## If it were a country, California would have the fifth largest economy in the world.


**SOUTHERN CALIFORNIA HAS TREMENDOUS POTENTIAL TO REDUCE EARLY MARKET RISK AND MATCH SUPPLY AND DEMAND ACROSS MULTIPLE MARKET SECTORS AT THE SCALE NEEDED TO DRIVE DOWN COST BARRIERS AND DEVELOP AN ECONOMICALLY SELF-SUSTAINING, EXPANDING, MULTI-SECTOR RENEWABLE HYDROGEN MARKET. THE REGION IS HOME TO SOME OF THE NATION'S BUSIEST PORTS, WORLD-CLASS NATIONAL LABORATORIES AND UNIVERSITIES, INNOVATIVE TECHNOLOGY DEVELOPERS, AND A BROAD RANGE OF PUBLIC AND PRIVATE ORGANIZATIONS COMMITTED TO DECARBONIZATION.**

Combined with the state's robust environmental and energy policy landscape and its recent history of investment in hydrogen research, development, and demonstration projects, these advantages could help Southern California leverage shared infrastructure and innovative, proven technologies to reduce emissions, create jobs, and spur economic growth, with the primary objective of delivering a cleaner and brighter economic future to the communities that have been most burdened by the negative impacts associated with fossil-fuel transportation, and, in particular, heavy-duty trucks. Green hydrogen most commonly refers to hydrogen that is produced via water electrolysis, a process that splits water into hydrogen and oxygen using electricity generated from renewable sources such as solar, wind, or geothermal power.

## HYDROGEN IS THE LIGHTEST, SMALLEST, AND MOST ABUNDANT ELEMENT IN THE UNIVERSE.

It also has great potential to accelerate the energy transition and decarbonize how we produce, store, and utilize energy. Some of the most promising potential uses include storing intermittent renewable energy; converting to a "zero-emission" fuel for port applications, aviation, and heavy-duty freight hauling; decarbonizing high-heat, industrial processes; and serving as a feedstock for industrial processes.[14]

Green hydrogen is typically produced via water electrolysis, a process that splits water into hydrogen and oxygen using electricity generated from renewable sources such as solar, wind, or geothermal power.

According to the International Energy Agency's (IEA) June 2019 report, The Future of Hydrogen, "[C]lean hydrogen is currently enjoying unprecedented political and business momentum."[15] The report concluded that "now is the time to scale up technologies and bring down costs to allow hydrogen to become widely used."[16] Further, the IEA found that:

- Hydrogen can help "decarbonize a range of sectors—including long-haul transport, chemicals, cement, iron, and steel—where it has proven quite difficult to reduce emissions."[17]
- Hydrogen is versatile. Hydrogen can be transported as a gas via pipeline or truck or as a liquid by truck and ship. It can be converted into electricity to power homes and buildings or into fuels for cars, trucks, ships, and planes.[18]
- Hydrogen can enable greater penetration of renewables by storing energy produced during periods of oversupply—preventing curtailment—and expending it during periods of undersupply days, weeks, or even months later. Hydrogen can also transport energy from regions where renewable energy is abundant to those that lack solar and wind resources.[19]
- Critical support for hydrogen is growing among governments, renewable electricity suppliers, industrial gas producers, electricity and gas utilities, automakers, oil and gas companies, major engineering firms, and cities.[20]

Although interest in green hydrogen is on the rise, hydrogen has been studied for more than 200 years and used in industry for many decades. The first documented production of hydrogen via water electrolysis occurred in 1800 and the first fuel cell was demonstrated in 1845.[21]

More recently, in the 1950s, the National Advisory Committee for Aeronautics (NACA) conducted research showing hydrogen's potential and demonstrated that liquid hydrogen could be safely used in manned flight.[22] In 1954, the U.S. Air Force sought to improve the performance of the U-2 high-altitude spy plane by using hydrogen.[23] Lessons learned about liquid hydrogen plants and test facilities proved valuable to the National Aeronautics and Space Administration (NASA) in its emerging space program, which explored the use of liquid hydrogen as rocket fuel.[24] Today, hydrogen is used in a wide variety of industrial processes, including oil refining and the production of ammonia, methanol, cement, sustainable aviation fuel, renewable diesel, and steel. Today, most hydrogen standards are collaboratively developed by the Hydrogen Industry Panel on Codes, the International Code Council, and the National Fire Protection Association.[25]



**Green hydrogen, most commonly refers to hydrogen that is produced via water electrolysis, a process that splits water into hydrogen and oxygen using electricity generated from renewable sources such as solar, wind, or geothermal power.**

## “Clean renewable hydrogen for ships and heavy-duty vehicles means cleaner air and reduced carbon pollution.”

—Terry Tamminen
AltaSea President/CEO[26]

**With a population of almost 40 million people, California is the nation's most populous state and one of the most forward-thinking.[27] It also has a history of playing an outsized role in setting national policy on a variety of topics, including minimum wage, unionization, immigrant rights, and cross sector environmental strategies, along with aggressive renewable energy goals.[28 29 30 31]** Indeed, how policy issues are addressed in California—whether through legislation, regulation, technology adoption, or judicial decision—often sets the standard for other states and the nation.[32]


As a result, resources invested in the development of a hydrogen hub in California have the potential for a catalyzing effect on the development of a national hydrogen network.

California possesses numerous other characteristics that make it well suited to serve as a hydrogen hub:

- **History of Hydrogen Investment:** Between 2008 and 2021, the State of California invested approximately $242 million (M) in hydrogen research, development, and demonstration projects through a variety of public agencies, including the California Energy Commission (CEC) and the California Air Resources Board (CARB).[33] This investment includes:
  - $224M in investments from the CEC's Clean Transportation Program, including $169.4M supporting the deployment of publicly available hydrogen refueling infrastructure; $30.1M for medium- and heavy-duty hydrogen refueling infrastructure deployment; $17.2M for fuel standards and equipment certification, light-duty fuel cell vehicle deployment, medium- and heavy-duty fuel cell vehicle demonstration, and regional alternative fuel readiness planning; and $7.9M for hydrogen production.
  - $18M in investments in hydrogen research on a variety of topics, including production, storage, grid support, transportation and building applications, and long-term research strategies.

These agencies have also allocated $22+M in upcoming research investments into renewable hydrogen production, hydrogen blending into the existing California natural gas system, hydrogen-based power generation systems, truck and bus technology and heavy-duty infrastructure, the effects of hydrogen on end use appliances, and the role of green hydrogen in a decarbonized California.[34]

The state is also proposing additional funding related to hydrogen, including:

- $160M to meet state goals for 2025 light-duty passenger vehicle infrastructure, including the addition of 21 hydrogen stations to meet the state's goal of 200 hydrogen stations.[35]
- $1,500M for specialized (drayage, transit, school) heavy-duty electric and hydrogen refueling infrastructure.[36]
- $125M for zero-emission vehicle manufacturing.[37]
- $100M for scaling green hydrogen production and use.[38]
- $110M for industrial decarbonization, including via hydrogen.[39]
- $140M for long-duration storage, including via hydrogen.[40]

- **Robust Economy:** As mentioned above, California possesses one of the world's strongest economies. Its 2021 GDP was $3.36 trillion, representing 14.6% of the U.S. economy.[41] If it were a country, it would have the fifth largest economy in the world after the United States, China, Japan, and Germany.[42 43]

| COUNTRY | GDP ($T USD) [44 45] |
|---|---|
| UNITED STATES | $22.996 |
| CHINA | $17.734 |
| JAPAN | $4.937 |
| GERMANY | $4.223 |
| CALIFORNIA | $3.356 |
| UNITED KINGDOM | $3.187 |
| INDIA | $3.173 |
| FRANCE | $2.937 |
| ITALY | $2.100 |
| CANADA | $1.991 |
| KOREA, REP. | $1.799 |

- **Early Adoption of Hydrogen Technology:** As of July 1, 2022, California had 56 hydrogen stations, 65% of which are located in Southern California.[46 47] As of the end of 2021, the state also had the largest number of hydrogen fuel cell electric vehicles (FCEVs) on the road of any state—approximately 10,127.[48] This represents approximately 71% of the total number of hydrogen FCEVs sold in North America, 14,225 (August 2022).[49]

**The following table illustrates additional California hydrogen-related data as of August 31, 2022[50]**

| | |
|---|---|
| FUEL-CELL BUSES (FCEBs) IN OPERATION IN CALIFORNIA | 66 |
| FCEBS IN DEVELOPMENT IN CALIFORNIA | 103+ |
| HYDROGEN STATIONS AVAILABLE IN CALIFORNIA (OPEN - RETAIL) | 54 |
| TOTAL RETAIL HYDROGEN STATIONS IN DEVELOPMENT IN CALIFORNIA | 117 |
| TRUCK HYDROGEN STATIONS IN OPERATION IN CALIFORNIA | 3 |
| TRUCK HYDROGEN STATIONS FUNDED IN CALIFORNIA | 9 |

- **Favorable Energy and Environmental Policy Landscape:** California is working toward its aggressive 100 percent zero-carbon energy planning goal by 2045, along with other local policies and a "lead by example" adoption of clean energy and transportation technologies.[51] See Section 6 for more information.

- **Innovation Ecosystem:** California is home to a robust network of organizations that fund and conduct energy research projects, including those focused on hydrogen. Prominent among these organizations are the University of California, California State University, multiple DOE-funded national laboratories, the CEC, CARB, and a variety of private organizations, such as Toyota Motor Corporation. See Section 7 for more information.

> **"Hydrogen…has the potential to help the state reduce emissions from the transportation sector, meet the unique needs of industrial and commercial uses, and be used as a fuel for firm generation and energy storage."**
>
> — Hydrogen Fact Sheet
> California Energy Commission[52]

Within California, Southern California is exceptionally well situated to jumpstart an economically self-sustaining, expanding, multi-sector green hydrogen market that could reduce emissions, create jobs, and spur economic growth, with the primary objective of delivering a cleaner and more sustainable economic future to the communities that have been most burdened by the negative impacts associated with fossil fuel transportation, and, in particular, heavy duty trucks.

The region is home to some of the nation's busiest ports, world-class national laboratories and universities, innovative technology developers, and a broad range of public and private organizations committed to decarbonization. Southern California also hosts 20 Department of Defense facilities, including Vandenburg Air Force Base, Naval Information Warfare Systems Command, Marine Corps Air Station Miramar, and Marine Corps Base Camp Pendleton.[53] These facilities are critical to national security and require the type of reliable, resilient energy system that a Southern California green hydrogen market would seek to develop.

With more than 60% (23,606,469) of the state's population (39,237,836), Southern California encompasses the state's ten southernmost counties: Los Angeles, Imperial, Riverside, Orange, San Bernardino, Santa Barbara, San Diego, Ventura, San Luis Obispo, and Kern.[54] [55] It includes seven major metropolitan areas, including Los Angeles, San Diego, and San Luis Obispo.[56] Los Angeles County is the largest county in California by population, with 9,829,544 residents.[57] The larger statistical area—encompassing five counties including Los Angeles, Ventura, and Orange—is second in the nation in size only to the New York City metropolitan area.[58]

As discussed previously, Southern California had a GDP of $1.6 trillion in 2021, which would make it the 13th largest economy in the world, between Brazil and Australia.[59]

Characteristics unique to Southern California include:

**Broad Commitments to Decarbonization:** Throughout Southern California, many municipalities and large organizations have committed to renewable energy, including renewable electricity that can be used to produce renewable hydrogen. Examples include:

- **LA100:** The City of Los Angeles has set ambitious goals to transform its electricity supply, aiming for a 100% renewable energy power system by 2045, along with a push to electrify the building and transportation sectors.[60]
- **Clean Air Action Plan:** The Port of Los Angeles and the Port of Long Beach have jointly committed to a "zero-emissions goods movement future—with ultimate goals of zero emissions for cargo handling equipment by 2030 and zero emissions for on-road drayage trucks serving the ports by 2035."[61]
- **Shanghai-Los Angeles Green Shipping Corridor:** This partnership of a group of 97 cities around the world representing one twelfth of the world's population—the C40 Cities—plus numerous ports, shipping companies, and cargo owners is striving to create a zero-emissions trans-Pacific trade route.[62]
- **Angeles Link:** As part of its commitment to the decarbonization of its energy delivery and operations, SoCalGas is proposing to develop what could be the "nation's largest green hydrogen energy infrastructure system, the Angeles Link, to deliver clean, reliable energy to the Los Angeles region" and "support the integration of renewable electricity resources such as solar and wind."[63]
- **HyDeal Los Angeles:** The Green Hydrogen Coalition is an "initiative to develop the first scaled ecosystem for green hydrogen in North America, targeting under $2.00/kg delivered green hydrogen in the LA Basin."[64]
- **San Diego's 2022 Climate Action Plan (CAP):** The City of San Diego's "2022 CAP establishes a community-wide goal of net zero by 2035, committing San Diego to an accelerated trajectory for greenhouse gas reductions."[65]
- **Maritime Clean Air Strategy:** The Port of San Diego's "Maritime Clean Air Strategy (MCAS) and its vision, 'Health Equity for All,' represent the Port's commitment to environmental justice. It is one of the most ambitious clean air policy documents of its kind in the state. In fact, nearly all the MCAS goals and/or objectives go beyond what is currently required by the State of California."[66]
- **100% Renewable Energy:** 30+ municipalities across California have adopted 100% renewable energy through their community choice aggregation programs.[67] Many of these are in Southern California, including Irvine, Huntington Beach, and Buena Park.

## The Port of Los Angeles and the Port of Long Beach, handle more containers per ship call than any other port complex in the world.

**End-User Diversity:** The region has a wide variety of potential industrial end-users, including cement and steel producers, commercial fleets, heavy-duty transportation including commercial fleets, and some of the world's busiest ports.

- **The San Pedro Bay Port Complex:** Comprising the Port of Los Angeles and the Port of Long Beach, this complex handles more containers per ship call than any other port complex in the world and is responsible for 74% of the U.S. West Coast's market share and 35% of the total U.S. market share of all containerized international waterborne trade in the U.S.[68] Collectively, both ports are associated with the operation of a wide variety of heavy-duty freight-hauling trucks and cargo handling equipment, most of which is currently powered by diesel fuel. This tally includes numerous drayage trucks. The ports are also home to large numbers of diesel-powered cargo handling equipment, such as yard tractors, forklifts, top handlers, reach stackers, straddle carriers, and rubber tire gantry cranes.
- **State Fleet Vehicles:** The State of California operates a decentralized fleet of approximately 50,000 vehicles used by dozens of agencies, many of which operate in Southern California.[69] As of February 2021, roughly 8.4% of this fleet was comprised of battery electric vehicles (BEVs) and FCEVs.[70] Following the requirements of AB 739 (Skinner, 2017), the state seeks to increase this number to 15% by the end of 2025 and to 30% by the end of 2030.[71] Additionally, beginning no later than FY2024-25, SB 498 (Skinner, 2017) requires the Department of General Services to ensure that at least 50% of the light-duty vehicles purchased for the state vehicle fleet each year are zero-emission.[72] Finally, the Advanced Clean Cars II rule set forth by CARB to meet Executive Order N-79-20, which states that 100% of new cars and light-duty trucks sold in California by 2035 will be zero-emission vehicles.[73]
- **Transit Agencies:** California is home to several regional transit agencies exploring the use of hydrogen fuel cell buses. In Southern California, the SunLine Transit Agency is at the forefront of this transition. Currently, SunLine operates 16 hydrogen fuel cell buses[74] and has plans to convert its entire fixed-route fleet to zero-emissions buses by 2035 and its paratransit fleet by 2032.[75] Similarly, San Diego's North County Transit District (NCTD) was recently awarded a grant to help fund the purchase of eight hydrogen fuel cell electric buses. NCTD also has the objective to deploy 25 hydrogen fuel cell electric buses by March 2025, and to have an entirely zero-emission fleet by 2042.[76] [77]
- **Cement Producers:** Southern California includes the majority of the state's nine cement plants, which collectively produce approximately 9.8 Mt of cement per year[78] and consume roughly 34.28 petajoules (PJ) of heat from fuel combustion and 1,340 gigawatt hours (GWh) of electricity.[79] SB 596 requires the state board, by July 1, 2023, to develop a comprehensive strategy for the state's cement sector to achieve net-zero emissions of greenhouse gases associated with cement used within the state by 2045.[80]

- **Renewable Diesel Production:** In 2021, California refineries produced 42,000,000 gallons of renewable diesel.[81] In this process, high-pressure hydrogen is used to remove oxygen from the feedstocks. Currently, renewable diesel producers are the single largest category of hydrogen consumers in California.

**Southern California is also well situated to take advantage of four near-term, mutually reinforcing opportunities identified by the IEA to jumpstart the adoption of renewable hydrogen:**

**Make Industrial Ports the Nerve Centers for Scale-Up of Clean Hydrogen:** Southern California includes the Port of Los Angeles and the Port of Long Beach. Collectively, these two ports handle approximately 35% of the U.S. market share of all containerized international waterborne trade in the U.S.[82] Both have committed to a zero-emissions goods movement future, with initial zero-emission targets in 2030 and 2035 and are keenly interested in the role that renewable hydrogen can play in helping them achieve their decarbonization goals.[83 84]

**Build on Existing Infrastructure:** Southern California would not be starting from scratch in its efforts to develop a green hydrogen market as part of a state-wide renewable hydrogen hub. **In 2004, through EO-S-07-04, then-Governor Arnold Schwarzenegger initiated the California Hydrogen Highway Network (CaH2Net) with assistance from Terry Tamminen, the then Secretary of the California Environmental Protection Agency.** This led to the development of a blueprint plan that gathered input from over 200 stakeholders and detailed the actions needed to create a **"Hydrogen Highway"** that would increase the odds that hydrogen fueling stations would be in place to meet the demand of hydrogen FCEVs entering California roads.[85 86] Today, Southern California leads the nation in hydrogen mobility with a growing network of hydrogen

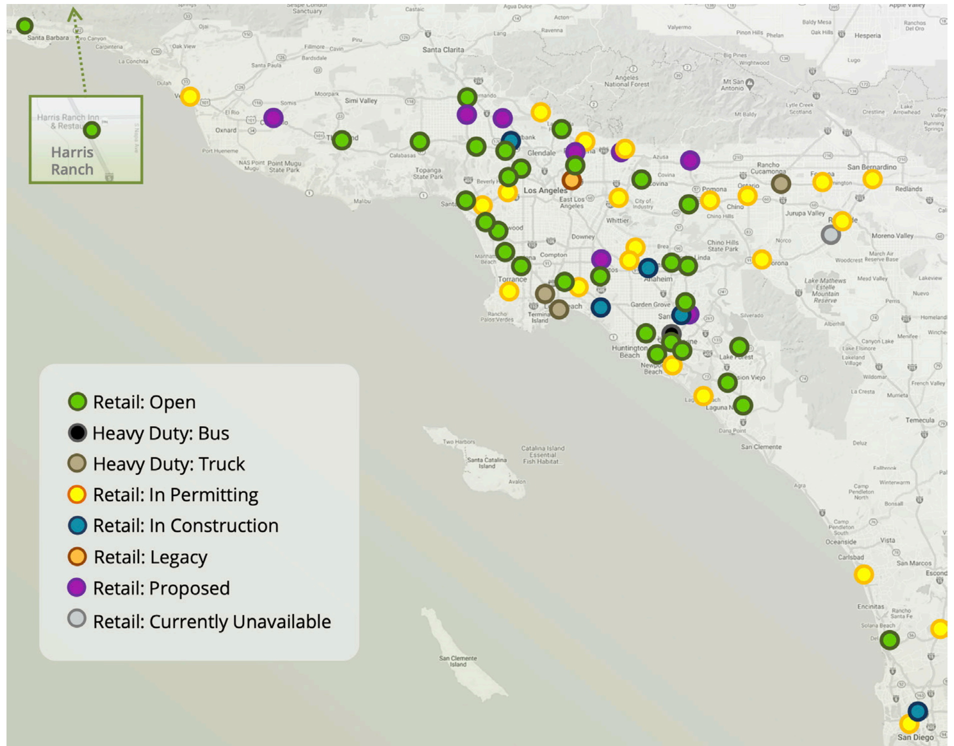



Figure 1: Southern California includes a growing network of existing and planned hydrogen refueling stations.[90]

fueling stations, a nascent hydrogen corridor network, and multiple hydrogen technology demonstration projects, including a multiyear demonstration at the San Pedro Bay ports of multiple new class-8 hydrogen-powered fuel cell electric trucks and the development of hydrogen refueling infrastructure to fill Toyota vehicles.[87 88 89] The region is also home to a growing network of existing gas transmission and distribution pipelines as well as the skilled workforce necessary to operate such infrastructure.

**Expand Hydrogen in Transport:** **With 7.5% of the total DMV registrations in the United States, the Southern California region is one of the nation's largest transportation markets.**[91 92] Driven by EO-N-79-20 and other state and regional initiatives, the region has begun the transition away from fossil fuels to zero-emission options. Southern California is also home to numerous projects demonstrating hydrogen fuel cell buses, cargo handling equipment, and medium- and heavy-duty trucks. EO-N-79-20 requires that:

**1) 100% of in-state sales of new passenger cars and trucks are to be zero-emission by 2035; 2) 100% of in-state sales of medium- and heavy-duty trucks and buses are to be zero-emission by 2045, where feasible; and 3) 100% of off-road vehicles and equipment sales are to be zero-emission by 2035 where feasible.**[93]

**Launch First International Zero-Emissions Shipping Routes:** The Port of Los Angeles, Port of Shanghai, and C40 Cities are working with leading industry partners to create a zero-emissions trans-Pacific trade route.[94] The goals of the route planners include reducing greenhouse gas emissions from the movement of cargo throughout the 2020s and beginning the transition to zero-carbon-fueled ships by 2030 in a bid to slash emissions from one of the world's busiest cargo routes. Hydrogen and hydrogen-derived fuels will likely play a major factor in developing these zero-emissions trade routes.[95]



## Southern California would not be starting from scratch in its efforts to develop a green hydrogen market.

**As of January 1, 2022, Los Angeles County had a population of 9,829,544.**[96] According to the U.S. Census, 13.2% of those residents—approximately 1,301,682 people—live in poverty.[97] Many live in areas categorized as disadvantaged communities as defined by California's SB 535 (De Leon, 2012)[98] and low-income communities and households, which are defined by AB 1550 (Gomez, 2016)[99] as census tracts or households at or below 80% of the statewide median income or at or below the threshold designated as low-income by the California Department of Housing and Community Development's Revised 2021 State Income Limits.[100]

DISADVANTAGED LOW-INCOME BOTH

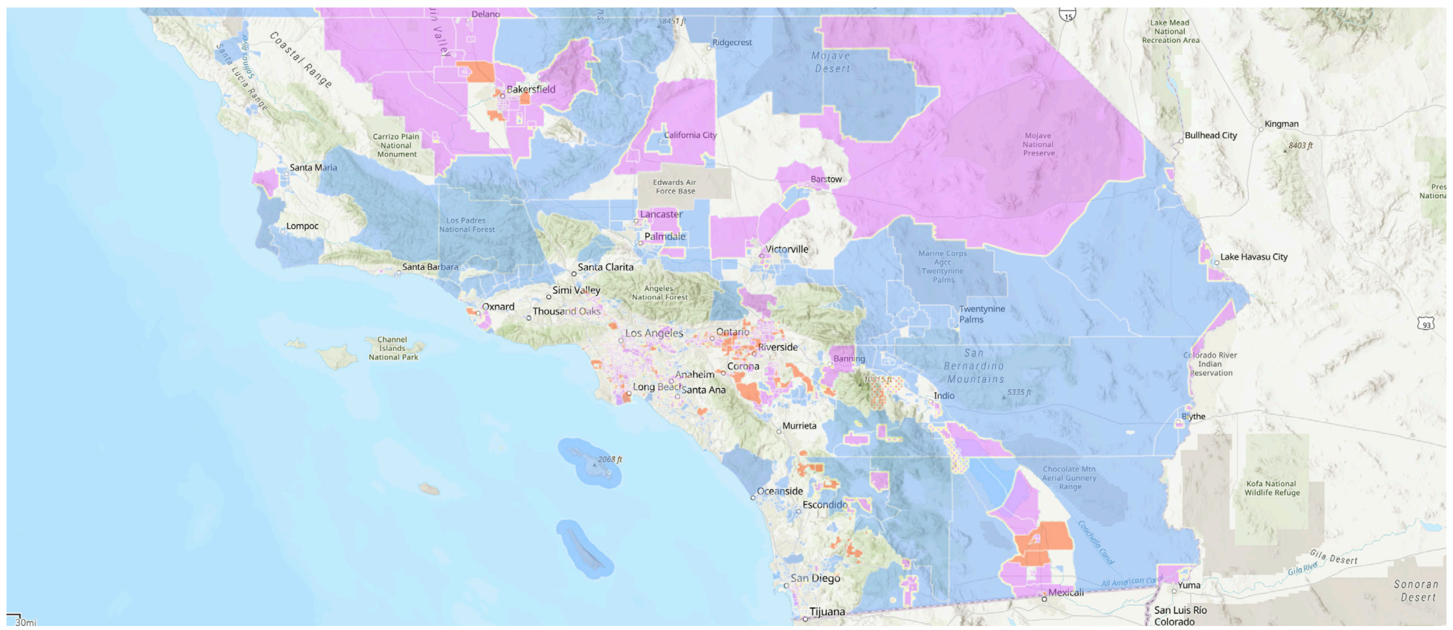


Figure 2: Map of Southern California's disadvantaged (pink) and low-income (blue) communities. Orange areas are categorized as both disadvantaged and low-income.[101]

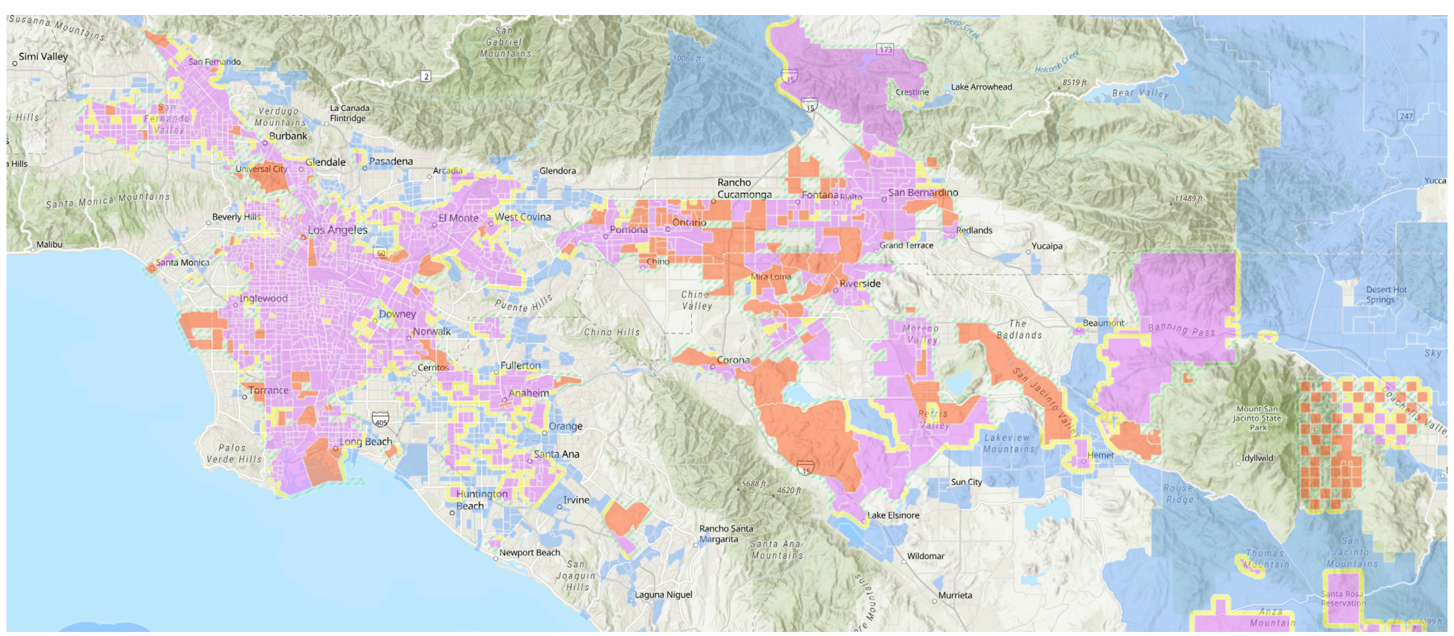


Figure 3: Map of Los Angeles area disadvantaged (pink) and low-income (blue) communities. Orange areas are categorized as both disadvantaged and low-income.[102]



**Such communities have been disproportionately impacted by the negative environmental impacts associated with fossil-fuel-based transportation and have also been left out of many of the benefits of California's growing green economy. Examples of these disproportionate impacts include:**

- **Reduced Access to Clean Energy:** To date, many of the benefits of Southern California's green economy have bypassed disadvantaged communities. For example, adoption rates of solar energy are eight times higher in California's top 5% most advantaged communities in comparison to the bottom 5%.[103]

- **Air Quality and Health:** On average, Latinos and African Americans breathe in roughly 40% more particulate matter (PM) from cars, trucks, and buses than White Californians.[104] Low-income populations are especially vulnerable to this air pollution due to underlying health problems, poor nutrition, and proximity to industrial facilities.[105]

- **Higher Mortality Rates:** African Americans in Los Angeles are nearly twice as likely to die from a heat wave than other Los Angeles residents, and families living below the poverty line are unlikely to have access to air conditioning or cars that allow them to escape the heat.[106] A study in the New England Journal of Medicine found that Hispanics and Asians, but especially Blacks, had a higher risk of premature death from particle pollution than Whites did.[107] By replacing fossil fuels correlated with cargo handling, heavy-duty transportation, and industry, a hydrogen hub could substantially reduce greenhouse gas and criteria air pollutant emissions, which could mitigate the negative impacts correlated with poor air quality associated with heavy-duty transportation.

- **Reduced Economic Opportunity:** A warming climate may dramatically reduce or shift job opportunities in sectors such as agriculture and tourism, which predominantly employ people of color.[108] When combined with poor air quality, its toll is even more serious, reducing people's ability to work and the ability of ecosystems to perform functions needed by societies.[109]

The Los Angeles region has historically suffered from some of the worst air quality impacts in the United States.[110] Areas near the Port of Los Angeles and the Port of Long Beach are categorized in CalEnviroScreen 4.0 as suffering from a variety of negative environmental and socioeconomic impacts, including high concentrations of ozone and particulate matter (PM), excess traffic, poverty, and unemployment.[111] Replacing the diesel-powered drayage trucks that carry goods into and out of the ports will not only improve air quality in these disadvantaged communities but also throughout California's Inland Empire, an area west of Los Angeles comprising San Bernardino and Riverside Counties.[112] The Inland Empire faces many challenges, including:[113]

- "Only 20% of adults in the IE have a four-year college degree or higher, versus 32% for California and 30% for the nation."
- "San Bernardino County ranks 50th out of 58 California counties for clinical care, which includes ratios of population-to-care providers, preventive screening practices, and insurance coverage."
- "In San Bernardino County, 18.2% of the population lives below the poverty line, primarily females, a number that is higher than the national average of 13.1%."
- "About 41% of IE households have a language other than English spoken in the home."
- It receives "only $25.55 per capita philanthropic investment, compared to $262.99 per capita average investment in California."

**Low-income populations are especially vulnerable to air pollution due to underlying health problems, poor nutrition, and proximity to industrial facilities. A hydrogen hub could substantially reduce air pollutant emissions, which could mitigate the negative impacts.**

The development of a sustainable green hydrogen economy in Southern California could help mitigate these negative impacts. To maximize the long-term viability of a green hydrogen economy, it must also include the extensive and ongoing participation by members of the region's disadvantaged and low-income communities. Fortunately, Southern California is home to a widespread network of community-based organizations (CBOs), environmental groups, and environmental justice (EJ) organizations that can maximize the likelihood that the benefits of a green hydrogen economy flow to disadvantaged and low-income communities. These groups could work with technology developers, academia, and industry to support adoption of the following principles by new hydrogen economy:

- **Empowerment:** Commitment to identifying and engaging key stakeholders in Southern California, with the goals of better understanding community interests and concerns, negotiating meaningful Community Benefits Agreements, and enacting plans for ongoing and meaningful participatory or third-party monitoring of equity metrics.

- **Inclusion:** Include individuals from disadvantaged and low-income communities in this and future phases of the project through:

  - The creation of career and job opportunities.
  - Incorporation of faculty, graduate students, and undergraduates from regional Minority Serving Institutions and Hispanic Serving Institutions for research activities.
  - Support for STEM education among surrounding disadvantaged populations.
  - Use of a consent-based siting process to locate green hydrogen projects within disadvantaged and low-income communities.

- **Targeted Benefits:** Seek to deliver benefits to disadvantaged and low-income communities within Southern California. Examples include:

  - Reducing GHG emissions by approximately 13.2 million metric tons (MMT) per year, which will in turn result in roughly $900M in savings associated with the social costs of carbon emissions.[114] The Social Cost of Carbon calculates the avoided economic damages from changes in net agricultural productivity, human health, wildfires, droughts, excessive heat, and other hidden economic costs that arise from increased global warming.[115 116]

Given that stationary emissions sources impacted by a Southern California green hydrogen market are primarily located near disadvantaged communities, and transport corridors tend to run near and even bisect these communities, the reduction in emissions in these areas could drive substantial impact for disadvantaged communities.[117]

  - Reductions in emissions of diesel particulate matter and criteria air pollutants.
  - Generating new jobs. On average, 13.5 new full-time jobs are created for every $1 million spent on wind or solar power versus only 5.2 per $1 million spent on fossil fuels.[118] Further, green jobs pay, on average, $3 more per hour than new jobs in traditional industries.[119] New jobs created would include technicians, installers, manufacturing professionals, trainers, insurers, educators, scientists, engineers, chemists, and project managers.
  - Green job training to facilitate the transition of engineers, managers, skilled laborers, and others employed by the fossil fuel industry to new jobs in the green hydrogen economy.

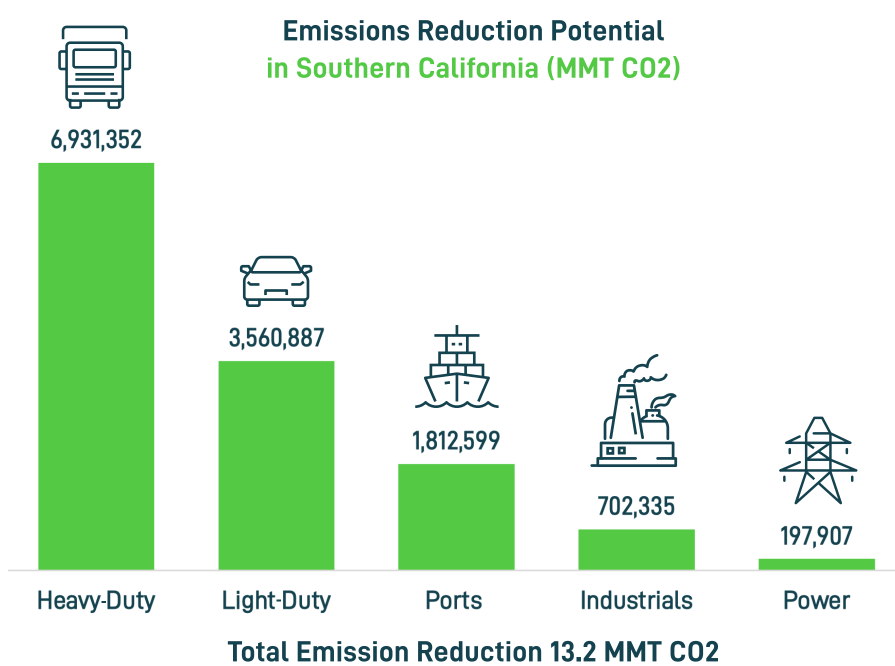



Figure 4: Emissions reduction potential in Southern California. Source: SoCal System Value Benefits Model, 2022. Accenture Analysis.



> **"California has the market experience, workforce talent, public and private investment base, and renewable resources to partner with the federal government to create an economically resilient, expanding hydrogen hub that helps accelerate national success."**
>
> — Director, GO-Biz
> Senior Economic Advisor
> to Governor Newsom[120]

Southern California benefits from the state's commitment to a 100 percent zero-carbon energy planning goal by 2045, along with other local policies and "lead by example" adoption of clean energy and transportation technologies.[121] Policies that support this goal as well as the development of a renewable hydrogen hub include:

- **AB 1279 (Muratsuchi, Garcia, 2022):** "Establishes a clear, legally binding, and achievable goal for California to achieve statewide carbon neutrality as soon as possible, and no later than 2045, and establishes an 85% emissions reduction target as part of that goal."[122]
- **Clean Transportation Program:** Through this program, the CEC is investing in an initial network of 100 public hydrogen stations across California to support the fuel cell electric cars that are on the road now, and to encourage more consumers to consider these zero-emission vehicles.[123]
- **SB 1505 (Lowenthal, 2006):** Requires that 33.3% of hydrogen for transportation comes from renewable sources.[124]
- **AB 8 (Perea, 2013):** CARB must annually aggregate and report the number of hydrogen vehicles that manufacturers project will be sold or leased over the next three years and the total number of hydrogen vehicles registered in the state. It also allocates up to $20 million per year to fund publicly available hydrogen stations until there are at least 100 in the state.[125]
- **SB 1075 (Skinner, 2022):** Requires the CEC to study and model potential growth for hydrogen and its role in decarbonizing the electrical and transportation sectors of the economy. This bill also requires the consideration of potential uses of green electrolytic hydrogen in all decarbonization strategies of the CEC and the Public Utilities Commission.[126]
- **Advanced Clean Cars I:** CARB's "Advanced Clean Cars program builds upon the zero-emission vehicle (ZEV) regulation in place since 1990, and encourages rapid increases in deployment of ZEV technologies, such as hydrogen fuel cell and battery-electric vehicles."[127]
- **Advanced Clean Cars II:** In August 2022, CARB approved this rule that establishes "a year-by-year roadmap so that by 2035 100% of new cars and light trucks sold in California will be zero-emission vehicles, including plug-in hybrid electric vehicles."[128]
- **California Public Utilities Commission (CPUC):** In its Integrated Resources Plan (IRP) proceeding the CPUC issued a Ruling that proposes to meet a significant portion of new capacity for electricity generation with "green" or "renewable" hydrogen rather than fossil fuels.[129] The IRP Ruling's renewable hydrogen mandate aims "to help support a transition toward greater use of renewable hydrogen to replace natural gas."[130]
- **Hydrogen Program:** This program carves out $100 million in the state budget for financial incentives to eligible in-state hydrogen projects for the demonstration or scale-up of production, processing, delivery, storage, or end use of hydrogen. Financial incentives provided may be used as matching funds by selected entities that have received a federal hydrogen hub grant.[131]
- **Long-Duration Storage:** This program shall provide $140 million in financial incentives for projects, located at storage facilities that have power ratings of at least one megawatt and can reach a target of at least eight hours of continuous discharge of electricity. The goal is for these facilities to deploy innovative energy storage systems to the electrical grid for purposes of providing critical capacity and grid services. An eligible project consists of an energy storage system—such as hydrogen—that is interconnected to the electrical grid in California or to a California balancing authority.[132]
- **Low Carbon Fuel Standard (LCFS):** This program is "designed to decrease the carbon intensity of California's transportation fuel pool and provide an increasing range of low-carbon and renewable alternatives, which reduce petroleum dependency and achieve air quality benefits."[133]
- **Renewable Portfolio Standard (RPS):** Administered by the CEC and the CPUC, the RPS requires "electric utilities and other load-serving entities to procure increasing amounts of renewable energy to serve customer demand. The RPS requires utilities to procure 33 percent of retail sales from renewable resources by 2020 and 60 percent by 2030."[134]
- **Global Warming Solutions Act of 2006:** Set a statewide limit on the sources responsible for 85% of California's greenhouse gas emissions and established a price signal needed to drive long-term investment. Hundreds of millions of dollars have been annually appropriated for clean car and truck incentives from the state's cap and trade revenues.[135]
- **July 22, 2022, Governor's Letter to the California Air Resources Board:** Governor Newsom declared his request that the CEC establish a planning goal of at least 20 GW of offshore wind generation by 2045, demonstrating the state's continuing commitment to renewable energy generation.[136]
- **Budget Trailer Bills (AB 179 (Reyes, 2019)[137] and AB 209 (Committee on Budget, 2022)[138]) Food Production Investment Program:** This program will provide $25 million in financial incentives for the implementation of projects at eligible food production facilities to accelerate the adoption of advanced energy and other decarbonization technologies to support electrical grid reliability and reduce GHG emissions. Projects must develop and deploy novel decarbonization technologies and strategies.

RED CROSS CELEBRATES ZEV PILOT WITH FLEET OF FCEVs

California is home to a robust network of organizations that fund and conduct energy research projects, including those focused on hydrogen.

**University of California (UC):** With more than 27,000 research personnel and 800 research labs, centers, and institutes, the University of California is a world leader in clean energy research, development, and innovation. Its $5.17 billion budget represents about one-tenth of all academic research conducted in the United States.[139]

Specific energy-related highlights of the UC system include:

- **Advanced Power and Energy Program (APEP), UC Irvine:** The APEP "at the University of California, Irvine addresses the development and deployment of efficient, environmentally sensitive, sustainable power generation and energy conversion worldwide."[140] APEP encompasses the National Fuel Cell Research Center, which facilitates and accelerates the development and deployment of fuel cell technology and systems.[141]

- **California Institute for Energy and Environment (CIEE), UC Berkeley:** CIEE partners with the CEC, the CPUC, the DOE, "utilities, and other research sponsors to help form the agenda for research in energy science, technology, and policy—identifying the most critical avenues on the complex route to California's energy goals."[142]

- **Center for Energy Research (CER), UC San Diego:** CER fosters research in energy research to solve the energy challenges of the 21st century. The center's work "spans from fundamental physics and chemistry of nuclear fusion, lasers, and advanced materials to renewables grid integration research on battery energy storage, solar inverters, and solar forecasting."[143]

- **Scripps Institution of Oceanography, UC San Diego:** The institution is set to design and build a new coastal research vessel with a first-of-its-kind hydrogen-hybrid propulsion system.[144]

- **UC Davis' Energy and Efficiency Institute (EEI):** The EEI "is a leading university institution focused on addressing critical energy challenges and improving energy use through research, education, and engagement. The EEI is home to innovative research centers and programs in buildings, transportation, water, and agriculture & food production; has more than 50 affiliated faculty; and hosts an interdisciplinary graduate program in energy systems."[145]

- **UC Davis' Institute of Transportation Studies (ITS):** ITS has been performing technical and modeling research on hydrogen and fuel cell vehicles for over 20 years. ITS is currently working on a variety of research pertaining to hydrogen systems under the "California Hydrogen Systems Analysis" study.[146]

**California State University (CSU):** Several CSU campuses have specialized campus centers and institutes dedicated to the technical, economic, and environmental aspects of energy use.

- **California Energy Research Center, CSU Bakersfield:** CERC facilitates the engagement of CSU Bakersfield faculty and students in collaborative research efforts with local energy-related industry and agencies for the benefit of the local community, the region, and the state of California. CSU Bakersfield is a Hispanic Serving Institution.[147]

- **Energy Research Center, CSU Northridge (CSUN):** "The primary purpose of the Energy Research Center is to promote, research and development projects in new or alternative energy sources as well as conservation and sustainability practices at CSUN."[148]

- **Hydrogen Research and Fueling Facility, CSU Los Angeles (Cal State LA):** The Cal State LA Hydrogen Research and Fueling Facility is the largest university-located hydrogen fueling facility in the U.S. "On November 12, 2014, the Cal State LA Hydrogen Research and Fueling Facility became the first in the world to sell hydrogen fuel by the kilogram directly to retail customers."[149]

- **Schatz Energy Research Center, California Polytechnic Institute, Humboldt:** The Schatz Center "has provided 30 years of cutting-edge research, thought leadership, and project development in the planning and deployment of community-scale renewable energy. The Schatz Center began with a focus on hydrogen as a storage medium for intermittent renewable energy. This evolved into research and development on fuel cells, electric vehicles and hydrogen fueling infrastructure."[150]

- **Sustainable Energy Center, CSU San Diego:** This program provides research opportunities for both academic and industry researchers and fosters cutting-edge renewable energy research through a focus on public and private sector partnerships.[151] Present hydrogen research includes hydrogen-fueled gas turbine and renewable hydrogen production from wastewater.[152 153]

**Private Universities**

- **Stanford Energy—Hydrogen Initiative:** This initiative "convenes collaborations between research groups at Stanford University from engineering, science, policy, and business to work with industry, governments and thought leaders to accelerate the use of hydrogen to achieve deep decarbonization of the global energy system in order to address climate change. Over 30 Stanford research groups and 150 researchers are working on hydrogen-focused areas."[154]

- **Xiang Research Group, Caltech:** As part of the DOE HydroGEN Benchmarking project, this group works on advanced water-splitting technologies, including high/low temperature electrolysis and photoelectrochemical and solar thermochemical water splitting. Additionally, the Benchmarking group also hosts an annual HydroGEN Workshop and brings together the research community from four advanced water-splitting pathways in order to discuss and review roadmaps, techno-economic analysis and the deployment of renewable hydrogen productions.[155]

**National Laboratories:** California manages three DOE-funded national laboratories:

- **Lawrence Berkeley National Laboratory (LBNL):** "LBNL's mission is to create advanced new tools for scientific discovery and to work on problems of great scale, enabling transformational solutions for energy, health, and environment."[156]

- **Lawrence Livermore National Laboratory (LLNL):** "LLNL has a mission of strengthening the United States' security through development and application of world-class science and technology to: enhance the nation's defense; reduce the global threat from terrorism and weapons of mass destruction; and respond with vision, quality, integrity, and technical excellence to scientific issues of national importance."[157]

- **Los Alamos National Laboratory (LANL):** "LANL's mission is to develop and apply science and technology to ensure the safety, security, and reliability of the U.S. nuclear deterrent; reduce global threats; and solve other emerging national security and energy challenges." LANL is managed by the UC System.[158]

**California Energy Commission (CEC):** The CEC plans a variety of hydrogen investments:

- $160M to meet state goals for 2025 light-duty passenger vehicle infrastructure, including the addition of 21 hydrogen stations to meet the state's goal of 200 hydrogen stations.[159]

- $1,500M for specialized (drayage, transit, school) heavy-duty electric and hydrogen refueling infrastructure.[160]

- $125M for zero-emission vehicle manufacturing.[161]

- $100M for scaling green hydrogen production and use.[162]

- $110M for industrial decarbonization, including via hydrogen.[163]

- $140M for long-duration storage, including via hydrogen.[164]

**California Department of Conservation's Pilot Forest Biofuels Gasification Program:** This program makes $50 million available for creating carbon-negative hydrogen and/or liquid fuel from forest biomass.[165]

**Other Hydrogen Initiatives:** Numerous private entities within Southern California conduct other hydrogen-related activities:

- **Toyota Research & Development:** With Hydrogen focused R&D at its Gardena California facility, the organization seeks to adapt Toyota's industry leading automotive hydrogen fuel cell technology with the "goal of packaging virtually everything needed to create clean, emissions free electricity into a standardized kit that can provide power to various mobile platforms or act as a stationary generator."[166]

- **SoCalGas RD&D:** This program seeks to identify and support third-party projects and technologies that could save energy, reduce GHG emissions, improve air quality, and increase the safety, reliability, and affordability of energy. Just in 2021, SoCalGas invested nearly $17 million in hundreds of energy technology and clean fuels projects, including many focused on hydrogen.[167]

- **San Diego Gas & Electric (SDG&E):** SDG&E is deploying multiple projects to advance hydrogen innovation:[168]
  - **Borrego Springs Hydrogen Project:** SDG&E will use an electrolyzer and a fuel cell to provide long-duration energy storage to an existing microgrid.
  - **Palomar Energy Center Hydrogen project:** SDG&E will produce hydrogen with an electrolyzer and solar energy at its Palomar combined cycle plant for a variety of use cases (blending hydrogen with natural gas for electric generation, fuel cell electric vehicle fueling, and generator cooling).
  - **UC San Diego Hydrogen Blending project:** In September 2022, SDG&E submitted a proposal to the CPUC to demonstrate the feasibility of injecting up to 20% clean hydrogen into an isolated section of a natural gas line that serves common building equipment in a UC San Diego apartment complex to fill knowledge gaps and eventually help inform the creation of a system-wide hydrogen blending standard.

- **AltaSea:** The organization has created a 35-acre urban, ocean-based campus at the Port of Los Angeles. The cutting-edge 400,000 square foot campus is built on a historic pier with unparalleled access to the deep ocean. One of the areas of focus at the campus is renewable energy, including hydrogen.

- **Plug Power:** Plug Power seeks to advance a fully integrated green hydrogen ecosystem. Focused on production, storage, delivery and energy generation, the company is developing the largest green hydrogen production facility on the U.S. West Coast in Fresno County. Once the facility is completed, it will be capable of producing 30 metric tons of liquid green hydrogen per day.[169]

**California's rich innovation ecosystem has supported hydrogen-related R&D efforts for several decades. Today, this ecosystem stands ready to cooperate in the grand effort of creating an economically and environmentally sustainable green hydrogen market that could serve as a cornerstone for a nationwide market that could support the decarbonization of the nation's energy, transportation, and power industries.**


**MOMENTUM IS BUILDING AROUND THE DEVELOPMENT OF A GREEN HYDROGEN ECONOMY IN SOUTHERN CALIFORNIA. BUILT ON THE FOUNDATION OF A DIVERSE PUBLIC-PRIVATE COALITION, THIS NEW ECONOMY COULD ADVANCE DECARBONIZATION ACROSS MULTIPLE SECTORS—PORTS, TRANSPORTATION, INDUSTRY, AND AVIATION—SPUR ECONOMIC GROWTH, AND DELIVER A CLEANER AND MORE SUSTAINABLE ECONOMIC FUTURE TO THE COMMUNITIES THAT HAVE BEEN MOST BURDENED BY THE NEGATIVE IMPACTS ASSOCIATED WITH FOSSIL-FUEL-BASED TRANSPORTATION.**

Further, a growing Southern California green hydrogen market would fully support the state's efforts to leverage federal investment from the recently passed Infrastructure, Investment, and Jobs Act and the development of an economically and environmentally sustainable statewide Renewable Hydrogen Hub that integrates similar efforts in Northern California and California's Central Valley.

Southern California organizations will continue to work with GO-Biz and the rest of the Governor's Administration as it leads public and private stakeholders toward the goal of submitting a single, state-sponsored application encompassing projects throughout California to the DOE's "Regional Clean Hydrogen Hubs" funding program.

Due to the relative maturity of hydrogen technology and demand, a Southern California market will initially include green hydrogen production, storage, and transport, with initial end use applications focused on industry, transportation, power generation, and ports.

**To succeed, a green hydrogen economy based in Southern California would seek to achieve several key objectives and realize associated benefits, including:**

| OBJECTIVE | BENEFITS |
|---|---|
| Advance equity and inclusion | A thriving Southern California green hydrogen economy could 1) foster a welcoming and inclusive environment for individuals and organizations from disadvantaged and low-income households and communities; 2) rely on mechanisms such as Community Benefits Agreements, consent-based siting, and participatory monitoring to maximize the likelihood that disadvantaged populations will have ongoing and meaningful input; and 3) deliver targeted benefits—including sustainable jobs and emissions reductions—to disadvantaged communities. |
| Advance multi-sector decarbonization in Southern California | By leveraging shared production, transmission, and distribution infrastructure and innovative, proven technologies, a Southern California green hydrogen economy could reduce risk, spur further investment, and advance decarbonization across multiple hard-to-electrify sectors, such as heavy-duty freight hauling, cement production, and steel manufacturing. |
| Foster a culture of innovation | A key component of growing a Southern California green hydrogen economy is a commitment to the pursuit of new commercially viable technologies and net-zero solutions that accelerate decarbonization and maximize system-value outcomes. A viable economy will reduce the risk of technology adoption, provide a testing ground for new equipment and processes, and pave the way for further advancements and growth. |
| Realize emissions reduction targets of more than 13 MMT-$CO_2$e/year by 2035 | A Southern California green hydrogen economy has the potential to reduce emissions by more than 13 MMT-$CO_2$e/year by 2035 through the displacement of fossil fuels.[170] These carbon emissions reductions could, in turn, be associated with reductions in emissions of particulate matter and NOx. |
| Create local economic opportunity | A Southern California green hydrogen economy will create local economic opportunity by creating high-quality, stable union jobs and other work opportunities in the clean energy space for local residents, and by working with institutions of higher education, apprenticeship programs, and other workforce development agents to create and train highly skilled hydrogen infrastructure workers and transition the oil and gas workforce to clean energy jobs. |
| Explore all avenues for green hydrogen production | By relying on electrolytic production of green hydrogen as a core production methodology but exploring other options—including the use of low-carbon biogas or renewable natural gas—a Southern California green hydrogen market could open the door to a broad range of potential green hydrogen producers. Ultimately, this market would focus on the carbon intensity score of the hydrogen produced and not on the production method. |

# “In 2021, California was the nation’s top producer of electricity from solar, geothermal, and biomass energy.”

— U.S. Energy Information Administration State Profile and Energy Estimates[171]

Green hydrogen via electrolysis will require significant renewable energy sources to power electrolyzers. Short-term hydrogen demand can be met with renewable energy from solar curtailment, but in the long-term, dedicated renewable energy production for hydrogen production will be needed. In the short term, seasonal redirection of unused energy capacity can satisfy most hydrogen demand but dedicated renewable energy production for hydrogen will be critical to offset curtailment seasonality and for long-term demand.

**WITH AN ABUNDANCE OF RENEWABLE ENERGY, NUMEROUS CURRENT AND PLANNED UTILITY-SCALE SOLAR INSTALLATIONS, POTENTIAL ACCESS TO UNDERGROUND STORAGE, AND THE PROPOSITION FOR THE NATION’S LARGEST GREEN HYDROGEN PIPELINE NETWORK, SOUTHERN CALIFORNIA IS WELL POSITIONED TO PRODUCE AN ABUNDANT SUPPLY OF GREEN HYDROGEN.**[172]

California is recognized worldwide for transitioning its electricity system to one that relies increasingly on clean sources of energy, such as solar, wind, and geothermal. In fact, in May 2022, the state produced more power than was needed for a few hours using only renewable energy capacity.[173] The CEC estimated that in 2020 59% of the state’s electricity came from renewable and zero-carbon sources.[174]

According to the U.S. Energy Information Administration (EIA), in 2021, California was:[175 176]

- Second in the nation in total electricity generation from renewable resources, including generation from small-scale solar PV generation.
- The nation’s top producer of electricity from solar, geothermal, and biomass resources.
- The nation’s fourth-largest producer of electricity from conventional hydroelectric power.
- The nation’s sixth-largest producer of electricity from wind energy.

## 9.1 Solar Generation

California and in particular, Southern California, is rich in solar resources. In 2021:

- Solar energy supplied 17% of the state’s utility-scale electricity net generation.[177]
- California produced 32% of the nation’s total solar PV electricity generation and 69% of the nation’s utility-scale solar thermal electricity generation.[178]
- California had almost 15,500 megawatts of utility-scale solar power capacity, more than any other state. When small-scale facilities are included, the state had almost 28,000 megawatts of total solar capacity.[179]



# Southern California is rich in solar resources.

CALIFORNIA PRODUCED **32%** OF THE NATION’S TOTAL SOLAR PV ELECTRICITY GENERATION

CALIFORNIA IS THE NATION’S **6TH LARGEST** PRODUCER OF ELECTRICITY FROM WIND ENERGY

NATION’S TOP PRODUCER OF ELECTRICITY FROM SOLAR, GEOTHERMAL, AND BIOMASS RESOURCES.

**California’s greatest solar resources are in the state’s southeastern deserts, where all of its solar thermal facilities and most of its largest solar PV plants are located.**[180] As seen in Figure 5, much of Southern California receives more than 5.75 kWh/m²/day, with virtually all of it receiving more than 5.0 kWh/m²/day. These figures place Southern California among the top-ranked areas in the United States for solar irradiance and, therefore, suitability for solar power installations.

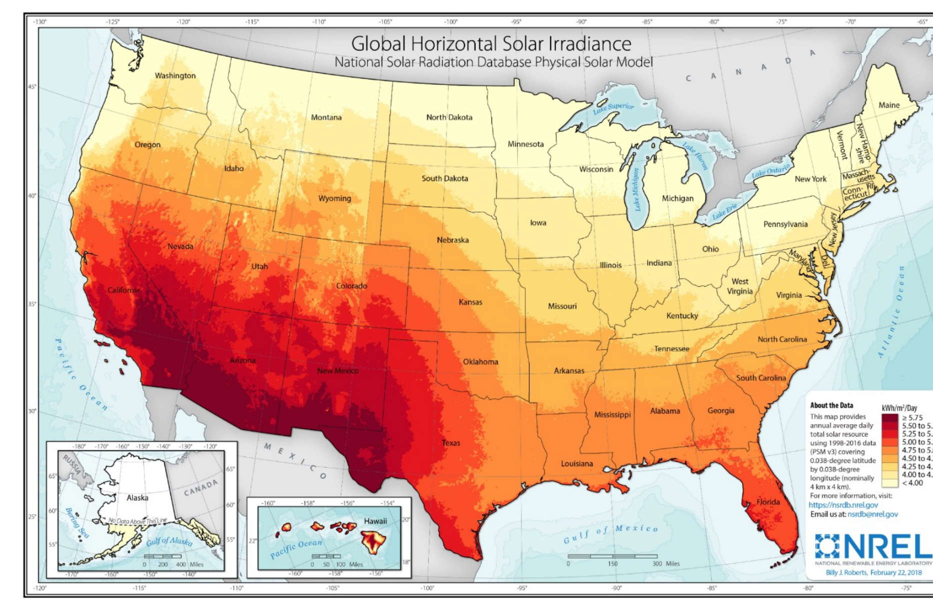



Figure 5: Much of Southern California receives an average of more than 5.75 kWh/m²/day of solar irradiance.[181]

**About the Data**
This map provides annual average daily total solar resource using 1998-2016 data (PSM v3) covering 0.038-degree latitude by 0.038-degree longitude (nominally 4 km x 4 km).

**kWh/m²/Day**
- ≥ 5.75
- 5.50 to 5.75
- 5.25 to 5.50
- 5.00 to 5.25
- 4.75 to 5.00
- 4.50 to 4.75
- 4.25 to 4.50
- 4.00 to 4.25
- < 4.00

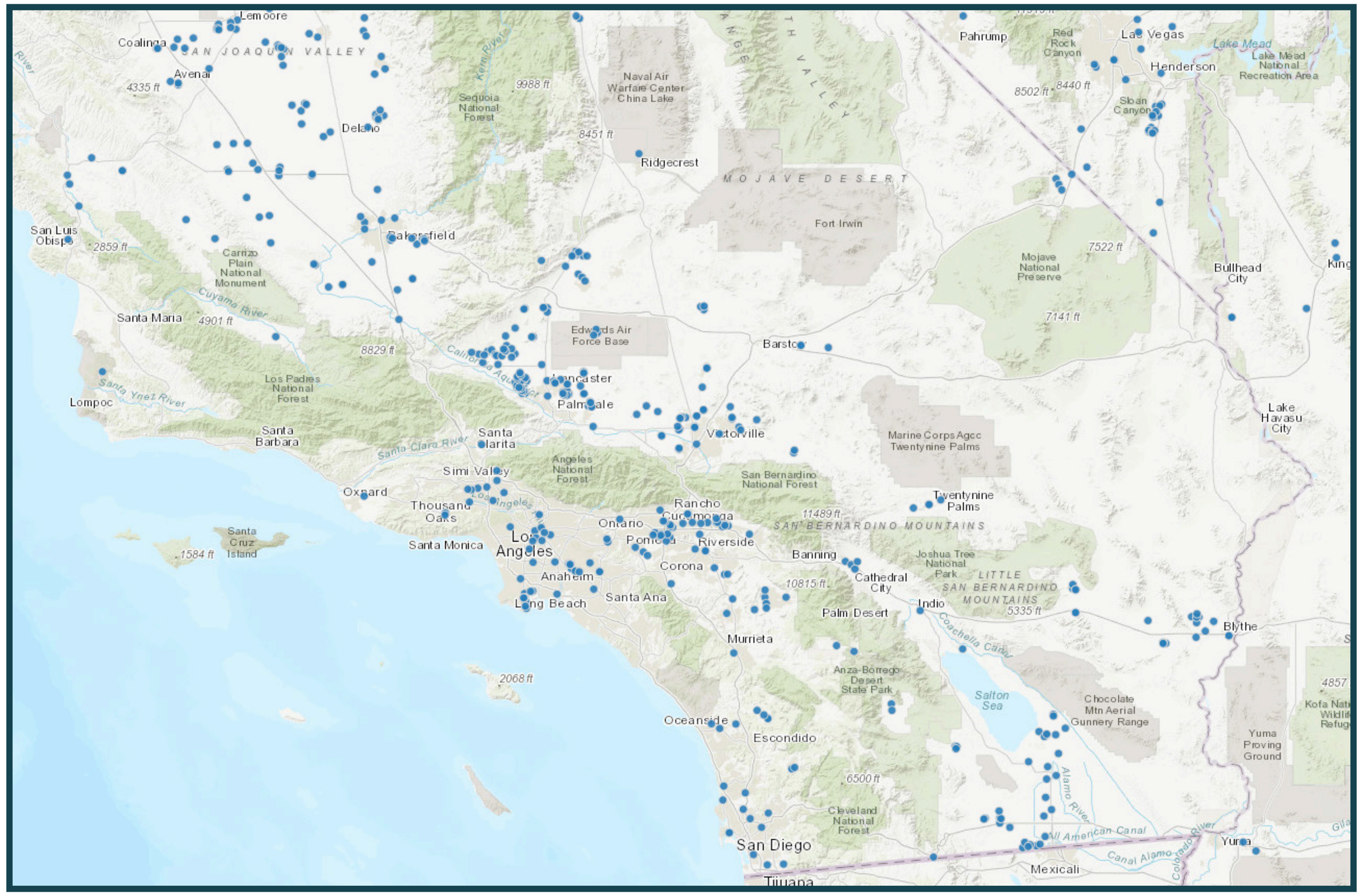



Figure 6: Operable solar electric generating plants in Southern California.[182]

## Indeed, Southern California is home to many operable electric generating plants.

**On the path to achieving the state's 2045 zero-carbon targets, solar is expected to be a significant source of renewable energy in California for both the grid and hydrogen production.** In addition to utility-scale solar projects, solar generation equipment can be installed on residential or commercial rooftops or co-located at hydrogen production sites.

### 9.2 Geothermal Generation

In the U.S., California is the top producer of electricity from geothermal resources.[183] In 2021, the state produced about 70% of the nation's utility-scale geothermal-sourced electricity, and geothermal power accounted for almost 6% of California's utility-scale generation.[184] The state has four major areas of geothermal resources, including near the Salton Sea in Southern California.[185]



Figure 7: Operable geothermal electric generating plants in Southern California.[186]

### 9.3 Wind Generation

**In 2021, wind accounted for 8% of California's in-state electricity generation, and the state ranked sixth in the nation in wind-powered generation.**[187 188] California's wind power potential exists at several areas around the state, both onshore and offshore.[189] The majority of the state's wind turbines are in six major wind resource areas, including three in Southern California: San Diego County, San Gorgonio, and Tehachapi.[190] As of December 2021, California had almost 6,300 megawatts of wind capacity.[191]

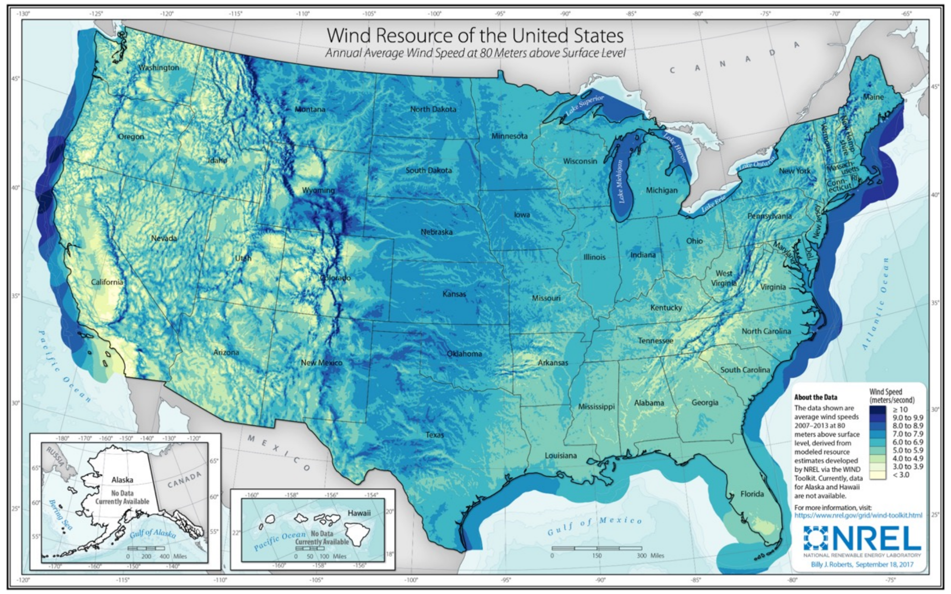



Figure 8: Southern California is rich in wind resources that could be utilized to generate green hydrogen.[192]

**About the Data**
The data shown are average wind speed 2007-2013 at 80 meters above surface level, derived from modeled resource estimates developed by NREL via the WIND Toolkit. Currently, data for Alaska and Hawaii are not availble.

**Wind Speed (meters/second)**
- ≥ 10
- 9.0 to 9.9
- 8.0 to 8.9
- 7.0 to 7.9
- 6.0 to 6.9
- 5.0 to 5.9
- 4.0 to 4.9
- 3.0 to 3.9
- < 3.0

## Salt Formations

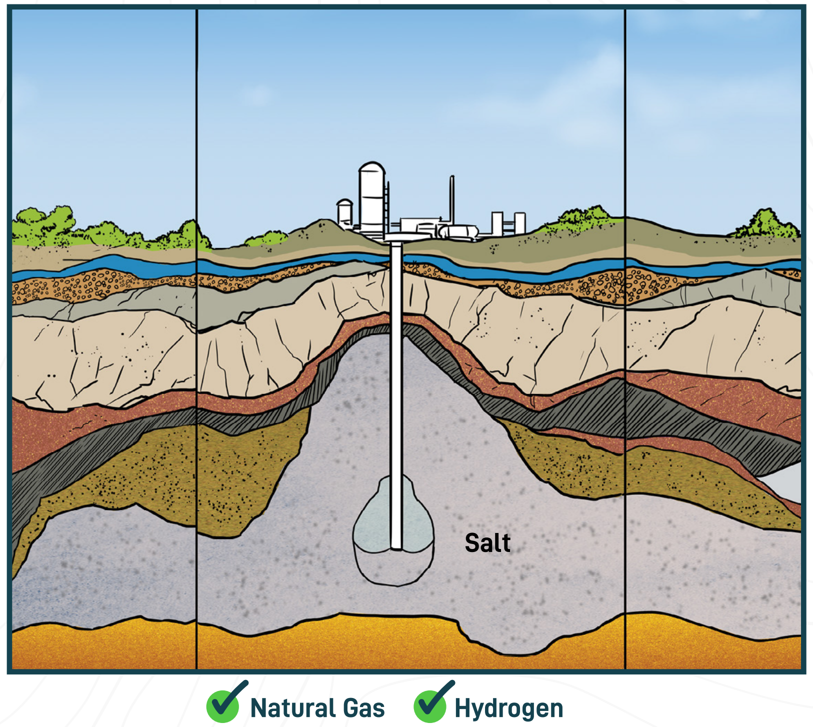



Figure 9: Underground salt formations are well suited to storing hydrogen.[193]

### 9.4 Storage

Aboveground storage of hydrogen using pressurized containers is commonly used and is a mature storage technology. Aboveground pressurized systems may be the technology of choice for short-duration storage, as they are low-cost, can be used in many locations, are easily transported, and can be filled and emptied quickly.

Salt caverns are a known method of storing large volumes of hydrogen underground. BloombergNEF estimates that there are six salt cavern projects that already store hydrogen (three in the U.S. and three in the U.K., all used by the chemical industry).[194] Although economically viable salt domes are not found in California, there are salt domes located outside of the state that could be potentially utilized for large-scale storage. Potential sites include salt caverns in Arizona and Utah.

### 9.5 Curtailment

Southern California is incorporating increasing amounts of renewable energy into its electric system in support of its ultimate commitment to 100 percent zero-carbon energy by 2045 (Section 7). At times, however, California's renewable resources can generate more electricity than is needed at any given moment, producing an energy surplus.[195]

To maintain the balance between supply and demand, the California Independent System Operator (CAISO) reduces—or curtails—the production of energy from these renewable resources. California curtailment peaked at approximately 600 GWh in April 2022.[196] While this approach works as an operational tool, it also means that Southern California is not maximizing the value of its renewable energy resources.[197]



## Renewable Curtailment in California

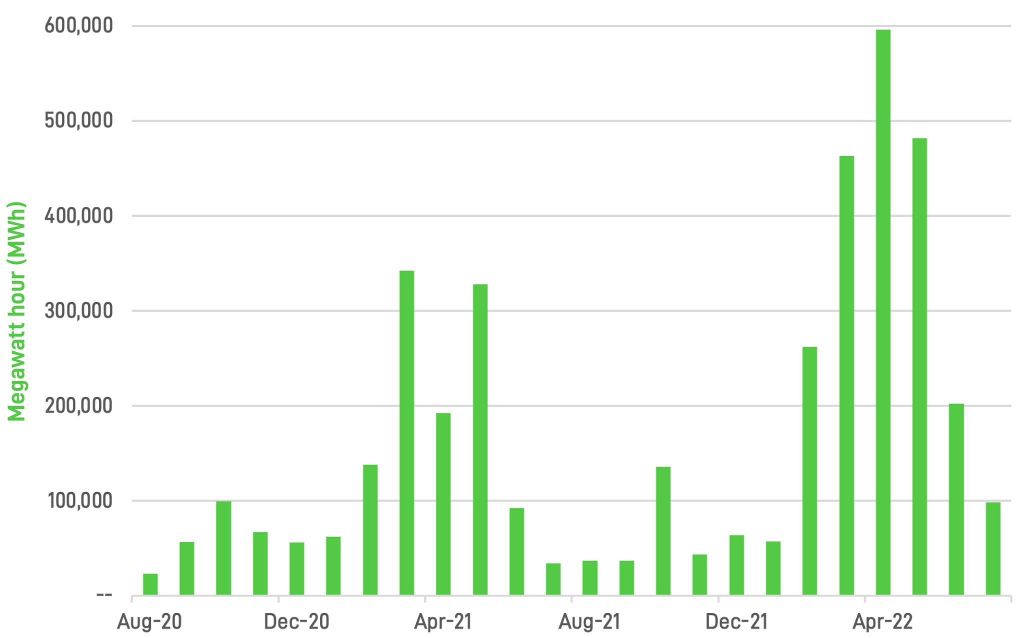



Figure 10: California wind and solar curtailment totals by month.[198]

As renewable energy production increases, seasonal curtailment is only expected to increase. By using this excess renewable energy to produce green hydrogen and then storing it underground or in tanks, a Southern California hydrogen economy could shift excess energy from periods of oversupply to periods of undersupply.[199]

**BY BETTER BALANCING ELECTRICITY SUPPLY WITH DEMAND FOR ELECTRICITY, THE STATE WILL BE ABLE TO MINIMIZE OR ELIMINATE CURTAILMENT OF RENEWABLE ENERGY AND ACHIEVE ITS ZERO-CARBON GOALS FASTER.**

## 9.6 Other Supply Considerations

Renewable energy is only one consideration involved in securing a reliable supply of green hydrogen. Other required resources include water, land, electrolyzers, pipelines, fueling stations, and storage.


Figure 11: Supply considerations for green hydrogen.



## 9.7 Water

Water consumption for hydrogen production is expected to reach 14,000 - 29,000 $m^3$ by 2035, which represents less than 1% of California's total water consumption in 2021.[200] To conserve water generally, and also in response to the ongoing drought, however, a Southern California green hydrogen market would seek to incorporate water from a diverse array of sources, including gray or reclaimed water, to minimize the impact on the state's already strained water system.

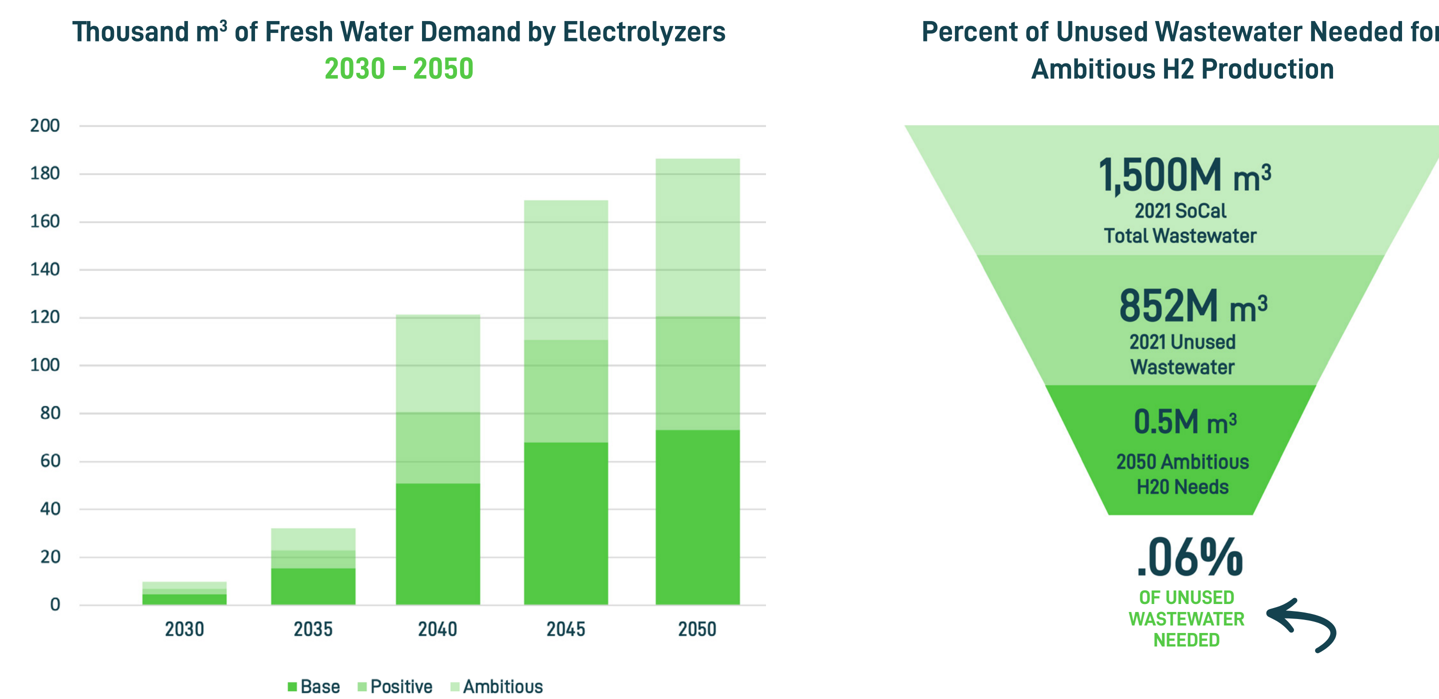



Figure 12: Estimated pure water needed by 2035. This analysis assumes that water demand is expected to remain relatively linear with hydrogen production. Assumptions include: 1) electrolyzer water consumption of 9L of water for each kg-$H_2$ produced and 2) water consumption triples if wastewater is used for hydrogen production due to losses during the purification process.[201]

**THE OPTIMUM LOCATIONS FOR ELECTROLYZERS WITHIN SOUTHERN CALIFORNIA HAVE NOT YET BEEN DETERMINED, BUT IT IS CLEAR THAT PROXIMITY TO WATER SOURCES WILL BE CRITICAL.**

Alternative water sourcing from wastewater or gray water needs to be considered for hydrogen production to reduce the impact on Southern California's natural aquifers and reservoirs. Gray or wastewater solutions would require additional resources and infrastructure to purify the water, leading to additional energy and resource consumption to produce green hydrogen. Wastewater hydrogen production solutions are still nascent; projects under development are still in testing or proof-of-concept phases. Assuming that wastewater hydrogen production solutions are commercialized and require triple the amount of water, only 504,000 cubic meters would be required—less than 0.1% of Southern California's 2021 unused wastewater.[202]

## 9.8 Electrolyzers

Electrolyzer availability will be critical for the development of a scaled green hydrogen economy in Southern California. Current annual production capacity is unable to meet the forecasted market demand and needs to grow exponentially in the near term. In fact, by 2036, projected electrolyzer demand will consume all of U.S.-produced electrolyzers unless additional manufacturing capacity is created.[203]

1.5 GW of U.S. electrolyzer manufacturing capacity is expected by 2025. U.S. producers each currently have or plan on building one plant, each of which would require approximately 12-24 months to build and become operational.[204] Based on these current and planned capabilities, U.S. manufacturers could produce electrolyzers with a cumulative total capacity of 10 GW. New funding from the federal Inflation Reduction Act (IRA) of 2022 is expected to be a key enabler of accelerating the production growth rate. The DOE's 2022 Fuel Cell and Electrolyzer supply chain analysis predicts that U.S. manufacturing capacity will be able to reach approximately 130 GW per year by 2050.

**GW of Electrolyzers Produced in U.S. vs SoCal Electrolyzer Demand**
**2022 – 2040**

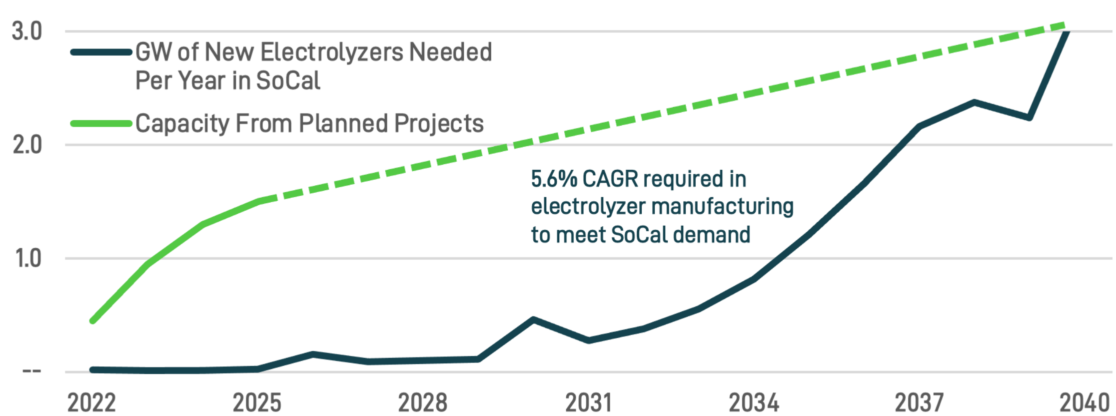



Figure 13: GW of electrolyzers produced in the U.S. versus demand for electrolyzers in Southern California.[205]



## 9.9 Fueling Stations

Transit is expected to be the largest consumer of hydrogen in the future, namely from regional and long-haul trucking.[206] Thus, initial hydrogen refueling stations are expected to be concentrated along key transit corridors and to be scaled to support medium- and heavy-duty vehicles.

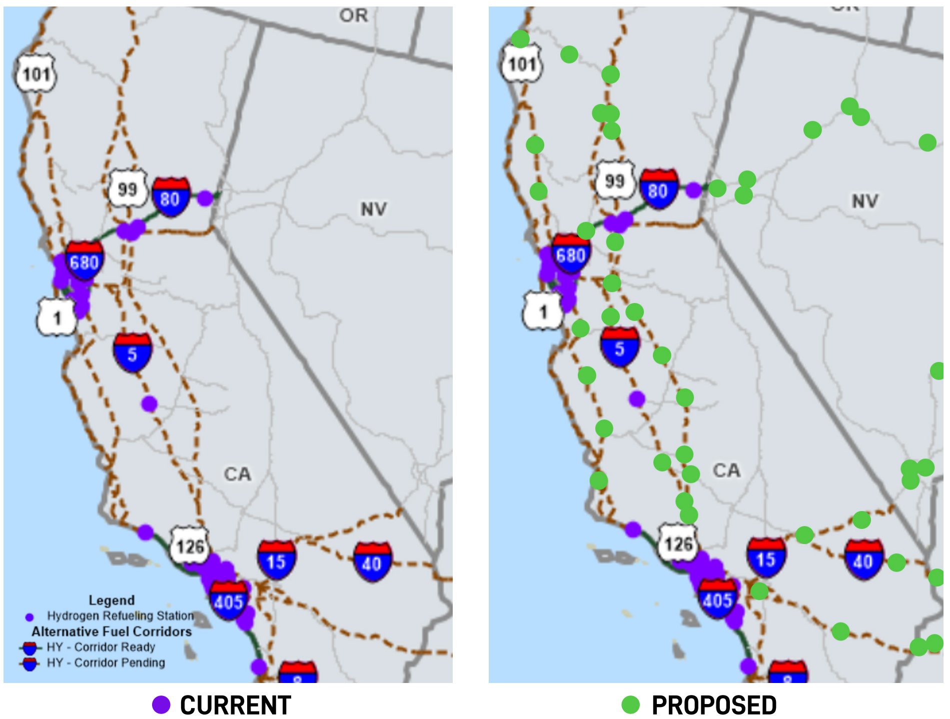
**Hydrogen fueling stations will most likely be located next to sources of hydrogen demand—such as key transit corridors, ports, and industry—and hydrogen pipeline routes, which will enable easy and affordable supply chain management.**

Research from the West Coast Collaborative found that 62 fueling stations would be required to support medium- and heavy-duty vehicles in California in the near term.[207] These stations would support anywhere from 3,000 to 15,000 kg-$H_2$/day.[208] These figures represent roughly 600-3,000 car refuels per day or 100-500 heavy-duty truck refuels.[209 210]

## 9.10 Shared Infrastructure

A green hydrogen economy would require extensive shared infrastructure to support distribution to end users, including hydrogen fueling stations along transit corridors, hydrogen pipelines from demand to supply sites, and hydrogen storage capabilities.

Figure 14: Map of current and proposed hydrogen fueling stations and hydrogen corridors in California.




### PIPELINE & STORAGE CAPACITY CONSIDERATIONS

**Potential Pipeline Route Mileages**

| START POINT | END POINT | MILES |
|---|---|---|
| LANCASTER | POWER GEN STATIONS | 60-150 |
| LANCASTER | PORTS | 152 |
| MOJAVE | LANCASTER | 250 |
| BLYTHE | PORTS | 287 |
| AZ STORAGE | PORTS | 300+ |
| BLYTHE | POWER GEN STATIONS | 230-280 |
| AZ STORAGE | POWER GEN STATIONS | 300+ |
| NORCAL-SACRAMENTO | PORTS | 410 |

Specific routes will be determined upon project selection, however there are several general criterial to consider for initial routes: **Proximity to early heavy users (such as ports), Connectivity to storage facilities, Co-location along key transit corridors**

Source: Accenture Strategy Analysis, 2022.

**Potential Hydrogen Storage Considerations**

- The LA Basin does not have adequate local storage capabilities to service expected green hydrogen demand.
- Salt caverns are often discussed as viable options to store hydrogen; however, they are not an option in Southern California. Several exist in Arizona and Utah.
- To ensure the reliability and consistent supply of hydrogen a minimum of 2X the daily demand will need to be stored. And, if production of green hydrogen relies on curtailment, seasonal storage must be considered as well.

**Hydrogen Infrastructure Demand Consumer Strategy**

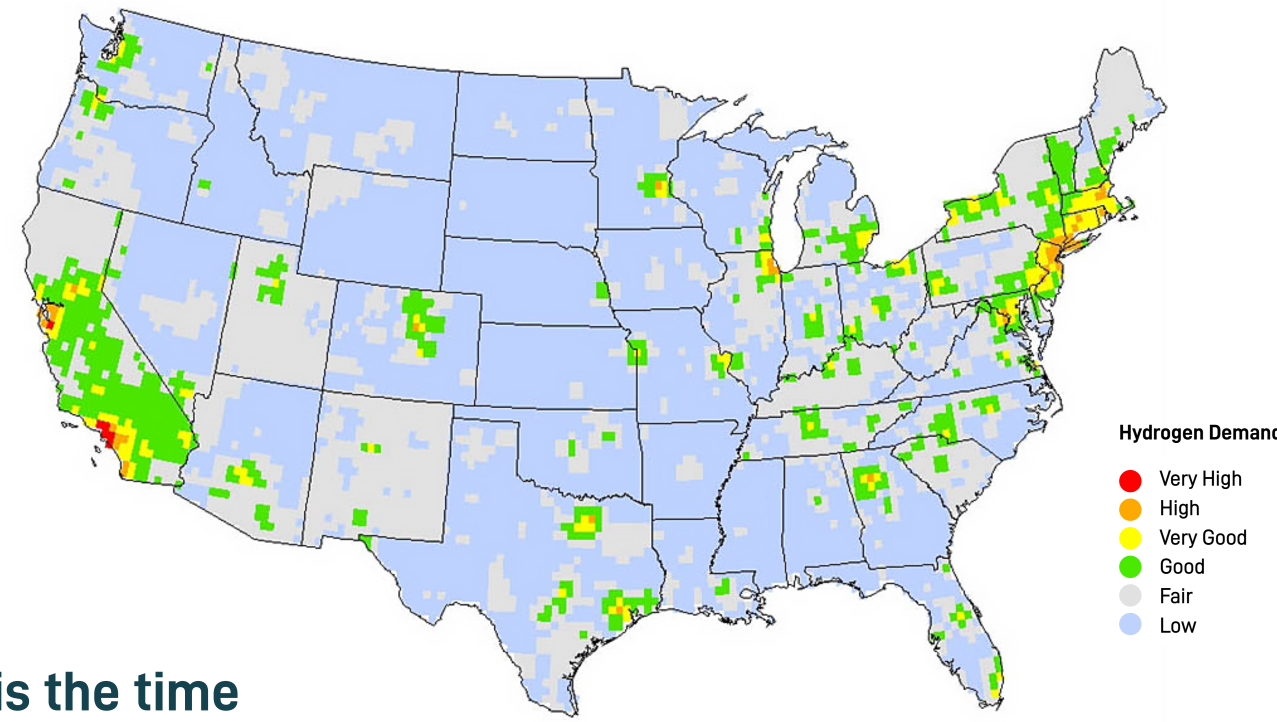



Figure 15: Hydrogen infrastructure demand across the U.S.[213]

> **“Now is the time to scale up technologies and bring down costs to allow hydrogen to become widely used.”** 211
>
> — The Future of Hydrogen
> June 2019

**IN ITS 2019 REPORT PREPARED FOR THE G20, JAPAN 2019, THE IEA CONCLUDED THAT “CLEAN HYDROGEN IS CURRENTLY ENJOYING UNPRECEDENTED POLITICAL AND BUSINESS MOMENTUM.”[212]**

There are few places on the globe where that conclusion is more apt than Southern California; assuming federal, state, and regional legislation and incentives continue to support the adoption of hydrogen technologies and subsidize the price of hydrogen production and fuel cell vehicles. Potential demand for green hydrogen is high in Southern California. In fact, according to the National Renewable Energy Laboratory (NREL), demand for hydrogen is very high in parts of Southern California (Figure 15).

In Southern California, across the hard-to-electrify sectors of ports, transportation, power generation, and industrials, demand is expected to exceed 800 kilotons (kT)/year by 2035[214] and 5,000 kT/year by 2050 (in our positive Scenario).[215] To a great extent, that demand is driven by Executive Order N-79-20 and SB100.[216 217]

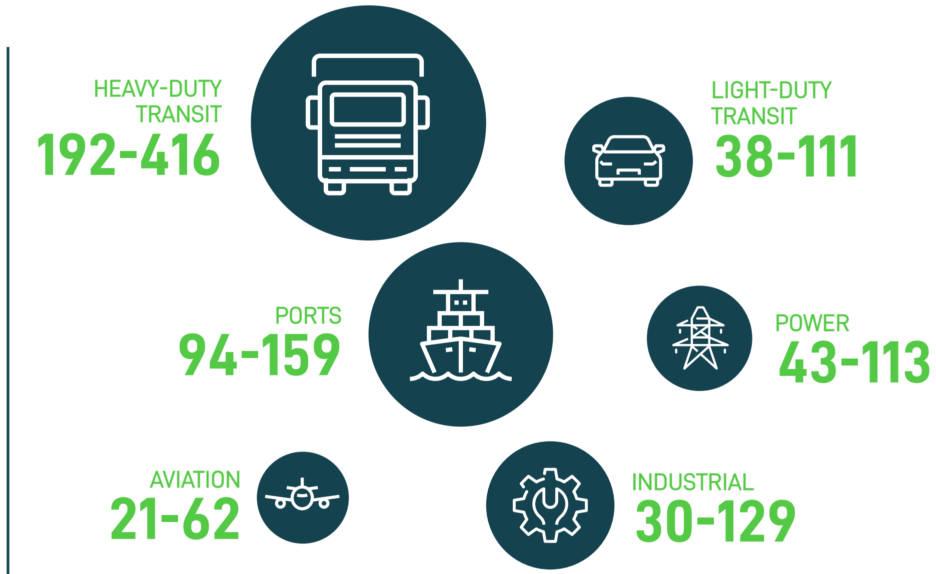


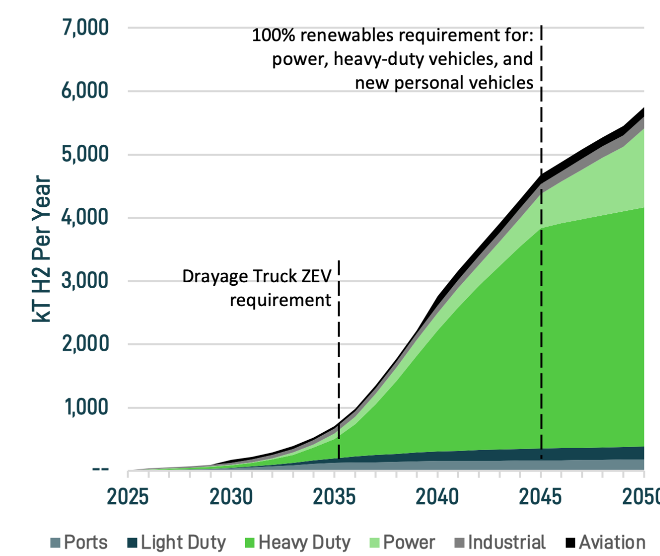
**kT H2 Estimate Across Industries 2035**

**420-990 kT H2 Demand in 2035**

Initial H2 demand originates with port early adoption and establishment of a hub, then affiliate industries ramping up

Figure 16: Expected demand for green hydrogen across six key sectors by 2035.[218]




**kT of Hydrogen**
**2025 - 2050, Positive Scenario**

Values represent ‘middle’ (positive) scenario for legislatively supported green H2 adoption.

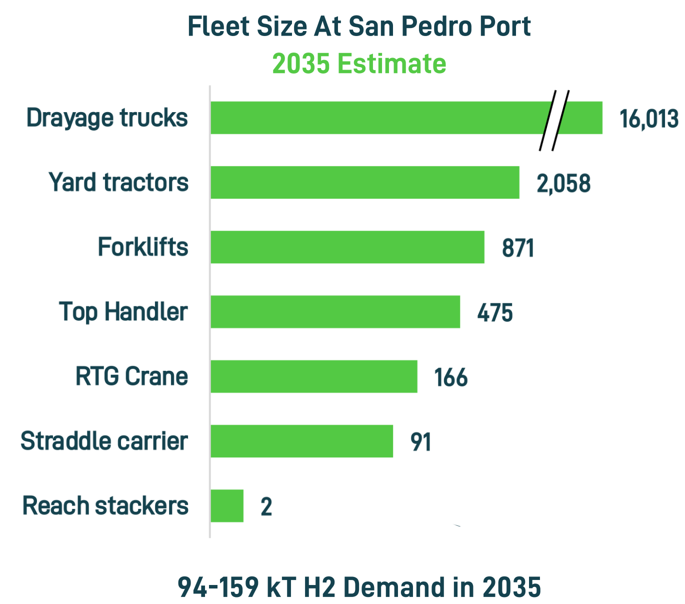
Figure 17: Projected long-term green hydrogen demand potential in Southern California.[219]

**Demand in Southern California follows four key drivers:**

1. Transit applications represent the majority of expected hydrogen demand across applications: port drayage trucking, commercial trucking, public transit, and passenger vehicle transit.
2. Ports are expected to be heavy early adopters of hydrogen due to Executive Order N-79-20's mandate for drayage trucks to be zero-emission vehicles by 2035.[220] The Port of Los Angeles and Port of Long Beach currently have >13,000 active drayage trucks, and >20,000 drayage trucks in total.
3. Legislation requires that energy will need to be 100% renewable by 2045. The majority of power in California, however, is expected to come from solar, with hydrogen being used more as a means for serving peak and nighttime loads.
4. Industrial demand will come mostly from refineries, renewable diesel, sustainable aviation fuel, and cement, which are likely to adopt green hydrogen when it is cost-advantageous for them to do so.

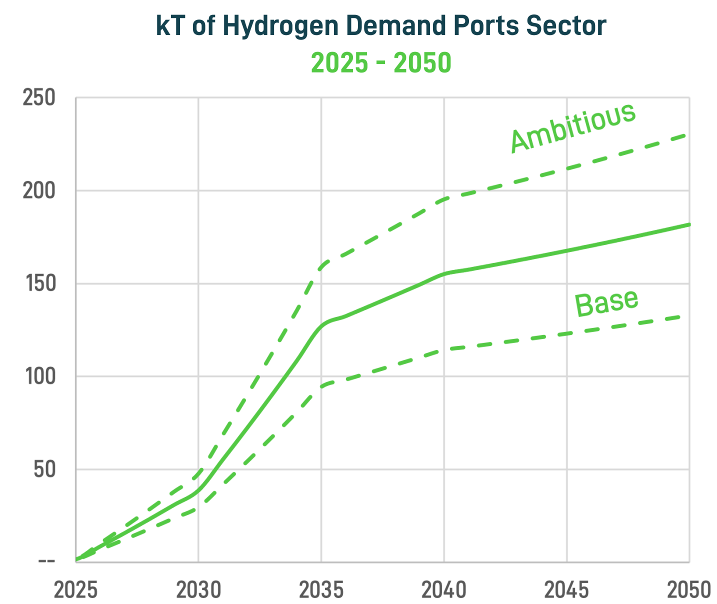
### 10.1 Demand by Sector: Ports

The Ports of Los Angeles and Long Beach are guided by the Clean Air Action Plan (CAAP) and its aggressive climate action goals, including zero emissions for cargo handling equipment by 2030 and zero emissions for on-road drayage trucks serving the ports by 2035.[221] These ports have also agreed to transition all other equipment—locomotives, harbor craft, etc.—to zero-emissions but have not yet set a target date.[222] Between the two ports, these goals will impact thousands of pieces of equipment, most of which still run on diesel fuel. Similar targets are set forth in the Maritime Clean Air Strategy (MCAS), which guides the Port of San Diego—the fourth largest port in California and one of 18 Military Strategic Ports in the United States—with the target of 100% cargo trucks being zero emissions by 2030 and all cargo handling equipment zero emissions by 2035.[223]




Drayage trucks represent >95% of H2 demand due to legislation regarding drayage trucks. Other vehicle types consume >2x H2/day but have smaller fleet sizes.

Figure 18: Port equipment that can be transitioned to hydrogen.[224]



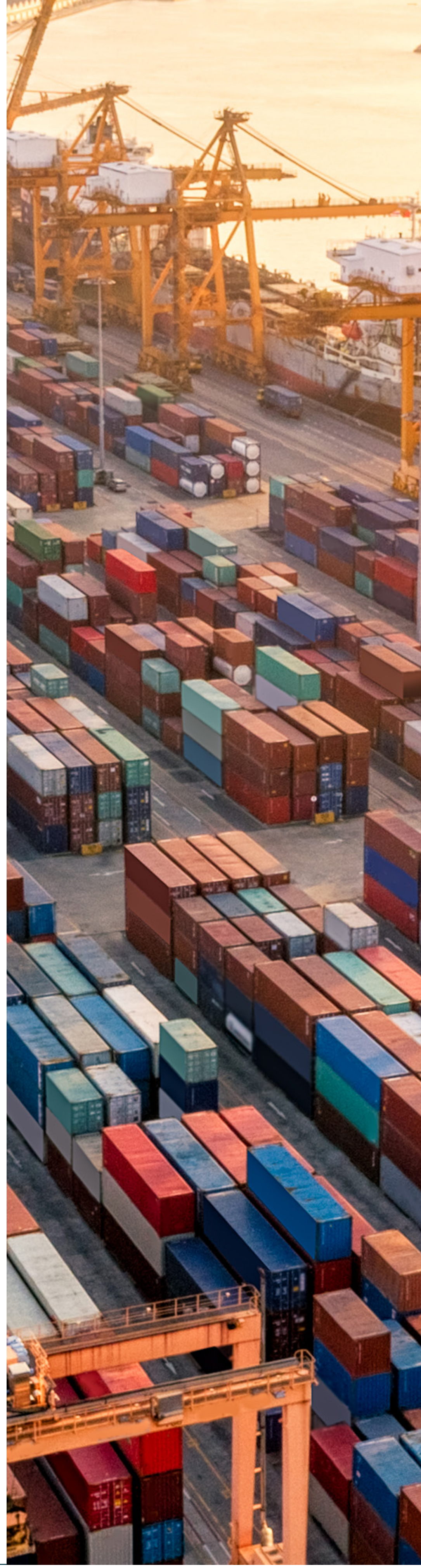

Note: Figures largely omit Ship Service which could be a large incremental driver of H2 demand. Ships have long equipment lifecycles, so we will omit until we learn more of possible adoption.

Figure 19: Long-term hydrogen demand potential at the Ports of Los Angeles and Long Beach.[225]

**Key drivers of hydrogen demand at the ports include:**

1. **California Executive Order N-79-20:** This order states that "100 percent of medium- and heavy-duty vehicles in the State be zero-emission by 2045 for all operations where feasible and by 2035 for drayage trucks."[226] Collectively, the two San Pedro Bay ports have numerous drayage trucks in operation. This is the fleet to be converted to FCEV or BEV. These drayage trucks are the biggest potential source of demand at the ports, with demand surpassing combined equipment demand even with lower adoption rates. In fact, potential market participants estimate that drayage trucking could represent three times as much demand as cargo handling equipment in 2035. Drayage trucks can refuel both within and outside of the ports, providing the potential to drive broader hydrogen refueling station buildout in the Los Angeles Basin.
2. **Other Cargo-Handling Equipment:** This category includes yard tractors, forklifts, top handlers, rubber tire gantry (RTG) cranes, straddle carriers, and reach stackers. These types of equipment use significant energy but can have longer lead times. At the San Pedro Bay ports, more than 90% of emissions come from three pieces of cargo handling equipment: top handlers, RTG cranes, and yard trucks. Due to their duty cycles—often as long as 20 hours per day—hydrogen is preferable to battery-electric operations when transitioning away from diesel.[227]
3. **Additional Sources:** This category includes ship service during hoteling when the ships require auxiliary power for onboard services at port. It is anticipated that hydrogen adoption will happen slowly in this use case. Southern California stakeholders also anticipate slow hydrogen adoption in locomotives, which have extremely long lifecycles, and in grid-related shore power.[228]

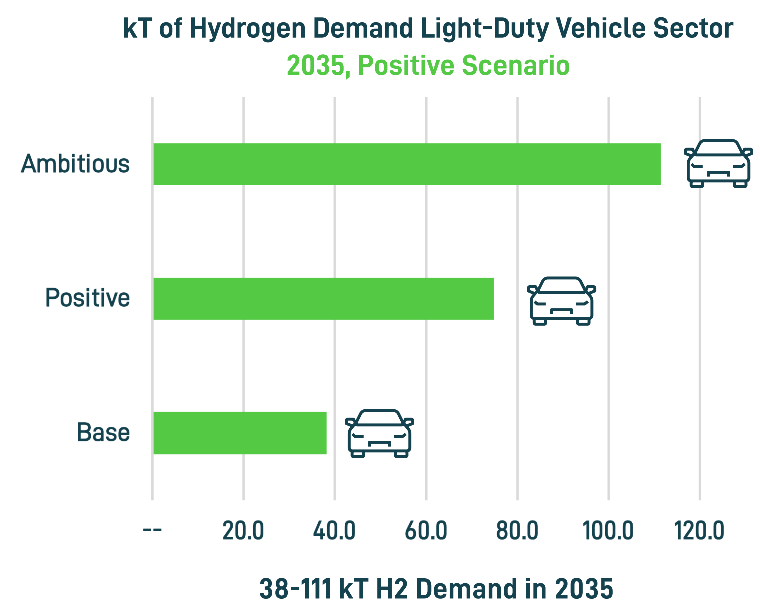
**OF NOTE, THE PORT OF LOS ANGELES, PORT OF SHANGHAI, AND C40 CITIES ARE WORKING WITH LEADING INDUSTRY PARTNERS TO CREATE A TRANS-PACIFIC TRADE ROUTE.[229] GOALS INCLUDE REDUCING GREENHOUSE GAS EMISSIONS FROM THE MOVEMENT OF CARGO THROUGHOUT THE 2020S AND BEGINNING THE TRANSITION TO ZERO-CARBON-FUELED SHIPS BY 2030 IN A BID TO SLASH EMISSIONS FROM ONE OF THE WORLD'S BUSIEST CARGO ROUTES. A SHANGHAI-LOS ANGELES GREEN SHIPPING CORRIDOR WOULD DRIVE SIGNIFICANT DEMAND FOR GREEN HYDROGEN IN THE LOS ANGELES BASIN.**



### 10.2 Demand by Sector: Transit, Light-Duty

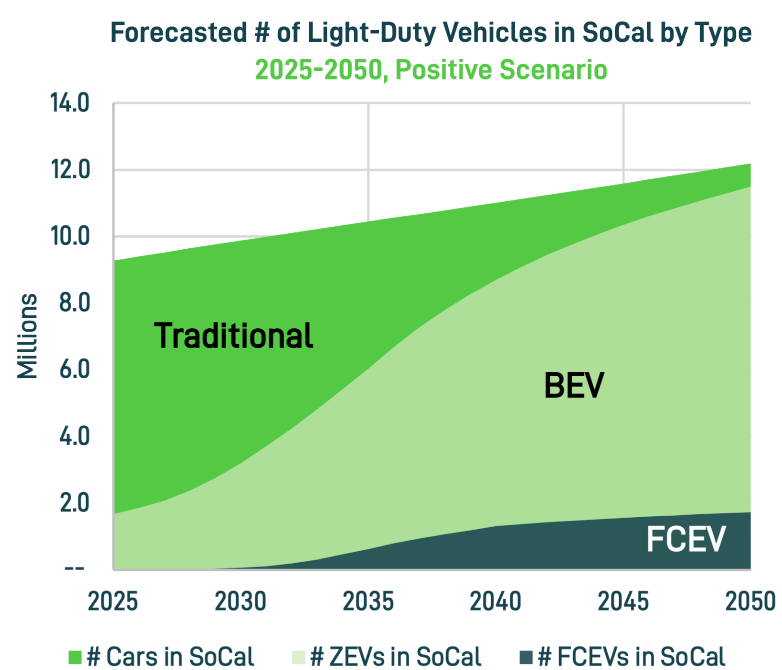
Moving forward, passenger vehicles will represent a significant portion of hydrogen demand. Battery electric vehicles (BEVs), however, are most likely to be the dominant zero-emission light-duty vehicle. An Accenture market analysis shows that up to 20% of such vehicles are likely to convert to hydrogen FCEVs.[230] Assuming state and regional legislation and incentives continue to support the adoption of hydrogen technologies and subsidize the price of hydrogen production and fuel cell vehicles, it is anticipated that hydrogen demand associated with light-duty transit will reach 38-111 kT/year by 2035.

**EQUITY CONCERNS MAY DRIVE ADDITIONAL DEMAND AND POLICY INTERVENTIONS FOR LIGHT-DUTY HYDROGEN FCEVS, BECAUSE LOWER-INCOME HOUSEHOLDS IN MULTI-FAMILY DWELLINGS MAY NOT HAVE THE ABILITY TO PLUG IN BATTERY-ELECTRIC CARS AT NIGHT AND MAY STRUGGLE TO GAIN ACCESS TO CHARGING STATIONS DURING THE DAY. FCEVs solve that issue, however, due to their rapid fill times. This transition will be fast tracked in light of the new state policy that ends the sale of petroleum powered vehicles by 2035.[231]**




Light duty adoption of hydrogen is highly subject to fluctuations based on availability of refueling capability.

Figure 20: Expected light-duty hydrogen demand.[232]




Note: Base and Ambitious scenarios show lower and higher FCEV amounts, respectively.

Figure 21: Long-term light-duty demand potential.[233]

**Key drivers for light-duty transit hydrogen demand include:[234]**

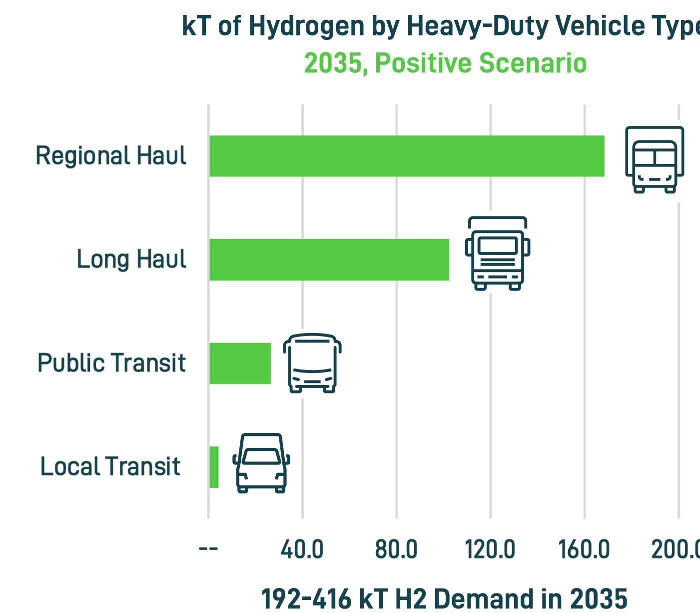
**1. California Governor's Executive Order N-79-20:** This order states that "100 percent of in-state sales of new passenger cars and trucks will be zero-emission by 2035."[235] While the executive order only applies to new cars, the average lifespan of a car is roughly seven years, meaning the replacement rate of BEVs and FCEVs around 2035 should uptick substantially. CARB has now established the Advanced Clean Cars II rule, which requires that 100% of new cars and light-duty trucks sold in California by 2035 must be zero-emission vehicles.[236]

**2. Need for New Refueling Infrastructure:** FCEVs for personal use are at a disadvantage to BEVs because of the new refueling infrastructure that is needed. Hydrogen refueling stations are currently relatively rare and can have high downtimes. By contrast, people can charge BEVs at home or work or on the road.

It is unclear that green hydrogen specifically will be dominant in this sector until it reaches price parity with fossil-based hydrogen.

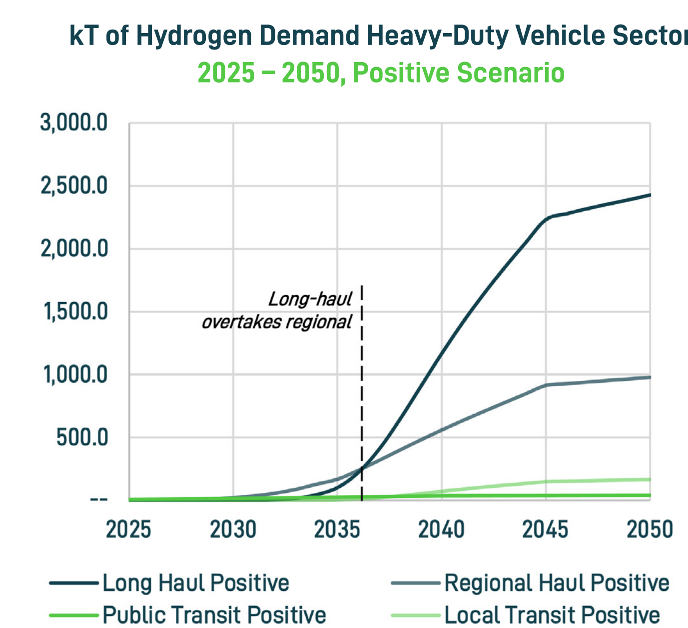
### 10.3 Demand by Sector: Transit, Heavy-Duty

Regional commercial transit represents the largest sources of hydrogen demand in the long-term, largely stemming from legislative zero-emission requirements and the inherent technological benefits—energy density and hauling capability—of hydrogen over battery-powered trucks.[237] Assuming that state and regional legislation and incentives continue to support the adoption of hydrogen technologies and subsidize the price of hydrogen production and fuel cell vehicles, it is anticipated that hydrogen demand associated with heavy-duty transit will reach 192-416 kT/year by 2035.




Regional haul (largely 'back to base') is expected to be the largest early adopter of hydrogen due to nascency of technology and lack of refueling infrastructure to support long-haul.

Figure 22: Expected hydrogen demand by 2035 for heavy-duty transit.[238]




Long-haul trucking is expected to overtake regional for highest H2 demand late 2030s – early 2040s, based on scenario (and factors such as refueling infrastructure and speed of tech advancement).

Figure 23: Projected long-term heavy-duty transit hydrogen demand.[239]

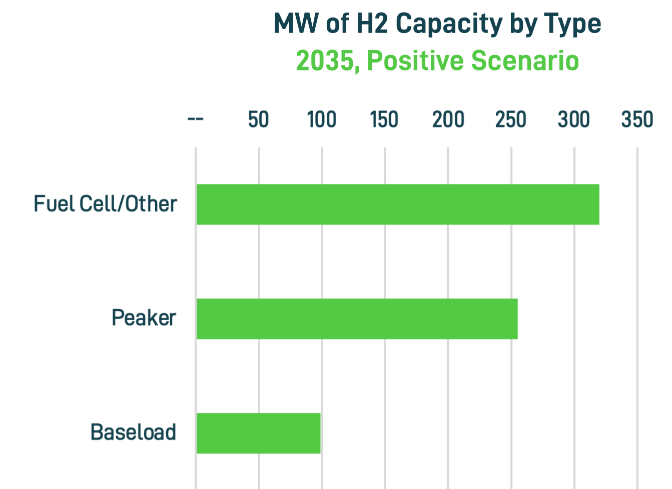

Key drivers for heavy-duty transit hydrogen demand include:[240]

- **1. California Governor's Executive Order N-79-20:** This order states that "100 percent of medium- and heavy-duty vehicles in the State be zero-emission by 2045 for all operations where feasible."[241] CARB has now established the Advanced Clean Cars II rule, which requires that 100% of new cars and light-duty trucks sold in California by 2035 must be zero-emission vehicles.[242]
- **2. Regional Trucking:** Regional trucking is expected to have the highest initial hydrogen demand, but long-haul trucking will have the largest long-term demand due to the heavier loads, longer distances travelled, and greater number of hours on the road in comparison to other trucks.
- **3. Refueling Infrastructure:** Initial industry conversations highlighted a specific need for hydrogen refueling infrastructure along key transit corridors, such as I5, to support trucking.
- **4. Public Transit:** Public transit has stringent mandates to go zero emissions by 2040.[243] However, overall fleet sizes are smaller compared to regional and long-haul trucking and thus, may have overall lower demand than regional and long-haul trucking.
- **5. Local Transit:** Local transit has relatively low utilization and involves light loads and short distances travelled. Thus, it is expected to be a minor driver of hydrogen demand in heavy-duty transit in comparison to long-haul trucking.



## 10.4 Demand by Sector: Power[244]

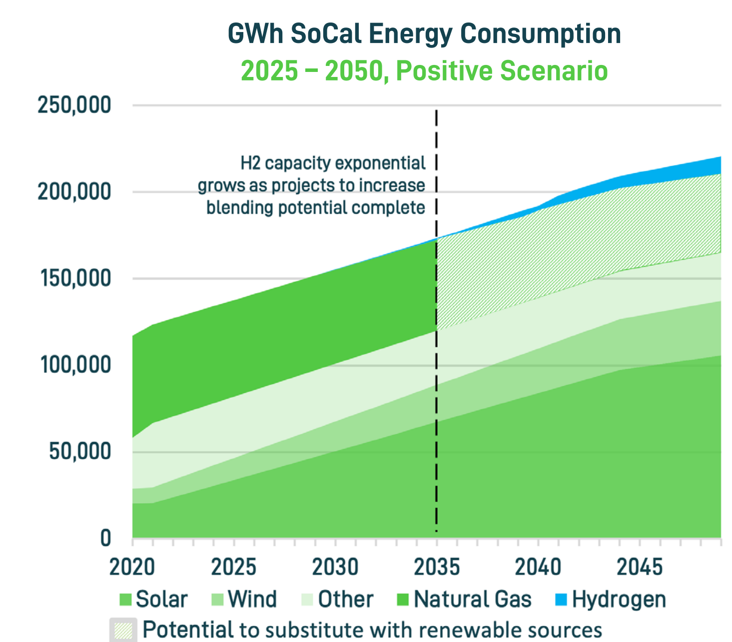
Because California is expected to require 100% of grid-energy to be renewable by 2045, it is anticipated that most hydrogen use in this sector will be by natural gas "peaker" plants or as a long-term—30+ hours—storage option for renewable energy. Assuming that state and regional legislation and incentives continue to support the adoption of hydrogen technologies and subsidize the price of hydrogen production and fuel cell vehicles, it is anticipated that hydrogen demand associated with the power sector will reach 43-113 kT/year by 2035.




Hydrogen's primary use as a power source will be in existing Peaker plants and new fuel cell facilities; converting existing baseload is not viable due to the energy loss in H2 production.

LADWP plants represent only 5 out of the 34 NG plants modelled or 5% of overall 2035 demand.

Figure 24: Expected hydrogen power capacity in 2035.[245]




Capacity projects are derived from the goals outlined in SB 100. We then take the CEC's Energy Demand 2018-2030 forecast to project Southern California's 2030-2050 demand. The difference in these two numbers is unmet demand which CAISO historically has bought out of state, we forecast a percent of this being met with fuel cell power plants mainly.

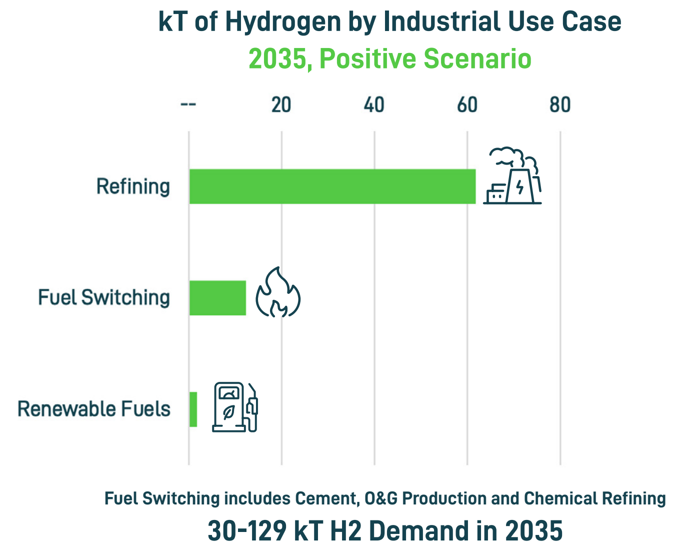
Figure 25: Long-term energy consumption for Southern California.[246]

**Key drivers for hydrogen demand in the power sector include:**

- **1. California Senate Bill 100 (SB100):** This bill establishes a target for renewable and zero-carbon resources to supply 100 percent of retail sales and electricity procured to serve all state agencies by 2045.[247]
- **2. Solar Power:** Solar will still be the primary method of grid energy production in California and peak loads will need to be serviced by stored energy, which hydrogen could support.
- **3. Curtailment:** California already curtails over 1 million MWh of solar annually—a number increasing rapidly—that can be used for the production of hydrogen.[248]
- **4. Fuel Cells:** Industry experts hypothesize that most early hydrogen power will be via fuel cells.[249]

### 10.5 Demand by Sector: Industrials

Refineries and renewable diesel plants are the largest industrial consumers of hydrogen; however, they can produce their own hydrogen via steam methane reforming (SMR) and do not require electrolytic green hydrogen. Unless some new regulation mandates them to do so, they will utilize green hydrogen only when it is cheaper than or at least at price-parity with fossil-based hydrogen. **If federal, state, and regional legislation and incentives continue to support the adoption of hydrogen technologies and subsidize the price of hydrogen production and fuel cell vehicles, it is anticipated that hydrogen demand associated with industrials will reach 30-129 kT/year by 2035.**




Note: Figures omit the 4 on-site co-generation facilities that primarily use NG today; they are primarily baseload generation. Fuel Switching refers to demand from switching chemical heating fuels to burn hydrogen instead.

Figure 26: Expected industrial hydrogen demand by 2035.[250]

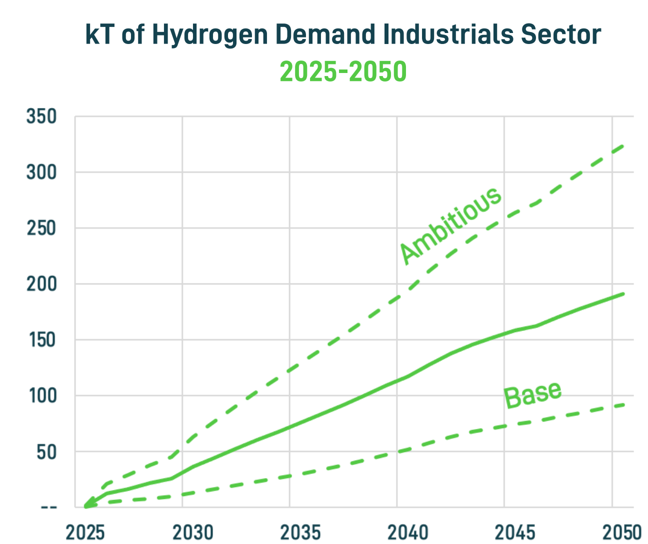



Figure 27: Projected long-term industrial hydrogen demand.[251]

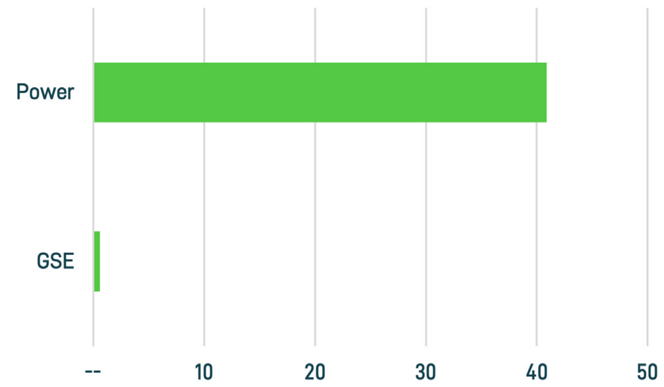
**Key drivers for hydrogen demand in the industrials sector include:**

- **1. Fossil-Based Hydrogen Production:** Refineries are California's current largest current consumer of hydrogen. 65% of the hydrogen demand for oil refining in the Western U.S. is attributed to California.[252] Although refineries can produce their own gray hydrogen through SMR, limiting their demand, lowering carbon intensity targets on transportation fuels via LCFS may drive refineries towards decarbonizing their hydrogen fuel. Hydrogen demand from refineries in California may decrease if local oil and gas demands decrease due to factors such as ZEV and renewables legislation or if refineries shut down and move out of state.

- **2. Construction or Conversion:** Construction of more renewable diesel/sustainable aviation fuels plants, or conversion of existing refineries. Those plants use hydrogen to convert waste fats and oils (for example used cooking oil) and vegetable oils to diesel and aviation fuel.

- **3. Non-Refinery Demands:** Non-refining demands for hydrogen are likely to come from fuel switching for chemical and industrial heating processes, especially in hard-to-electrify sectors. Although hydrogen contains less energy content than natural gas, for certain non-refinery entities, environmental benefits and meeting emission targets may drive the transition to hydrogen. However, combustion of hydrogen is much less efficient than natural gas.[253]

**kT of Hydrogen by Aviation Use Case**
**2035, Positive Scenario**

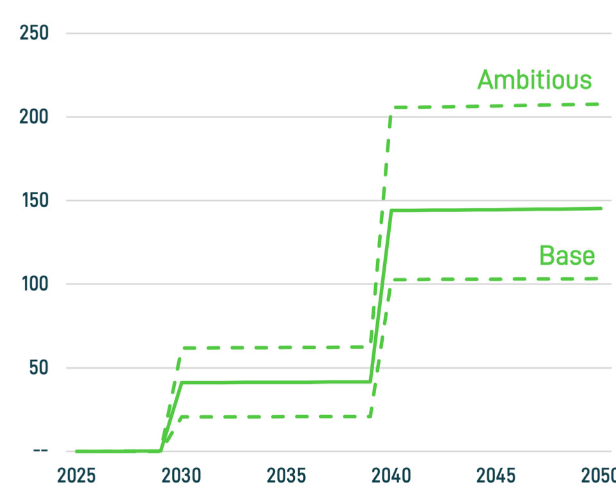



**21-62 kT H2 Demand in 2035**

Demand is driven primarily by the conversion of LAX's CUP NG facility to H2. The largest consumers of H2 in GSE are Baggage/Cargo Tugs and Medium duty transportation.

Figure 28: Kilotons of hydrogen by source.[255]

**kT of Hydrogen Demand Aviation Sector**
**2035, Positive Scenario**




Airport H2 demand is dominated by power generation at LAX: the step-function reflects one-time conversions of the on-site NG generation facilities to blended NG/H2 to pure H2.

Figure 29: Estimated airport demand for hydrogen.[256]

### 10.6 Demand by Sector: Aviation

The aviation industry is not expected to be a large driver of hydrogen demand until hydrogen-fueled aircraft are commercially viable, which is unlikely to occur until roughly 2050.[254] The aviation industry is, however, a likely candidate for hydrogen adoption in other areas, in large part due to its regulated nature, diverse vehicle fleets, and unique power needs. Assuming that state and regional legislation and incentives continue to support the adoption of hydrogen technologies and subsidize the price of hydrogen production and fuel cell vehicles, it is anticipated that hydrogen demand associated with aviation will reach 30-129 kT/year by 2035.

**Key drivers for hydrogen demand in aviation include:**

- **1. Lack of Hydrogen Aircraft:** It is unlikely that this industry will be able to meaningfully decarbonize until green aircraft are developed. Such aircraft are currently under development, with estimates for commercial deployment ranging from near term to 2050, depending on the application.

- **2. Ground Support Equipment (GSE):** Near term, GSE can be decarbonized. If airlines require ZEVs, then entire fleets could transition quickly. However, GSE fleet sizes are smaller in comparison to other potential demand sources.

**TERRY TAMMINEN** **ARNOLD SCHWARZENEGGER**

Sacramento, California – April 22, 2004
The unveiling of the California Hydrogen Highway Network

Moving forward, parties interested in participating in the development of a green hydrogen market in Southern California will continue to engage additional stakeholders—including community-based organizations, hydrogen producers, technology developers, and hydrogen end users—and align their activities with the larger goals of GO-Biz and the statewide hydrogen hub application.

Simultaneously, aspiring market participants will continue the process of identifying and analyzing anchor projects and refining estimates of regional hydrogen supply and demand, as well as system value benefits. Ultimately, Southern California participants will seek to provide new economic opportunities and significant environmental benefits to disadvantaged communities by leveraging shared infrastructure and innovative, proven technologies to reduce emissions, create jobs, and spur economic growth.

DOE funding to support the development of a thriving statewide Renewable Hydrogen Hub and its regional components in Northern, Central, and Southern California, in particular, would be money well spent. Southern California has abundant natural resources, a resourceful innovation and R&D ecosystem, and a network of public and private partners dedicated to the creation of an economically and environmentally self-sustaining green hydrogen economy that will reduce risk and cost for future developers and end users across the supply chain.

This, in turn, will help California maintain its position as a global leader in green hydrogen research, development, demonstration, and commercialization, thereby helping the U.S. remain competitive globally and develop a nationwide network of interconnected clean hydrogen hubs.

**To take part in this exciting process, visit socalh2.org**

1 https://www.greenbiz.com/article/how-many-jobs-does-clean-energy-create
2 https://www.iea.org/reports/global-hydrogen-review-2021
3 https://newsroom.socalgas.com/press-release/socalgas-proposes-to-develop-united-states-largest-green-hydrogen-energy
4 https://afdc.energy.gov/stations/states
5 https://spectrumnews1.com/ca/la-west/environment/2022/06/07/socalgas-pursues-hydrogen-future-with-angeles-link
6 https://h2fcp.org/sites/default/files/FCEV-Sales-Tracking.pdf
7 Green hydrogen" generally refers to hydrogen produced through electrolysis using renewable energy. See, e.g., Cal. Energy Comm'n, Draft 2021 Integrated Energy Policy Report, CEC-100-2021-001-V3 (Jan. 2022) ("Draft 2021 IEPR"), Vol. III, p. 66, available at https://www.energy.ca.gov/data-reports/reports/integrated-energy-policyreport/2021 -integrated-energy-policy-report. However, ultimately, the cluster would focus on the carbon intensity score of the hydrogen produced and not on the production method. The Department of Energy recently announced its intention to develop a carbon intensity score for hydrogen, see: https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-production-standard.pdf
8 https://web.archive.org/web/20220829032837/https://www.statista.com/statistics/248023/us-gross-domestic-product-gdp-by-state/
9 Ibid.
10 https://timesofsandiego.com/business/2021/12/08/ucla-southern-californias-economy-bigger-than-brazils-at-1-6-trillion/
11 Ibid.
12 https://web.archive.org/web/20220912223912/https://www.census.gov/quickfacts/fact/table/CA/PST045221
13 https://www.energy.gov/eere/fuelcells/hydrogen-storage
14 https://news.climate.columbia.edu/2021/01/07/need-green-hydrogen/
15 International Energy Agency, The Future of Hydrogen (June 2019) at 13. Available at https://iea.blob.core.windows.net/assets/9e3a3493-b9a6-4b7d-b499-7ca48e357561/The_Future_of_Hydrogen.pdf
16 Ibid., p.13.
17 Ibid., p.13.
18 Ibid., p.13.
19 Ibid., p.13.
20 Ibid., p.13-14.
21 https://www.altenergymag.com/article/2009/04/the-history-of-hydrogen/555/
22 https://history.nasa.gov/SP-4404/part2-sum.htm
23 Ibid.
24 Ibid.
25 https://www.nrdc.org/experts/christian-tae/hydrogen-safety-lets-clear-air
26 Personal communication with Terry Tamminen, AltaSea President/CEO.
27 https://web.archive.org/web/20220912223912/https://www.census.gov/quickfacts/fact/table/CA/PST045221
28 https://www.theguardian.com/us-news/2021/jan/22/biden-administration-california-kamala-harris-gavin-newsom
29 https://laborcenter.berkeley.edu/union-effect-in-california-3/
30 https://ww2.arb.ca.gov/our-work/topics/climate-change
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