ANGELES LINK PHASE 1
DEMAND STUDY
FINAL REPORT – DECEMBER 2024

SoCalGas commissioned this Demand Study from Accenture and EPRI.
The analysis was conducted, and this report was prepared, collaboratively.

Acknowledgements

We gratefully acknowledge the peer review and guidance provided by the following organizations in support of this study, including but not limited to:

- National Renewable Energy Lab
- South Coast Air Quality Management District
- University of California Los Angeles
- University of California Irvine
- University of California Davis

We gratefully acknowledge the organizations who participated in this study as interviewees, including but not limited to:

- AES Corporation
- California Dairies, Inc.
- Clearway Energy Group
- Daimler Truck North America
- Hyundai Motor Company
- National Cement
- Nikola Corporation
- Orange County Transportation Authority
- Pilot Flying J
- Port of LA
- Republic Services, Inc.
- Burbank Water & Power
- Vista Metals Corporation
- World Energy

Disclaimer: The analysis and conclusions set forth in this report do not represent the views of any one particular organization but take into account the inputs from interviews and peer reviews as interpreted by SoCalGas.

Table of Contents

List of Figures

List of Tables

List of Acronyms

ACF – Advanced Clean Fleets

ACT – Advanced Clean Trucks

ANL – Argonne National Laboratories

ARCHES – Alliance for Renewable Clean Hydrogen Energy Systems

BEV – Battery Electric Vehicle

CAAP - Clean Air Action Plan

CARB – California Air Resources Board

CapEx – Capital Expenditure

CCUS – Carbon Capture, Utilization and Storage

CEC - California Energy Commission

CHC – Commercial Harbor Craft

CHE – Cargo Handling Equipment

CPUC – California Public Utilities Commission

DOE – U.S. Department of Energy

EO – Executive Order

FCEB – Fuel Cell Electric Bus

FCEV – Fuel Cell Electric Vehicle

GHG – Greenhouse Gas

GSE – Ground Support Equipment

HDV – Heavy-Duty Vehicle

IEPR - Integrated Energy Policy Report

LADWP – Los Angeles Department of Water and Power

LAWA – Los Angeles World Airports

LCFS - Low Carbon Fuel Standard

LCOH - Levelized Cost of Hydrogen

LDV – Light-Duty Vehicle MDV – Medium-Duty Vehicle

NREL – National Renewable Energy Laboratory

OEM – Original Equipment Manufacturer

OGV – Ocean-Going Vessels

OpEx – Operating Expenditure

PAG - Planning Advisory Group

RPS - Renewable Portfolio Standard

SAF – Sustainable Aviation Fuel

SB – Senate Bill

SCAQMD - South Coast Air Quality Management District

SMR - Steam Methane Reforming

SoCalGas – Southern California Gas Company

TPY – Tonnes per Year

ZEV – Zero-emission Vehicle

0. Executive Summary

0.1. Demand Study Overview

On December 15, 2022, the California Public Utilities Commission (CPUC) adopted Decision 22-12-055 (Decision), which authorized Southern California Gas Company (SoCalGas) to establish the Angeles Link Memorandum Account to record the costs of performing Angeles Link Phase 1 feasibility studies. The Demand Study is one of the feasibility studies being performed, which analyzes total potential demand for clean renewable hydrogen in SoCalGas's service territory through 2045 across three sectors: mobility, power generation, and industrial. Consistent with the Decision, Angeles Link is intended to transport only 100% clean renewable hydrogen to these sectors. This report sets forth the scope, methodology, and results of this study.

0.2. Summary Results

The Demand Study projects demand for clean renewable hydrogen across the mobility, power generation, and industrial sectors in SoCalGas's service territory through 2045. Three scenarios were modelled over the time period of 2025-2045 with the results indicating 1.9 Million (M) tonnes per year (TPY) of hydrogen by 2045 in its conservative scenario, 3.2M TPY in the moderate scenario, and 5.9M TPY in the ambitious scenario. Demand comes primarily from the Mobility sector in the conservative scenario, driven by heavy-duty vehicles (HDVs). In the moderate and ambitious scenarios, the Power and Industrial sectors play an increasingly large role with Power becoming the largest sector by demand volume. Figure 1 below defines the scenarios that were evaluated, and the sectors included in each scenario.

Figure 1: Demand Model Scenario Definition and Subsectors Included

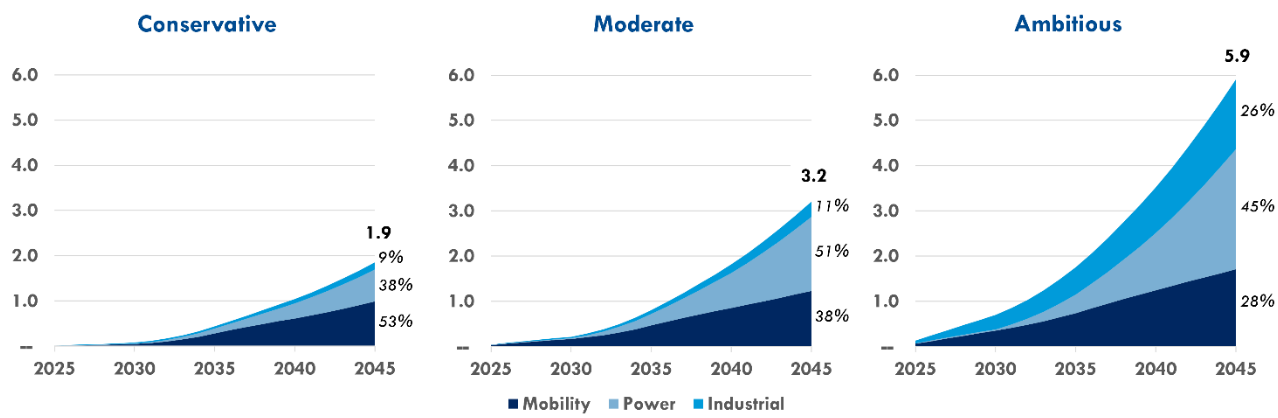
Conservative	Scenario assumes lower adoption rates for hydrogen across a limited set of use-cases within prioritized sectors and sub-sectors, primarily driven by existing legislation. **Mobility:** Heavy Duty Vehicles, Medium Duty Vehicles, Cargo Handling Equipment, Ground Support Equipment, Agricultural Equipment, Construction & Mining Vehicles, Commercial Harbor Craft, Ocean Going Vessels* **Power:** Peaker, Baseload **Industrials:** Cogeneration, Food & Beverage, Metals, Stone, Glass, and Cement, Paper, Chemicals, Aerospace and Defense
Moderate	Scenario assumes increased hydrogen adoption across an expanded set of use-cases within prioritized sectors and sub-sectors, driven by existing legislation. **Mobility:** Heavy Duty Vehicles, Medium Duty Vehicles, Cargo Handling Equipment, Ground Support Equipment, Agricultural Equipment, Construction & Mining Vehicles, Commercial Harbor Craft, Ocean Going Vessels* **Power:** Peaker, Baseload **Industrials:** Cogeneration, Food & Beverage, Metals, Stone, Glass, and Cement, Paper, Chemicals, Aerospace and Defense
Ambitious	Scenario assumes more ambitious policies are put in place and businesses are incentivized to support widespread hydrogen adoption within prioritized sectors and sub-sectors. **Mobility:** Heavy Duty Vehicles, Medium Duty Vehicles, Cargo Handling Equipment, Ground Support Equipment, Agricultural Equipment, Construction & Mining Vehicles, Commercial Harbor Craft, Ocean Going Vessels*, Aviation **Power:** Peaker, Baseload **Industrials:** Refineries, Cogeneration, Food & Beverage, Metals, Stone, Glass, and Cement, Paper, Chemicals, Aerospace and Defense

*OGV vessel demand modeling reflects hydrogen for diesel fuel replacement only (does not include bunker fuel replacement)

Figure 2 below shows the total hydrogen demand across the conservative, moderate, and ambitious scenarios through 2045, as well as the breakdown of demand across the three sectors. SoCalGas's service territory-wide hydrogen demand is anticipated to scale up starting around 2030 across all three sectors.

Figure 2: Clean Renewable Hydrogen Demand Forecast in SoCalGas's Service Territory, by Scenario

(2025-2045, values in Million TPY)



The findings point to potentially widespread demand across these sectors and the significance of hydrogen in decarbonizing California's mobility, power generation, and industrial sectors should these levels be achieved.

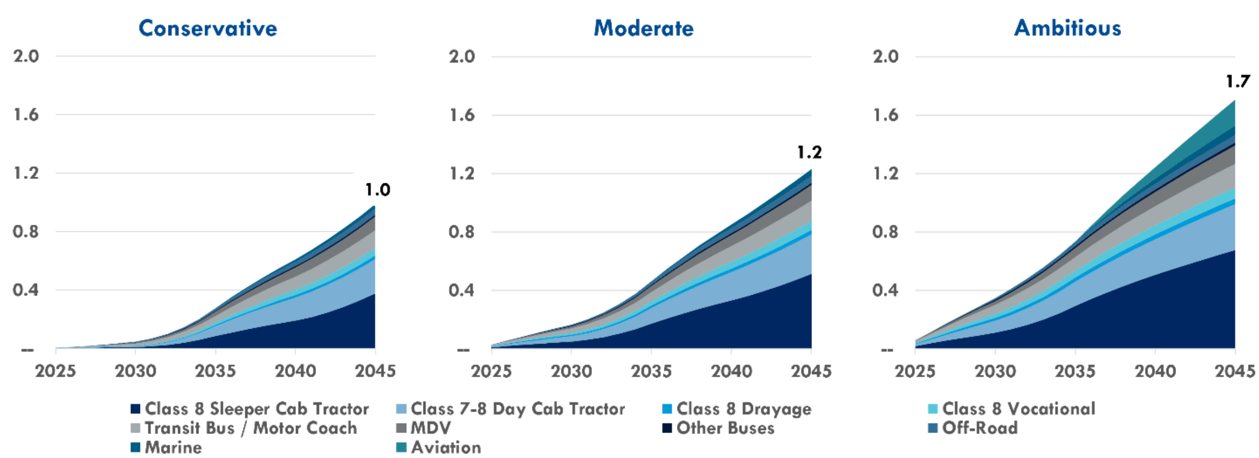
0.2.1. Mobility

Clean renewable hydrogen demand in the mobility sector is projected to reach between 1.0 and 1.7M TPY by 2045. The principal driver of mobility sector demand is the Advanced Clean Fleets (ACF) regulation, which requires zero-emission vehicles (ZEV) sales starting in 2024 for drayage trucks and "high-priority" (large private) fleets; and ZEV sales for all fleets by 2035. Therefore, across all the study's scenarios, HDVs—including Class 7-8 sleeper cabs, day cabs, drayage trucks, vocational vehicles—as well as transit buses, represent the majority of the mobility sector's demand by 2045. Many of these HDVs currently refuel along key transit corridors, a pattern that is expected to continue regardless of their conversion to fuel cell electric vehicles (FCEV) or battery electric vehicles (BEV).

In addition, operational characteristics such as long-range requirements, heavy load requirements, long duty-cycles, and fast fueling requirements lead to heavy duty applications—

Class 8 sleeper cabs, day cabs, and drayage trucks, as well as transit buses—being prime candidates for hydrogen adoption over alternative low-carbon technologies. These HDV applications comprise roughly 80% of total 2045 mobility sector demand across scenarios. Outside of this, clean hydrogen demand for off-road applications is expected to remain moderate in SoCalGas's service territory, largely due to relatively small fleet sizes, small daily fuel consumption rates, or the competitive value propositions of alternative fuels, namely battery electric. For marine and aviation applications, hydrogen derivatives such as ammonia and methanol and synthetic fuels such as sustainable aviation fuel (SAF) are expected to play a significant role in decarbonization, though hydrogen fuel cell technology may achieve significant enough penetration to constitute notable demand for clean renewable hydrogen. Figure 3 shows the breakdown of clean renewable hydrogen demand in the mobility subsectors.

Figure 3: Total Expected Clean Renewable Hydrogen Demand in the Mobility Sector
(2025-2045, values in Million TPY)



Early hydrogen demand ramp-up (pre-2035) will be largely dependent on Original Equipment Manufacturer (OEM) production rate and on announced programs such as Port of Los Angeles and Port of Long Beach's Clean Air Action Plan, which sets targets for terminal operators to achieve 100% ZEV cargo handling equipment (CHE) by 2030. After 2035, many significant regulations such as ACF will come into full effect, requiring 100% of new truck sales to be ZEV. As such, modelled hydrogen demand is expected to noticeably increase when this takes effect. Additionally, in September 2023, CARB proposed 2023 Low Carbon Fuel Standard (LCFS) amendments which would increase the stringency of carbon intensity reduction targets through 2030 and extend targets through 2045. The proposed amendments would also create incentives for clean fuel production and refueling infrastructure, which could further accelerate ZEV adoption and hydrogen demand.[1]

0.2.2. Power Generation

Clean renewable hydrogen demand in the power generation sector is expected to range between 0.7M and 2.7M TPY by 2045. Policy is a key driver for the sector, including Senate Bill (SB) 100[2]—requiring California's power generation system to be 100% carbon-free by 2045, and SB1020[3] which accelerates the SB100 mandate requiring 90% of all retail sales of electricity be from renewable energy resources by 2035. California Air Resources Board (CARB) forecasts that roughly 9 GW of incremental hydrogen capacity will be needed as an electricity resource in California by 2045 in their CARB 2022 Scoping Plan for Achieving Carbon Neutrality[4] (Scoping Plan). Additionally, Los Angeles Department of Water and Power's (LADWP) target of supplying 100% renewable energy by 2035 will likely be a major contributing factor in the adoption of hydrogen in the region.[5]

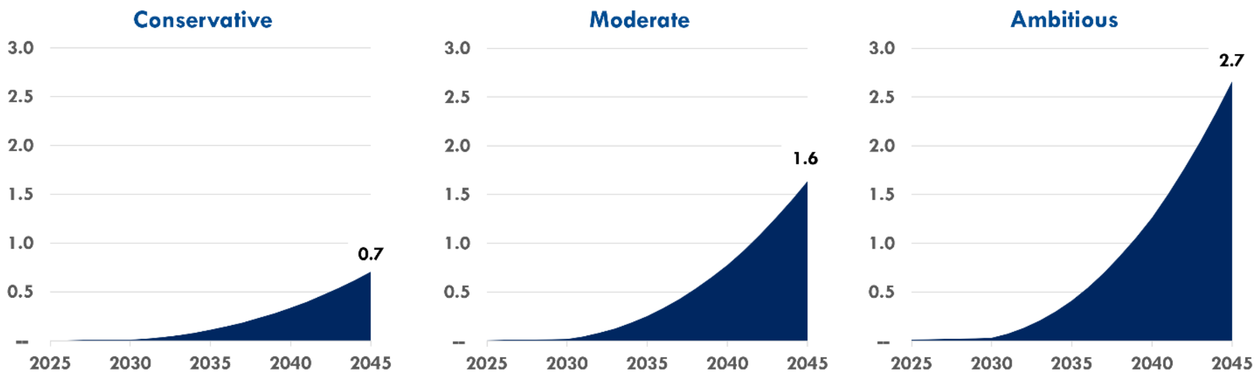
Firm dispatchable power, up to 45GW, is estimated to be needed in California's future,[6] and hydrogen can be one of those resources. Hydrogen provides value as firm dispatchable and flexible power generation, helping power producers manage the anticipated daily to seasonal fluctuations in the production of renewable energy and to help ensure continuous, reliable electricity service—particularly during heat waves and other extreme weather events that extend beyond the duration of current battery storage. As the amount of solar and other intermittent renewable energy resources on the electric grid increases, and as traditional dispatchable generating resources change, clean renewable hydrogen can play a key role and be called upon when needed. The specific utilization and capacity factors of each power plant will have a significant influence on potential hydrogen demand. Figure 4 reflects these trends.

---

[1] California Air Resources Board. "Low Carbon Fuel Standard 2023 Amendments". https://ww2.arb.ca.gov/sites/default/files/2023-09/lcfs_sria_2023_0.pdf
[2] California Legislative Information. "Senate Bill No. 100". https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB100
[3] California Legislative Information. "Senate Bill No. 1020". https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202120220SB1020
[4] California Air Resources Board. "2022 Scoping Plan for Achieving Carbon Neutrality". Figure 4-5. (December 2022). https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf
[5] Los Angeles 100% Renewable Energy Study (LA100). https://maps.nrel.gov/la100/la100-study/report
[6] EDF. "California needs clean firm power, and so does the rest of the world." https://www.edf.org/sites/default/files/documents/SB100%20clean%20firm%20power%20report%20plus%20SI.pdf

Figure 4: Total Expected Clean Renewable Hydrogen Demand in the Power Sector

(2025-2045, values in Million TPY)



There are a variety of technological and operational considerations that will impact the level of hydrogen demand in the power sector. This demand study focused on hydrogen combustion turbines only, with OEMs generally targeting 2030 for 100% hydrogen capable combustion technologies based on public announcements and interviews.[7,8,9] It is worth noting that interviews and analysis in this sector found that many existing natural gas combustion turbines in SoCalGas's service territory may be capable of utilizing mixed fuels of up to 30% hydrogen by volume with certain retrofits.[10,11,12] Modifications to fuel delivery systems would be required, and doing so could provide a near-term pathway for hydrogen adoption for existing gas

---

[7] Euractiv. "GE eyes 100% hydrogen-fueled power plants by 2030". (May 2021). https://www.euractiv.com/section/energy/news/ge-eyes-100-hydrogen-fuelled-power-plants-by-2030/

[8] U.S. Environmental Protection Agency. "Hydrogen in Combustion Turbine Electric Generating Units: Technical Support Document." (May 2023). https://www.epa.gov/system/files/documents/2023-05/TSD%20-%20Hydrogen%20in%20Combustion%20Turbine%20EGUs.pdf

[9] Siemens Energy. "Zero Emission Hydrogen Turbine Center." https://www.siemens-energy.com/global/en/home/products-services/solutions-usecase/hydrogen/zehtc.html#:~:text=H%E2%82%82%20capabilities%20of%20our%20medium,to%20reach%20100%25%20by%202030.

[10] U.S. Environmental Protection Agency. "Hydrogen in Combustion Turbine Electric Generating Units: Technical Support Document." (May 2023). https://www.epa.gov/system/files/documents/2023-05/TSD%20-%20Hydrogen%20in%20Combustion%20Turbine%20EGUs.pdf

[11] S&P Global. "Hydrogen-capable natural gas turbines gain traction in power sector." (March 2022). https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/natural-gas/031622-hydrogen-capable-natural-gas-turbines-gain-traction-in-power-sector

[12] Consistent with the Decision, Angeles Link is intended to transport pure clean renewable hydrogen in the pipeline, and any analysis of hydrogen blending refers strictly to "behind-the-meter" operations, not within SoCalGas control.

combustion turbines. Over time, as combustion technologies mature, hydrogen uptake is expected to grow as well.

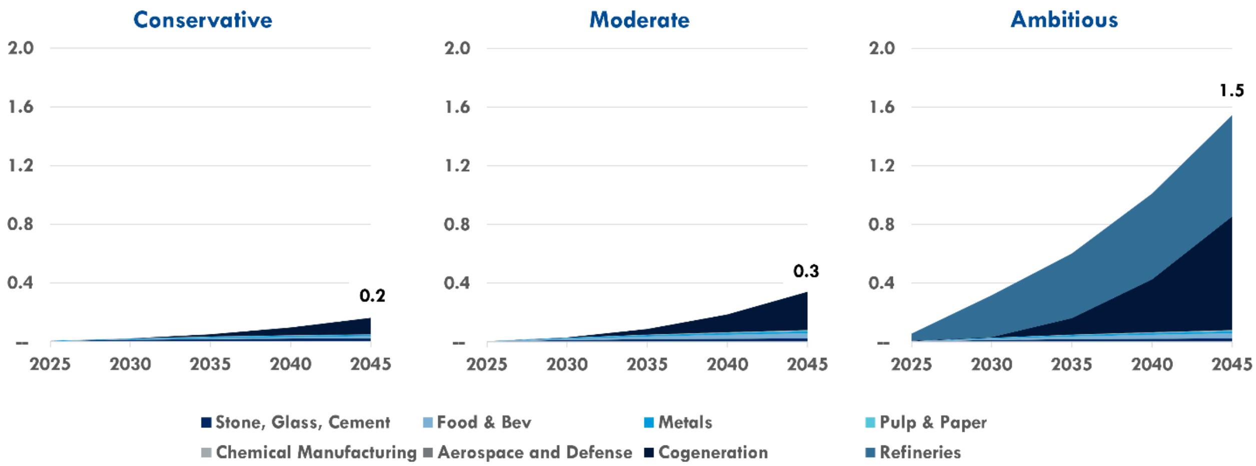
0.2.3. Industrial Sector

Demand volume in the industrial sector is expected to range between 0.2M and 1.5M TPY by 2045. California has a large industrial base, and its size and diversity of end users creates significant potential for long-term hydrogen demand in a wide range of industrial applications. This study focused on quantifying demand in the industrial's subsectors of metals, food & beverage, stone, glass, & cement, aerospace & defense, and refineries, and included evaluation of on-site power cogeneration.

Many industrial end users across subsectors are interested in the potential of clean renewable hydrogen, however a lack of legislative mandates and large capital requirements for equipment upgrades suggest that additional industrial-specific incentives may be needed to accelerate hydrogen demand. One subsector that may see higher policy and market drivers like what is seen in the Power sector is cogeneration at industrial facilities. However, there remains significant uncertainty around the future of cogeneration in California, with the CARB Scoping Plan projecting all cogeneration to be retired by 2045.[13] Outside of cogeneration, the most significant source of industrials-sector potential hydrogen demand is refineries. Refineries use significant amounts of fossil-fuel derived (gray) hydrogen today, namely for applications such as hydrocracking and removing sulfur from petroleum. However, as demand for carbon-based traditional fuels (such as diesel, gasoline, or jet fuel) decreases, the amount of hydrogen demand for refining and developing these products may decrease. In response to these expected declines in traditional fuel demand, refineries are considering conversions to producing synthetic fuels such as renewable diesel which would use significant amounts of clean hydrogen as hydrotreatment of renewable feedstocks requires considerably more hydrogen than desulfurization of diesel.[14] Given the uncertainties of this conversion, refineries are included in the ambitious scenario only, accounting for the large uptick in industrials demand between moderate and ambitious scenarios. Outside of cogeneration and refining, demand from other industrial subsectors are largely a result of fuel switching, and while relatively small, will likely be a steady and therefore important source of demand.

[13] California Air Resources Board. "2022 Scoping Plan". https://ww2.arb.ca.gov/our-work/programs/ab-32-climate-change-scoping-plan/2022-scoping-plan-documents
[14] U.S. Energy Information Administration. "Biofuels Explained." https://www.eia.gov/energyexplained/biofuels/biodiesel-rd-other-basics.php

Figure 5: Total Expected Clean Renewable Hydrogen Demand in the Industrial Sector
(2025-2045, values in Million TPY)



Future demand in the industrial sector will depend on the pace of technological advancements for key use cases. Progress is being made in this area, with several 100% hydrogen-compatible burners and furnaces being piloted in Europe as an example. The speed at which industrial equipment currently in operation may be replaced will also be a key driver of hydrogen adoption timelines in the industrial sector.[15]

0.3. Stakeholder Feedback

The input and feedback from the Planning Advisory Group (PAG) and Community Based Organization Stakeholder Group (CBOSG) have been an important part of the process to develop this Demand Study. For example, in response to stakeholder input, SoCalGas has: (1) shared detailed calculation methodologies and source data with stakeholders, (2) distinguished between total addressable market for hydrogen demand and portions of demand best served by Angeles Link (Angeles Link Throughput), and (3) clarified comparisons between the Demand Study and other third-party reports.

All feedback received is included, in its original form, in the quarterly reports, which also contain the responses to feedback and are submitted to the CPUC and published on SoCalGas's website. Certain comments identified in the quarterly reports were not incorporated into the final Demand Study due to reasons such as being out of scope,

[15] Heat Treat Today. "Global Steel Manufacturer Develops Historic Hydrogen Heat Treat." (May 25, 2020). https://www.heattreattoday.com/industries/manufacturing-heat-treat/global-steel-manufacturer-develops-historic-hydrogen-heat-treat/#:~:text=For%20the%20first%20time%20ever%2C%20heat%20treaters%20have,furnace%20at%20the%20Hofors%20rolling%20mill%20in%20Sweden

anticipated to be addressed in Phase 2, requiring third-party actions beyond SoCalGas's control, or raising issues better suited for third parties other than SoCalGas. Key feedback that was incorporated through the development of the Demand Study is summarized in the Stakeholder Feedback section.

0.4. Conclusion

The Demand Study findings indicate potential for significant demand—1.9M TPY to 5.9M TPY—for clean renewable hydrogen across the mobility, power, and industrials sectors by 2045 in SoCalGas's service territory. Further research may be required in future phases of Angeles Link to assess demand economics in more detail as well as further refine potential pipeline configurations to bring together supply and demand of clean renewable hydrogen. The demand study findings can be updated in future phases once approved by the CPUC.

1. Introduction

1.1. Background and Context

Hydrogen is an essential component of economy-wide decarbonization, particularly in sectors with few other decarbonization alternatives. In the Decision, the CPUC limits any future hydrogen transported in Angeles Link to clean renewable hydrogen, which is defined as hydrogen that does not exceed a standard of four kilograms of carbon dioxide-equivalent produced on a lifecycle basis per kilogram of hydrogen produced and does not use any fossil fuel in its production process.[16] Clean renewable hydrogen is a zero-emission fuel solution for hard-to-electrify sectors. For example, it provides faster refueling times and reduced weight for FCEVs relative to BEVs, reducing operational and cargo capacity impacts. Hydrogen is a low carbon energy carrier capable of being transported across long distances and stored for extended periods of time.

According to the U.S. Department of Energy's (DOE) "Pathways to Commercial Liftoff: Clean Hydrogen", hydrogen has a strong potential to support the decarbonization of long-haul trucking, maritime fuels, aviation fuels, chemicals, iron and steel, and refining, which collectively make up 10-25% of global energy-related carbon emissions.[17] Hydrogen can also contribute to the decarbonization of buses and short-haul trucks, other transportation, firm dispatchable power generation, cement, and other industries, which collectively accounts for an additional 25-40% of global energy-related carbon emissions. The report predicts that by 2050, clean renewable hydrogen could reduce overall U.S. carbon dioxide emissions by 10% compared to 2005 baseline levels.

State and federal interest in building out a hydrogen economy has risen in recent years, beginning with the passage of up to $7 billion of Clean Hydrogen Hub funding to support the development of 6-10 hydrogen hubs across the United States as part of the Biden Administration's Infrastructure Investment and Jobs Act[18] and the subsequent selection of the

[16] California Public Utility Commission. "Decision Approving the Angeles Link Memorandum Account to Record Phase One Costs." (December 15, 2022). https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M500/K167/500167327.PDF

[17] Department of Energy, "Pathways to Commercial Liftoff: Clean Hydrogen" (March 2023). https://liftoff.energy.gov/wp-content/uploads/2023/05/20230523-Pathways-to-Commercial-Liftoff-Clean-Hydrogen.pdf

[18] Department of Energy, "Bipartisan Infrastructure Law: Additional Clean Hydrogen Programs (Section 40314): Regional Clean Hydrogen Hubs Funding Opportunity Announcement" (September 22, 2022). https://oced-exchange.energy.gov/Default.aspx#FoaId4dbbd966-7524-4830-b883-450933661811

California Hydrogen Hub[19]. In addition, a notice of intent for $1 billion of funding to support demand-side initiatives was released in July 2023 to promote investment in hydrogen hubs, accelerate the hydrogen economy, and encourage private sector participation.[20] The recent Inflation Reduction Act also provides new incentives for hydrogen, with the 45V tax credit created to incentivize hydrogen production. The 45V tax credit awards up to $3/kg of hydrogen produced to projects with a lifecycle greenhouse gas (GHG) emissions intensity of less than 0.45 kilograms per kilogram of hydrogen.[21]

In November 2022, California created the world's first plan to achieve net-zero carbon pollution by 2045.[22] As the world's fifth largest economy, the state is taking ambitious measures to reduce pollution and increase deployment of renewable energy and other low-carbon technologies. Achieving this goal requires a combination of innovative solutions to bring decarbonization alternatives of best-fit to each market subsector.

In 2022 California established the Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES). ARCHES is a public-private hydrogen hub consortium of over 150 industry partners of hydrogen suppliers and end users across the state, including SoCalGas, in partnership with the Governor's Office of Business and Economic Development (GO-Biz).[23] ARCHES's focus is on creating clusters of hydrogen production, transport, storage, and use to support the development of a statewide hydrogen economy.[24] ARCHES submitted an application to the DOE for the Regional Clean Hydrogen Hubs Funding Opportunity and aims to utilize local renewable resources to produce hydrogen and decarbonize the regional economy. ARCHES was one of 7 hubs selected for up to $1.2 billion in federal funding in October 2023.[25] In July 2024, ARCHES and the DOE announced the signing of a $12.6 billion agreement to build the California hydrogen hub, including the up to $1.2 billion in federal

[19] Office of Clean Energy Demonstrations. "Regional Clean Hydrogen Hubs Selections for Award Negotiations." https://www.energy.gov/oced/regional-clean-hydrogen-hubs-selections-award-negotiations
[20] Department of Energy, "Notice of Intent: H2Hubs Demand-side Support" (July 25, 2023). https://oced-exchange.energy.gov/FileContent.aspx?FileID=9a1e375b-218e-4ae7-8fd0-c9a529a404ec
[21] Center for Strategic & International Studies. "How the 45V Tax Credit Definition Could Make or Break the Clean Hydrogen Economy". https://www.csis.org/analysis/how-45v-tax-credit-definition-could-make-or-break-clean-hydrogen-economy
[22] State of California, "California Releases World's First Plan to Achieve Net Zero Carbon Pollution" (November 16, 2022). https://www.gov.ca.gov/2022/11/16/california-releases-worlds-first-plan-to-achieve-net-zero-carbon-pollution/
[23] Alliance for Renewable Clean Hydrogen Energy Systems. https://archesh2.org/
[24] Ibid
[25] ARCHES, "California wins up to $1.2 billion from feds for hydrogen" (October 20, 2023). https://archesh2.org/california-wins-up-to-1-2-billion-from-feds-for-hydrogen/

funding that was announced last year.[26] As part of that agreement, DOE awarded ARCHES with $30 million for the first tranche of funding (out of the total project federal cost share of $1.2 billion) to begin Phase 1, which is expected to last up to 18 months for activities including planning, design, and community and labor engagement. This new development supports California's clean energy and climate goals with a strong commitment on community benefits and is a central focus of SoCalGas. Key priorities of ARCHES' efforts include environmental justice, equity, economic leadership, and workforce development. As reflected in ARCHES' July 17, 2024 press release, the ARCHES projects will span statewide, covering the full hydrogen lifecycle from production to use, including, but not limited to:

- Renewable Hydrogen Production – More than 10 sites will produce enough clean renewable hydrogen to fuel the projects below and kickstart the buildout of the greater hydrogen ecosystem.
- Ports of Long Beach, Los Angeles & Oakland – These projects will replace diesel-powered cargo-handling equipment with hydrogen fuel cell equivalents and associated fueling infrastructure, reducing emissions and community health impacts while reimagining large-scale transportation operations.
- Heavy Duty Trucks and Transit Buses – ARCHES plans to build over 60 hydrogen fueling stations to enable over 5,000 Class 6-8 fuel cell electric trucks and over 1,000 fuel cell electric buses–directly replacing diesel fuel with a zero-emission option in our City streets and freeways across the State and making the air in California's most impacted communities healthier to breathe.
- Clean Power – Both the Los Angeles Department of Water and Power and Northern California Power Agency will transition key power plants to 100 percent renewable hydrogen. Distributed fuel cells will be used to support grid operations throughout the state and to provide resilience in key regions of the state, including the Federally Recognized reservation of the Rincon Band of Luiseño Indians.
- Scripps Marine Vessel – A first-of-its-kind hydrogen-powered 140-foot, 50-person marine research vessel will use liquid hydrogen to replace tens of thousands of gallons of diesel fuel per year. The vessel will convert 75 percent of its emissions to be fossil-free, significantly reducing CO2 emissions and demonstrating a sustainable path forward for smaller water and harbor crafts.

In addition to existing state-wide zero-emission legislation and goals, the State has allocated funds towards key elements of the hydrogen value chain, including $20 million in grant funds to

[26] ARCHES, "California's Renewable Hydrogen Hub Officially Launches" (July 17, 2024). https://archesh2.org/arches-officially-launches/

support the development of 100 publicly available hydrogen refueling stations across the state with California Assembly Bill 126.[27]

1.2. Purpose and Objectives

Ordering Paragraph 6 of the Decision requires SoCalGas to provide the following findings (among others) from its Phase 1 feasibility studies:

- "Identification of the demand and end uses for the Project" (Ordering Paragraph 6.a)
- "Identification of the ratepayers who would be end-users, including current natural gas customers and future customers" (Ordering Paragraph 6.c)

The Demand Study has identified both existing and future SoCalGas ratepayers who would be potential end-users of Angeles Link. Existing ratepayers include power generation facilities, industrial customers such as metal fabrication shops, food and beverage manufacturing/processing facilities, stone/glass/cement facilities, pulp and paper, chemicals, mobility customers such as bus fleet operators and other heavy-duty vehicle operators that take service from SoCalGas CNG stations, and refineries, among others. Future potential ratepayers, who are not currently served by SoCalGas and could benefit from Angeles Link, include non-utility served heavy-duty vehicle operators, commercial harbor craft operators, ocean-going vessel operators, and locomotive operators. This study is limited to identification of certain but not all potential end uses that may drive potential demand for clean renewable hydrogen and does not attempt to evaluate the rate treatment of Angeles Link's construction and operation and maintenance costs, which is expected to occur in future phases. Continued analysis in future phases of Angeles Link will further identify and refine potential customers and beneficiaries of Angeles Link.

1.3. Scope

The aim of the Demand Study is to provide a comprehensive and market-validated outlook for clean renewable hydrogen demand in the mobility, power generation, and hard-to-electrify industrial sectors from present day to 2045. The main objectives include:

1. Identifying and validating demand, major end uses, and representative end users from present to 2045 across the Mobility, Power Generation, and Industrials sectors. Sectors, subsectors, and scenarios included in the analysis can be seen in figure below.
2. Consolidating results into a final report, consisting of timeline, demand map, and a list of representative adopters and non-adopters

---

[27] State of California, "AB-126 Vehicular air pollution: Clean Transportation Program: vehicle registration and identification plate service fees: smog abatement fee: extension." (October 9, 2023). https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202320240AB126

3. Supporting integration of demand results into other Phase 1 studies, including the Pipeline Sizing and Design Criteria study, the Production Planning and Assessment study, and the High-Level Economics and Cost Effectiveness study (referred as the Cost Effectiveness Study).

Figure 6: Demand Model Scenario Definition and Subsectors Included

Conservative	Scenario assumes lower adoption rates for hydrogen across a limited set of use-cases within prioritized sectors and sub-sectors, primarily driven by existing legislation. **Mobility:** Heavy Duty Vehicles, Medium Duty Vehicles, Cargo Handling Equipment, Ground Support Equipment, Agricultural Equipment, Construction & Mining Vehicles, Commercial Harbor Craft, Ocean Going Vessels* **Power:** Peaker, Baseload **Industrials:** Cogeneration, Food & Beverage, Metals, Stone, Glass, and Cement, Paper, Chemicals, Aerospace and Defense
Moderate	Scenario assumes increased hydrogen adoption across an expanded set of use-cases within prioritized sectors and sub-sectors, driven by existing legislation. **Mobility:** Heavy Duty Vehicles, Medium Duty Vehicles, Cargo Handling Equipment, Ground Support Equipment, Agricultural Equipment, Construction & Mining Vehicles, Commercial Harbor Craft, Ocean Going Vessels* **Power:** Peaker, Baseload **Industrials:** Cogeneration, Food & Beverage, Metals, Stone, Glass, and Cement, Paper, Chemicals, Aerospace and Defense
Ambitious	Scenario assumes more ambitious policies are put in place and businesses are incentivized to support widespread hydrogen adoption within prioritized sectors and sub-sectors. **Mobility:** Heavy Duty Vehicles, Medium Duty Vehicles, Cargo Handling Equipment, Ground Support Equipment, Agricultural Equipment, Construction & Mining Vehicles, Commercial Harbor Craft, Ocean Going Vessels*, Aviation **Power:** Peaker, Baseload **Industrials:** Refineries, Cogeneration, Food & Beverage, Metals, Stone, Glass, and Cement, Paper, Chemicals, Aerospace and Defense

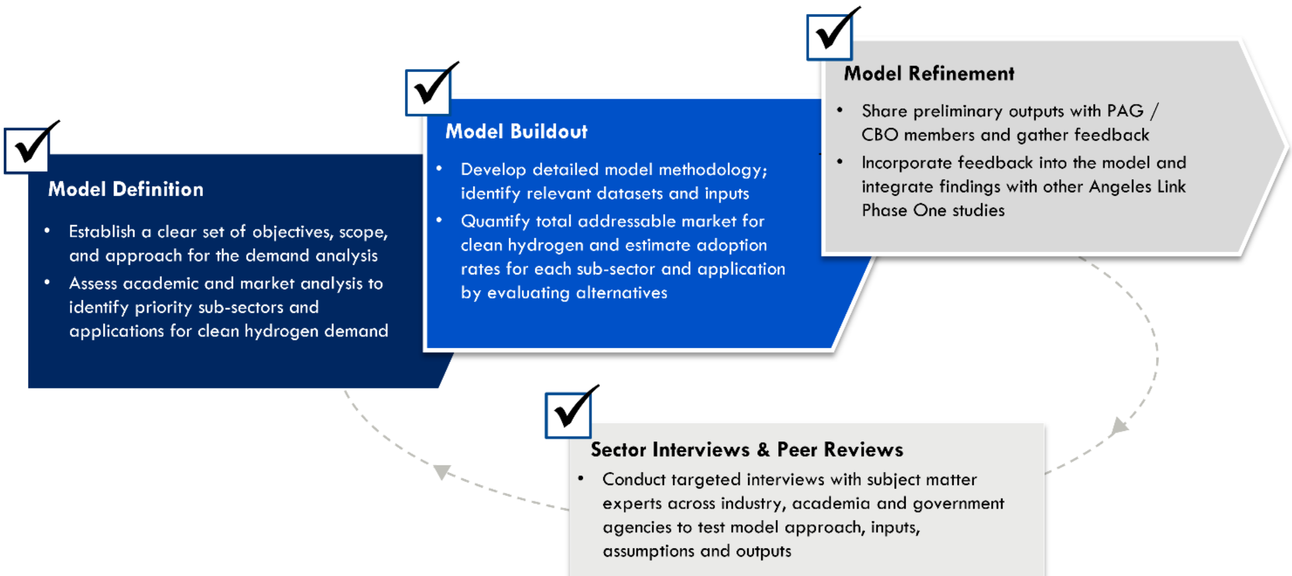
* OGV vessel demand modeling reflects hydrogen for diesel fuel replacement only (does not include bunker fuel replacement)

1.4. Methodology

1.4.1. Demand Analysis Approach

The Demand Study followed three main steps designed to embed rigor and third-party review throughout the full analysis process. These steps are described in the figure below:

Figure 7: Demand Analysis Approach



At the onset of the Demand Study, subsectors were prioritized for quantitative analysis based on current emissions, current natural gas usage, and a qualitative evaluation of potential for hydrogen in the subsector. The potential hydrogen demand for prioritized subsectors has been analyzed, with quantitative demand results outlined in this report. Subsectors not prioritized for quantitative analysis were not modelled, but potential opportunities for additional demand in these subsectors has been noted in this report. Throughout the analysis process, targeted interviews were conducted with subject matter experts across industry, academia, and government agencies to test these adoption inputs and assumptions, the model approach, and model outputs.

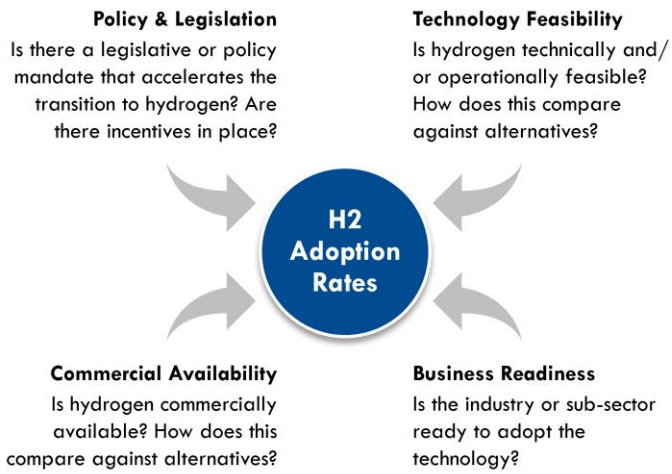
A variety of simplifying assumptions were used to develop a reasonable range for hydrogen demand within the Angeles Link Phase 1 timeline. Areas where simplifying assumptions have been used provide an opportunity for more detailed analysis in the future to improve the granularity and confidence level of demand projections. Please refer to Section 2.4.3. Simplifying Assumptions for additional information on these assumptions, and Section 8, Future Considerations, for opportunities for more refined analysis. Other assumptions may also be refined in future Angeles Link work, and other areas for recommended further analysis are identified throughout the report where applicable.

1.4.2. Adoption Factors

Four primary factors were used to determine future hydrogen adoption across sectors: policy & legislation,[28] technology feasibility, commercial availability, and business readiness. These factors reflect whether hydrogen is likely to be adopted in a specific subsector and to what extent hydrogen is likely to be adopted versus alternatives.

Adoption factors have been quantified and inputted into the demand model where possible, with the different levels of adoption in 2045 and curves of the adoption rate from 2025-2045 reflecting the substantial variations in adoption factors between subsectors. Sector-specific treatment and considerations are described in the following findings by sector sections.

Figure 8: Hydrogen Adoption Factors



1.4.3. Simplifying Assumptions[29]

The Demand Study has various simplifying assumptions for the purpose of meeting the study objectives in a timely manner. Simplifying assumptions and plans to address them are outlined below:

- **Price of Hydrogen:** The forecasted cost of clean renewable hydrogen was not factored into the potential demand analysis in order to understand the total potential of hydrogen

---

[28] Throughout the report, the word “legislation” is used to refer to law, rules, and regulations, whether passed/adopted on at the federal, state, regional, or local level.

[29] This section responds to stakeholder feedback by explaining SoCalGas’s rationale for simplifying assumptions regarding the cost of hydrogen with respect to forecasted demand. Additional details on how stakeholder feedback was incorporated is below in Section 6, Stakeholder Feedback.

as a fuel in the Los Angeles Basin and SoCalGas territory. In addition, the key drivers for hydrogen use in many cases in this Demand Study are policy mandates such as SB100, Advanced Clean Trucks (ACT), and ACF, as well as technical feasibility. SoCalGas received several comments from stakeholders on the draft study stating that the price of hydrogen will impact demand. The forecasted cost of clean renewable hydrogen is an important factor in projecting adoption and will need to be assessed in future phases of Angeles Link. Although analysis and forecasts of delivered levelized cost of hydrogen (LCOH) were outside the scope of this Demand Study, the LCOH analysis was evaluated in the Cost Effectiveness Study and may be further refined in future Angeles Link phases. SoCalGas will also utilize forecasts of clean renewable hydrogen costs to refine demand volumes in future phases.

  - **Mobility:** The CapEx and OpEx of hydrogen FCEVs were evaluated against alternatives, with fuel prices omitted.
  - **Power:** The CapEx of retrofitted hydrogen combustion equipment versus CCUS and battery alternatives were considered, and the price of hydrogen was assumed equivalent to the price of natural gas.
  - **Industrials:** The CapEx of retrofitted hydrogen combustion equipment versus CCUS and battery alternatives were considered, and the price of hydrogen was assumed equivalent to the price of natural gas.

Demand analysis refinements may be considered in the future as economic projections are updated.

- **Power System Reliability & Capacity Factors:** This study has not conducted a grid level system reliability analysis to understand how hydrogen capacity can support California's electric reliability standards as renewable penetration increases; therefore, the current analysis does not attempt to model the full power system or forecast future electric grid demand. Additional future assessments will be needed to understand reliability more thoroughly, particularly in the context of increased electric demand and its potential impact on hydrogen capacity and capacity factors.

- **Readily Available Hydrogen:** The demand study assumed that hydrogen will be readily available so as not to constrain the analysis with supply side limitations. This assumption may require future refinement to incorporate findings from other Angeles Link studies and industry updates.

2. Key Findings

Based on the assumptions used in this study, potential clean renewable hydrogen demand across SoCalGas's service territory could range between 1.9M and 6.0M TPY by 2045. Demand is projected to be highest in the mobility sector in the conservative scenario, followed by the power generation and industrials sectors, respectively. In the moderate and ambitious scenarios, the power sector accounts for the largest portion of hydrogen demand, followed by the mobility sector and then the industrials sector.

2.1. Mobility

- **Mobility can drive early adoption and scale.** 1.0M to 1.7M TPY of hydrogen demand is expected from the Mobility sector, accounting for 53% in the conservative scenario and 28% in the ambitious scenario. Since hydrogen fuel cell vehicles and associated transportation infrastructure is already being rolled out in SoCalGas's service territory, mobility applications may be the largest source of near-term clean hydrogen demand.

- **The operational characteristics required for on-road HDV applications lend favorably towards hydrogen adoption over alternatives.** Characteristics such as range requirements, load requirements, duty-cycle requirements, and fueling requirements all lend themselves positively towards adopting hydrogen over battery electric alternatives. Importantly, these characteristics should be considered in unison—as opposed to looking at any one of these characteristics in isolation. When doing so and evaluating FCEVs vs. BEVs, maximizing tonne-mile potential of a vehicle lends favorably to FCEVs over BEVs. If a fleet operator is looking to maximize freight transported over time, they would look more favorably on FCEVs.

- **Mobility demand is likely to be concentrated along transit corridors**, largely reflecting current diesel consumption today. Large fleet operators, particularly those moving freight, are unlikely to want their operations to change. Warehouse locations, refueling locations, and associated infrastructure have developed where they are now and have been optimized. So, to minimize any future investment required or changes in operations, we expect that fleet operators will look for diesel replacements that can operate as similarly as possible to diesel trucks today (short refueling times, long range, and a distributed fueling network). In SoCalGas's service territory, there are currently over 50 truck stops, nearly 100 cardlock facilities, and over 4,000 gas stations publicly listed by the CEC.[30] Their scale and locations reflect breadth of current refueling infrastructure.

[30] California Energy Commission. https://hub.arcgis.com/datasets/ec575b2693f64199866bc18744d232fe/explore

- **FCEV OEMs need to achieve economies of scale to achieve vehicle price reductions and mass adoption.** ZEVs can still be 2-6x more expensive than ICE vehicles (particularly for the heaviest-duty vehicles), though prices are steadily dropping.[31] Meanwhile 60 OEMs have announced planned sales of electric medium-duty vehicles (MDV), HDVs, or buses by 2024, whereas only 10 OEMs have done so for the equivalent hydrogen vehicles (According to CALSTART's ZETI tool, as of September 2023).[32] While the number of OEMs announcing production is not necessarily correlated to the amount of vehicles produced, these figures highlight the challenges faced for FCEV mass adoption. That said, many of these OEM announcements are for MDVs, which generally have lower operational requirements (range, load, etc.) and therefore favor conversion to BEV or FCEV.

- **A secondary market for ZEVs may reduce adoption barriers.** Secondary markets create liquidity, encourage price transparency, and enable lower prices. While a secondary market is not necessarily a requirement for mass-adoption of ZEVs, there are many fleet operators today—importantly, drayage fleet operators—who tend to procure ICE vehicles on the secondary market due to affordability concerns. So, with ZEV prices still significantly above ICE vehicle prices, these operators may face substantial costs to purchase new ZEVs and to comply with state requirements. There are very few heavy-duty ZEVs in use today beyond those in pilot programs, and few incentive mechanisms in place to support primary and secondary ZEV markets, so, more affluent fleet operators may be hesitant to assume the financial risks associated with being first movers; the less affluent fleet operators may be even more hesitant to adopt ZEVs until affordability issues are resolved. The creation of ZEV resale credits to provide financial assurances for early adopters and to create affordability for purchasers on the secondary market could enable wider adoption of ZEVs.

- **Marine and aviation applications could have significant demand for clean hydrogen.** Long-haul and regional aircraft, as well as cargo ships, consume substantial amounts of fuel. The inherent long replacement cycle (often 30+ year asset lifetimes), high duty-cycles, and the inter-state and international aspect of these applications mean that adoption of a new standard fuel could take many years.

---

[31] Argonne National Labs. "Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains." (April 2021). https://publications.anl.gov/anlpubs/2021/05/167399.pdf

[32] CALSTART ZETI. https://globaldrivetozero.org/tools/zeti/

2.2. Power Generation

- **Power could become the anchor hydrogen infrastructure driver** if capacity factors reach scenarios assessed in this demand study**.** Power represents between 0.7M and 2.7M TPY of hydrogen demand by 2045, accounting for 38% of total demand in the conservative scenario and 51% in the ambitious scenario. These results reflect the important and complementary role clean renewable hydrogen could play to renewable energy as a dispatchable resource that can be ramped up or down in response to changes in solar and wind generation and can provide long-duration storage. This Phase1 Demand Study does not attempt to forecast future electric load growth; however, CARB has projected in their 2022 Scoping Plan[33] that hydrogen will play a larger role in serving future load growth and be part of the resource mix that helps California meet its SB100 retail sales target. CARB projects 9 GW of incremental hydrogen capacity on top of 33 GW of gas generation that will be needed to meet SB100 targets by 2045, and the Demand Study estimates 10-13 GW of hydrogen capacity adoption within today's existing power capacity levels (in other words assuming conversion from only existing gas-fired plants in operation today, not incremental capacity). The relatively high hydrogen demand projected in the power sector positions power generation as a key source of the demand volume needed to kickstart infrastructure development.

- **Future hydrogen capacity factors remain uncertain.** Capacity factors will be dependent on the makeup of the overall power system, the future demand of the electric grid, and the cost and availability of hydrogen fueled power generation relative to other forms of generation. The cost of hydrogen as a fuel source will be a critical factor. Timing of supply and demand will also impact capacity factors for hydrogen fueled power generation. Even at very low annual capacity factors, the hourly flow rates needed to support power generation during peak demand periods could be significant, making cost-effective and reliable delivery of hydrogen to power plants a key consideration and serving as a determining factor for pipe sizing. In addition, achieving sufficient local reliability will be an important element that impacts future capacity factors and the need for firm dispatchable power.

- **Legislation is a key enabler.[34]** SB100 and SB1020 are key pieces of legislation driving power-sector decarbonization in California. SB100 established a state goal of 100% electric retail sales from renewable energy resources and zero-carbon energy resources

[33] California Air Resources Board. "2022 Scoping Plan for Achieving Carbon Neutrality". Figure 4-5. (December 2022). https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf
[34] This section has been revised in response to stakeholder feedback regarding the requirements of SB100 and SB1020.

by 2045, and SB1020 established that eligible renewable energy resources and zero-carbon energy resources would supply 90% of all retail sales of electricity to California end-use customers by December 31, 2035. Additional legislation making hydrogen in gas turbines eligible for SB100 compliance could specifically drive the adoption of clean renewable hydrogen in this sector, as the combustion of hydrogen is not RPS compliant nor is zero-carbon resources defined to include hydrogen.[35,36] For example, while this report does not advocate for any particular policy outcomes, it is noted that if hydrogen was included in the CPUC's Integrated Resource Plan and was eligible for SB100, that could increase hydrogen demand. LADWP's target of supplying 100% renewable energy by 2035 is a key driver of early renewables adoption as well.

- **The transition to hydrogen will be gradual.** In the near term, as utilities prepare for SB100 and SB1020 requirements, analysis suggests that existing natural gas combustion turbines within SoCalGas's service territory can be modified to burn blended volumes of up to 30% hydrogen and that technologies capable of utilizing 100% volumes of hydrogen can be available by 2030.[37,38,39] Despite the gradual nature of a hydrogen transition in the power sector, power purchase agreements between renewables companies and hydrogen producers or hydrogen-based power producers and utilities can be used to provide certainty for hydrogen power projects, making them more attractive to investors and helping establish a stable market for hydrogen-generated electricity. Public acceptance will also be crucial for enabling this hydrogen transition.

2.3. Industrials

- **Hydrogen has been recognized as a clean fuel alternative for hard-to-electrify industries.** The breadth of industries in California presents a plethora of potential hydrogen use cases, with industries such as metals, food and beverages, stone, glass, and cement, chemicals, and aerospace facing difficulties decarbonizing through electrification. For example, part of CARB's actions in their 2022 Scoping Plan include

[35] California Energy Commission. "Renewable Portfolio Standard Eligibility Guidebook." https://www.energy.ca.gov/programs-and-topics/programs/renewables-portfolio-standard
[36] Hydrogen produced without fossil fuels and used in a fuel cell is an eligible RPS resource per the https://www.energy.ca.gov/programs-and-topics/programs/renewables-portfolio-standard
[37] Mitsubishi Power. "Hydrogen Gas Turbine." https://solutions.mhi.com/power/decarbonization-technology/hydrogen-gas-turbine/
[38] GE Gas Power. "Hydrogen fueled gas turbines." https://www.ge.com/gas-power/future-of-energy/hydrogen-fueled-gas-turbines
[39] Siemens Energy. "Zero Emission Hydrogen Turbine Center." https://www.siemens-energy.com/global/en/home/products-services/solutions-usecase/hydrogen/zehtc.html

hydrogen fueling 25% of process heat by 2035 and 100% by 2045 for the chemicals, pulp, and paper sector, and include dedicated hydrogen pipelines in the 2030s to serve industrial clusters.[40] However, this breadth of industries presents challenges given the fragmented nature of the market.

- **Power cogeneration and refinery chemical usage represent the largest industrials demand centers for clean hydrogen in Central and Southern California.** Within SoCalGas's service territory, model results indicate potential hydrogen demand of 0.2M to 1.5M TPY by 2045. In the conservative and moderate scenarios, industrials accounts for 9-26% of total demand. Demand outside of refining and cogeneration applications is primarily from fuel switching applications (often heating), where direct electrification is competitive.

- **Technology Research and Development (R&D) continues to be needed to accelerate commercialization across other sectors, which means ramp up may take some time.** Customers will likely want to see clear demonstrations of the value of conversion to hydrogen before interrupting their existing capabilities and systems that are optimized for operational efficiency. In the food and beverage industry, gas catalytic-style hydrogen-capable burners can be used for baking, drying and space conditioning, but these are under development and are 5-10 years away from commercialization. In the metals industry, infrared emitting hydrogen-capable burners are also under development. Purpose-built 100% hydrogen furnaces, ovens and boiler systems are being modelled and will be in demonstration in the coming years that can provide metals industry customers with more efficient by-design hydrogen fueled process heating alternatives. For example, companies in Europe are expecting to produce green steel by as early as 2025 using clean hydrogen.[41]

- **Legislation/Regulation will be important to accelerate the timeframe and scale of hydrogen's impact.** Decarbonization of industrial sectors is difficult and costly given the typically long lifetime of equipment, the potential need for facility-wide retrofits, and the currently integrated natural gas usage. Where companies are not willing to take on these costs and challenges, legislative and regulatory targets and incentives can serve as drivers of hydrogen demand and growth. For example, if CARB created programs similar to LCFS for stationary sources, this would authorize those companies to participate in a carbon reduction program while receiving incentives to pay for the more

[40] California Air Resources Board. "2022 Scoping Plan for Achieving Carbon Neutrality". Table 2-1. (December 2022). https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf
[41] European Commission. "The HYBRIT story: unlocking the secret of green steel production." (June 20, 2023). https://climate.ec.europa.eu/news-your-voice/news/hybrit-story-unlocking-secret-green-steel-production-2023-06-20_en

expensive fuel and equipment. Cement is one early example where we see legislation taking place and where we expect hydrogen demand for fuel switching to take shape first, with existing legislation through SB 596 that mandates a reduction in emissions from cement producers by 40% of 1990 levels by 2030 and net-zero by 2045.

2.4. Cross-Sector Takeaways

- **There exists a wide breadth of use cases for hydrogen in SoCalGas's service territory, providing a stable source of demand under any scenario**. Multiple hard-to-electrify subsectors have been evaluated across mobility, power generation, and industrials, with many subsectors showing positive potential for hydrogen. This study reveals that hydrogen is a feasible decarbonization alternative that can fit into and strengthen the broader state decarbonization portfolio. Subsector diversification will drive economies of scale across hydrogen production, transportation and distribution, and consumption, ultimately leading to a growing hydrogen market in the future.

- **Legislation and regulation can have a significant impact to accelerate hydrogen adoption.** As demonstrated by the rapid displacement of traditional fuels by alternative fuels driven by the CARB LCFS Program—in Q1 2023, CARB announced that 50% of California diesel fuel was replaced by clean fuels[42]—market dynamics can shift based on legislation and regulation. For example, the recent demand-side funding mechanism released by the DOE could help spur significant demand from a diverse set of off-takers. If additional funding, tax incentives, and regulations to incentivize end-users to adopt clean renewable hydrogen solutions were established, those programs would also be expected to accelerate and increase adoption across all market sectors. Future legislation and policy, plus increased stringency of existing carbon regulatory programs, have the potential to impact the industrials sector in particular, where there have been minimal targeted legislative targets and policy incentives to date. In the mobility and power sectors, California has already been leading proactively on the policy front, with aggressive targets for clean power through SB100 and for the mobility through the Advanced Clean Cars II, ACT and ACF regulations. Similarly, if clean renewable hydrogen is included in the list of approved fuels for the SB100[43] and SB1440 programs in the future, it is expected that would have the effect of driving down costs for clean renewable hydrogen, similarly to how the RPS program reduced the cost of solar and wind.

---

[42] California Air Resources Board. "For first time 50% of California diesel fuel is replaced by clean fuels". (August 2023). https://ww2.arb.ca.gov/news/first-time-50-california-diesel-fuel-replaced-clean-fuels

[43] Clean hydrogen is eligible in SB100, however in the first SB100 report, the CEC decided not to model hydrogen in any of the scenarios.

- **Public-private partnerships are an attractive arrangement that can lower the cost of hydrogen adoption and scale up technological and commercial availability of hydrogen-related technology.** According to the DOE's Commercial Liftoff Report for Hydrogen, scaling clean renewable hydrogen will require a 4-10x scale-up of capital by 2030.[44] This includes the investment of both public and private sector capital. Federal investment can enable the financing of innovative projects and scale deployment rapidly. The development of contracting mechanisms to de-risk hydrogen projects, with the support of public entities, could incentivize additional investment across the private sector. Policy and market-based solutions to increase capital availability in the hydrogen economy will help mitigate cost and technical challenges for clean renewable hydrogen adoption across all sectors. In California, ARCHES was established to establish a federally co-funded clean renewable hydrogen hub in the state and to create an economically sustainable and expanding renewable hydrogen market in California and beyond.

- **Technology cost is a key limiting factor to hydrogen adoption in the short-term.** Today, converting to hydrogen technology poses significant capital expenditures and debt servicing across the mobility, power, and industrials sectors that may inhibit financial feasibility in the short- to medium-term. For mobility, the costs of hydrogen refueling infrastructure for FCEVs will be high in early years, as there will be fewer users per station until there is greater adoption across the market. For power generation, there will be cost to retrofit existing combustion turbines to be 100% hydrogen capable—today, existing power plants that can burn more than a trace amount of hydrogen are rare, although 30% blends by volume may be possible in the near future with retrofits to delivery systems. For industrials, the cost of retrofit and replacement of existing equipment could be significant and any change to existing processes could impact efficiency and for certain processes, product quality. Beyond technology costs alone, the DOE has set targets of achieving $1 per kilogram hydrogen by 2030 with their Hydrogen Shot initiative.[45]

- **Readily available hydrogen supply through connective infrastructure will be critical to supporting long-term adoption.** Whether available at refueling stations or through common carrier access pipelines, both public and private users of clean hydrogen will rely on connective infrastructure. The demand study assumed that hydrogen will be readily available so as not to constrain the analysis with supply side

[44] Department of Energy. "Pathways to Commercial Liftoff: Clean Hydrogen." (March 2023). https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf
[45] Department of Energy. "Hydrogen Shot." (2021). https://www.energy.gov/eere/fuelcells/hydrogen-shot

limitations. But, fulfilling the demand for clean renewable hydrogen presupposes that sufficient and stable supply of hydrogen, as well as the connective infrastructure that will bridge supply and demand, exist. Hydrogen pipelines such as Angeles Link could serve as this bridge. The DOE's Hydrogen Strategy Report highlights the importance of hydrogen infrastructure in scaling and commercialization, noting that "If regional networks prioritize shared, open-access infrastructure they can help to reduce the delivered cost of hydrogen."[46]

- **Community engagement and support is critical.** There is a broad range of stakeholders interested in the development and study of Angeles Link, including potential end users, potential suppliers, environmental and environmental justice community groups, ratepayer advocacy groups, union organizations, state agencies, and others. SoCalGas has invited these stakeholders to join a Planning Advisory Group and public webinars, townhalls, and workshops to gather feedback and technical advice and collaboration on Project design and development.[47] Stakeholder engagements help build public trust and approval through close community engagement and support the design and development of Angeles Link.

[46] "U.S. National Clean Hydrogen Strategy and Roadmap." https://www.powermag.com/wp-content/uploads/2023/06/us-national-clean-hydrogen-strategy-roadmap.pdf
[47] California Public Utility Commission. "Decision Approving the Angeles Link Memorandum Account to Record Phase One Costs." (November 7, 2022). https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M498/K339/498339407.PDF

3. Findings by Sector

3.1. Mobility

3.1.1. Introduction

California's mobility sector accounts for 37% of the state's GHG emissions, nearly 80% of nitrogen oxide pollution, and 90% of diesel particulate matter pollution.[48] California has set targets to achieve net zero emissions by 2045 across all sectors, and decarbonizing the mobility sector will be key to reaching these goals.[49] In the push to decarbonize the mobility sector, both hydrogen fuel cell and battery electric technologies have shown promise for many applications. This study estimates the potential for hydrogen adoption in the mobility sector, with particular focus on the use cases best fit for this fuel type. The mobility sectors modelled include four primary subsectors: on-road vehicles, off-road vehicles, marine, and aviation.

3.1.2. Mobility Landscape

3.1.2.1. California State Policy and Legislative Initiatives for a Zero-Emission Mobility Sector

California is a clear leader in ambitious decarbonization initiatives, from establishing new policies and mandates to supporting the adoption of renewable technologies. In line with the State's goal to achieve carbon neutrality by 2045, the State and many entities within it have passed legislation or submitted plans to significantly decarbonize the mobility sector, including but not limited to:

- **Executive Order (EO) N-79-20** – Issued by Governor Gavin Newsom in 2020, setting targets for achieving net zero in the mobility sector by 2045.[50]

- **ACF** – Regulation adopted by CARB and the State of California in 2023 requiring 100% of new truck purchases by fleets be ZEV by 2035, and as early as 2024 for some

[48] California Air Resources Board. "California Greenhouse Gas Emissions for 2000 to 2020". (October 26, 2022). https://ww2.arb.ca.gov/sites/default/files/classic/cc/inventory/2000-2020_ghg_inventory_trends.pdf
[49] California Air Resources Board. "California releases final proposal for world-leading climate action plan that drastically reduces fossil fuel dependence, slashes pollution." (November 16, 2022). https://ww2.arb.ca.gov/news/california-releases-final-2022-climate-scoping-plan-proposal
[50] State of California. "Executive Order N-79-20". (September 23, 2020). https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf

vehicles.[51]

- **ACT** – Regulation adopted by CARB and the State of California requiring ZEV sales to achieve certain milestones from 2024 to 2035 and beyond.[52]

- **Innovative Clean Transit (ICT)** – Requires each transit agency to submit a complete Zero-Emission Bus Rollout Plan (Rollout Plan).[53]

- **Advanced Clean Cars II (ACCII)** – Regulation adopted by CARB and the State of California requiring 35% of new car sales to be ZEV starting in 2026, ramping up to 100% of sales by 2035.[54]

- **Clean Air Action Plan (CAAP)** – Strategy set forth by the Port of Los Angeles and Port of Long Beach (together known as the San Pedro Bay Ports) to reduce emissions in the port area by requiring 100% of CHE to ZEV by 2030.[55]

- **Clean Shipping Act of 2023** – Bill passed in 2023 requiring commercial vessels to operate with 100% zero emission fuel by 2040.[56]

- **Low Carbon Fuel Standard (LCFS)** – Covered under the AB 32 Scoping Plan (Assembly Bill 32 (AB 32)) which is an emissions trading rule designed to reduce the average carbon intensity of transportation fuels.[57]

- **SCAQMD Warehouse Indirect Source Rule (ISR)** – approved in 2021 requires warehouses greater than 100,000 square feet to directly reduce nitrogen oxide (NOx) and diesel particulate matter (PM) emissions, or to otherwise reduce emissions and

---

[51] California Air Resources Board, "Advanced Clean Fleets Regulation Summary" (May 17, 2023). https://ww2.arb.ca.gov/our-work/programs/advanced-clean-fleets
[52] California Air Resources Board, "Advanced Clean Trucks" (2019). https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/fro2.pdf
[53] California Air Resources Board. "ICT-Rollout Plans." (2023). https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit/ict-rollout-plans
[54] California Air Resources Board. "Advanced Clean Cars II Regulations: All New Passenger Vehicles Sold in California to be Zero Emissions by 2035." https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/advanced-clean-cars-ii
[55] The Port of Los Angeles. "Clean Air Action Plan." (2023). https://cleanairactionplan.org/
[56] 118th Congress, "Clean Shipping Act of 2023" (April 6, 2023). https://robertgarcia.house.gov/sites/evo-subsites/robertgarcia.house.gov/files/evo-media-document/garcro_029_xml.pdf
[57] California Air Resources Board. "Low Carbon Fuel Standard." https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard/about

exposure of these pollutants in nearby communities.[58]

- **Cap-and-Trade** – California's cap-and-trade program sets annual reductions in the cap or amount of permissible emissions.[59]

The significant volume of legislation and zero-emissions guidelines in California are key driving factors for the adoption of hydrogen and battery technologies in the mobility sector.

3.1.2.2. Hydrogen in the Mobility Sector

There are over twelve thousand FCEVs, mainly passenger cars, on the road today in California.[60] These light-duty vehicles (LDV) have been some of the earliest proofs of concept for fuel cell technology. Meanwhile the early adopters of fuel cell technologies for heavy-duty applications has come from California's Transit agencies, with announced plans to purchase over 2,100 fuel cell electric buses (FCEB) across the state.[61] There are currently over 12,000 transit buses (of all types) in operation across the state.[62] Local transit operators are some of the earliest adopters of FCEBs, recognizing clean renewable hydrogen as an attractive solution for decarbonization of their fleets, given hydrogen's ability to support multiple shifts each day with fast refueling times. Several manufacturers are currently developing fuel cell trucks for on-road heavy-duty applications as well, including Toyota, Hyundai, and Nikola, who are developing fuel cell Class 8 semi-trucks with reported ranges of up to 500 miles when fully

[58] South Coast AQMD. "South Coast AQMD Governing Board Adopts Warehouse Indirect Source Rule. (May 2021). board-adopts-waisr-may7-2021.pdf (aqmd.gov)
[59] California Air Resources Board. "Cap-and-Trade Program." https://ww2.arb.ca.gov/our-work/programs/cap-and-trade-program/about
[60] California Energy Commission. "Zero Emission Vehicle and Infrastructure Statistics." (2023). https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics
[61] California Air Resources Board. "Fuel Cell Electric Bus Deployment in California." (2023). https://ww2.arb.ca.gov/sites/default/files/2022-10/FCEB-Deployment-Map.pdf
[62] California Air Resources Board. "California transitioning to all-electric public bus fleet by 2040". https://ww2.arb.ca.gov/news/california-transitioning-all-electric-public-bus-fleet-2040

loaded.[63, 64, 65] With refueling in as little as 20 minutes today, Nikola has demonstrated that their fuel cell electric semi-truck can travel as much as 900 miles in a single day. [66]

California is also leading in hydrogen refueling infrastructure and commitments with 57 out of 58 on-road, public refueling stations nationwide being in California (as of July 2023).[67] In its 2022 Annual Evaluation of FCEV Deployment, CARB projected 176 open stations by 2026 and 2027 in the state, 35 of which are being planned in Los Angeles County.[68] Additionally, the CEC, as part of the Clean Transportation Program, is providing funds to support the development of 100 public fueling stations across California.[69] Additionally, many transit agencies are developing private cardlock hydrogen fueling stations for their FCEB fleets as well. These stations could support fast fueling in 2019 the DOE released updated targets to achieve 8 kg H2/min fueling flow rates by 2030 and 10 kg H2/min by 2050.[70] Infrastructure readiness is a critical factor influencing business readiness to adopt hydrogen or electric technologies.

---

[63] Green Car Reports. "Hyundai will test 500-mile hydrogen fuel-cell semis in California". (July 27, 2021). https://www.greencarreports.com/news/1133014_hyundai-will-test-500-mile-hydrogen-fuel-cell-semis-in-california

[64] Toyota. "Toyota, Kenworth Prove Fuel Cell Electric Truck Capabilities with Successful Completion of Truck Operations for ZANZEFF Project." (September 2022). https://pressroom.toyota.com/toyota-kenworth-prove-fuel-cell-electric-truck-capabilities-with-successful-completion-of-truck-operations-for-zanzeff-project/

[65] Nikola. "Nikola Celebrates the Commercial Launch of Hydrogen Fuel Cell Electric Truck in Coolidge, Arizona." (September 2023). https://www.nikolamotor.com/press_releases/nikola-celebrates-the-commercial-launch-of-hydrogen-fuel-cell-electric-truck-in-coolidge-arizona/#:~:text=Nikola's%20ground%2Dbreaking%20hydrogen%20fuel,as%20low%20as%2020%20minutes.

[66] Securities Exchange Commission. "Nikola President & CEO Steve Girsky Chat Transcript." (September 13, 2023). https://www.sec.gov/Archives/edgar/data/1731289/000173128923000252/exhibit991firesidechat91323.htm

[67] US DOE Alternative Fuels Data Center. "Alternative Fueling Station Counts by State." https://afdc.energy.gov/stations/states

[68] CARB. "2022 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development" https://ww2.arb.ca.gov/sites/default/files/2022-09/AB-8-Report-2022-Final.pdf

[69] State of California, "AB-126 Vehicular air pollution: Clean Transportation Program: vehicle registration and identification plate service fees: smog abatement fee: extension." (October 9, 2023). https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202320240AB126

[70] Department of Energy. "DOE Advanced Truck Technologies Subsection of the Electrified Powertrain Roadmap Technical Targets for Hydrogen-Fueled Long-Haul Tractor-Trailer Trucks" (October 31, 2019). https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf

While current hydrogen fueling stations are generally being built for LDVs or FCEBs, these investments are critical to promoting shared infrastructure and the viability of hydrogen technology that can be leveraged by HDV applications in the future. There are currently no final standards or example stations tailored for HDV applications, resulting in considerable uncertainty surrounding commercial costs. However, as the hydrogen ecosystem develops around LDVs, FCEBs, and fuel cell HDVs, the technologies developed to support certain applications can be leveraged to help grow hydrogen usage for other applications. In 2018, the California Fuel Cell Partnership published its vision for 2030, reflecting the input and consensus of more than 40 partners; according to this vision, the Partnership will pursue a network of 1,000 hydrogen refueling stations and one million FCEVs in California by 2030.[71]

For hydrogen fuel cell technologies to become commercially available and affordable, fuel cell production needs to be ramped up to achieve the cost reductions and operational efficiencies of economy of scale. While cell type and stack composition may change and be optimized by application, fuel cells can generally be used across applications, meaning that the fuel cells manufactured for LDVs or HDVs could be used in off-road vehicles. To facilitate mass-production of fuel cells, DOE has set targets of $60 per kilowatt (kW) for fuel cell stacks by 2050.[72] Additionally, the federal government has announced several funding opportunities to provide funding to accelerate fuel cell development, such as $750 million as a part of IIJA to research Fuel Cell Membrane Electrode Assembly and Stack Manufacturing and Automation, Fuel Cell Supply Chain Development, and more.[73]

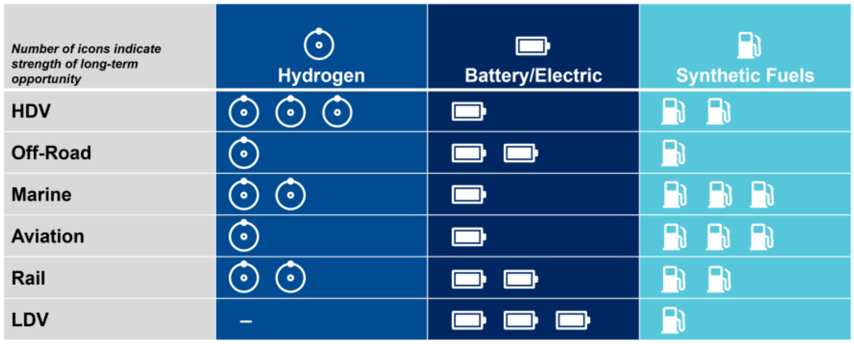
3.1.2.3. Decarbonization Pathways and Alternatives[74]

There are typically three types of low-carbon alternatives to traditional fuels in the mobility sector: electric (either direct electrification or battery), hydrogen (used in fuel cells or combusted), or synthetic fuels (such as renewable diesel or SAF). Each of these alternatives

[71] California Fuel Cell Partnership. “The California Fuel Cell Revolution.” (August 28, 2018). https://h2fcp.org/sites/default/files/CAFCR-Presentation-2030.pdf
[72] Department of Energy. "DOE Advanced Truck Technologies Subsection of the Electrified Powertrain Roadmap Technical Targets for Hydrogen-Fueled Long-Haul Tractor-Trailer Trucks.” (October 31, 2019).
https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf?Status=Master
https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf
[73] Department of Energy. “EERE Funding Opportunity Announcements, DE-FOA-0002922: BIPARTISAN INFRASTRUCTURE LAW: CLEAN HYDROGEN ELECTROLYSIS, MANUFACTURING, AND RECYCLING, Area of Interest 2, Topic 4.”
https://eere-exchange.energy.gov/Default.aspx#FoaIda9a89bda-618a-4f13-83f4-9b9b418c04dc
[74] This section responds to stakeholder comments regarding analysis of alternatives to clean renewable hydrogen in the Demand Study.

and their associated technologies has their own benefits and challenges over current fossil fuel technologies, and the future cost, performance, and development trajectories of each technology is uncertain.

Figure 9: Mobility Application Decarbonization Alternatives Assessment



The DOE's U.S. National Blueprint for Transportation Decarbonization outlines the plausibility of various decarbonization fuel alternatives across some of the mobility subsectors.[75]

<u>Battery Electric</u>

CARB states in their 2022 Scoping Plan that the primary ZEV technologies available today are battery electric and hydrogen fuel cell electric vehicles, and that both types of vehicles are rapidly growing in performance, affordability, and popularity.[76] Today, battery technologies are prevalent among LDV applications, building upon the momentum of the hybrid electric technologies before them. However, for marine, aviation, and heavy-duty applications, both technologies are still in relatively nascent stages. There are several companies working on BEVs in the heavy-duty sector today, particularly for on-road applications. While achieving sufficient range for long-haul BEVs may be technically possible, high battery costs, reduced cargo capacity, and relatively long charging times could limit the economic and operational feasibility of electric semi-trucks for long haul applications compared to those operating on regional and urban routes. Additionally, charging technology for heavy-duty trucks will require much higher power than for LDVs. For example, analysis by Argonne National Labs (ANL) on the SAE J3271 fast charging system states that a long-haul trucker driving a Class 8 tractor would require a 1.6-MW charge to recover 400 miles of charge within a 30-minute break.[77] 1.6 MW can be enough to power 1,600 homes. So, achieving a charging rate appropriate for

[75] US DOE. "The U.S. National Blueprint for Transportation Decarbonization." https://www.energy.gov/sites/default/files/2023-01/the-us-national-blueprint-for-transportation-decarbonization.pdf
[76] California Air Resources Board. "2022 Scoping Plan for Achieving Carbon Neutrality". (December 2022). https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf
[77] Argonne National Labs. "Charging for Heavy-Duty Electric Trucks." (March 2023). https://www.anl.gov/sites/www/files/2023-03/MCS_FAQs_Final_3-13-23.pdf.

heavy-duty trucks would mean significant electric infrastructure upgrades, posing challenges for grid management due to steep load peaks.

The battery electric market for off-road mobility is well-developed for many applications. For example, airport ground support equipment (GSE) can be particularly well-suited for electrification because of its low-end torque, frequent starts and stops, long downtime, and short-range requirements.[78] Electric technologies for other mobility subsectors are still emerging.

<u>Synthetic Fuels</u>

Hydrogen produced from electricity can be combined with byproduct or captured CO2 to produce a wide variety of synthetic fuels (also known as eFuels). Synthetic fuels are typically hydrocarbon-based fuels (except for synthetic ammonia) making them similar in composition to the traditional fuels they are meant to replace. They are a good fit for applications that have fuel system energy density requirements higher than what electric and hydrogen technologies can offer. Because many synthetic fuels can be used as a “drop-in” replacement for existing fossil fuels (i.e., in traditional combustion engines, jet engines, and other existing technologies), they also present an attractive value proposition for applications where capital costs are prohibitively high for electrification or hydrogen technologies.

Synthetic renewable diesel is a prime example of a synthetic drop-in liquid fuel. Other types of synthetic fuels include synthetic versions of SAF, methanol, ammonia, and dimethyl ether. By 2021, California was consuming over 28 million barrels of renewable diesel annually. Perhaps the largest consideration for synthetic fuels is that while they may present a path to reduced emissions (since they offer a utilization option for CO_2 that may have otherwise been emitted at the source), they contain carbon and therefore have direct GHG emissions. As such, the full emissions lifecycle of captured CO_2 and emitted CO_2 (and other pollutants) needs to be considered for synthetic fuels to become the long-term solution to decarbonization.

3.1.3. Model Scope and Key Assumptions

3.1.3.1. Model Scope

The mobility sector analysis focused on vehicles operating in SoCalGas’s service territory, based on the total vehicles in eleven counties: Imperial, Kern, Kings, Los Angeles, Orange, Riverside, San Bernardino, San Luis Obispo, Santa Barbara, Tulare, and Ventura. Analysis was conducted for applications that would use hydrogen fuel cells only (hydrogen combustion

[78] NREL. “Electric Ground Support Equipment at Airports.” (Dec. 12, 2017). https://afdc.energy.gov/files/u/publication/egse_airports.pdf

technologies and synthetic fuels were excluded).[79] The specific scope and assumptions utilized in the model are summarized below.

Table 1: Scenario Definitions for Mobility: Subsectors Modelled[80]

Scenario Definition Characteristic		Conservative	Moderate	Ambitious
Subsector	**On-Road**	• Heavy Duty Vehicles • Medium Duty Vehicles		
	Off-Road	• Cargo Handling Equipment • Ground Support Equipment • Agricultural Equipment • Construction & Mining Equipment		
	Marine	• Commercial Harbor Craft • Ocean-Going Vessels (OGV)*		
	Aviation	• n/a	• n/a	• Aircraft

3.1.3.2. Key Assumptions and Adoption Levers

The key levers influencing Demand Study outputs by scenario are the hydrogen adoption rates. These adoption rates are determined for each scenario and modelled by application category by assessing the four factors of legislation, technology feasibility, commercial availability, and business readiness. Hydrogen FCEV adoption rates may vary across each scenario based on each of the legislation, commercial availability, and business readiness assumptions; technology feasibility evaluations remain constant across the scenarios.

Total demand was calculated at the vehicle application level across the three modeling scenarios, with scenarios defined as follows:

[79] Any potential clean renewable hydrogen demand for the development of synthetic fuels is accounted for in the Industrials sector portion of the Demand Study as the synthetic fuel production facilities, not the vehicles, would represent the locations and facilities of clean renewable hydrogen demand.

[80] The Demand Study quantifies clean renewable hydrogen demand for vehicle classes 2b-8, given the viability of hydrogen for these vehicle classes and the current state of the market for other decarbonization alternatives. LDVs are excluded from the scenarios due to the general market push towards electrification of this vehicle class. However, given the number of vehicles currently on the road (over 13 million passenger cars in SoCalGas's service territory), potential hydrogen demand may be significant, even at low FCEV market penetration.

Table 2: Scenario Definitions for Mobility: Hydrogen Adoption Rate Factor Definition

Scenario Definition Characteristic		Conservative	Moderate	Ambitious
Adoption Factors	**Policy & Legislation**	Consideration of existing policy & legislation		Consideration of existing policy and legislation, and additional legislation beginning in 2025
	Commercial Readiness	Conservative timeline to achieve cost parity with decarbonization alternatives	Moderate timeline to achieve cost parity with decarbonization alternatives	Ambitious timeline to achieve cost parity with decarbonization alternatives
	Technical Feasibility	Evaluated per vehicle application group but held constant across scenarios		
	Business Readiness	Conservative assessment of market readiness to adopt hydrogen vehicles	Moderate assessment of market readiness to adopt hydrogen vehicles	Ambitious assessment of market readiness to adopt hydrogen vehicles

<u>Policy & Legislation</u>

To model the transition from ICE to ZEV technologies, legislation applicable to each mobility subsector was reflected. This legislation generally impacts the sale or purchase of new vehicles needing to be ZEVs and assumes that vehicles will not be forced to retire early). As such, vehicle and application retirement rates were also modelled, using CARB estimates and industry research to determine when vehicles would naturally retire.

For on-road applications, legislation may be the most influential driver of hydrogen adoption. The ACF regulation,[81] passed April 28, 2023, lays out decarbonization timelines and requirements for high priority medium- and heavy-duty fleets, government-owned fleets, and drayage fleets to convert to ZEVs. Some of ACF's highlights include:

[81] California Air Resources Board. " Advanced Clean Fleets Regulation Summary." (2023). https://ww2.arb.ca.gov/our-work/programs/advanced-clean-fleets

- 100% of truck sales starting 2035 will be ZEV for all fleets.
- 100% of truck sales starting 2024 will be ZEV for ACF priority fleets.
- 100% of new drayage trucks registered with CARB need to be ZEV starting 2024, and 100% of drayage trucks need to be ZEV starting 2035 to be allowed to enter the ports and modal railyards.

ACF complements the previously adopted ACT regulation, which requires manufacturers to sell ZE trucks and school buses, as well as the issued 2020 EO N-79-20, which set goals for the State to achieve 100% ZEV sales for new trucks by 2035 and for MDV and HDV by 2045. This comprehensive approach encompasses both the supply and demand sides of the market, which will transition a significant amount of the MDV and HDV subsectors to cleaner transportation options.

For non-on-road applications, legislation is sparser. But similar adoption principles to those outlined in ACF are utilized. Vehicle lifespans vary significantly by application, so retirement and replacement rates vary.

Technology Feasibility

The feasibility of adopting hydrogen-powered vehicles is driven by the vehicle operational characteristics, such as range, load, or duty-cycle requirements. Operational characteristics are assessed to determine if hydrogen fuel cell solutions are a fit for each application, versus other decarbonization alternatives (such as BEVs). A series of factors was defined for each mobility subsector, and each vehicle application category was evaluated across these factors to determine the likelihood of adopting hydrogen over decarbonization alternatives.

Commercial Availability

Commercial availability assesses the availability and cost-competitiveness of hydrogen FCEVs compared to other zero-emission alternatives (namely, BEVs) and traditional diesel and gasoline vehicles (until new diesel/gasoline vehicles are no longer allowed to be sold in California). CapEx and OpEx (excluding fuel cost) analysis were conducted to determine if and when FCEV and BEV technologies would achieve relative cost parity with each other and with traditional vehicles.

Business Readiness

Business readiness is a factor included in determining hydrogen adoption rates to reflect the relative readiness of fleet operators to adopt hydrogen technology. For example, companies such as Walmart, AB InBev, and many others who operate or who contract large on-road fleets for distribution of their products have set targets to achieve Net Zero by 2040.[82] With such commitment, some companies and certain industries will lead the adoption of ZEVs and FCEVs as early adopters, and some others will be fast followers. Targets such as these may lead to an acceleration in FCEV or BEV adoption beyond what would otherwise be legally required by statute or regulation. CARB affirms that promoting private investment in the transition to ZEV technology is one of their strategies for achieving success in their scoping plan.[83] Business readiness could be caused by either faster infrastructure availability to support hydrogen vehicles, or the early retirement of ICE vehicles and associated earlier adoption of FCEVs.

3.1.4. Mobility Demand Study Results

3.1.4.1. Overview

The mobility sector analysis shows potential demand in SoCalGas's service territory ranging from 1.0M TPY in the conservative scenario to 1.7M TPY in the ambitious scenario by 2045, as depicted in the figure below. The on-road subsector accounts for 83% to 93% of potential mobility sector hydrogen demand in 2045 across scenarios, driven primarily by heavy-duty Class 8 vehicle applications and transit buses; off-road, marine, and aviation applications make up the remainder.

Forecasted potential hydrogen demand for the mobility sector takes a noticeable uptick in 2035 onwards across all scenarios, largely due to the regulations for on-road vehicles that have been passed which effectively require 100% ZEV sales starting in 2035. This would imply that as today's vehicles retire in the 2030s, they will largely be replaced by ZEVs, of which many could be FCEVs (pending application). The distribution of demand across subsectors remains relatively similar across scenarios.

While the proportion of demand for the off-road subsector may be relatively low, these applications have an important role to play in supporting the early adoption of hydrogen. For example, the San Pedro Bay Ports are pursuing adoption of various FCEV technologies today in support of their Clean Air Action Plan goals of having 100% of their CHE being ZEV by 2030. This early net zero target strongly supports the State's decarbonization goals (non-road applications account for 10% of emissions in California).

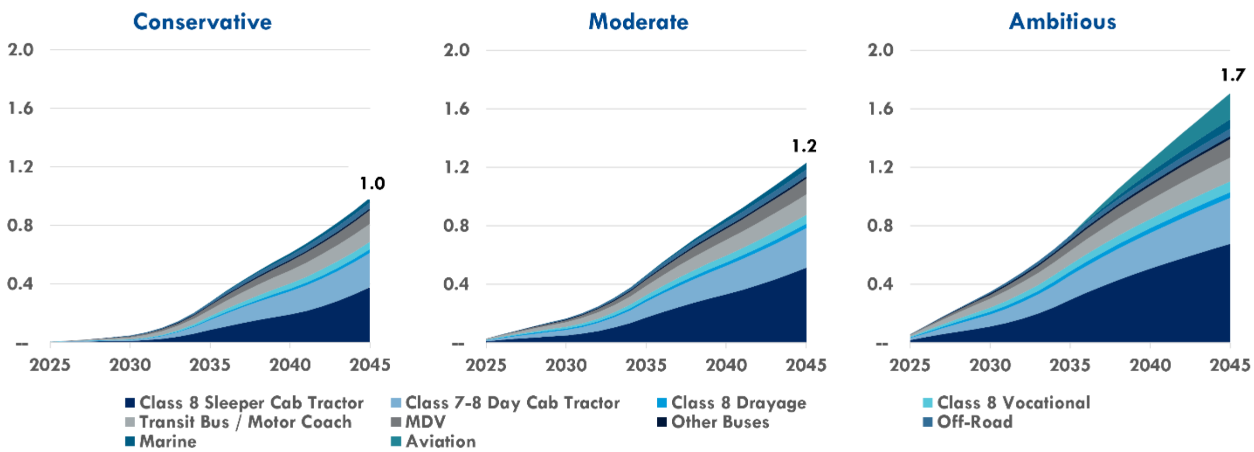
[82] Walmart. "Climate Change." (2023). https://corporate.walmart.com/esgreport/environmental/climate-change ; Anheuser-Busch InBev. "Our Ambition to Achieve Net Zero." https://www.ab-inbev.com/assets/pdfs/Net%20Zero%20Executive%20Summary_FINAL%2012pm.pdf

[83] California Air Resources Board. "2022 Scoping Plan for Achieving Carbon Neutrality". (December 2022). https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf

The marine and aviation subsectors account for 3% to 14% of mobility sector hydrogen demand in 2045 across scenarios. This large spread is a reflection that there is a large degree of uncertainty regarding clean hydrogen's role for these applications: the development of synthetic fuel alternatives such as SAF or clean ammonia or methane for shipping may win out in these applications over hydrogen for use in fuel cells. To reflect these uncertainties, only the ambitious scenario only includes potential clean hydrogen demand for fuel cell aircraft; for marine applications only hydrogen for diesel replacement is considered (in all scenarios).

Figure 10: Total Expected Mobility Sector Clean Renewable Hydrogen Demand by Subsector

(2025-2045, values in Million TPY)



Adoption beyond the conservative case will be dependent on the hydrogen adoption rates across legislation, commercial availability, technical feasibility, and business readiness factors as described above. Additional incentives enticing early retirement of vehicles or supporting early adoption of hydrogen vehicles would be valuable to accelerate the adoption curve and the creation of a second-hand vehicle market.[84]

[84] U.S. Department of Energy. "Biden-Harris Administration to Jumpstart Clean Hydrogen Economy with New Initiative to Provide Market Certainty and Unlock Private Investment." (July 5, 2023). https://www.energy.gov/articles/biden-harris-administration-jumpstart-clean-hydrogen-economy-new-initiative-provide-market

Figure 11: Total Expected Mobility Sector Hydrogen Demand by Scenario and Application Group

(2045, in Thousands TPY)

Sub-Sector	Conservative	Moderate	Ambitious
Heavy Duty Vehicles	691	879	1,109
Medium Duty Vehicles	91	105	124
Buses	135	153	178
Off-Road	41	47	52
Marine	31	46	65
Aircraft	--	--	178
Total	988	1,230	1,707

3.1.4.2. Subsector Results

On-Road Vehicles

Overview

Most of the projected mobility sector demand is driven by on-road applications: 93% in the conservative scenario and 83% in the ambitious scenario. There can be several explanations for this high concentration, including:

- SoCalGas's service territory includes a dense population center around Los Angeles, with roughly 50% of the state's population. This means that demand for on-road vehicle fuel is high, and demand for agricultural or mining related off-road applications is minimal compared to more rural areas.
- The San Pedro Bay Ports account for 29% of all containerized international waterborne trade in the U.S., and 75% of all containerized cargo destined for the West Coast.[85] This volume and value of goods means that many trucks—not just drayage trucks—are accessing fuel in SoCalGas's service territory.
- Legislation for zero-emission on-road vehicle applications has been established and continues to be refined and added to, whereas specific legislation for non-on-road applications has been slower to develop.

The top 5 vehicle on-road applications assessed—Class 8 Sleeper Cab Tractors, Class 7-8 Day Cab Tractors, Class 8 Vocational Trucks, Class 8 Drayage Trucks, and Transit Buses—together account for 88% of projected on-road hydrogen demand and 82% of projected mobility sector hydrogen demand by 2045 in the conservative scenario. These vehicles have

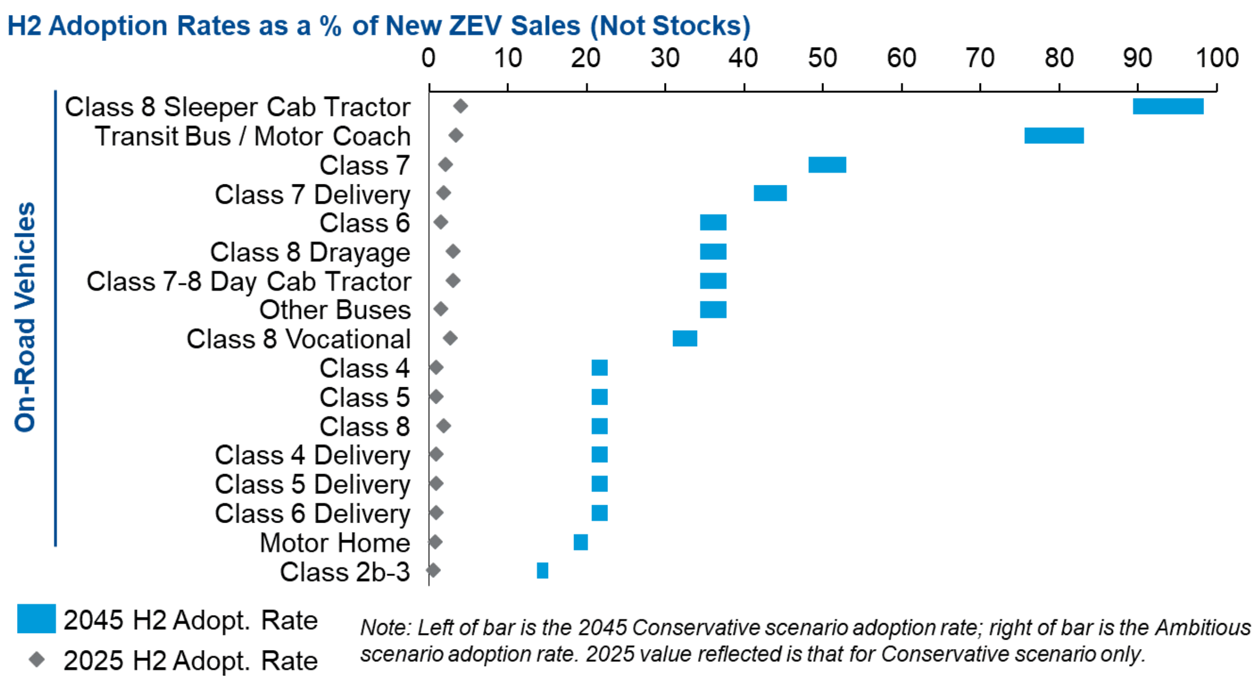
[85] The Port of Los Angeles. "Facts and Figures." (2023). https://www.portoflosangeles.org/business/statistics/facts-and-figures

several things in common, leading to their high hydrogen usage—relatively large fleet sizes, high fuel consumption rates, high duty cycles, and high load requirements. As described above, these characteristics can lend themselves towards a higher likelihood of hydrogen technologies for many applications.

Hydrogen Adoption Rate Evaluation

New ICE vehicles effectively cannot be sold in California after 2035, which makes BEV or FCEV technologies the two leading options for decarbonizing on-road transportation. Accordingly, these two alternatives were evaluated for each modelled vehicle application group to determine the adoption rates. Long-term FCEV 2045 adoption rates across the conservative to ambitious scenarios by application group can be seen below in the figure below. BEV adoption rates would be the inverse of the FCEV adoption rates.

Figure 12: Hydrogen FCEV Adoption Rates of New Sales of On-Road ZEVs



Hydrogen (FCEV) adoption rates vary significantly by application. For 2025, hydrogen adoption rates are as low as 1% in the conservative scenario (meaning that BEVs or other non-hydrogen ZEV technologies would be the dominant technology). Some of the key factors influencing adoption rates are the expected fit of the FCEV technology to the application, and the expected advancements in price reduction and vehicle availability. The following characteristics were considered for evaluating the fit of FCEV technology to on-road vehicle applications:

- **Range Requirements.** Trucks that must travel long distances are generally determined to favor FCEV adoption over BEV adoption. This can be due to a series of factors which may vary by application but include considerations such as faster refueling times and longer ranges.

- **Load Requirements.** Fuel cells are generally lighter-weight relative to batteries, meaning BEVs generally face a higher penalty in terms of cargo capacity reduction relative to FCEVs due to federal and state vehicle weight restrictions. This is especially true for vehicles that need to travel long distances which would require significantly more battery capacity. So, vehicle applications with higher payloads—at least some of the time—were assessed to have a higher likelihood of adopting hydrogen. This includes vehicles such as Class 8 Sleeper Cab Tractors, Day Cab Tractors, Heavy-Duty Vocational Vehicles (such as garbage or cement trucks) and Drayage Trucks. FCEV semis have much lower mass sensitivity to range, so they can achieve long haul operation without as much cargo loss.

- **Duty Cycle Requirements.** Many vehicles may be operated by different drivers throughout the day. For example, some drayage truck fleets accessing the San Pedro Bay Ports will operate in three 8-hour shifts and will operate 24/7. Transit buses often operate in two 8-hour shifts per day as well. When multiple, extended shifts per day are required, this is evaluated as having a high duty cycle, and driving favorability of FCEV technology over BEV technology. Particularly in cases where vehicles are expected to operate nearly 24-hours per day, there is little downtime time for refueling, so leveraging hydrogen refueling—in a matter of minutes, as opposed to battery recharging which may take hours—is operationally advantageous.

- **Fueling Infrastructure Requirements**. Charging or refueling infrastructure is a critical factor influencing FCEV vs BEV adoption. Some vehicles operate with back-to-base operations, meaning that they typically refuel or recharge at the same location every day. Other vehicles operate with distributed fueling operations, meaning they refuel in various locations every day. Based on the type of fueling operations and the ease or difficulty of establishing refueling or recharging infrastructure, certain vehicle applications may be more or less likely to convert to BEV or to FCEV technology. For example, vehicles such as transit buses or vocational trucks, generally operate in back-to-base operations. Depending on the size and location of these operations, developing hydrogen fueling infrastructure may be easier than developing charging infrastructure, such as where significant additional grid capacity would need to be developed to support centralized, high-power charging operations. Meanwhile delivery vehicles, which operate back-to-base but do not travel such long distances with high duty cycles would require less new infrastructure build to support charging, making BEV technology more feasible.

While fit for application is critical, fleet operators cannot or will not buy FCEV or BEV technologies if they are not available to purchase or if they are cost prohibitive. As such hydrogen adoption rates were modelled to take the CapEx and OpEx for each vehicle class into account using ANL's BEAN Model[86] to assess when FCEVs might achieve relative cost parity versus alternatives.

<u>Off-Road Vehicles</u>

Cargo-Handling Equipment (CHE)

There are around 4,000 pieces of CHE operating today at the San Pedro Bay Ports, and the role of CHE within the overall mobility sector is relatively small. Accordingly, CHE accounts for 2.3% of mobility-sector demand in the conservative scenario and 1.7% in the ambitious scenario (23-29k TPY) by 2045. Despite the small percentages of total hydrogen demand, CHE may play a pivotal role in the hydrogen mobility market. As an early adopter, it may serve as an example of successful hydrogen rollout that can be replicated by other sectors.

While there is no CHE-specific legislation in California driving adoption, the Clean Air Action Plan sets more aggressive targets than those otherwise defined in EO-N-79-20, which states "a goal of the State to transition to 100 percent zero-emission off-road vehicles and equipment by 2035 where feasible;"[87] the CAAP sets targets for terminal operators to achieve 100% zero-emission CHE by 2030.[88]

Assessment of the technology feasibility of hydrogen-based solutions for CHE was conducted across five key factors: load factor, duty cycle, the relative maturity of electric vehicle alternatives, the space required for refueling, and infrastructure challenges for electrification. Some vehicle applications such as ship-to-shore cranes are almost entirely electrified at Port of Los Angeles and Port of Long Beach today, indicating minimal likelihood of hydrogen adoption in coming years. These cranes are stationary and can be connected to the grid directly. Meanwhile, several pieces of container handling equipment are already running pilot projects with both hydrogen and battery technologies. Mobile, heavier-duty CHE types have significant power requirements and little downtime to charge, so transitioning them to BEVs is

---

[86] Argonne National Laboratory. https://vms.taps.anl.gov/tools/ As of the publishing of this report, the BEAN model is now referred to as TechScape.
[87] State of California Executive Department. "Executive Order N-79-20". (September 23, 2020). https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf
[88] Port of Los Angeles. "San Pedro Bay Ports Release Final 2021 Cargo-Handling Equipment Assessment." (August 25, 2022). https://cleanairactionplan.org/2022/08/25/san-pedro-bay-ports-release-final-cargo-handling-equipment-assessment/

expected to decrease equipment productivity, require increased equipment count to compensate, and require significant electric infrastructure upgrades to support high-power charging during shift breaks.

With the above in mind, port container handling equipment and terminal tractors (also known as yard tractors) are assessed to have the highest adoption rates across the CHE applications. Together these two applications account for over 90% of hydrogen demand from the CHE subsector by 2045 across all scenarios. There are over 2,000 terminal tractors operating today, which are assessed to consume an average of 8.7 kg of hydrogen per day; there are over 550 pieces of container handling equipment assessed to consume an average of 62.2 kg H2 per day. These pieces of equipment are identified by the CAAP Feasibility Assessment for CHE[89] as having a relatively high fit for hydrogen technology adoption.

Airport Ground-Support Equipment (GSE)

GSEs make up <1% of overall mobility-sector clean renewable hydrogen demand with just 1.5-1.9k TPY expected by 2045. This demand is largely modelled to come from the Los Angeles World Airports (LAWA) GSE Emissions with emission reduction goals of 75% by 2030.[90]

The operational characteristics of GSE tend to align best with battery electric decarbonization alternatives. GSE is characterized by having relatively low duty cycles, centralized fueling operations, and minimal challenges for establishing charging infrastructure. LAWA itself has already established the LAX Electric Ground Support Equipment Incentive Program—a clear nod of existing preference towards BEV technologies[91]—and has over 30% of its GSE fleet today operating fully electric.[92]

While the immediate hydrogen potential for GSE at LAWA and other airports in SoCalGas's service territory may not be high in the near-term without changes in policy, potential upside may come if there is legislation passed to support hydrogen powered zero emission aircraft. If

---

[89] San Pedro Bay Ports. "Clean Air Action Plan 2018 Feasibility Assessment for Cargo Handling Equipment". (September 2019). https://kentico.portoflosangeles.org/getmedia/8bbb559a-0270-415b-a79a-3265fa3bbb59/final-cargo-handling-equipment-che-feasibility-assessment

[90] Los Angeles World Airports. "Sustainability Action Plan for Los Angeles World Airports." (2019). https://www.lawa.org/en/lawa-sustainability

[91] Los Angeles World Airports. "LAX Electric Ground Support Equipment Incentive Program." (June 2023). https://www.lawa.org/-/media/lawa-web/environment/files/gse-emissions-reduction-program/lax-egse-incentive-program.ashx

[92] Los Angeles World Airports. "Striving for Zero: LAX Ground Support Equipment Emissions Reduction Program" (March 3, 2020). https://anesymposium.aqrc.ucdavis.edu/sites/g/files/dgvnsk3916/files/inline-files/LAX%20GSE%20Presentation_030220.pdf

this were to happen, hydrogen fuel availability and fueling infrastructure on-site at airports could lower barriers to FCEV GSE conversion and increase demand above that estimated in this model.

Agriculture, Mining, and Construction Equipment (Other Off-Road Equipment)

Other off-road equipment is projected to account for 17-21k TPY of hydrogen demand by 2045 (1.3% of mobility-sector demand in the ambitious scenario; 1.7% of mobility-sector demand in the conservative scenario). As described above, there are many reasons why hydrogen demand by non-on-road equipment may be relatively low in SoCalGas's service territory. While there are over 160,000 pieces of other off-road equipment modelled, only two types of equipment are expected to consume more than 5 kg of hydrogen per day on average: heavy agricultural equipment (25.3 kg/day) and off-highway trucks (18.5 kg/day), and there are just over 400 and 1,300 of these vehicle types in the covered geography, respectively.

Non-road vehicles and equipment used in the agriculture, construction, and mining industries account for significant energy (primarily diesel) demand. Vehicles used by these industries, such as tractors and haul trucks, are similar in some respects (e.g., weight and power versus energy requirements) to on-road MDVs and HDVs, but they are potentially more difficult to electrify. This is due in part to infrastructure challenges that make charging more difficult and expensive, as these equipment types are often located in more temporary or remote locations. For this reason, decarbonizing these segments will in general more likely rely on hydrogen fuel cell vehicles to a greater extent than in on-road transportation.

Meanwhile there is little mining equipment in SoCalGas's service territory, but a relatively large amount of specialty construction equipment such as pavers or equipment working in (often) urban construction sites. While these pieces of equipment may operate with relatively high duty cycles when in use, they may also see longer periods without use. Access to recharging or refueling infrastructure may be sparse depending on the specific project site where equipment is operated.

Finally, there is no current specific legislative requirements for these off-road vehicles to convert to zero-emission alternatives other than State's goal to achieve 100% emission reduction of off-road vehicles *"where feasible"* by 2035, as indicated in EO N-79-20.

Marine Vessels

Commercial Harbor Craft (CHC)

CHCs are projected to account for just 9-13k TPY of hydrogen demand by 2045 as there are relatively few vessels in this category (<3,000). These vessels can have multiple engines (typically a main engine for propulsion and an auxiliary engine for powering on-board systems, though this varies by vessel type). Depending on the specific vessel and engine type, decarbonization solutions may include hydrogen, battery, or synthetic fuels such as methanol or ammonia.

Through mid-2023, zero-emission regulation for CHC focused on requiring upgrade to cleaner more modern engines, requiring widespread adoption by 2034, but fell short of requiring zero-carbon fuels. However, the Clean Shipping Act of 2023 expands upon this and requires 100% emissions reduction by 2040 for most vessels.[93]

For some niche applications, short-run ferries traveling less than three nautical miles over a single run and new excursion vessels (whale watching or dinner cruises), more ambitious legislation has already been passed, requiring new vehicle purchases of these vessel types to be ZEV starting 2024.[94] There are already some pilot projects in California demonstrating hydrogen technologies-such as the Sea Change ferry in San Francisco, the first hydrogen fuel cell passenger ferry in the United States.[95] While these demonstration projects show promise for some CHC applications, tugboats stand out as possible high adopters of fuel cell technology given their operational characteristics and sometimes 24/7 shifts.

OGVs

OGVs are modelled to account for 22-52k TPY of potential mobility sector hydrogen demand by 2045, representing 2.2-3.1% of mobility-sector demand. This value, however, has a large potential upside as it only reflects hydrogen demand from replacement of diesel fuel consumption. CARB recognizes the importance of hydrogen fueled OGVs with their 2022 Scoping Plan including the need for 25% of OGVs to utilize hydrogen fuel cell technology by 2045 as part of their action plans.[96]

The recent introduction of the Clean Shipping Act of 2023—requiring almost all vessels to be fully ZEV by 2040—could significantly increase the amount of hydrogen demand by OGVs.

---

93 Alex Padilla U.S. Senator for California. “Padilla, Whitehouse Introduce Bills to Reduce Ocean Shipping Emissions.” https://www.padilla.senate.gov/newsroom/press-releases/padilla-whitehouse-introduce-bills-to-reduce-ocean-shipping-emissions/#:~:text=Padilla%27s%20Clean%20Shipping%20Act%20of,in%20the%20House%20of%20Representatives.

94 California Air Resources Board. “Final Regulation Order Commercial Harbor Craft Regulation.” https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2021/chc2021/chcfro.pdf, page 67

95 California Air Resources Board. “LCTI: Zero-Emission Hydrogen Ferry Demonstration Project.” https://ww2.arb.ca.gov/lcti-zero-emission-hydrogen-ferry-demonstration-project#:~:text=The%20Sea%20Change%20is%20a%2070-foot%20aluminum%20catamaran%2C%20designed,Marine%20shipyard%20in%20Bellingham%2C%20WA.

96 California Air Resources Board. “2022 Scoping Plan for Achieving Carbon Neutrality”. Table 2-1. (December 2022). https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf

However, the adoption of synthetic fuels such as synthetic methanol or ammonia represent the most likely alternatives that the industry is considering due to their increased energy density (lower volume of storage required relative to hydrogen). According to IEA analysis "*Ammonia and hydrogen are the main low-carbon fuels for shipping adopted over the next three decades in the IEA Net Zero Emissions by 2050 Scenario, their combined share of total energy consumption in shipping reaching around 60% in 2050.*"[97, 98]

The adoption of such clean fuels by OGVs may require significant international collaboration and the establishment of green shipping corridors that require the usage of clean fuels among trade partners. While California can influence local emissions requirements near its shores, CARB and others support that US EPA has primary authority to control emissions from marine vessels.[99] Locally in California meanwhile, regulations require emissions regulation while at berth using shore power or while near shore.[100]

Aviation

Clean renewable hydrogen demand for fuel cells in the aviation sector is only considered in the ambitious scenario of the study, as synthetic fuels (namely SAF) are widely considered to be the most dominant decarbonization pathway for the aviation sector. Hydrogen demand for SAF is represented in the industrials sector. Making the case for a role for hydrogen fuel cell solutions, CARB in their 2022 Scoping Plan Scenario lays out that by 2045, 20% of aviation fuel demand may be satisfied by hydrogen or battery alternatives (implying that the remaining 80% would be satisfied by SAF).[101] Many third- party studies cite hydrogen or battery powered aircraft as being single-digit percentages of overall sustainable aviation demand, so this demand study models the scenario of 25% of CARB's non-SAF portion (e.g., 5% of total

---

[97] IEA. "Maritime shipping to fall short of net zero emissions target." (May 20, 2021). https://www.reuters.com/business/energy/maritime-shipping-fall-short-net-zero-emissions-target-iea-2021-05-20/#:~:text=%22Ammonia%20and%20hydrogen%20are%20the,2050%2C%22%20said%20the%20IEA

[98] IEA. "Net Zero by 2050: A Roadmap for the Global Energy Sector (2021)". https://www.energy.gov/sites/default/files/2021-12/IEA%2C%20Net%20Zero%20by%202050.pdf

[99] California Air Resources Board. "2022 State Strategy for the State Implementation Plan". https://ww2.arb.ca.gov/sites/default/files/2022-08/2022_State_SIP_Strategy.pdf

[100] California Air Resources Board. "Zero-Emission Off-Road Strategies." https://ww2.arb.ca.gov/sites/default/files/2020-11/ZEV_EO_Off-Road_Fact_Sheet_111820.pdf

[101] California Air Resources Board. "2022 Scoping Plan for Achieving Carbon Neutrality". Table 2-1. (December 2022). https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf

aviation energy demand) would be hydrogen.[102] With this consideration, aviation accounts for roughly 10% of anticipated mobility sector clean renewable hydrogen demand in the ambitious case scenario at 178k TPY by 2045.

3.1.5. Potential Opportunities for Demand Upside

3.1.5.1. Light-Duty Vehicles

There are nearly 30 million cars in California today—over half of which are registered in SoCalGas's service territory[103]—and nearly a quarter of all new car sales in California are ZEVs.[104] While most of these new vehicle sales are battery electric, the amount of hydrogen FCEVs is increasing exponentially. Even if FCEVs have relatively low adoption rates compared to BEVs, the sheer number of vehicles may lead to significant hydrogen demand. Specifically, as traditional ICE vehicles retire, and as new legislative requirements for new LDV sales come into effect—namely, Advanced Clean Cars II, requiring 100% of LDV sales to be ZEV by 2035[105]—there may be significant hydrogen demand from the LDV sector. Potential hydrogen demand by these vehicles may require a broader geographic distribution of fueling infrastructure (similar to how gas stations are more spread out than truck stops), however if each passenger car consumes an average 0.5 kg of fuel per day, the overall demand can be significant. In particular, with over 16,000 light-duty FCEVs having been sold to date in California,[106] these passenger cars may play a pivotal role in facilitating the early market for clean hydrogen and in piloting some of the technologies that may later be used in the heavy-duty and other subsectors.

3.1.5.2. Rail

Today, most of California's 11,000-line haul and 500 switcher locomotives run on diesel (~378M gal/year in CA), producing over 640 TPY of PM2.5 and over 29,000 TPY of NOx

---

[102] Mission Possible Partnership. "Making Net Zero Aviation Possible." https://3stepsolutions.s3-accelerate.amazonaws.com/assets/custom/010856/downloads/Making-Net-Zero-Aviation-possible.pdf

[103] California Energy Commission. "Light-Duty Vehicle Population in California" https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/light-duty-vehicle

[104] California Energy Commission. "New ZEV Sales in California" https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/new-zev-sales

[105] California Air Resources Board. "Advanced Clean Cars II." https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/advanced-clean-cars-ii

[106] California Energy Commission. "New ZEV Sales in California" https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/new-zev-sales

emissions.[107] To mitigate these emissions, regulations such as the In-Use Locomotive Regulation, approved by CARB on April 27, 2023, will set emissions reduction requirements for Tier 4 engines or higher by 2035.[108] These regulations set the stage for a transition to zero-emission rail operations. The regulation took effect in January 2024 and is expected to increase the use of zero-emission technology. As part of this transition, various projects are underway across the state such as VeRail Technologies' collaboration with the Port of Los Angeles to develop a zero-emission switcher locomotive.[109] Also, part of CARB's 2022 Scoping Plan assumes that line haul and passenger rail rely primarily on hydrogen fuel cell technology.[110]

3.1.5.3. Ocean Going Vessels

The model for OGVs only includes hydrogen as a potential substitute for current diesel fuel consumption. However, the main source of fuel demand from OGVs is typically bunker fuel (sometimes referred to as heavy fuel). This fuel is traditionally relatively inexpensive and can have significant emissions, and it is used to power main engines when operating in international waters where there is little regulation on emissions. If bunker fuel usage were to be replaced with hydrogen or hydrogen-based alternatives, it could represent an immense potential upside for clean renewable hydrogen at the San Pedro Bay Ports (or for the production site of such hydrogen-based alternatives). This scenario is plausible if green shipping corridors are to be developed with the U.S. wherein ships transiting to and from the port have emissions restrictions. Particularly, since the San Pedro Bay Ports are some of the busiest ports in the world, they could represent a highly concentrated demand center for hydrogen powered ships. The San Pedro Bay Ports have been described as "critical gateways to the U.S. economy," and are responsible for approximately 70% all U.S.-international trade by tonnage, 40% of all containerized cargo, and about 30% of all containerized exports.[111] With such legislation such as California's Clean Shipping Act of 2023 requiring a 100% reduction in carbon intensity by 2040,[112] and the International Marine Organizations (IMO)

[107] California Air Resources Board, "The In-Use Locomotive Regulation was approved by the Board on April 27, 2023". https://ww2.arb.ca.gov/our-work/programs/reducing-rail-emissions-california/locomotive-fact-sheets
[108] Ibid
[109] Port of Los Angeles / Port of Long Beach
[110] California Air Resources Board. "2022 Scoping Plan for Achieving Carbon Neutrality". Table 2-1. (December 2022). https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf
[111] Port of Los Angeles. "San Pedro Bay Ports Announce New Measures to Speed Cargo Throughput." (September 2021). https://www.portoflosangeles.org/references/news_091721_speedcargo#:~:text=Ports%20are%20critical%20gateways%20to,30%25%20of%20all%20containerized%20exports.
[112] Congress. "H.R. 4024 – Clean Shipping Act of 2023". (June 2023). https://www.congress.gov/bill/118th-congress/house-bill/4024/text?s=1&r=4#:~:text=Introduced%20in%20House%20(06%2F12%2F2023)&text=To%20amend%20the%20Clean%20Air,vessels%2C%20and%20for%20other%20purposes.

2020 implementation of the MARPOL treaty—which limits the allowable sulfur content of marine fuels used by GOVS in international waters to 0.5% by weight[113]—there are many forces which may increase hydrogen demand by OGVs.

3.2. Power Generation

3.2.1. Introduction

The power sector, which encompasses baseload and peaker plants currently operational in SoCalGas's service territory, is the second sector considered. California is a leader in power sector decarbonization, and its GHG emissions have consistently fallen over the past decade. Currently, in-state emissions from the power sector in California contribute to 11% of the state's overall GHG emissions footprint.[114]

Aggressive targets have been set to reduce the power sector's consumption of fossil fuels, with SB100 requiring net-zero electric retail sales by 2045.[115] In tandem, there has been a significant increase in renewables such as wind and solar on the California grid, with future growth expected as electrification in mobility, residential, commercial, and industrial sectors continues to increase.[116] However, renewables are not able to fully replace the role of natural gas generation in the energy system due to their inherent intermittency. These growing variable renewable resources do not provide the consistent, dispatchable, and firm generation needed to balance supply and demand on the grid at both the daily level – when the sun sets at night – and at the seasonal level – when sunlight decreases during wintertime. Dispatchable, firm generation, currently obtained through the combustion of natural gas, plays a critical role in balancing the grid when demand outstrips renewable supply and in providing power when variable renewable resources are not available or when needed during extreme weather events, ultimately providing for overall system reliability.

---

[113] International Maritime Organization. "IMO 2020 sulfur limit implementation-carriage ban enters into force". (March 2020). https://www.imo.org/en/MediaCentre/PressBriefings/pages/03-1-March-carriage-ban-.aspx

[114] California Air Resources Board. "California Greenhouse Gas Emissions for 2000 to 2020 Trends of Emissions and Other Indicators". (October 26, 2022). https://ww2.arb.ca.gov/sites/default/files/classic/cc/inventory/2000-2020_ghg_inventory_trends.pdf

[115] California Energy Commission. "SB 100 Joint Agency Report". (September 3, 2021). https://www.energy.ca.gov/publications/2021/2021-sb-100-joint-agency-report-achieving-100-percent-clean-electricity

[116] California Energy Commission. "New Data Shows Growth in California's Clean Electricity Portfolio and Battery Storage Capacity." (May 25, 2023). https://www.energy.ca.gov/news/2023-05/new-data-shows-growth-californias-clean-electricity-portfolio-and-battery

As this renewable transition continues and grows, clean renewable hydrogen will play a significant role in providing a zero-carbon alternative to natural gas while maintaining necessary grid reliability. Hydrogen can be used for power generation regardless of the season or time of day, as hydrogen produced by electrolysis can be stored during times of high renewable supply and dispatched in the hours or seasons when demand overtakes supply. With modifications to fuel delivery systems, many existing combustion turbines are already capable of blending hydrogen at low percentages, and technical feasibility of fully hydrogen capable combustion technologies is projected to be complete within the next decade.[117, 118,119] It should be noted that consistent with the Decision, Angeles Link is intended to transport pure clean renewable hydrogen in the pipeline, and any analysis of hydrogen blending refers strictly to "behind-the-meter" operations, not within SoCalGas control. As power plant owners and operators are looking to eliminate emissions while maintaining the dispatchable generation that natural gas provides, hydrogen is emerging as a priority dispatchable power solution for California.

[117] Siemens Energy. "H2 capabilities of our medium-sized gas turbines". https://www.siemens-energy.com/global/en/home/products-services/solutions-usecase/hydrogen/zehtc.html#:~:text=H%E2%82%82%20capabilities%20of%20our%20medium,to%20reach%20100%25%20by%202030.

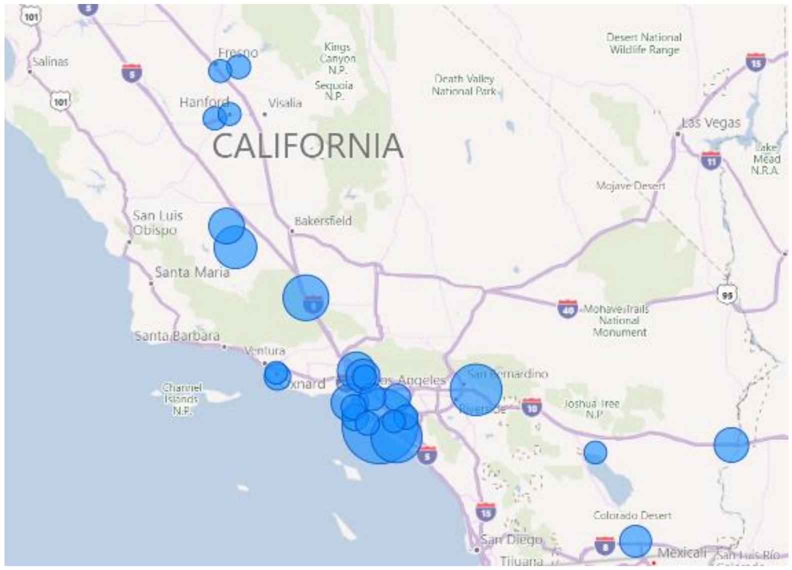
[118] Euractiv. "GE eyes 100% hydrogen-fueled power plants by 2030". (May 2021). https://www.euractiv.com/section/energy/news/ge-eyes-100-hydrogen-fuelled-power-plants-by-2030/

[119] Fuel cells for the power sector were not included in analysis.

3.2.2. Power Landscape

3.2.2.1. California State Policy and Legislative Initiatives

Figure 13: Current Natural Gas Consumption by Power Plants in SoCalGas's Service Territory by Zip Code



Size of Bubble: Natural Gas Consumption for Electricity (MMBTU). Does not include power generation in San Diego.[120]

- **SB100:** A consequential piece of legislation for hydrogen adoption in the power sector is the California's SB100, which established a state goal of 100% electric retail sales from renewable energy resources and zero-carbon resources energy by 2045.

- **LA100:** Another key policy is the LA100 plan, which set a target for LADWP to achieve 100% carbon-free generation by 2035.[121]

- **EPA Clean Power Plants Rule**: U.S. EPA recently finalized a rule to set GHG standards for new and existing power plants that seeks to reduce nationwide power

[120] U.S. Energy Information Administration. "Form EIA-923 detailed data with previous form data (EIA-906/920)". https://www.eia.gov/electricity/data/eia923/
[121] National Renewable Energy Laboratory. "LA100: The Los Angeles 100% Renewable Energy Study". https://www.nrel.gov/analysis/los-angeles-100-percent-renewable-study.html

plant emissions.[122] The rule applies to existing coal-fired and new natural gas-fired power plants and requires these plants to control 90 percent of their carbon pollution. Certain sources may elect to co-fire hydrogen for compliance with EPA's final standards of performance. Under EPA's 111(d) rules, existing plants are regulated by state plans that meet EPA's standards and are approved by the EPA. CARB has stated that California's suite of programs will deliver more reductions than implementing EPA's existing power plant standards and thus will likely submit a state plan which utilizes SB100, RPS, and the Cap-and-Trade program as equivalent.[123, 124]

Most existing natural gas power plants in SoCalGas's service territory (and in CA) are expected to run for reliability only and thus are unlikely to have capacity factors greater than 50% when the blending requirements begin. However, many stakeholders have urged the EPA to lower the existing plant capacity factor threshold, which would increase the number of power plants potentially subject to the EPA rules and California's EPA-approved State Plan.[125]

- **CARB's 2022 Scoping Plan for Achieving Carbon Neutrality:** This scoping plan includes the need for 9 GW of hydrogen combustion turbines as an incremental electricity resource by 2045[126] to meet the state's carbon neutrality goals. CARB assumes hydrogen production via electrolysis which falls within Angeles Link's definition of clean renewable hydrogen consistent with D.22-12-055. Whether considering hydrogen conversion of a portion of today's existing power generation capacity or new incremental hydrogen capacity, both the Demand Study's analysis and CARB's analysis

[122] Environmental Protection Agency. "New Source Performance Standards for Greenhouse Gas Emissions From New, Modified, and Reconstructed Fossil Fuel-Fired Electric Generating Units; Emission Guidelines for Greenhouse Gas Emissions From Existing Fossil Fuel-Fired Electric Generating Units; and Repeal of the Affordable Clean Energy Rule, 89 FR 39798." (May 9, 2024). https://www.federalregister.gov/documents/2024/05/09/2024-09233/new-source-performance-standards-for-greenhouse-gas-emissions-from-new-modified-and-reconstructed.

[123] Environmental Protection Agency. "CARB's comment letter to EPA Aug 8, 2023". https://www.regulations.gov/docket/EPA-HQ-OAR-2023-0072/comments?pageNumber=4&sortBy=postedDate&sortDirection=desc Docket Documents tab

[124] Environmental Protection Agency. "Greenhouse Gas Standards and Guidelines for Fossil Fuel-Fired Power Plants." (June 2023). https://www.epa.gov/system/files/documents/2023-06/111%20Power%20Plants%20Stakeholder%20Presentation_Webinar%20June%202023.pdf

[125] Environmental Protection Agency. https://www.regulations.gov/docket/EPA-HQ-OAR-2023-0072/comments?pageNumber=4&sortBy=postedDate&sortDirection=desc

[126] California Air Resources Board. "2022 Scoping Plan for Achieving Carbon Neutrality". Figure 4-5. (December 2022). https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf

point towards the eventual need for hydrogen fueled thermal power generation capacity to provide clean firm dispatchable power in the state of California.

3.2.2.2. Hydrogen in the Power Sector

Hydrogen's application in the power generation sector will likely be in situations when intermittent renewable energy resources like wind and solar cannot supply the load necessary to support grid reliability. Unlike conventional power plants (such as natural gas-fired plants, nuclear, etc.), solar and wind resources cannot be fully dispatched, at will, to help meet demand, and in these instances, hydrogen supply will need to ramp up quickly, almost mirroring the drop-off of renewable energy. Initially hydrogen may be used in less significant amounts during times of the day when intermittent renewable energy is abundantly available and less expensive than clean renewable hydrogen. However, less dispatchable electricity makes it more difficult for grid managers to balance electricity supply and demand in a system with wide swings in net electricity demand. Hydrogen also has the capability of being stored for long durations, providing power during seasonal swings or extreme weather events.

On February 8, 2023, the Los Angeles City Council voted to convert LADWP's Scattergood Generating Station Units 1 and 2 from methane gas plants to hydrogen-ready plants, with an in-service date of December 30, 2029. LADWP has identified this project as a crucial step for the city to meet its goal of being 100% carbon-free by 2035.[127] LADWP plans to eventually implement conversions in other gas plants like the Harbor and Haynes and Valley Generating Station.[128] Using the LADWP's plans to convert the 830 MW Scattergood plant to 100% clean renewable hydrogen as an example, it is expected that hydrogen will be highly prioritized as an alternative fuel in the power sector. In addition, ARCHES has indicated that the California hydrogen hub would include transitioning key Los Angeles Department of Water and Power and Northern California Power Agency power plants to 100 percent renewable hydrogen.[129]

[127] Kevin Clark. "L.A. authorizes conversion of largest gas plant to hydrogen" Power Engineering. (Feb. 9, 2023). https://www.power-eng.com/hydrogen/l-a-authorizes-conversion-of-largest-gas-plant-to-green-hydrogen/#gref

[128] Ibid

[129] ARCHES, "California's Renewable Hydrogen Hub Officially Launches" (July 17, 2024). https://archesh2.org/arches-officially-launches/

Figure 14: Major Hydrogen Projects in the Power Sector[130] [131] [132] [133] [134] [135]

California Hydrogen Projects

Scattergood Repowering Project

LADWP is repowering their Scattergood plant with turbines capable of burning significant quantities of hydrogen, with ~400MW of H2 capacity buildout at Scattergood by 2038

400MW Net generation output by 2038

Intermountain Power Project

Project is retiring the existing coal-fueled units at the Utah IPP site, installing new natural gas-fueled electricity generating units capable of utilizing hydrogen

840MW Net generation output

Lodi Hydrogen Power Plant

PG&E has successfully installed a Siemens turbine at the Lodi Energy Center that can blend 45% hydrogen with natural gas, greatly reducing emissions

225MW Net generation output as of 2022

United States and Worldwide Hydrogen Projects

Hillabee Generating Station (Alabama)

Constellation will significantly lower greenhouse gas emissions by blending high concentrations of hydrogen with natural gas, reaching 38% without major modifications to the plant

753MW Net generation output as of 2023

Blueprint for Real Zero Proposal (Florida)

NextEra Energy envisions converting all of its Florida natural gas firing facilities to hydrogen. Collectively these plants will produce 16GW from green hydrogen.

16GW Net generation output by 2040

Low Carbon Energy Hub (Europe)

RWE and Equinor are building gas turbines in Germany served by a hydrogen pipeline between Germany and Norway, moving ~4M tons hydrogen/year with a target of 2030 for pipeline construction

3GW H2 power plant capacity, with a pipeline equivalent capacity of 18GW

3.2.2.3. Decarbonization Pathways and Alternatives[136]

CCUS

CCUS in thermal power generation separates CO_2 emissions from a power plant's flue gas or syngas stream to prevent its release into the atmosphere. The captured CO_2 is sequestered or converted to a long-lived product, resulting in an overall reduction in CO_2 emissions. CCUS can serve as an alternate and potentially complementary pathway along with hydrogen in

---

130 Intermountain Power Agency. "IPP Renewed." https://www.ipautah.com/ipp-renewed/

131 Hydrogen Insight. "Los Angeles moves forward with $800m plan to convert 830MW gas-fired power plant to run on green hydrogen". https://www.hydrogeninsight.com/power/los-angeles-moves-forward-with-800m-plan-to-convert-830mw-gas-fired-power-plant-to-run-on-green-hydrogen/2-1-1401866

132 Lodi News. "Lodi to be base for hydrogen pilot program providing power to NorCal." (June 2022). https://www.lodinews.com/news/article_a18bc96e-e788-11ec-80fa-7730df49a97e.html

133 Utility Drive. "Constellation sets hydrogen-gas plant blending record, but more advances needed for utility-scale use: experts." (June 2023). https://www.utilitydive.com/news/constellation-energy-hydrogen-blending-test-hillabee-power-plant/652000/

134 NextEra Energy. "A Plan for Real Zero." https://www.nexteraenergy.com/real-zero.html

135 Equinor. "Equinor and RWE cooperating on energy security and the energy transition." Equinor and German energy major RWE to cooperate on energy security and decarbonization - Equinor

136 This section responds to stakeholder comments regarding consideration of alternatives to clean renewable hydrogen in the Demand Study.

supporting the future power system with clean firm power.[137] The CARB scoping plan projects CCUS as a pathway to meet decarbonization goals, with carbon removal targets of ~25 MMT CO2 for carbon capture and storage and ~64.4 MMT CO2 for direct air capture.[138] Although the economic case for CCUS in the power sector can be challenging at times, with costs potentially exceeding revenues for combined cycle gas turbines,[139] there exists strong policy support at the federal level with tax credits and incentives.[140] Furthermore, CCUS faces some of the similar early-stage challenges as hydrogen in terms of infrastructure availability and requires a significant ramp up of pipelines and transportation systems to be a feasible solution for power plants. A combination of factors such as CO2 capture capacity, utilization, distance to storage, existing equipment, and infrastructure availability at the plant level will determine whether CCUS is implemented at a specific plant.[141] For additional information on CCUS, as an alternative, please refer to the Alternatives Study (Section 4).

Battery Storage

Instead of generating electricity with peaker plants during times of high electricity and fuel prices, batteries and energy storage can be used to either 1) store renewable energy; or 2) "peak shift" by using lower cost energy stored during off-peak periods to meet the demand. However, current battery storage does not provide the duration necessary to fully replace power plants and carry a significant price tag compared to alternatives. Research performed by ANL and Massachusetts Institute of Technology found that supplementing renewable plants with battery storage is a "weak substitute" for the natural gas plants currently in place.[142] In California, where renewables experience sharp declines in the fall and winter, hydrogen has the potential to be a more feasible solution for long-duration energy storage. Hydrogen's long duration storage capabilities can prevent curtailment of excess renewables and when paired with adequate storage reserves, enable the use of that energy in seasons of higher demand.

---

[137] EDF. "California needs clean firm power, and so does the rest of the world." https://www.edf.org/sites/default/files/documents/SB100%20clean%20firm%20power%20report%20plus%20SI.pdf

[138] California Air Resources Board. "2022 Scoping Plan Documents". https://ww2.arb.ca.gov/our-work/programs/ab-32-climate-change-scoping-plan/2022-scoping-plan-documents

[139] US Department of Energy. "Pathways to Commercial Liftoff: Carbon Management." (April 2023). https://liftoff.energy.gov/wp-content/uploads/2023/04/20230424-Liftoff-Carbon-Management-vPUB_update.pdf

[140] Congressional Research Service. "The Section 45Q Tax Credit for Carbon Sequestration" (August 2023). https://sgp.fas.org/crs/misc/IF11455.pdf

[141] US Department of Energy. "Pathways to Commercial Liftoff: Carbon Management." (April 2023). https://liftoff.energy.gov/wp-content/uploads/2023/04/20230424-Liftoff-Carbon-Management-vPUB_update.pdf

[142] Applied Energy Volume 175. De Sisternes, Fernando J.; Jenkins, Jesse D.; Botterud, Audun. "The value of energy storage in decarbonizing the electricity sector." (August 2016). https://www.sciencedirect.com/science/article/abs/pii/S0306261916305967

Spatial and cost considerations will serve as constraints for battery storage, with a Clean Air Task Force analysis of CAISO data suggesting power system costs rise exponentially as renewable penetration with battery storage climbs.[143] Although there are limitations to using energy storage in large quantities, as discussed above, there is value in leveraging both hydrogen and battery storage in parallel to build a clean energy system in California.

3.2.3. Model Scope and Key Assumptions

3.2.3.1. Model Scope

The power sector demand projected encompasses all peaker and baseload plants in SoCalGas's service territory with capacity greater than 1 MW.[144] Plant-level retirement plans or published projected hydrogen demand is incorporated into the model where available.

The model assumes all future hydrogen consumption in the power sector will come from fuel switching of currently operating power plants. New power plant builds were not factored in this assessment, although as mentioned previously, CARB's 2022 Scoping Plan forecasts 9.3[145] GW of incremental hydrogen capacity[146]. The analysis models future hydrogen-fired power plants and does not include hydrogen fuel cells for the power sector. The near-term path utilizes hydrogen blending with transition to full hydrogen firing over time. Blending hydrogen requires modification to fuel delivery systems. As the content of hydrogen in the fuel blend increases, retrofits are required that upgrade combustion hardware with components capable of burning higher blends of hydrogen, up to 100% in the future. Although grid load is expected to increase in the future as electrification increases, this study did not attempt to forecast future grid load.

Table 3: Power Subsector Definitions and Opportunity Profiles

Power Subsector	End Use Application	Definition	Clean Hydrogen Opportunity

[143] Clean Air Task Force, EDF. "Growing the Grid: A Plan to Accelerate California's Energy Transition." (October 2022). https://www.catf.us/2022/10/report-outlines-roadmap-accelerating-californias-clean-energy-transition/
[144] Although we expect the majority of demand to come from plants >1MW, potential future analysis may consider additional demand from plants <1MW.
[145] CARB 2022 Scoping Plan, Appendix H: AB 32 GHG Inventory Sector Modeling, AB 32 GHG Inventory Sectors Modeling Data Spreadsheet (pg 118), Electricity tab, Hydrogen CT row (2045) https://ww2.arb.ca.gov/sites/default/files/2024-01/nc-2022-sp-appendix-h-ab-32-ghg-inventory-sector-modeling.pdf.pdf
[146] Comparison to Other Studies section and Q1 2024 Response to Comments, Global Response 2.1. https://www.socalgas.com/sites/default/files/SoCalGas-Q1-2024-Angeles-Link-Project-Quarterly-Report_FINAL.pdf

Baseload	Grid reliability, resource adequacy	The minimum amount of power required over a 24-hour period to meet base load.	Support grid stability while reducing emissions
Peaker	Grid reliability, resource adequacy	Power supplied to meet peaks in demand over a 24-hour period and can include simple and combined cycle gas turbines	Increasingly volatile demand will require clean resources like H2 to support grid reliability.

The study focused mainly on baseload and peak load opportunities for hydrogen, given the impending technological feasibility of incorporating hydrogen into natural gas plant fuel mixtures.

3.2.3.2. Key Assumptions and Adoption Levers

The four adoption factors of policy and legislation, commercial availability, technical feasibility, and business readiness are the primary drivers of adoption rates in the power sector, with these adoption factors influencing the quantity of current natural gas capacity transitioned to hydrogen, the utilization of this hydrogen capacity, and the timeline of adoption.

Commercial availability and technical feasibility drive the switch of current natural gas capacity to hydrogen, with capacity adoption based primarily on the technology costs and revenue opportunities of conversion to hydrogen compared to other forms of owned capacity against power purchases. Informed “what-if” analysis scenarios were used for the utilization of capacity, measured by the capacity factor for hydrogen combustion turbines.

<u>Policy & Legislation</u>

Recent SB100 and LA 100 policies are the primary drivers for increasing amounts of renewable energy on the electric grid. Due to its statewide applicability, the major policy that has impacts on the rate of hydrogen transition is California’s SB100, which accelerates the states Renewable Portfolio Standard program to 100% clean, zero carbon, and renewable energy by 2045. Clean renewable hydrogen can play a supporting role in reaching these targets, by providing dispatchable generation when it is needed to complement renewable energy generation.

California’s Cap-and-Trade program will also be a key driver of decarbonization in the power sector. As one of the largest multi-sectoral emissions trading systems in the world, covering around 450 businesses including electric power plants that meet the 25,000-metric tonne CO_2

emission threshold.[147] As we approach 2045, the cap will get progressively lower with minimal allocation of free allowances to electric utilities, causing a switch to clean, renewable fuels.[148]

Technology Feasibility

The feasibility of hydrogen blending at low percentages in the short term and 100% hydrogen capable combustion turbines in the mid and long-term impacts the timeline of hydrogen adoption as well as the level of hydrogen that can be adopted in the power sector. Technology feasibility for blending in the short term has been evaluated at the plant level based on current combustion turbine configurations, where data is available. Input from OEMs has been used to determine current blending percentages at a market level, as well as timelines for 100% hydrogen capabilities feasibility.

The study found that the combustion systems of many current natural gas units have hydrogen capabilities up to a maximum of 30% by volume, providing a near-term pathway for hydrogen adoption. However, while current combustion systems are technically capable of blending up to 30% by volume, few units can burn any more than a trace amount of hydrogen today without modifications because of current limitations in fuel delivery systems. Utilizing the near-term pathway for blending that is available within current combustion systems will require additional piping, blending skid, control system, safety, and code requirements.

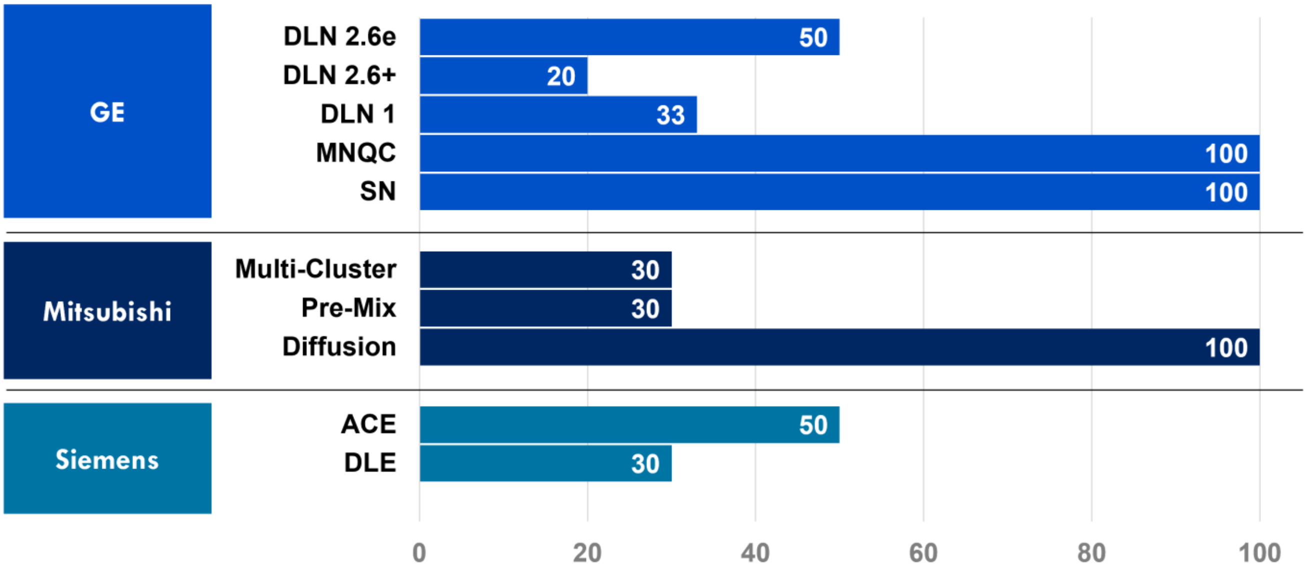
As hydrogen fuel delivery systems and combustion technologies improve over time, hydrogen fueling capability is expected to grow as OEMs supply systems with inherent hydrogen capability. Although gas turbines with combustion systems capable of burning 100% hydrogen are not available at this time, interviews with major manufacturers confirmed that technical feasibility for 100% hydrogen capable combustion systems is targeted by 2030 and is in fact a goal of many of those same manufacturers.

[147] Center for Climate and Energy Solutions. “California Cap and Trade.” https://www.c2es.org/content/california-cap-and-trade/

[148] California Air Resources Board. “Cap-and-Trade Program: Allowance Distribution Factsheet.” https://ww2.arb.ca.gov/resources/documents/cap-and-trade-program-allowance-distribution-factsheet

Figure 15: Current H2 Capability across Major Power Manufacturer Models

(% by Volume)



Source: EPRI Analysis [149,150,151]

Both retrofits and complete replacements are available for OEMs that develop this technology. There has been focus by the OEMs to develop retrofit solutions for an already installed fleet. However, when these programs are complete, they would likely be offered if plants were to do a complete replacement as well. Most OEMs offer their highest hydrogen capability technology as standard on their new gas turbines.

It is not yet clear, however, whether 100% hydrogen capability will be realistic for all assets, or if the expected feasibility timeline will hold true. If reaching technological feasibility takes longer than expected, hydrogen adoption could follow a different curve than what is described in this study. Additionally, the implementation of 4-hour battery storage may impact the adoption rates of hydrogen as a fuel source as that amount of battery storage could provide much of the peak demand needed to augment intermittent renewable energy sources. For additional detail, please refer to the Alternatives Study (section 4 and Appendix 7.).[152]

[149] GE Gas Power. "Hydrogen Fueled Gas Turbines." https://www.ge.com/gas-power/future-of-energy/hydrogen-fueled-gas-turbines

[150] Siemens Energy. "Zero Emission Hydrogen Turbine Center." https://www.siemens-energy.com/global/en/priorities/future-technologies/hydrogen/zehtc.html

[151] Mitsubishi Heavy Industries Group. "Decarbonizing Power Generation with Minimal Modifications." https://iea.blob.core.windows.net/assets/64c27e00-c6cb-48f1-a8f0-082054e3ece6/Renewables2022.pdf

[152] Note, the Alternatives Study considered a 12-hour battery, utilizing 4-hour battery modules adding up to 12 hours, to serve inter-day loads and the required ramping needs to support reliability requirement lasting longer than a few hours.

Despite uncertainties in exact H2 percentages and timelines, it is likely that manufacturers and third parties will be able to provide technologies that can reach high blending levels of over 90% by volume by 2030.

Commercial Availability

Commercial availability assesses the readiness of hydrogen technologies as well as the cost competitiveness of them against alternatives including 4-hour batteries and CCUS, all relative to the cost of power purchases[153]. Estimated cost equivalence between natural gas and hydrogen fuel at an MMBTU level is a driving assumption. Section 4 of the Cost Effectiveness Study provides additional insight into fuel and charging costs.

Business Readiness

Interviews with power plant operators suggest that multiple years may be needed to put in place the necessary processes, permits, and engineering plans for hydrogen upgrades. Although this can take place in parallel with pipeline operator and OEM timelines, the announcement and finalization of construction plans for hydrogen transport infrastructure as well as go to market timelines for turbine technologies will enable business decisions, permitting, and engineering studies to begin. This has been reflected in the Demand Study through a progressive increase in 100% hydrogen turbine adoption starting at 2030, with a small number of early adopters beginning to move to hydrogen in 2030 as technology becomes available. As 2045 approaches, adoption progressively increases, reflecting the expected gradual increase in business readiness.

Additional assumptions

- Hydrogen for power generation is likely used in peak situations that will require high flow rates of hydrogen to the units to fill the need for generation when wind and solar cannot generate. Subsequently, hydrogen will need to ramp quickly to make up for power lost as wind and solar go offline. This demand will be most significant when events such as extreme weather or net load ramps are widespread across SoCalGas's service territory and beyond.[154] Even when events are not widespread, the demand of ramping individual units on and offline will be a major draw on demand.
- Equipment cost assumptions have been made across hydrogen, batteries, and CCUS to determine the likelihood for plants to convert to hydrogen. CapEx costs have been

[153] Refer to the Cost Effectiveness study, section 4, for additional details on cost effectiveness and the Project Options and Alternatives Study (the Alternatives Study), section 7, for the 12-hour battery as a stack of 4-hour batteries.
[154] IEA. "Renewables 2022: Analysis and Forecast to 2027". https://iea.blob.core.windows.net/assets/64c27e00-c6cb-48f1-a8f0-082054e3ece6/Renewables2022.pdf

estimated for both blending as well as full conversion to hydrogen based on turbine size and current hydrogen capability. The Cost Effectiveness Study provides further information on capital costs in section 4.
- To understand the total potential of hydrogen, the cost of hydrogen has been set equal to the incumbent fuel.

Scenario Definition

As with all three sectors, three scenarios were modelled for the demand study. A range of “what-if” capacity factor scenarios were evaluated to determine the total power generation from hydrogen in 2045. Capacity factors were not modelled and were instead input directly to understand what the potential demand could be across a range of different capacity factors. Interviews with OEMs and operators suggest that hydrogen capacity factors could reach 8-10% by 2045, driving the conservative case. The 30% capacity factor in the ambitious case is based on historical EIA natural gas capacity factor data in California which has fluctuated between roughly 25% - 35% over the past 10 years.[155] These EIA natural gas capacity factors are based on an average of aging once through cooling power plants and peakers, which generally have low capacity factors, and combined cycle pants, which have much higher capacity factors. A 20% capacity factor scenario is used in the moderate case to reflect a midpoint between the conservative and ambitious cases. The probability of each capacity factor was not evaluated. Modeling the anticipated electric load increase and grid reliability requirements in future phases may help to determine which capacity factor is most likely, since capacity factors may be influenced by several factors such as electric demand, electricity imports, costs of energy sources, reliability, and ramping needs among others. Details of the scenarios for the power sector are included in the table below.

[155] EIA. “State Electricity Profiles.” https://www.eia.gov/electricity/state/california/state_tables.php

Table 4: Scenario Definitions for the Power Sector

Scenario	Description
Conservative	10% system-wide capacity factor for H2 turbines in 2045
Moderate	20% system-wide capacity factor for H2 turbines in 2045
Ambitious	30% system-wide capacity factor for H2 turbines in 2045

Projected capacity factors as well as commercial viability will be additional key factors in driving demand. SB100 legislation assumptions and technology feasibility regarding timelines for current blending capabilities and timelines for 100% H2 turbines remain consistent across the conservative, moderate, and ambitious scenarios.

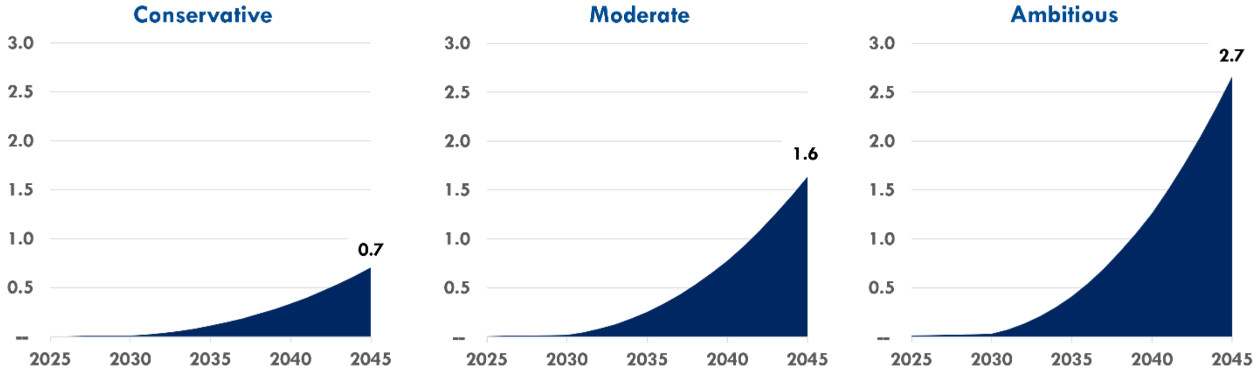
There will be a ramp up of this capacity from the near zero level of today to the level reached in 2045. Midpoint time ranges are based off a ramp which uses the same assumptions.

3.2.4. Power Demand Study Results

3.2.4.1. Overview

The analysis modelled potential hydrogen demand in the baseload and peaker subsectors by 2045 in three scenarios. The results suggest that, next to mobility, power generation represents another important source of potential demand, at between 0.7M – 2.7M TPY by 2045. This demand is projected to rapidly expand starting in 2030 due to technological readiness and key legislation, namely SB100. As electrification grows across mobility and other end-use energy sectors, clean renewable hydrogen can play a vital role in providing a low-carbon alternative to natural gas and in supporting grid reliability as more intermittent renewable energy sources come online.

Figure 16: Total Expected Clean Renewable Hydrogen Demand in the Power Sector
(2025-2045, values in Million TPY)



As hydrogen ramps up or down in response to changes in solar and wind energy, demand for hydrogen in power generation is expected to occur during periods of peak demand and will be most necessary during extended and extreme events. While the modelled annual capacity factors for power generation using hydrogen are lower in the conservative and moderate scenarios than current rates for natural gas, the hourly flow rates needed to support power generation during peak demand periods could be significant, making cost-effective and reliable delivery of hydrogen to power plants a necessity. More detailed analysis of the electric grid and the effect of increasing penetration of intermittent renewable energy could uncover a need for additional reliance on hydrogen combustion turbines in certain locations with infrastructure delays or for system reliability.

"The H2 demand will be present as power plants can eat through supply as needed. Turbines can take oversupply off with no problem" -Turbine OEM

3.2.4.2. Subsector Results

Peaker and Baseload

As California's energy landscape changes, we expect to see a notable change in the way plants operate, and these changes are reflected in projected hydrogen demand. Although capacity factor assumptions in conservative and moderate scenarios are lower than the current system wide natural gas capacity factors that we see from natural gas today in California, we do not expect to see total dispatchable capacity requirements decline significantly from the capacity in place today in SoCalGas's service territory. In addition, if California is not able to rely as heavily on imports as it competes with other states that attempt to decarbonize their electric grid,[156] demand for clean fuels like hydrogen for power generation may further increase. Therefore, projected hydrogen power generation capacity in 2045 may increase, with estimates of 10 to 13 GW across scenarios. This projection is directionally aligned with CARB's Scoping Plan[157] in showing the significant need for hydrogen fueled thermal power generation capacity by 2045. CARB's Scoping Plan also projects through 2045 a consistent need for 33 GW of firm gas generation, which will require some type of solution to achieve SB100's emissions targets, such as the use of carbon capture or conversion to a zero-carbon fuel. For further detail on the CARB Scoping Plan, other agency entity projections, and the Demand Study's projections, refer to the Comparison to Other Studies section in this report. The decision to use hydrogen in the power generation sector will likely be made at the individual plant level, but if some choose to use hydrogen as an alternative to fossil fuels, this could potentially increase hydrogen capacity numbers beyond this study's estimates.

The hydrogen capacity in the future has been estimated based on analysis of the hydrogen upgrade probability by plant. This analysis is based on the costs and predicted revenues of electricity produced from hydrogen in combustion turbines, as well as those from natural gas with CCUS and battery, with all three compared against the cost of purchased power. What we see is that given a fuel price parity assumption to natural gas, hydrogen makes a strong economic case against alternatives, with hydrogen upgrade probabilities over 50% across scenarios. This is due to the low CapEx costs of retrofitting existing combustion turbines to utilize hydrogen compared to CCUS and battery costs for equivalent capacity.

These high capacities contrasted against declining capacity factors paint the picture of the future of hydrogen as a fuel source for combustion turbines: there will be a significant capacity in place when needed, during the highest peak days, while at the yearly level utilization may seem comparatively lower. This behavior shows that it is important that hydrogen can come online quickly, driving the importance of a hydrogen infrastructure that mimics the behavior of today's natural gas infrastructure.

[156] CAISO has flagged long term electric resource diversity and potential capacity shortfall concerns in California resource planning proceedings. CAISO. "Comments of the California Independent System Operator Corporation, Order Instituting Rulemaking to Continue Electric Integrated Resource Planning and Related Procurement Processes, R-20-05-003". http://www.caiso.com/Documents/Oct23-2020_Comments-on-Integrated-Resource-Planning-R20-05-003.pdf

[157] California Air Resources Board. "2022 Scoping Plan for Achieving Carbon Neutrality". Figure 4-5. (December 2022). https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf

3.2.5. Potential Opportunities for Demand Upside

3.2.5.1. Microgrids and Backup Power Generation[158]

Microgrids are electric power grids that can function independently from the larger grid system, with increasing potential in remote areas and for critical facilities such as hospitals. Clean hydrogen can be introduced into microgrids to enhance community energy resilience by leveraging distributed renewable energy production, storage, and use. Local electricity generation reduces strain and supports the electric grid and is able to supply critical and emergency energy with zero GHG emissions during power outages. Furthermore, adding hydrogen to microgrids enables seasonal and long-term storage that cannot be provided by batteries. SoCalGas is already testing the potential of hydrogen for microgrids through the H2 Innovation Experience clean-powered microgrid and home.[159] Additional projects are taking place across California, with PG&E undertaking a hydrogen microgrid project at their California Resiliency Center substation, enabling islanding from the larger grid during public safety power shutoff events.[160] Although hydrogen demand for microgrid applications was not analyzed, this application could serve as a potential upside to hydrogen demand projected in this demand study.

3.3. Industrials

3.3.1. Introduction

As the largest manufacturing state in the country, California has roughly 25,000 industrial enterprises. There is significant concentration of industrial activity within Central and Southern California, contributing approximately 23% of the state's overall GHG emissions.[161] Within the industrials sector, there is a strong diversity of subsectors, seen in the figure below. Much of this natural gas used is in currently hard-to-electrify subsectors that rely on high temperature processes.

While there are currently few state policy and regulatory drivers to abate GHG emissions in this sector, hydrogen technology in the industrials sector has seen significant growth in maturity and adoption in industrial facilities globally, largely due to emissions mandates in Europe. As hydrogen technology becomes more proven and commercially available, industrial

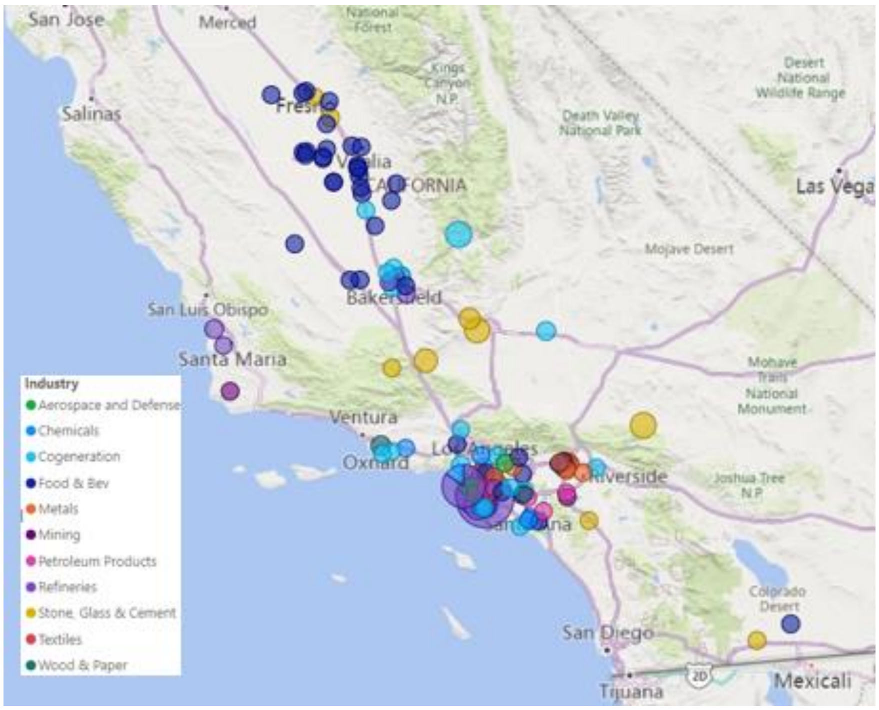
[158] This section responds to stakeholders who recommended that the Demand Study consider additional end uses, including microgrids and clean backup power generation.
[159] SoCalGas. "[H2] Innovation Experience. https://www.socalgas.com/sustainability/h2home
[160] Microgrid Knowledge. "Utilities Eye Hydrogen Microgrids for Decarbonization, Resilience." (May 2023). https://www.microgridknowledge.com/utility-microgrids/article/33005764/utilities-eye-hydrogen-microgrids-to-meet-decarbonization-goals-provide-resilience
[161] California Air Resources Board. "Current California GHG Emission Inventory Data." (2022). https://ww2.arb.ca.gov/ghg-inventory-data

end users in California are expected to adopt technology at a similar pace. Certain high-natural gas use end-customers such as refineries and cogeneration facilities are likely to drive demand volumes, but hydrogen adoption is projected to be broader across many different subsectors in the region.

3.3.2. Industrials Landscape

There is a wide variety of industries located in Central and Southern California, with a significant concentration in the LA Basin area.

Figure 17: Map of Industrial Sites in Central and Southern California



Source: CARB Industrial Facilities, SME Input

3.3.2.1. Hydrogen in the Industrials Sector

California's industrials sector consists of a diverse range of subsectors. Considering their total emissions, natural gas consumption, and number of facilities, this analysis primarily focuses on quantifying the demand from:

- Fuel switching in the food and beverage, metals, stone, glass, and cement industries as well minor demand from secondary subsectors for the three scenarios,
- Refineries in the ambitious case.
- Demand from all cogeneration plants, which are primarily located on industrial facilities.

Table 5: Hydrogen in the Industrials Sector

	Opportunities	Drawbacks	Use Cases
Hydrogen	• Decarbonization of high temperature energy intensive processes (>400ºF)	• Technology readiness is still in early stages. • Steady supply of H2 is required	• Furnaces • Kilns

3.3.2.2. Decarbonization Pathways and Alternatives[162]

Electrification and CCUS are expected to be significant alternatives to hydrogen adoption. Electrification will be a strong deterrent to natural gas usage in lower-temperature processes across subsectors. CCUS is primarily a viable alternative in larger facilities, particularly in the cement industry. Since over 60% of emissions in this sector comes from the production of the raw material in cement, as opposed to fuel combustion, CCUS provides an alternative to capture larger amounts of carbon emissions.[163] For further information, refer to the Alternatives Study, section 4.

[162] This section responds to stakeholder comments regarding consideration of alternatives to clean renewable hydrogen in the Demand Study.

[163] Applied Energy Volume 317. Nhuchhen, Daya R.; Sit, Song P.; Layzell, David B. "Decarbonization of cement production in a hydrogen economy." (July 2022). https://www.sciencedirect.com/science/article/pii/S0306261922005529

Table 6: Electrification and CCUS in the Industrials Sector

	Opportunities	Drawbacks	Use Cases
Electrification	• Decarbonization of low or medium heat processes (<400ºF) • Few process changes with new equipment	• Not easily viable for use in high temperature processes (e.g., furnaces) • Electricity prices may be cost prohibitive. • Large volumes of heat required may be challenging	• Refrigeration • Pressurization • Sterilization
CCUS	• Reduction of emissions at the source • Potential monetization of CO_2 for fuel production • Federal incentives and benefits including 45Q tax credit[164]	• Practical mainly for larger facilities with significant emissions, making CCUS more difficult in smaller distributed industries such as food & beverage. • Industries with lower-purity CO_2 streams show difficult project economics for CCUS[165]	• Large industrial plants (e.g., cement, refineries)

3.3.3. Model Scope and Key Assumptions

3.3.3.1. Model Scope

For each subsector, the development of each adoption lever was evaluated over the analysis period of 2025 – 2045. The following section details the subsectors analyzed as well as the trends amongst the four key adoption levers over time.

[164] Congressional Research Service. "The Section 45Q Tax Credit for Carbon Sequestration" (August 2023). https://sgp.fas.org/crs/misc/IF11455.pdf
[165] US Department of Energy. "Pathways to Commercial Liftoff: Carbon Management." (April 2023). https://liftoff.energy.gov/wp-content/uploads/2023/04/20230424-Liftoff-Carbon-Management-vPUB_update.pdfgy.gov)

Table 7: Industrial Subsector Definitions and Opportunity Profiles

Industrial Subsector	Scenarios Included	Subsector Overview	Clean Hydrogen Opportunity
Metals	All	• Primarily concentrated in the Los Angeles Basin. • Large presence of fabricated metal facilities with some high emissions usage primary metals. • No production of raw steel in SoCalGas's service territory.	• Fuel switching from natural gas for high temperature equipment such as boilers and furnaces. • Hydrogen-based direct reduction of iron (DRI) used in raw steel processing (No presence in SoCal).
Food & Beverage	All	• Large number of facilities, primarily concentrated in Central California, near Bakersfield. • Wide variety of food and beverage industries (e.g., dairies, breweries).	• Fuel switching from natural gas for industrial equipment such as heating, cooling, and refrigeration.
Stone, Glass, Cement	All	• Major cement facilities located in Kern County, with smaller glass and cement facilities distributed in the LA Basin. • SB 596: 100% net zero GHG target in cement by 2045.	• Short- and medium-term opportunities are for fuel switching for high temperature equipment (e.g., kilns). • Potential long-term opportunity for synthetic methanol, not currently quantified.
Pulp & Paper	All	• Few facilities, concentrated in the LA Basin. • Significant cogeneration operations at paper plants and are captured in cogeneration section.	• Fuel switching from natural gas for high-temperature industrial equipment such as boilers and kilns.

Chemicals	All	• Few mid-sized chemical facilities, concentrated in LA Basin. • Primary chemicals presence in SoCal is in H2 production, which is not in scope.	• Fuel switching from natural gas for industrial equipment such as boilers. • Use as feedstock in chemical processing.
Aerospace & Defense	All	• Large number of businesses in Los Angeles, however, few have sizeable onsite manufacturing. • Many aerospace parts are manufactured in metal fabrication shops, captured in metals category.	• Fuel switching from natural gas for industrial equipment such as boilers. • Could serve as an early adopter given the strategic importance of the defense sector.
Cogeneration	All	• Largest presence is on oil fields in Kern County and refineries near the Port of Los Angeles. • Locations on additional commercial and industrial facilities.	• Fuel switching from natural gas to hydrogen blending and hydrogen turbines.
Refining	Ambitious Only	• Highly concentrated near the Port of Los Angeles and in San Joaquin Valley. • At present, hydrogen used in refineries is produced mainly from natural gas by SMR.	• Clean fuel switching from natural gas, and transitioning from grey to clean, renewable hydrogen for refinery direct processes and production of renewable diesel and SAF.

3.3.3.2. Key Assumptions and Adoption Levers

Policy and Legislation

Currently there is little industry-specific legislation that drives a transition to hydrogen in the industrials sector, either in California or nation-wide. California's SB596 states that the cement industry must decrease 1990 levels of emissions by 40% by 2030 and reach net-zero emissions by 2045. However, given the strong presence of alternatives in the industry, namely CCUS, this is not assumed to be a major demand driver. California’s cap-and-trade program will also serve as a driver for decarbonization in the industrials sector, although the extent to which this program drives decarbonization may vary by facility.

Technology Feasibility

For most industrial facilities within SoCalGas’s service territory, the primary opportunity for hydrogen will be fuel switching for process heat, switching from natural gas-based combustion to hydrogen-based combustion technology, as well as cogeneration. This fuel switching opportunity is most prevalent in high temperature equipment (e.g., furnaces, kilns) that are considered hard-to-electrify. In most industrial facilities, low concentration of hydrogen blending is possible without significant modifications to existing technology. However, 100% hydrogen-based technologies are required to achieve significant emissions reduction. Most hydrogen technology in this space has been in emerging stages; further technological development is expected as more facilities continue to conduct pilot programs and guide hydrogen technology manufacturers based on lessons learned. Hydrogen adoption for industrial and commercial sited cogeneration turbines is expected to follow the same levels of technical feasibility growth as the other turbines described in the Power sector section of this report.

However, among the different subsectors in the industrials sector analyzed in this Demand Study, there have been variances in the type of hydrogen-based technology that is being piloted and the processes that are required to implement these technologies.

Commercial Availability

Commercial availability of hydrogen technologies is increasing; however, most commercialized technologies remain focused on a narrow subset of use cases. Burners and combustion technologies remain in focus. Some burner models are in demonstration today and may be ready for product launch in the next three to five years. Developments and demonstrations in high temperature alloys and refractories use cases are more uncertain, with longer timelines to commercialization. Flame management and advanced combustion controls systems are projected to be ready for commercialization in the 5–10-year timeframe.

Business Readiness

Business readiness will be particularly important for hydrogen adoption in the industrials sector given the relative lack of legislative incentives. Even as hydrogen combustion technology becomes more technically feasible and commercially available, there are several facility-specific characteristics that impact when facilities adopt a technology, particularly in the case of fuel switching.

- **Equipment lifetimes:** Industrial technologies are very long-lived, with equipment such as furnaces lasting over 20 – 30+ years prior to retirement. It is difficult for facilities to switch to hydrogen equipment before current retirement timelines.

- **Retrofits vs. new equipment:** Industrial end-users are often risk averse (particularly with technologies that directly impact the final product), which would lead to technologies being repaired and their useful life being extended rather than switching to new hydrogen equipment.

- **Workforce Training**: Additional training is required for employees on proper procedures.

- **Lack of Facility Downtime:** Many facilities run 24/7 with minimal idle time apart from maintenance and repairs. The difficulty in stopping production limits facilities' abilities to pilot hydrogen technology.

Given these factors, facilities are more likely to wait until asset end of life prior to investing in hydrogen-based technologies in absence of legislative mandates or internal sustainability goals. This consideration has been incorporated into the model methodology through the addition of a lag parameter that adjusts adoption growth based on the equipment lifetimes.

Early adopters will likely be companies that have multiple facilities. At these companies, hydrogen technology can be piloted at one location and then more easily deployed at remaining facilities using learnings and best practices gained from the initial pilot.

3.3.3.3. Scenario Definition

As with all three sectors, three scenarios were modelled for the demand study. Details of the scenarios for the industrials sector are included in the table below.

Table 8: Scenario Definitions for Industrials

Scenario	Description
Conservative	Assumes that there is no growth in the industrials sector and that no new legislation mandating a shift to low-carbon alternatives is introduced. For cogeneration, 10% system-wide capacity factor for H2 turbines in 2045 is assumed.
Moderate	Assumes that there is growth of hydrogen demand in the industrials sector, but that there is no new legislation. For cogeneration, 20% system-wide capacity factor for H2 turbines in 2045 is assumed.
Ambitious	Assumes that there are market or legislative drivers that promote industrial decarbonization and therefore includes demand for hydrogen from refineries. For cogeneration, 30% system-wide capacity factor for H2 turbines in 2045 is assumed.

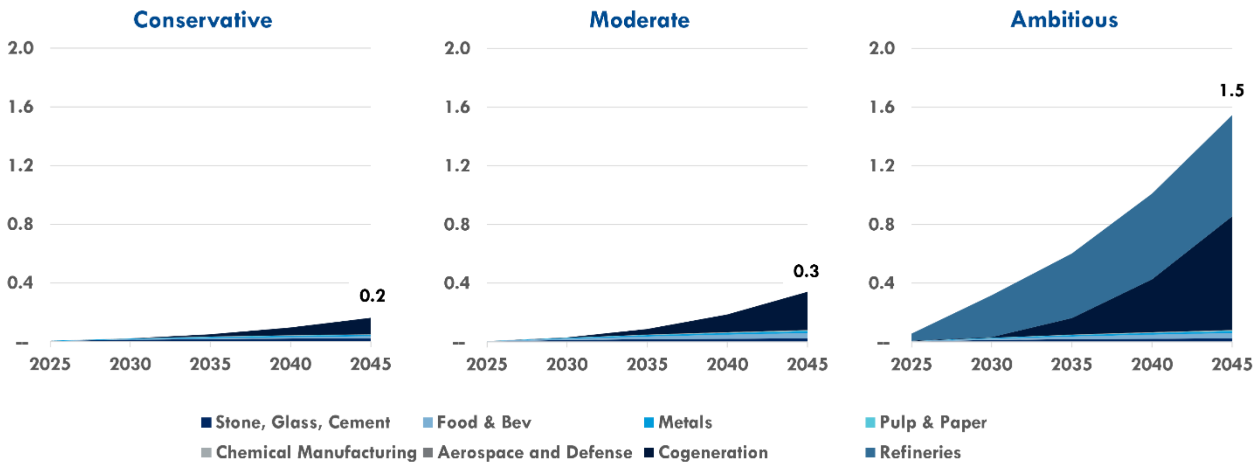
3.3.4. Industrials Demand Study Results

3.3.4.1. Overview

Potential hydrogen demand from the industrials sector within SoCalGas's service territory is expected to range from 0.2M to 1.5M TPY by 2045.

The demand scenario outcome will be heavily influenced by changes in the cost of capital requirements to transition to hydrogen and whether refineries make this switch. These two factors, in turn, can be largely determined by the enactment of legislation mandating emissions reductions in the industrials sector, as well as strategic decisions made by asset owners.

Figure 18: Total Expected Clean Renewable Hydrogen Demand in the Industrials Sector
(2025-2045, values in Million TPY)



The conservative scenario projects 0.2M TPY of demand by 2045 primarily from the food and beverage, metals, stone, glass, & cement industries, and cogeneration. In the moderate scenario, larger market-driven growth in hydrogen demand is assumed and the outlook increases to 0.3M TPY by 2045. In the ambitious scenario, refineries transition from current grey hydrogen to clean renewable hydrogen and capacity factors at cogeneration sites increase, driving demand to 1.5M TPY by 2045.

In the conservative and moderate cases, non-refinery industrial cogeneration facilities are expected to comprise most of the demand. This is largely due to increased technological developments and commercial availability in this sector compared to other industrials sectors. However, in the ambitious scenario, refineries are expected to be a significant portion of hydrogen in the industrials sector.

Currently, industrial entities in California are in the process of learning about and piloting hydrogen at large facilities. Consistent growth in technology readiness and commercial availability will be needed to reach projected demand. As more entities worldwide continue to pilot and integrate hydrogen-based technology, they will be able to serve as models for industrial companies in California.

In addition to increased education for stakeholders, targeted legislation that establishes a clear pathway to reduce emissions and incentives that reduce upfront capital costs and other adoption costs will be valuable in supporting a clean hydrogen transition. Legislation and mandates modelled after industrial emissions reduction standards seen in Europe or the mandates in the California mobility sector, such as the ACF regulation, can lead to increased and accelerated hydrogen adoption in the industrials sector. Sector-specific credit programs like the LCFS are already contributing to hydrogen's cost-competitiveness, and the extent of this contribution is expected to increase in the near future.[166]

3.3.4.2. Subsector Results

Metals

The hydrogen demand in the metals sector, comprising of primary and fabricated metals, is forecasted to range from 8.1K TPY in the conservative scenario to 12.3K TPY in the ambitious scenario. Like most industrials subsectors, there are no policy and legislation considerations for this subsector.

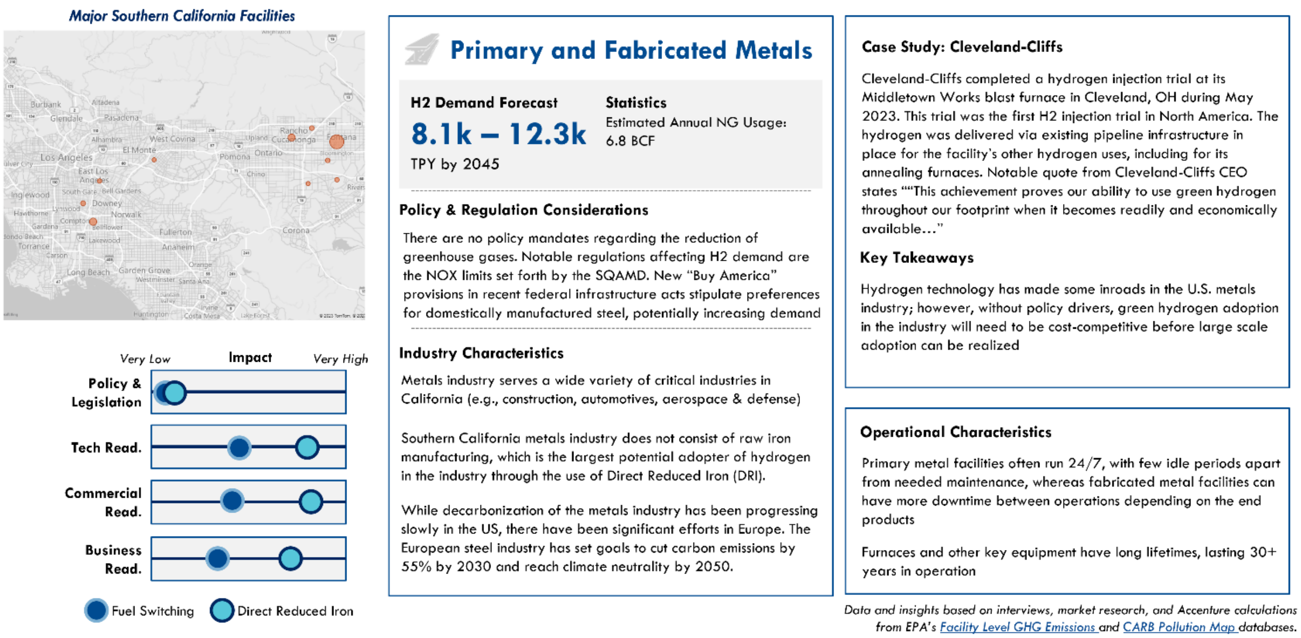
In the metal industry, technology is still emerging. Hydrogen-capable valve trains and piping are available today, but hydrogen-capable burners and furnaces for direct process heating and steam production are under development. For example, infrared-emitting hydrogen-capable burners that avoid flashback and mitigate concerns over thermal NOx formation, as well as fuel-agnostic burner designs are under development. These types of burners can decrease the risk of migration from hydrogen blends to full hydrogen adoption. 100% hydrogen furnace, oven and boiler systems will be in demonstration over the next three to five years, providing a potential pathway to broader commercial deployment. These systems have the potential to provide metal manufacturers with more efficient by-design hydrogen-fueled process heating alternatives. Flame management and advanced combustion controls systems are less certain.

One aspect of commercial availability in this sector is that individual companies are bringing technological innovations to different components of the metals process. For example, there have been different approaches for switching from natural gas to hydrogen in the development of steel pipes and the heating of the raw steel itself. It illustrates that innovation in this sector can be championed by varied entities and that solutions for vertically integrated hydrogen across metals facilities will need further development.

Given the lack of metals-specific policy drivers, adoption will largely be driven by business readiness and carbon pricing. Long equipment lifetime, facility wide retrofits, and integrated natural gas usage will slow initial growth until technology adoption processes and cost-benefit assessments have been better proven in the market.

[166] California Air Resources Board. "LCFS Electricity and Hydrogen Provisions." https://ww2.arb.ca.gov/resources/documents/lcfs-electricity-and-hydrogen-provisions

Figure 19: Hydrogen Adoption in the Metals Subsector



<u>Food and Beverage</u>

The hydrogen demand in the food and beverage sector is forecasted to range from 13.8k TPY in the low scenario to 36k TPY in the ambitious scenario. Like most industrials subsectors, there are no policy and legislation considerations for this subsector.

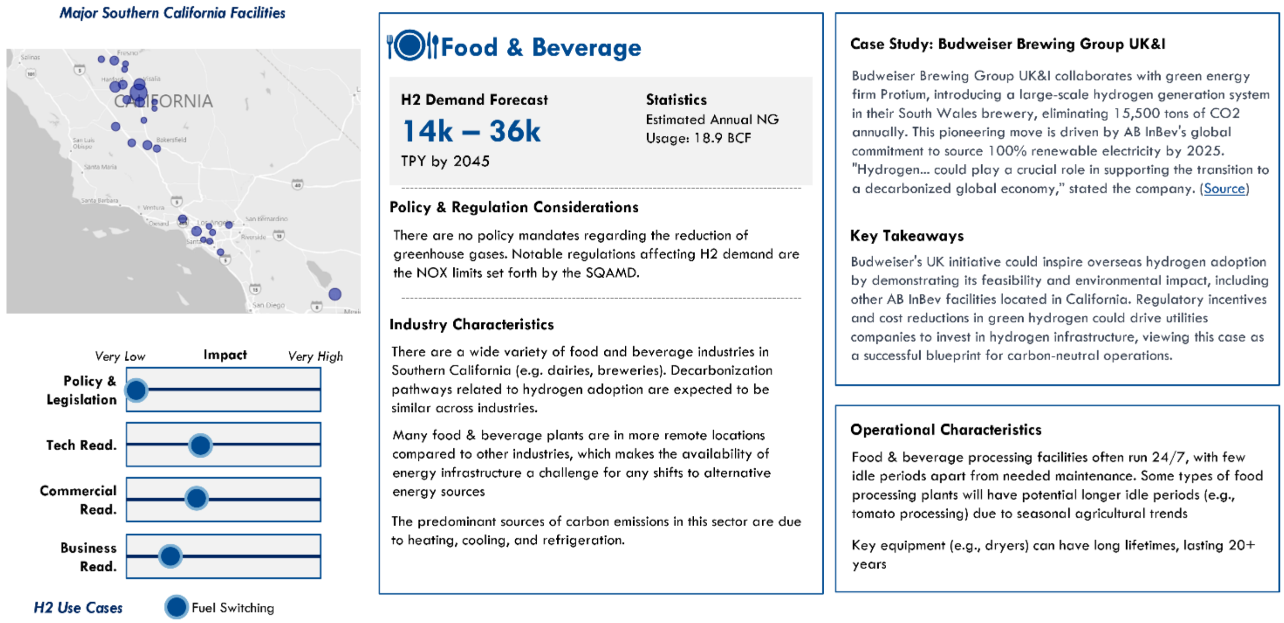
In the food and beverage industry, hydrogen use in process heating is technically feasible up to about 30% blending. However, increased blending ratios require many adjustments in fuel delivery process (e.g., BTU value, piping size, controls, burner sizes, and configurations.). In Central and Southern California, there is a remarkably diverse set of food and beverage entities. While many hydrogen-based combustion equipment will be applicable to different entities, some equipment will need to be purpose built for specific industries (e.g., dairy).

There are currently only a handful of hydrogen equipment manufacturers in the food and beverage industry, such as AMF Bakery Systems and RBS Oven Systems,[167] whose ovens can use hydrogen to bake a wide range of food products. These types of products can serve as replacements for aging, natural gas equipment but significant retrofits in other portions of the facility will be required. One benefit of this need for retrofits is that facilities may be willing to adopt multiple hydrogen-based equipment at once to avoid repeat retrofits and facility shutdowns.

---

[167] Reading Bakery Systems. "RBS Oven Systems: Baking for a Better Tomorrow." https://www.readingbakery.com/oven-systems.html

Figure 20: Hydrogen Adoption in the Food & Beverage Subsector



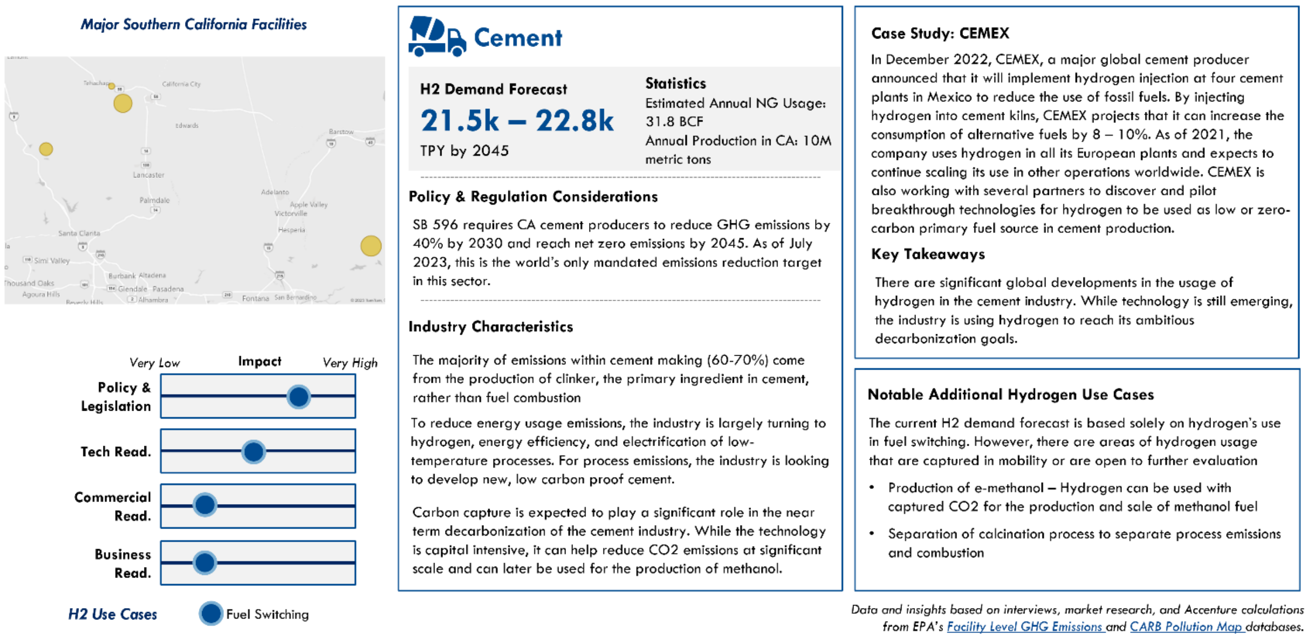
<u>Stone, Glass, and Cement</u>

The hydrogen demand in the stone, glass, and cement sector is forecasted to range from 21.5k TPY in the conservative scenario to 22.8k TPY in the ambitious scenario. Unlike most industrials sectors, there are decarbonization policy targets within the cement portion of this sector. SB 596 mandates that cement producers must reduce emissions by 40% of 1990 levels by 2030 and reach a goal of net-zero emissions by 2045.

In the cement industry, hydrogen may be blended with traditional fuels or used for specific process steps, but 100% hydrogen use as a fuel source currently has low technical feasibility due to the process changes that are required to implement the necessary technology. Hydrogen has a lower energy density compared to fossil fuels, which means much larger volumes of hydrogen are required to generate the same amount of heat. This could result in substantial modifications to cement kilns and downstream calciner processes that integrate kiln combustion gasses to recuperate waste heat.

Interviews with cement manufacturers affirm concerns about new hydrogen technologies disrupting process equipment, which is typically heavily integrated. A second emergent theme is the use of hydrogen for fuels production from captured cement carbon emissions. While there is industry interest in the potential increase in business, this use case described as more than 10 years out based on industry interviews and research on technology readiness. Greater technological feasibility and reduced cost of adoption would help establish a runway for increased clean renewable hydrogen demand.

Figure 21: Hydrogen Adoption in the Cement Subsector



Secondary Subsectors (Paper, Chemical, Aerospace, Other)

Additional industrials subsectors have been less engaged with hydrogen-based technology since they primarily deal with lower temperature processes that are more likely to switch to electrification as a decarbonization pathway. However, demand has been modelled for the limited high-process opportunities that are available in other sectors that have a presence in SoCalGas's service territory (e.g., paper, chemicals). The hydrogen demand in the pulp & paper sector is forecasted to range from 3.6k TPY in the conservative scenario to 5.1k TPY in the ambitious scenario. The hydrogen demand in the chemicals sector is forecasted to range from 1.7k TPY in the conservative scenario to 3.4k TPY in the ambitious scenario.

There will also be some potential for hydrogen adoption in other subsectors in Central and Southern California (e.g., textiles) that may have comparatively lower use of natural gas but may be inclined to adopt hydrogen technology to meet decarbonization targets. While these additional subsectors have not been modelled as part of this study, there may be an opportunity to capture demand from these sectors in further studies to better understand the needs of potential industrial off takers of hydrogen along pipeline routes.

Technology and commercial readiness for hydrogen in secondary subsectors are expected to follow similar adoption growth as the other primary industrials sectors. Once technologies such as 100% hydrogen – based boilers become more proven, they can be leveraged in these secondary subsectors and replace natural gas fueled equipment. However, given the relatively low natural gas usage in secondary subsectors, it is expected that there will be low business readiness to adopt major equipment changes.

Refineries

The hydrogen demand in the refinery sector, for non-cogeneration hydrogen use cases, is forecasted to range from zero TPY in the conservative scenario to 690k TPY in the ambitious scenario. The technical feasibility of hydrogen use is most advanced in the refining industry, where it is currently used as a feedstock in hydroprocessing operations to upgrade heavy oils, improve process conversion and yields, and remove impurities such as sulfur and nitrogen. Refineries and renewable diesel plants are already the largest industrial consumers of hydrogen, but hydrogen is primarily produced as a coproduct of naphtha reforming, a core process utilized in the production of gasoline, and via steam methane reforming (SMR) at refinery owned or third party dedicated hydrogen plants. The ready availability of hydrogen is one of key drivers for why clean, renewable hydrogen is not included in the conservative and moderate scenarios for Refineries. In contrast to carbon-free hydrogen produced by electrolysis powered by renewables, hydrogen produced via these incumbent refinery processes is considered to be very high in lifecycle carbon intensity. Clean renewable hydrogen is directly fungible with SMR produced hydrogen; however, scale and ratability of renewable hydrogen production and delivery may be of concern to refiners.

Secondary to feedstocks, the refining industry can also be source of demand for clean renewable hydrogen for natural gas blending and/or switching for fired heaters and boilers. Hydrogen uptake as fuel is expected to follow broader industry trends with one caveat. Unlike general industrial processes, refineries can and do produce their own fuel gas as a byproduct of the refining process. Because of this, refineries have the ability to manage fuel gas heating value internally, through LPG blending, and at times can be constrained operationally by their ability to balance indigenous fuel gas production.

External market forces such as adoption of alternative fuel-based vehicles (e.g., hydrogen based, electric), will also directionally reduce aggregate hydrogen demand among conventional petroleum refineries. However, some of this hydrogen demand attrition in petroleum refining is expected to be offset, albeit not one-for-one, by increased production of renewable diesel and SAF, both of which require hydrogen in the production process.

Business readiness to adopt clean, renewable hydrogen as feedstock is expected to largely be driven by the availability of steady supply at the volumes necessary for refinery operations. However, readiness for fuel-switching is expected to be slower and dependent on the ability of refineries to deal with facility wide retrofits that can adjust current natural gas and hydrogen supply processes.

Cogeneration

The hydrogen demand in the cogeneration sector, including refinery-sited cogeneration is forecasted to range from 115k TPY in the conservative scenario to 799k TPY in the ambitious scenario. However, there remains significant uncertainty around the future of cogeneration in California, with the CARB Scoping Plan[168] and SB100[169] scenarios projecting all cogeneration to be retired by 2045. It is possible that cogeneration does not drive any hydrogen demand if cogeneration plants are retired by 2045. If cogeneration does remain past 2045, the Demand Study projection may be conservative as the capacity factors used in the modeling are relatively low for industrial cogeneration.

Cogeneration is included in the Industrials sector as the vast majority of cogeneration facilities are located on industrial sites (e.g., refineries, oil fields). Technology and commercial readiness for hydrogen in cogeneration plants is expected to follow the same adoption rates as the peaker and baseload plants, detailed previously in the power subsector results section. Adoption of hydrogen turbines at industrial sited cogeneration plants may help drive adoption of hydrogen in other industrial processes since any hydrogen supply network used at cogeneration plants could be used to supply hydrogen to the core industrial processes.

3.3.5. Potential Opportunities for Demand Upside

3.3.5.1. Agriculture

The industrial sector is diverse in sub-sectors and potential users for clean renewable hydrogen. While many of the most prominent sectors are formally modelled in the Demand Study, the future of California's industrial landscape may evolve. Along with this evolution, there are many industrial processes that could switch to hydrogen in the future as market scale, commercialization, and technology is tested and improves. One of the largest potential areas for this is fertilizer production. California is a global leader in farming, and a large consumer of fertilizer, however the State currently imports all fertilizer used. The world currently produces 175 million tons of ammonia per year, mostly for fertilizer, accounting for 1-2% of global carbon emissions.[170] If clean renewable hydrogen were to be used to produce ammonia for fertilizer in State, then this could represent a huge upside for its demand and could help reduce global emissions. Additionally, clean ammonia is being considered as a

[168] California Air Resources Board. "AB 32 GHG Inventory Sectors Modeling Data Spreadsheet". https://ww2.arb.ca.gov/our-work/programs/ab-32-climate-change-scoping-plan/2022-scoping-plan-documents
[169] California Energy Commission. "2021 SB100 Joint Agency Report". https://www.energy.ca.gov/sb100
[170] Yale Environment 360. "From Fertilizer to Fuel: Can 'Green' Ammonia Be a Climate Fix?." (January 2022). https://e360.yale.edu/features/from-fertilizer-to-fuel-can-green-ammonia-be-a-climate-fix

potential shipping fuel for OGVs. However, there are safety and environmental concerns associated with the production and use of ammonia, so the future of ammonia remains uncertain in California.

Outside of ammonia and fertilizer production, there are many other potential avenues for hydrogen in agriculture: Hydrogen fuel cells may be used to power irrigation systems, many of which run on fossil fuels,[171] hydrogen could be used for agricultural drying (a high-heat processes to treat crops such as grains, nuts, etc., which may be difficult to electrify),[172]or hydrogen could be used to power greenhouses where a specific and constant energy supply is required to control the environment. These and many other potential use cases for hydrogen in the agriculture industry and beyond were not evaluated due to the diverse nature of the applications and their uncertainty in California's future.

4. Comparison to Other Studies

In response to the release of the draft demand study, some stakeholders submitted comment letters concerning the draft demand study's estimates vis-a-vis estimates of hydrogen demand in other agency or third-party reports. Hydrogen demand projections published over the past few years by government agencies and researchers vary on methodology and outcomes. Some government agency reports referenced in the comment letters, such as the CARB Scoping Plan,[173] forecast total hydrogen demand in California closer to the Demand Study's conservative scenario of 1.9M TPY of hydrogen in SoCalGas's service territory by 2045. The California Energy Commission's (CEC) 2023 Integrated Energy Policy Report (IEPR) uses the Scoping Plan as the basis for one of its two hydrogen demand scenarios for power generation and transportation, and forecasts statewide demand for clean renewable hydrogen in 2045 as high as 2.9M TPY. This is double the hydrogen demand the Scoping Plan considered for 2040 (estimated at 1,475,000 MT/year).[174] Other recent projections, such as those released by ARCHES, greatly exceed all the Demand Study's scenarios, including the ambitious scenario

[171] Penn State Extension. "Exploring the Potential of Hydrogen in Agriculture: Farming with a Green Future." (June 2023). https://extension.psu.edu/exploring-the-potential-of-hydrogen-in-agriculture-farming-with-a-green-future#:~:text=Currently%2C%20hydrogen%20is%20used%20in,of%20heat%20for%20these%20purposes.
[172] Iowa State University. "LP Gas Drying Estimate." (September 2004). https://crops.extension.iastate.edu/encyclopedia/lp-gas-drying-estimate#:~:text=LP%20gas%20requirements%20for%20high,0.025%20gal%2Fbu%2Fpt
[173] 2022 Carb Scoping Plan. Accessible at: https://ww2.arb.ca.gov/our-work/programs/ab-32-climate-change-scoping-plan/2022-scoping-plan-documents
[174] IEPR Update. Accessible at: 2022 Integrated Energy Policy Report Update (ca.gov) p. 105 https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report/2022-integrated-energy-policy-report-update

of 5.9M TPY. When looking at these projections holistically, the Demand Study's conclusions are near or within the range of recently released projections of hydrogen demand in California.

SoCalGas is aware that there may be sector-by-sector variances between some of the government agency hydrogen demand forecasts referenced in the comment letters and its Demand Study. While SoCalGas has reviewed the referenced reports in response to stakeholder comments, the Demand Study projections were not based on agency forecasts. SoCalGas's Demand Study projections were based on independently developed assumptions and analysis of potential hydrogen uptake in SoCalGas's service territory. Specifically, for each sector analyzed, assumptions were made on how legislation, technical feasibility, commercial availability, and business readiness could impact hydrogen consumption. Accenture and Electric Power Research Institute were contracted by SoCalGas to assist in the preparation of SoCalGas's Demand Study. Analysis was based on the latest market and technology information and was peer reviewed by experts at third parties, including National Renewable Energy Lab (NREL), South Coast Air Quality Management District (SCAQMD), University of California Los Angeles (UCLA), UC Irvine (UCI), and UC Davis (UCD).

Table 9 below, provides a comparison of demand projections by 2045 from various forecasts by agency or entity.

Table 9: Comparison of Demand Projection Near or by 2045

Agency or Entity	Demand Projections (Million Metric Tonnes)	Date Published	Area
ARCHES	17[175]	October 2023	State of California
CARB 2022 Scoping Plan[176]	1.9[177]	December 2022	State of California
CEC 2023 Integrated Energy Policy Report	2.9[178]	February 2024	State of California
NREL H2@Scale[179]	22 – 41	October 2020	United States
UC Davis California Hydrogen Analysis Project Report[180]	2.5[181]	April 2023	State of California
DOE National Clean Hydrogen Strategy and Roadmap 2023 (Roadmap)[182]	20 (2040)[183] 50 (2050)	June 2023	United States
SoCalGas Demand Study	1.9 Conservative 3.2 Moderate 5.9 Ambitious	January 2024	SoCalGas service territory
National Petroleum Council[184] (NPC)	11.1[185]	April 30, 2024	West Region

Many of the analyses that underpin the agency reports referenced in the comment letters were also initiated prior to or soon after significant clean hydrogen announcements, including the enactment of Senate Bill (SB) 1075 (Skinner) in September 2022 and U.S. DOE's selection of

175 Includes power generation, transportation (mobility), maritime, ports, and industry US DOE OCED, "California Regional H2Hub Community Briefing", slide 26. Accessible at: https://www.energy.gov/sites/default/files/2023-10/H2Hubs_California_Community_Briefing.pdf

176 2022 CARB Scoping Plan. Accessible at: https://ww2.arb.ca.gov/our-work/programs/ab-32-climate-change-scoping-plan/2022-scoping-plan-documents

177 Internal conversion of 0.2315 exajoules to tonnes that includes commercial, industrial, oil & gas extraction, petroleum refining, residential, TCU (transportation communication and utilities) and transportation; excludes electric generation.

178 Includes the quantity of hydrogen reported used in transportation in 2040 and CEC staff's estimate of the amount of clean and renewable hydrogen required to replace fossil gas combusted for electricity generation in 2045 as reported in the CARB 2022 Scoping Plan Update. Accessible at: https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report/2023-integrated-energy-policy-report

179 Includes refineries, metals, ammonia, biofuel, synthetic HC (methanol), and light-duty and medium/heavy-duty FCEVs. Accessible at: https://www.nrel.gov/news/program/2020/study-shows-abundant-opportunities-for-hydrogen-in-a-future-integrated-energy-system.html

ARCHES for up to $1.2 billion in federal hydrogen hub funding in October 2023 (and subsequent July 2024 $12.6 billion agreement, including up to $1.2 billion from the DOE and $11.4 billion in public and private matching funds, to build the California hydrogen hub). For example, the SB 100 Joint Agency Report referenced in one of the comment letters was published in September 2021; one year prior to the enactment of SB 1075 and two years prior to ARCHES award announcement. The 2022 CARB Scoping Plan was initiated in June 2021 and approved in December 2022; three months after the enactment of SB 1075 and 10 months prior to the ARCHES announcement. The 2023 CEC IEPR uses the 2022 Scoping Plan as the basis for multiple hydrogen demand scenarios and was approved in February 2024. The 2023 IEPR also states: "The initial assessment presented in this IEPR is not a forecast of adoption based on economic or other factors, but instead reflects exploratory 'what if' scenarios" for hydrogen." The 2023 IEPR also cites ARCHES' funding selection and states: "To complement the strong momentum and alignment of state and federal opportunities and in response to direction in SB 1075, CARB, in consultation with CEC, CPUC, the California Workforce and Development Board, and other partner agencies, [we] will be developing a comprehensive analysis of hydrogen. This includes analyzing and making recommendations on the increased production, deployment, and use of low-carbon intensity hydrogen." The analysis is currently under development, with expected stakeholder engagement opportunities in late 2024.

For comparative purposes, SoCalGas assumes statewide demand figures could be split 50/50 between SoCalGas's service territory (in Central and Southern California) and the remaining part of California. This is likely a conservative estimate since SoCalGas's customer base of approximately 21 million customers is more than the majority of the approximate CA population of 39.5 million,[186] and SoCalGas's service territory also contains both the Port of Los Angeles

[180] Fulton et al. UC Davis. 2023. Accessible at: https://escholarship.org/uc/item/27m7g841
[181] Includes key industries of ports, bio-refining, turbine electricity generation, chemicals, cement, possibly fertilizer (ammonia), steel, and institutional buildings, with overall demand more than 50% in the transportation sector. Accessible at: https://escholarship.org/uc/item/27m7g841
[182] USDOE 2023. Accessible at: https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/us-national-clean-hydrogen-strategy-roadmap.pdf?sfvrsn=c425b44f_5
[183] Includes power-to-liquid fuels, methanol, blending in natural gas for heat, energy storage/power sector, steel, biofuels, trucks, ammonia, refining and petrochemicals, and additional demands.
[184] NPC Harnessing Hydrogen Study, 2023, https://harnessinghydrogen.npc.org/downloads.php
[185] The NPC demand projection is for the West Region, which includes California, Nevada and Arizona, with California having the majority of the demand.
[186] https://data.census.gov/profile/California?g=040XX00US06

and Port of Long Beach, which are considered to be some of the most active Ports in the nation.[187]

While there may be differences in the amount of hydrogen demand projected in all the referenced studies, there is consensus among agencies and researchers that projected demand exists in the power, mobility, and industrial sectors, that demand in those sectors is expected to grow over the next two decades, and that additional analysis is needed to better forecast what demand will be.

5. Total Addressable Market vs Angeles Link Throughput Scenarios[188]

SoCalGas considers the assessment of the potential hydrogen demand within SoCalGas's service territory, referred to as the Total Addressable Market (TAM), as an important initial step in the Angeles Link Phase 1 studies. SoCalGas can use information about the potential TAM in its service territory to inform which sectors and regions could be served by Angeles Link. This data served to inform the expected range of throughput scenarios that could be served by Angeles Link. As the study evolved, Angeles Link throughput scenarios are a portion of the total addressable market demand for clean renewable hydrogen. These data and scenarios were in turn used as a basis to various Phase 1 studies such as the GHG Emissions Evaluation and NOx and other Air Emissions Assessment.

[187] Both ports together handle approximately 29% of all containerized international waterborne trade in the U.S. as documented in the Port of Los Angeles, FACTS AND FIGURES, available at: https://www.portoflosangeles.org/business/statistics/facts-and-figures.
[188] This section has been added in response to stakeholder feedback.

Figure 22: Angeles Link Throughput Scenarios

AL Throughput Scenarios ('000 MMTPY)	Scenario	2045
Conservative	Mobility	267
	Power	189
	Industrials	43
	Annual Total	**500**
Moderate	Mobility	384
	Power	510
	Industrials	106
	Annual Total	**1,000**
Ambitious	Mobility	433
	Power	675
	Industrials	392
	Annual Total	**1,500**

6. Stakeholder Feedback

SoCalGas presented opportunities for the PAG and CBOSG to provide feedback at four key milestones in the course of conducting this study: (1) the draft description of the Scope of Work, (2) the draft Technical Approach, (3) Preliminary Findings and Data, and (4) the Draft Report. These milestones were selected because they are critical points at which relevant feedback can meaningfully influence the study.

Table 10: Key Milestone Dates

Milestone	Date Provided to PAG/CBOSG	Comment Due Date	Responses to Comments in Quarterly Report
1. Draft Scope of Work	July 6, 2023	July 31, 2023	Q3 2023
2. Draft Technical Approach	September 7, 2023	September 25, 2023	Q3 2023/Q4 2023
3. Preliminary Findings and Data	August 21, 2023	September 25, 2023	Q3 2023/Q4 2023
4. Draft Report	January 17, 2024	February 23, 2024	Q1 2024

Feedback provided at the PAG/CBOSG meetings is memorialized in the transcripts of the meeting. Written feedback received is included in the quarterly reports, along with responses.

Meeting transcripts are also included in the quarterly reports. The quarterly reports are submitted to the CPUC and are published on SoCalGas's website.[189]

Feedback was incorporated as applicable at each milestone throughout the progression of the study. Some feedback was not incorporated for various reasons, feedback that was outside the scope of the Phase 1 Decision or feasibility study, and feedback that may be anticipated to be addressed in future phases.

A summary of stakeholder input that was incorporated throughout the development of the Demand Study and into the final report is summarized in Table 11 below.

Additionally, some administrative and other minor corrections were made to the final report for the Demand Study for clarity.

Table 11: Summary of Incorporated Stakeholder Feedback

STAKEHOLDER FEEDBACK	
Thematic Comments from PAG/CBOSG Members	**Incorporation of and Response to Feedback**
Demand Projections Stakeholders expressed concerns that the Demand Study overestimates hydrogen demand, especially when compared to forecasts put forth by other agencies, like CARB and the CEC. Moreover, some stakeholders believe that other clean energy alternatives will be cheaper than hydrogen, decreasing the demand for hydrogen and making it difficult for hydrogen to compete in the energy market.	In response to stakeholder feedback on the Demand Study methodology and on the draft report, SoCalGas added a new Section 5 to the final Demand Study report titled, "Comparison to Other Studies," which demonstrates how SoCalGas's forecasts compare to studies conducted by other agencies. This review demonstrates that the Demand Study's conclusions are near or within the range of recently released projections of hydrogen demand in California. While there may be differences in the amount of hydrogen demand projected across these studies, there is consensus among agencies and researchers that projected demand is expected to grow over the next two decades, and that additional analysis is needed to better forecast what demand will be.

[189] Each Quarterly Report can be accessed at: https://www.socalgas.com/regulatory/angeleslink

Transparency Stakeholders stated that the Demand Study should disclose underlying data, sources, and methodologies supporting its findings and should disclose information related to the selection and disclosure of interviewees.	Consistent with this stakeholder feedback, the Demand Study includes the Technical Appendix, which includes descriptions and walkthroughs of assumptions, data sources, calculations, and methodologies for assessing hydrogen demand. In addition, PowerPoint slides with calculations, and assumptions were provided in direct response to PAG feedback on the preliminary findings. A non-exhaustive list of interviewees has also been provided in the Demand Study.

Consideration of Cost Stakeholders suggested that the Demand Study should factor the cost of hydrogen into future demand projections.	SoCalGas recognizes that the forecasted cost of clean renewable hydrogen is an important factor in projecting future hydrogen adoption and will be assessing this in future phases of Angeles Link. The focus of the present study is to understand the total potential of clean renewable hydrogen as a fuel in the Los Angeles Basin and SoCalGas territory and the study made an assumption that the cost of hydrogen is equal to the incumbent fuel to evaluate that demand. In response to this feedback, Section 8 Future Considerations section has been added to the final Demand Study replacing the Recommendations for Future Analysis to reiterate the topics that may be considered in future phases of Angeles Link. Those topics include the price elasticity of hydrogen and its potential impact on demand volumes. In addition, in response to this feedback, additional text and an explanatory footnote has been added to the report's Methodology Section 2.4.3 (Simplifying Assumptions), acknowledging this feedback and clarifying the rationale for the simplifying assumptions related to the price of hydrogen for purposes of this feasibility study. Section 2.4.3 has also been updated to clarify that the separate High-Level Economics and Cost Effectiveness Study (Cost Effectiveness) evaluated the levelized cost of hydrogen (LCOH).

Study Area Stakeholders commented that the Demand Study should be limited to the portion of demand best served by Angeles Link, as distinguished from total demand in SoCalGas' service territory.	In response to the comments, SoCalGas added a new Section 6 in the report distinguishing between the total addressable market potential of hydrogen in SoCalGas territory and the portion of demand best served by Angeles Link. SoCalGas considers the assessment of the potential hydrogen demand within SoCalGas's service territory as an important initial step in the Angeles Link Phase 1 studies. SoCalGas can use information about the potential hydrogen market in its service territory to inform which sectors and regions could be served by Angeles Link. In addition, these data served to inform the expected range of throughput scenarios that could be served by Angeles Link. These data and scenarios were in turn used as a basis to various Phase 1 studies such as the GHG Emissions Evaluation and NOx and other Air Emissions Assessment. The Angeles Link throughput scenarios were assessed to be a portion of the total addressable market demand for clean renewable hydrogen.
End Uses Stakeholders recommended that SoCalGas should consider additional end uses, including microgrids and clean backup power generation.	SoCalGas has responded to stakeholder input by including a new Section 4.2.5 that addresses industrials demand called "Potential Opportunities for Demand Upside," including microgrids and backup power generation.

Alternatives Stakeholders commented that the Demand Study should incorporate an analysis of alternatives to clean renewable hydrogen.	In response to stakeholder comments, as the draft of the Demand Study was developed, SoCalGas included a section in the Demand Study for three sectors—power (Section 4.2.2.3), mobility (section 4.1.2.3), and industrial (section 4.3.2.2) —which discuss potential "Decarbonization Pathways and Alternatives" for each of these critical sectors. SoCalGas acknowledges the importance of considering complementary clean energy options alongside hydrogen to meet our climate goals. Additional analysis of alternatives is also provided in the separate Project Options & Alternatives Study.
Collaborative Efforts with Regulatory Agencies and OEMs Some stakeholders recommended that the Demand Study should clarify SoCalGas's collaborative efforts with CARB and air districts as well as Original Equipment Manufacturers.	Consistent with this feedback, aAs the Demand Study notes, SoCalGas engaged in market participant interviews and peer review sessions with entities such as academic, regulatory or government agencies (state and federal) when possible, to obtain objective feedback on approach, assumptions, and outputs. The South Coast Air Quality Management (SCAQMD) District provided guidance as SoCalGas developed the Demand Study, and SCAQMD peer reviewed the study prior to publication. Moreover, SoCalGas relied on many resources and studies provided by CARB when preparing the Demand Study, such as the 2022 Scoping Plan and the 2022 State Strategy for the State Implementation Plan.
Clean Hydrogen Demand vs. Hydrogen Demand Stakeholders stated that the evaluation of potential demand for clean renewable hydrogen demand should be distinguished from demand for hydrogen, more generally.	In alignment with this feedback and consistent with CPUC Decision 22-12-055, the Demand Study focused specifically on demand for clean renewable hydrogen.

7. Future Considerations

As noted in Section 2.4 Methodology, simplifying assumptions were made that present opportunities for more refined work. The following items may be considered in future phases of Angeles Link:

1. Full power system modeling, including load growth and electric sector reliability modeling to inform the extent to which hydrogen is needed and can be used to fulfill future reliability requirements.
2. Economic modeling to analyze the price elasticity of hydrogen and its potential impact on demand volumes.
3. More refined geographic demand with a focus on mobility to better understand how demand will be distributed across SoCalGas's service territory.
4. Further hydrogen demand assessments for transportation (e.g. LDVs, locomotives, and OGVs) and agricultural segments (e.g. ammonia for fertilizer production), as well as microgrid and backup power generation. These assessments aim to broaden the analysis and provide a better understanding of sector and aggregate demand.