October
2021

THE ROLE OF CLEAN FUELS

AND GAS INFRASTRUCTURE IN ACHIEVING CALIFORNIA'S NET ZERO CLIMATE GOAL

FULL REPORT

SoCalGas

TABLE OF CONTENTS

EXECUTIVE SUMMARY

In 2018, California Governor Edmund G. Brown, Jr. signed Executive Order B-55-18, establishing the goal "to achieve carbon neutrality as soon as possible, and no later than 2045, and achieve and maintain net negative emissions thereafter."[1] Achieving carbon neutrality across California's entire economy requires solving a complex challenge: how to boost renewable energy penetration while simultaneously decarbonizing hard-to-abate sectors like heavy industry and aviation, all while operating a resilient affordable energy system as the overall electric load continues to increase.

This technical analysis focuses principally on how decarbonization can succeed in California, the world's fifth largest economy. To achieve carbon neutrality, electricity demand is projected to double or more by 2045, powered by weather-dependent renewables, and there is no known prescriptive pathway or blueprint for fully decarbonizing at this magnitude. This study is designed to inform approaches for decarbonizing and achieving California's climate goals, contributing to collective efforts and a body of work by stakeholders and policymakers that has established California's climate policy leadership. A successful decarbonization pathway in California has applicability for net-zero efforts in Europe, Asia, and elsewhere.

Viable decarbonization pathways must be reliable, resilient and affordable. They offer relatively low technology risk and reduce challenges customers feel in converting their equipment and appliances.[2] To examine how best to achieve net-zero carbon while managing risk and delivering a reliable, resilient and affordable energy system, this analysis evaluates four potential decarbonization scenarios to address the challenge of meeting California's carbon neutrality goals:

1. **Resilient electrification**
2. **High penetration of clean fuels**[3]
3. **High penetration of carbon sequestration, and**
4. **No fuels network**

---

[1] State of California, Executive Department, "Executive Order B-55-18 to Achieve Carbon Neutrality," September 10, 2018, available at: https://www.ca.gov/archive/gov39/wp-content/uploads/2018/09/9.10.18-Executive-Order.pdf.
[2] United States White House, "Executive Order on Tackling the Climate Crisis at Home and Abroad," January 27, 2021, available at: https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/; International Energy Agency, "Net Zero by 2050: A Roadmap for the Global Energy Sector," May 2021, available at: https://iea.blob.core.windows.net/assets/beceb956-0dcf-4d73-89fe-1310e3046d68/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf; Rogelj et al., "Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development," Intergovernmental Panel on Climate Change Special Report, 2018, available at: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_Chapter2_Low_Res.pdf.
[3] As discussed in further detail below, "clean" is defined in this analysis as alternative fuels and/or carbon management resulting in a net-zero carbon footprint. The term is not intended to suggest or imply any other environmental attribute of the fuels.

Examination of these scenarios is anchored in detailed economy-wide modeling and fuels infrastructure analysis. With carbon net neutrality as the endpoint, each of these prospective scenarios takes into account cross-sector integration. The evaluation considered the following public interest assessment criteria:

1. **System reliability and resiliency**
2. **Solution for hard to abate sectors**
3. **Customer conversion challenges**
4. **Technical maturity**
5. **Affordability**

Going further, while a range of decarbonization pathways was analyzed, this analysis focuses on the value a clean fuels network can play in supporting California's path to carbon neutrality. Other decarbonization levers, such as electrification and renewable resource deployment, are assessed, primarily to explore and evaluate modeled interaction with the attributes of a clean fuels network. Likewise, the merits of a clean fuels network are considered in concert with these and other decarbonization implements.

This study examines three key questions that need to be answered when evaluating the role of a clean fuels network in California's path to full decarbonization:

1. **How can full carbon neutrality be achieved, and what considerations inform preferred pathways?**
2. **What is the potential role of clean fuels and a clean fuels network?**
3. **How could a clean fuels network be established in CA?**

Similar to other industry studies, including those commissioned by California Air Resources Board (CARB) and the California Energy Commission (CEC), this analysis relies on detailed decarbonization modeling that integrates demand-side end-use accounting and supply-side capacity expansion modeling, and it incorporates the full range of known energy sources required to achieve a decarbonized future.

---

[4]The modeling described herein was performed by an external consultant with deep subject matter expertise. Academic researchers with expertise and published scholarship on the relevant topics provided input on the study as follows:
- The modeling assumptions, methodology and conclusions were reviewed and validated by academic researchers at University of California Irvine (UCI) Advanced Power and Energy Program, Dr. Jeff Reed and Professor Jack Brouwer.
- The study and its conclusions were reviewed and validated by:
  - Erin M. Blanton, a senior research scholar at the Center on Global Energy Policy at Columbia University's School of International and Public Affairs;
  - Dr. Lew Fulton, Director of the Sustainable Transportation Energy Pathways Program, of the Institute for Transportation Studies at University of California Davis; Andrew Burke, Research Scientist; Dr. Tri Dev Acharya, Post Doctorate Fellow; and Vishnu Vijayakumar, PhD Candidate.

We appreciate their valuable input and suggestions.

Reaching beyond existing analytical approaches, this study includes a pioneering approach addressing the complexity of modeling full carbon net neutrality in the energy system, while also considering infrastructure implications for the fuels network. **The results consistently highlight the importance of clean fuels to achieve the goal of full carbon net neutrality in an affordable and resilient manner.**

The imperative for action is clear, and gas utilities like SoCalGas play a key role in helping reduce and abate emissions. SoCalGas aspires to be a leader in the energy transition and has established a goal of achieving net-zero carbon emissions by 2045 for scope 1, 2, and 3 emissions, in alignment with California's climate goals.[5] This study is the next step for re-envisioning SoCalGas and how we can achieve our climate leadership aspiration.

Regarding this study's scope, it is worthy to note that the analysis takes on challenges not previously examined in detail by other studies (as far as we are aware), including:

- **Cross-sectoral integration:** By envisioning comprehensive integration of the electricity and fuels systems, the analysis considers trade-offs among all energy demands including transportation, residential and commercial buildings, and the industrial sector.

- **Fuels system infrastructure and flexibility:** By assessing transmission and delivery infrastructure costs, the analysis more fully assesses the future value of the current natural gas system. Simplifying assumptions are sometimes made in other studies that underestimate this future value, failing to account for the potential to use existing gas pipelines to transport blends of clean fuels.

- **Assessing other critical factors – particularly resiliency:** Many factors beyond cost and reliability must be considered – resiliency, customer conversion challenges, technology risk, and hard-to-abate sectors. The value of resiliency – such as the ability to avoid system outages and withstand more frequent and extreme weather events – is emerging in response to events such as the Texas February 2021 winter storm Uri, and the California weather related blackouts in August 2020. Damages from winter storm Uri exceeded $20 billion and caused over 100 deaths.[6]

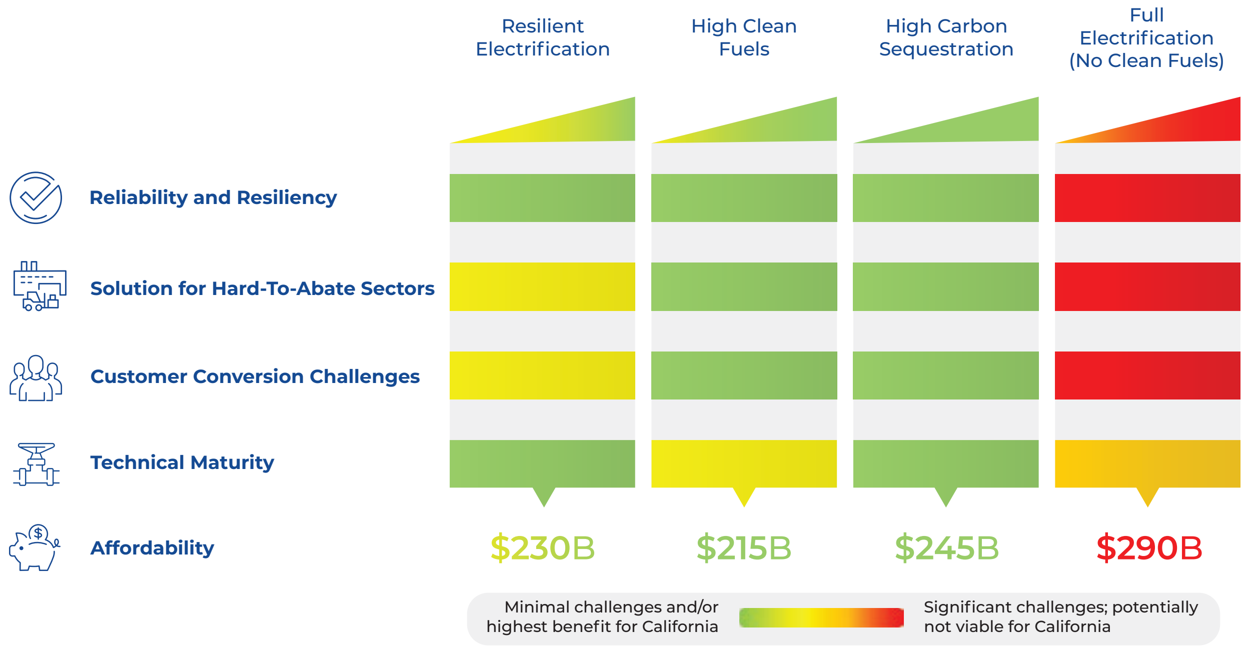
In common with other assessments of pathways to decarbonize energy systems, this study's conclusions are based upon analyses that inevitably involve unknowns. While the analysis of these scenarios is based on thorough modeling and assumptions, more will be learned as California proceeds towards implementation and execution along decarbonization pathways. As new learnings are revealed and uncertain assumptions are better understood, the implications of these scenarios could evolve.

[5] SoCalGas, "ASPIRE 2045: Sustainability and Climate Commitment to Net Zero," March 2021.
[6] National Oceanic and Atmospheric Administration, https://www.ncdc.noaa.gov/billions/events

Key findings of this analysis:

Scenarios resulting in the most successful[7] decarbonization highlight the importance of a clean fuels approach in reaching carbon neutrality. The three scenarios that performed best against the evaluation criteria express several key distinguishing sources of value and roles of a clean fuels network:

Exhibit ES.1: Assessment of scenarios along selected key criteria



The three scenarios featuring a clean fuels network are more affordable, resilient, and carry less technology risk than the "no fuels network" scenario. The presence of a clean fuels network minimizes challenges in and obstacles to California's energy transition. Based on the analysis herein, a clean fuels network is projected to save California energy customers between $45 billion and $75 billion over the course of the next 30 years in avoided costs that would otherwise be needed without a clean fuels network.[8]

Clean fuels are an important component of any solution to decarbonize hard-to-electrify parts of the California economy such as industry, heavy-duty transportation, and aviation.[9] Benefits include the relative ease of storing energy-dense molecules compared to electric battery storage based on current technology projections, and the specific end-use requirements such as high-grade heat in industry that is challenging to achieve without fuels.

---

[7]"Successful" is defined as meeting balanced goals of affordability, resiliency, minimizing customer conversion challenges, ability to solve for hard-to-abate sectors, and technical maturity.

[8]This corresponds to the difference in net present value (NPV) of costs between the No Fuels Network scenario and the other more plausible scenarios over the 2020-2050 period. This study estimates California's economy-wide cost to produce, deliver, and consume energy from 2020-2050. Costs vary depending on the demand side inputs and supply side assumptions and constraints applied to each scenario. Additional details can be found in the Appendix.

[9]Rocky Mountain Institute, "Hydrogen's Decarbonization Impact for Industry: Near-term challenges and long-term potential," January 2020, available at: https://rmi.org/wp-content/uploads/2020/01/hydrogen_insight_brief.pdf; US Department of Energy, Office of Energy Efficiency and Renewable Energy, "Sustainable Aviation Fuel: Review of Technical Pathways," September 2020, available at: https://www.energy.gov/sites/prod/files/2020/09/f78/beto-sust-aviation-fuel-sep-2020.pdf; Ogden, Joan M, "Prospects for Hydrogen in the Future Energy System," University of California, Davis, Institute of Transportation Studies, Research Report UCD-ITS-RR-18-07, March 2018, available at: https://escholarship.org/uc/item/52s28641.

Under the most cost-effective scenarios modeled, clean thermal generation (i.e., hydrogen[10] combustion, biogas combustion, and methane combustion with carbon capture) is critical to maintain the affordability and resilience of the electricity network in a net-zero future. A clean fuels network to support clean thermal generation is the most economical solution modeled.

A clean fuels network supports decarbonization and electrification. Clean fuels and a clean fuels network fill several valuable roles in a decarbonized world. As California decarbonizes and electrifies, a clean fuels network will play an increasingly vital role in providing reliability, resource adequacy, resiliency and peaking capacity. In the most feasible scenarios, renewable generation dramatically increases, resulting in a commensurate decline of annual gas demand for thermal electric generation; however, gas thermal electric capacity remains the same or even increases to provide reliability, as does peak hour demand by thermal generators for fuel. For building decarbonization, electrification and clean fuels (e.g., biofuels) are assumed to varying extents in all scenarios addressed in this analysis. Electrification is presumed to be a cost-effective decarbonization lever and all scenarios assume between 55-95% of building space heating stock is electrified by 2050. A clean fuels network plays several vital roles for buildings including leveraging its reliable underground network to enable resiliency, providing diversification, providing "peaking capacity" in constrained zones, and offering a decarbonization pathway for customer end uses.

A clean fuels network supports "hard-to-abate" sectors. Across all tenable scenarios, a clean fuels network enables full decarbonization by delivering fuels to the hardest-to-abate sectors (e.g., industrials with particular heat processing needs), and it is leveraged to transport new clean fuels such as hydrogen to meet the expected increased demand for new end-users (e.g., hydrogen-fueled electric vehicles).

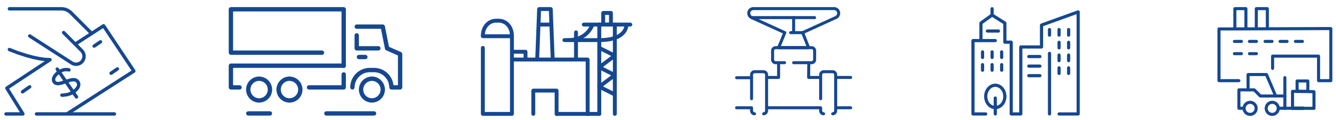
Pipelines to enable carbon management are a critical part of a clean fuels network that advances California's carbon neutrality goals. All the better performing scenarios highlighted a need for carbon capture and utilization, sequestration, or both. The scale of carbon management ranges from 15-30 MMT of CO2 that is captured and either used (e.g., through "power-to-liquids" conversion) or sequestered.

Diversification lowers risk. Pursuing a diverse set of decarbonization levers reduces the risk of over-dependence on any one technology or set of technologies. Continuing to scale different technologies and decarbonization tools can de-risk California's decarbonization pathways in an uncertain environment.

[10] References to and use of the word "hydrogen" in this study refer to net-zero emissions hydrogen; green or blue whereby carbon emissions are captured and stored.

Exhibit ES.2: Core Pillars of a Clean Fuels Network

Fuels diversification to create optionality to help de-risk decarbonization



Several public studies have highlighted the importance of clean fuels and a supporting clean fuels network. Those include studies from National Renewable Energy Laboratory (NREL) done for the Los Angeles Department of Water and Power (LADWP)[11] , the Rocky Mountain Institute's paper titled "Hydrogen's Decarbonization Impact for Industry"[12], the Columbia Center on Global Energy Policy study titled, "Investing in the US Natural Gas Pipeline System to Support Net-Zero Targets"[13] the American Gas Association's paper titled "Building a Resilient Energy Future: How the Gas System Contributes to US Energy System Resilience"[14], and the Hydrogen Council's main publications[15],[16] among others. These studies are briefly discussed in the body of this report.

---

[11]Cochran et al., "LA100: The Los Angeles 100% Renewable Energy Study," National Renewable Energy Laboratory, NREL/TP-6A20-79444, March 2021, available at: https://maps.nrel.gov/la100/report.

[12]Rocky Mountain Institute, "Hydrogen's Decarbonization Impact for Industry: Near-term challenges and long-term potential," January 2020, available at: https://rmi.org/wp-content/uploads/2020/01/hydrogen_insight_brief.pdf.

[13]Blanton et al., "Investing in the US Natural Gas Pipeline System to Support Net-Zero Targets," Columbia Center on Global Energy Policy, April 2021, available at:
https://www.energypolicy.columbia.edu/research/report/investing-us-natural-gas-pipeline-system-support-net-zero-targets.

[14]American Gas Foundation, "Building a Resilient Energy Future: How the Gas System Contributes to US Energy System Resilience," January 2021, available at: https://gasfoundation.org/wp-content/uploads/2021/01/Building-a-Resilient-Energy-Future-Full-Report_FINAL_1.13.21.pdf.

[15]Hydrogen Council, "Path to hydrogen competitiveness: A cost perspective," January 20, 2020, available at: https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf.

[16]Hydrogen Council, "Hydrogen Insights: A perspective on hydrogen investment, market development and cost competitiveness," February 2021, available at: https://hydrogencouncil.com/wp-content/uploads/2021/02/Hydrogen-Insights-2021-Report.pdf.

A clean fuels network can take significant advantage of a re-purposed infrastructure that offers an efficient means of transporting the significant volumes of clean fuels needed in the most tenable scenarios:

- **California could use existing infrastructure to accelerate clean fuels adoption.** Biogas, synthetic natural gas, and hydrogen blending all provide tools to achieve decarbonization goals without major changes in infrastructure. Some clean fuels such as biogas and synthetic natural gas are "drop-in fuels" which, when processed to meet gas quality standards, can be immediately used wherever traditional natural gas is used today. These zero- or even negative-carbon fuels could therefore be transported by today's infrastructure. International studies performed on pipelines and related infrastructure show that hydrogen can be blended in limited amounts (e.g., 20% by volume) into existing natural gas pipelines. Furthermore, much of today's infrastructure, including rights of way, can be repurposed to be dedicated to hydrogen. For example, 69% of the pipelines needed to build a European Hydrogen Backbone could come from re-purposing existing natural gas pipelines.[17]

- **A dedicated hydrogen delivery infrastructure can be the most efficient way to deliver pure hydrogen for specific end-uses:** A dedicated hydrogen transportation network is a cost-effective means for delivering hydrogen at scale to high volume end-uses, such as industrial customers and transportation hubs (e.g., ports and airports).

- **Carbon management transportation:** Studies have found carbon capture, utilization, and storage to be essential to reaching net-zero energy systems[18]; and that specific end-uses -- such as cement – can rely on carbon capture as the most economic method of decarbonization. The carbon from these point sources that is not co-located with a utilization or sequestration site will need to be transported. CO2 pipelines are the most cost-effective way to transport CO2 at scale over long distances.

While the benefits of a clean fuels approach are clear relative to modeled alternatives, significant investment with the right capabilities, and likely market transformation, are needed:

- **Achieving the public benefits of clean fuels and clean fuels infrastructure will require significant investment through 2050.[19]** The most tenable scenarios highlight the value of a clean fuels network in helping achieve the most affordable and resilient decarbonization pathways. Projected potential clean fuels investment needed through 2050 includes:

---

[17]Gas for Climate: A path to 2050, "Extending the European Hydrogen Backbone: A European Hydrogen Infrastructure Vision Covering 21 Countries," p. 11, April 2021, available at: https://gasforclimate2050.eu/wp-content/uploads/2021/06/European-Hydrogen-Backbone_April-2021_V3.pdf.

[18]Princeton University, "Net-Zero America: Potential Pathways, Infrastructure, and Impacts," December 15, 2020, available at: https://acee.princeton.edu/rapidswitch/projects/net-zero-america-project/; AGU Advances, "Carbon-Neutral Pathways for the United," January 14, 2021, available at: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2020AV000284.

[19]Based on high level estimates for utility and market participant investment in SoCalGas territory based on the high-carbon-sequestration scenario.

• ~$10 billion for hydrogen production
• ~$35 billion for upgrades to current systems for hydrogen blending and development of new hydrogen pipelines and storage
• ~$5 billion for developing carbon pipelines to transfer carbon from "source" to "sink"
• ~$10 billion to develop refueling stations for hydrogen vehicles and deployments of fuel cells (e.g., in wildfire zones) to drive critical resiliency needs
• This could be in addition to one-time costs and ongoing savings associated with decommissioning sections of the gas pipeline network where full electrification may occur.

Projected investments would occur across the energy supply chain within the SoCalGas service territory, potentially driven by a combination of utility and energy market participants.

Market transformation will be needed for California to successfully meet its decarbonization goals. Taking steps to have a clean fuels network in place in time to meet the levels of clean fuels and carbon management called for in the most tenable scenarios calls for rapidly scaling up activity today for several reasons, including: lead times to conduct piloting, testing and demonstration; providing adequate planning signals to end-use customers (e.g., industry, transportation); and facilitating more rapid scaling of hydrogen production.

California can be a clean fuels leader in North America if there is public and private sector support to accelerate the market transformation; this is similar to the market transformation of renewables on the electric grid stimulated by California over the past 20 years. Investments are needed to drive critical clean fuel technologies down the cost curve, pilot their use in California's specific context, and build the supporting infrastructure to deliver these fuels.

Current cost allocation and ratemaking mechanisms should be re-aligned to support the evolution to a clean fuels network. This would entail equitably allocating costs to beneficiaries of the network and help mitigate the risk of some customers facing rising rates in the future. Today's natural gas transmission and distribution providers are compensated primarily by residential and small business customers who pay largely based upon a volumetric rate. While a clean fuels network could potentially continue to meet residential and small business customer demand for natural gas, total demand is anticipated to decrease over time across all of the more affordable scenarios, driven by both building electrification and reduced use of natural gas power generators. Conversely, increasing electrification amplifies the need for and value of peak hourly and firm dispatchable energy delivery provided by the gas grid today, and a clean fuels network in the future. Thus, the value of gas transportation and delivery services is expected to transition to providing benefit for electric customers to meet evolving peak, reliability and resiliency needs amplified by increasing renewable deployment and electrification in homes and businesses. Updated cost allocation across all beneficiaries would more equitably spread costs and mitigate potentially increasing rates to remaining residential and small business customers.

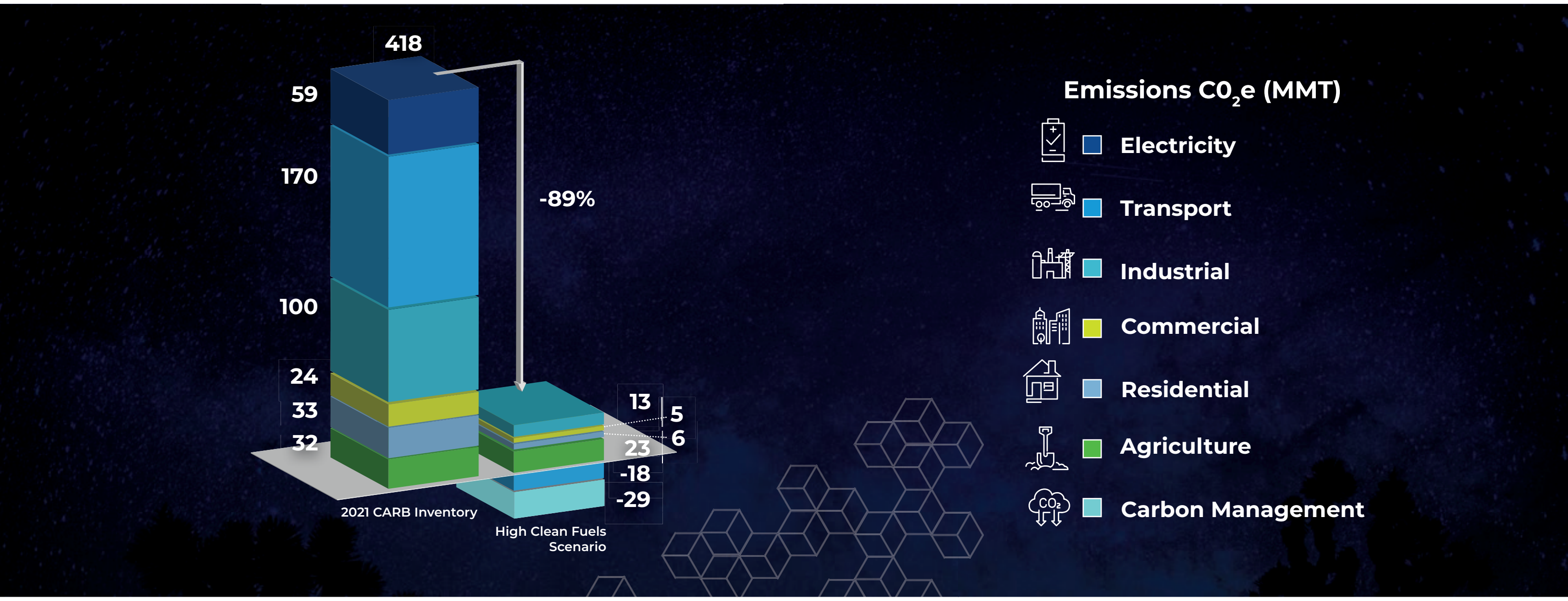
The transition to a net-zero carbon California and a supporting clean fuels network requires further analysis, research, piloting and testing to progress towards a reliable and sustainable transition. Additional research, analysis, and pilot design can address many unanswered questions and thus reduce the risk of potential negative consequences. For example:

- Testing carbon capture and sequestration (CCS) at scale in California's reservoirs[20]
- Expanded testing of blending hydrogen in existing infrastructure
- Understanding the impact of blended hydrogen more closely on California customers' equipment, and where necessary how certain customers would transition to "hydrogen-ready" equipment
- Assessing prospective pathways for scaling up electrification, thoroughly evaluating potential areas for decommissioning of the gas grid and planning for any needed transition ahead of time.

SoCalGas and regulated gas distribution utilities can provide several important capabilities to help drive the creation and operation of a clean fuels ecosystem. At present, SoCalGas can leverage its transmission and delivery infrastructure to continue to transport "drop-in-fuels" such as biogas and synthetic natural gas as well as blend-in hydrogen. Furthermore, SoCalGas has a long history of successfully engineering, funding, building, and operating critical energy infrastructure in California. SoCalGas can use these capabilities to support the development and operation of a clean fuels ecosystem to assist California in achieving its net-zero goals.

[20]Peridas, G., "Permitting Carbon Capture & Storage Projects in California," Lawrence Livermore National Laboratory, LLNL-TR-817425, February 2021, available at: https://www-gs.llnl.gov/content/assets/docs/energy/CA_CCS_PermittingReport.pdf (noting that California will need to deploy CCS to fully decarbonize and providing prospective pathways for permitting and deployment).

Exhibit ES.3 Modeled 2045 California Emissions Reductions by Segment – High Clean Fuels Scenario[21]:



Attaining the public benefits provided by a clean fuels ecosystem to achieve climate goals requires supportive statewide policies to help moderate costs, reduce risk, channel capital, and maintain a reliable, resilient energy system:

- **Reducing energy customer emissions will require continued investment in the safety and reliability of the existing infrastructure to transport the low carbon fuels needed to meet reduction targets and get to net-zero.** Many energy customers will need clean fuels, such as biogas and hydrogen, to decarbonize and achieve emissions targets and limits. Transportation and distribution infrastructure must be able to deliver the energy needed by those that will continue to rely on gaseous fuels. State policies should support the needed investment including by leveraging the emissions reduction capabilities of the gas system.

[21] - "Carbon Management" refers to strategies for capturing and storing carbon, including sequestration in natural and working lands.

- **A comprehensive statewide strategy is needed to supply customers with the clean, renewable and/or carbon-neutral fuels they need to reduce their respective emissions.** Achieving net-zero emissions will require scaling up production and supply of clean fuels such as hydrogen and biomethane. As discussed below, numerous countries around the globe recognize the value of a clean fuels network and are advancing supportive and transformative policies. Policies to enable scaleup and investment for sufficient supplies of clean fuels at the needed levels and a rate of deployment, such as a clean fuels procurement standard, are necessary to accelerate use and availability.

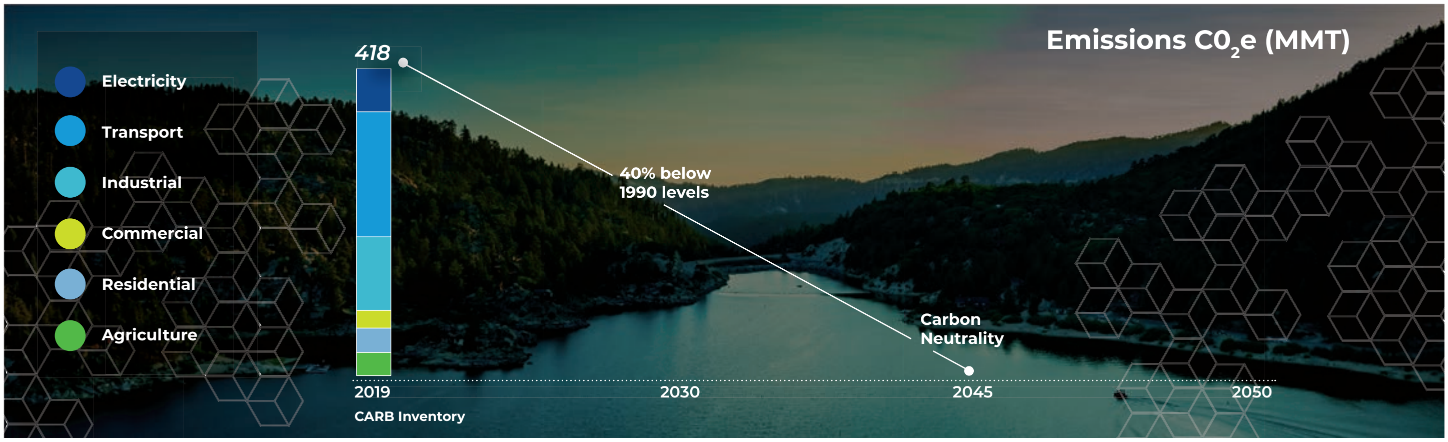
- **Planning policies focused on an integrated energy system are needed to manage affordability and resiliency.** Energy planning and policies should recognize that electricity, traditional gas and clean fuels complement each other for achieving decarbonization requirements. Thus, infrastructure and resource adequacy planning should take an integrated energy system approach to seek achievement of the greatest public interest benefits.

1.1 The Aspiration

California has set a goal of carbon neutrality by 2045[22] as it accelerates its response to climate change. SoCalGas and other state utilities play an essential role in the collective effort to address the challenges of climate change and to achieve California's carbon neutrality goals. In line with the need for action and SoCalGas's aspiration to be at the forefront of the energy transition, SoCalGas recently established a goal to achieve net-zero carbon emissions by 2045 for scope 1, 2, and 3 emissions, aligned with the state's climate goals.[23]

Driving to full carbon neutrality across all of California's economy introduces complex challenges. One example: identifying decarbonization pathways that are applicable to all sectors. This can be particularly challenging for sectors such as heavy industry, heavy-duty transportation, aviation, and shipping given their particular energy needs and the need for coordination across state lines. A second challenge centers around identifying reliable firm capacity to support increasing weather-dependent renewable energy deployment and electric load growth.

Exhibit 1.1 California Emissions and Targets



It will be crucial to address these and similar challenges while striving for reliability and resiliency in the energy system to withstand more frequent and more extreme weather events, wildfires, and droughts. The necessary response to the challenges of a changing climate will have profound effects on the way energy is produced, transported, and consumed. The ultimate goal for addressing these challenges is to provide clean, resilient, affordable, and safe energy for California.

This report lays out the potential role that clean fuels and a supporting clean fuels network play in helping to achieve this ultimate goal and overcoming some of the challenges in achieving carbon neutrality.[24] Clean fuels are defined in this analysis as alternative fuels that have a net-zero carbon footprint. Hydrogen, biogas, synthetic natural gas, biofuels and several synthetic gaseous and liquid fuels fall in that category as long as their production process and their end use do not lead to net-positive CO2 emissions:

[22]State of California, Executive Department, "Executive Order B-55-18 to Achieve Carbon Neutrality," September 10, 2018, available at: https://www.ca.gov/archive/gov39/wp-content/uploads/2018/09/9.10.18-Executive-Order.pdf.
[23]SoCalGas, "ASPIRE 2045: Sustainability and Climate Commitment to Net Zero," March 2021, available at: https://www.socalgas.com/sites/default/files/2021-03/SoCalGas_Climate_Commitment.pdf.
[24]This study provides an in-depth assessment of the role a clean fuels network could play to enable a decarbonized California with focus on the benefits from and approaches for scaling up clean fuels supply and infrastructure. It does not go into equivalent depth on non-fuels related infrastructure opportunities and deployment.

- **Carbon-neutral hydrogen** is defined herein as hydrogen produced with a net-zero carbon footprint. Green hydrogen is considered carbon neutral as it is produced through electrolysis from renewable electricity, a process that splits water into hydrogen and oxygen molecules through the passage of electric current and produces no CO2 emissions. Blue hydrogen, on the other hand, is produced from fossil methane (natural gas) in a reformation reaction with capture of CO2 emitted in the process. For blue hydrogen to be considered carbon-neutral, the associated carbon footprint along the value chain of fossil methane production and transportation as well as non-captured emissions in the hydrogen production process have to be offset.

- **Biogas** is comprised of non-fossil methane molecules, and can be produced from different feedstocks, including waste gases (such as those emitted from landfills, wastewater treatment plants, and dairy farms), and wet biomass (such as algae or forest residue).

- **Synthetic natural gas** can be produced by combining hydrogen and CO2 captured from any carbon emitting process, in a process called methanation. As long as the hydrogen is carbon-neutral and the captured carbon is from the atmosphere (via biomass or direct air capture), the produced natural gas is carbon neutral since its combustion returns the previously captured carbon to the atmosphere with no net increase in CO2 concentrations.

- **Biofuels** are fuels produced from biomass and could be gaseous or liquid, although most common biofuels are liquid, such as bioethanol and biodiesel. Their carbon footprint may vary widely depending on upstream emissions but can even be carbon negative.

- **Synthetic liquid fuels** can be produced through clean routes by using carbon neutral hydrogen and combining it with net-neutral CO2 in processes that result in longer hydrocarbon chains. Fischer-Tropsch is one common synthesis method.[25]

To move these fuels and their precursors (including CO2) from their sources to end-uses so that supply can meet demand, a clean fuels network is required. This network can be comprised of elements for capture, transportation, storage, and final delivery of molecules, such as pipelines, trucks, storage tanks/caverns/reservoirs, fuel cells, refueling stations, etc. (see Chapter 2 for more detail). Across the globe, governments, utilities, research institutions and businesses have recognized the value a clean fuels network provides for the energy transition.[26]

---

[25] The Fischer-Tropsch process is a catalytic chemical reaction in which carbon monoxide (CO) and hydrogen (H2) in the syngas are converted into hydrocarbons.

[26] For example, Germany and Chile are both countries with a National Hydrogen strategy. (German Federal Ministry for Economic Affairs and Energy, "National Hydrogen Strategy," October 2020, available at: https://www.bmwi.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.pdf?__blob=publicationFile&v=6; Chile Ministerio de Energia, "The National Green Hydrogen Strategy of Chile," March 2021, available at: https://fch.cl/wp-content/uploads/2021/03/20210309-Chilean-National-Green-H2-Strategy.pdf.) Both countries have signed an accord to boost international hydrogen cooperation to further both their national hydrogen strategies. (Reuters, "Germany and Chile sign accord to boost hydrogen cooperation," June 29, 2021, available at: https://www.reuters.com/business/energy/germany-chile-sign-accord-boost-hydrogen-cooperation-2021-06-29/.) The US Department of Energy's National Renewable Energy Lab (NREL) supported the Joint Institute for Strategic Energy Analysis on a report on the role of natural gas in deep decarbonization. (NREL, "Considering the Role of Natural Gas in the Deep Decarbonization of the U.S. Electricity Sector, Natural Gas and the Evolving U.S. Power Sector Monograph Series: Number 2," February 2016, available at: https://www.nrel.gov/docs/fy16osti/64654.pdf.) Globally, businesses as part of the Hydrogen Council are exploring the role of hydrogen in the energy transition. (Hydrogen Council, "Hydrogen Scaling Up: A Sustainable Pathway for the Global Energy Transition," November 2017, available at: https://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-scalingup-Hydrogen-Council.pdf.)

1.2 The Inspiration

While California has its unique context, it can look to countries that have already embarked on similar decarbonization journeys to understand the role clean fuels and a clean fuels network can play in achieving deep decarbonization.

There are three key challenges that other regions tackling climate change are also working to solve: (1) transitioning to a decarbonized energy system while maintaining system resiliency and affordability; (2) decarbonizing hard-to-abate sectors such as industry and heavy-duty transportation; and (3) reducing risk along the transition to full decarbonization as technologies mature and policies evolve. The analyses supporting this study, and learnings from around the world, demonstrate that a clean fuels network is important to solve these challenges.

Germany is a global leader in decarbonization, quickly ramping renewable capacity in the 2000s to 2010s. As Germany has pushed further towards decarbonization, it has realized the need for clean fuels. Germany is making strides in developing a clean fuels infrastructure, initiating a National Hydrogen Strategy which includes a $10 billion stimulus package to ramp up clean fuels technologies and international partnerships. With a forecasted hydrogen demand of approximately 100 TWh by 2030, up to 5 GW of total electrolyzer capacity is to be built by 2030. Germany's National Hydrogen Strategy highlights the use of green hydrogen to replace grey hydrogen in the steel, cement, and chemical industries as a main goal.[27] To deliver this hydrogen from production sites to demand, the German gas Transmission System Operators (TSOs), have presented a map of a 5,900 km of hydrogen pipeline network, 90% of it envisioned to be developed leveraging existing natural gas pipelines. The TSOs plan to build out 1,200 km by 2030, with 1,100 km of this built from repurposed natural gas pipelines.[28]

Japan's Green Growth Strategy includes hydrogen and clean fuels more broadly to help the country reach a carbon-neutral future. Japan is committing $19 billion to support green technologies, including the development of technology that uses hydrogen as a fuel for thermal power generation, while also anticipating widespread use of hydrogen for transportation and industry. Japan is pioneering the production of liquified hydrogen and the development of a global hydrogen supply chain, starting with routes between Australia and Japan.[29]

[27]German Federal Ministry for Economic Affairs and Energy, "National Hydrogen Strategy," pp. 9-10, October 2020, available at: https://www.bmwi.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.pdf?__blob=publicationFile&v=6.
[28]FNB Gas, "Transmission system operators publish H2 starter network 2030," May 14, 2020.
[29]Japanese Ministry of Economy, Trade, and Industry, "Green Growth Strategy Through Achieving Carbon Neutrality in 2050," December 2020, available at: https://www.meti.go.jp/english/press/2020/1225_001.html.

The United Kingdom set a target of net-zero greenhouse gas emissions for all sectors by 2050. Its recently released "Industrial Decarbonization Strategy" specifically explores how to enable decarbonization of industry, while maintaining a competitive industrial sector. The UK assessment concludes that several different technologies will be required to enable full industrial decarbonization, including low carbon hydrogen, carbon capture utilization and storage (CCUS), and electrification, along with energy efficiency.[30] The UK Hydrogen Strategy establishes a target of 5GW of low carbon hydrogen production by 2030 that could deliver total emissions savings of approximately 41MtCO2e between 2023 and 2032. Beyond the industrial sector, the UK is exploring hydrogen for buildings and transportation, while supporting domestic production of low carbon hydrogen.[31] The UK's work on hydrogen blending and hydrogen pipelines is described in Chapter 4.

The European Hydrogen Backbone (EHB) Initiative, a consortium of European gas TSOs, analyzed the need for hydrogen infrastructure in Europe to support the EU's climate goals, and assessed the potential to retrofit existing pipeline infrastructure for hydrogen. The EHB's latest report, released April 2021, highlights the need for almost 40,000 km of dedicated hydrogen pipeline by 2040; the analysis estimates that approximately 70% of that pipeline can leverage repurposed existing natural gas infrastructure.

The EHB concludes that this pipeline can connect industrial clusters and connect sources of hydrogen supply to hydrogen demand centers across the EU.[32] Leaders in California are evaluating similar approaches to full decarbonization. For example, Los Angeles Department of Water and Power (LADWP) has expressed the need to include hydrogen in its 100% renewable electricity plans. In light of this, LADWP is funding the conversion of the coal-fired Intermountain Power Plant to run on a blend of hydrogen and natural gas in the near-term, and ultimately convert it to a 100% green hydrogen-powered thermal plant.[33]

These global case studies demonstrate that, as countries analyze pathways and take on the specific challenges of decarbonizing hard-to-abate sectors and maintaining system resiliency with renewables, clean fuels are a major part of the solution. As seen from the examples in Germany, Japan, the UK, the EU, and others, many regions recognize this need and are already committing substantial capital towards clean fuels production and delivery.

---

[30] Government of the United Kingdom, Secretary of State for Business, Energy & Industrial Strategy, "Industrial Decarbonisation Strategy," March 2021, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/970229/Industrial_Decarbonisation_Strategy_March_2021.pdf.

[31] Government of the United Kingdom, "The Ten Point Plan for a Green Industrial Revolution: Building back better, supporting green jobs, and accelerating our path to net zero," pp. 10-11, November 2020, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/936567/10_POINT_PLAN_BOOKLET.pdf.

[32] Gas for Climate 2050, "Extending the European Hydrogen Backbone," April 2021, available at: https://gasforclimate2050.eu/wp-content/uploads/2021/06/European-Hydrogen-Backbone_April-2021_V3.pdf. Assumptions from the EHB's 2020 report are a basis for the clean fuels infrastructure sizing assumptions used in this analysis, as explained in the technical appendices. (See Appendix B).

[33] Los Angeles Department of Water and Power, "The Intermountain Power Project & Green Hydrogen," Presentation, November 13, 2020, available at: https://ww2.arb.ca.gov/sites/default/files/2020-07/ladwp_cn_fuels_infra_july2020.pdf.

Furthermore, prominent public studies highlight the importance of clean fuels and a supporting clean fuels network. The Los Angeles 100% Renewable Energy Study by LADWP and NREL ("LA100") expresses the need for "renewably produced and storable fuels" to maintain reliability in the power sector. The study shows that pathways to 100% decarbonization diverge on how to meet the last 10%–20% of energy demand that cannot be met by existing renewable and conventional storage technologies, and that the main solution currently available to maintain a reliable system that can withstand extreme events is to store and use renewable fuels, with hydrogen and biofuels being the key alternatives.[34]

Likewise, a recent published study by the Environmental Defense Fund and Clean Air Task Force concludes that affordable and reliable decarbonization in California requires "firm clean power" comprised of "carbon-free power sources that can be relied on whenever needed, for as long as they are needed."[35] Firm clean power resources, according to the study, include hydrogen made without life-cycle emissions, as well as geothermal, next generation nuclear and net carbon neutral natural gas-fired power plants equipped with CCS. The study explains that "clean firm technologies complement renewable energy to ensure reliability while keeping whole system costs low. We also find that having more than one clean firm power option helps reduce costs even further."[36]

An in-depth decarbonization analysis by the Columbia University Center on Global Energy Policy asserts that "for many of the needs natural gas currently meets, the eventual replacement may be zero-carbon gaseous fuels (e.g., hydrogen, biogas)."[37] It notes that "[t]hese fuels may play a significant role in supporting reliability and making the energy transition more affordable—but they, too, will require a pipeline network for efficient delivery to markets and end users." The analysis expresses several salient observations and conclusions regarding the complementary relationship between gas infrastructure and electrification explaining that:

- Retrofitting and otherwise improving the existing pipeline system is not a choice between natural gas and electrification or between fossil fuels and zero-carbon fuels
- Investments in existing infrastructure can support a pathway toward wider storage and delivery of cleaner and increasingly low-carbon gases while lowering the overall cost of the transition and ensuring reliability across the energy system
- In the same way that the electric grid allows for increasingly low-carbon electrons to be transported, the natural gas grid should be viewed as a way to enable increasingly low-carbon molecules to be transported.

[34] Cochran et al., "LA100: The Los Angeles 100% Renewable Energy Study," National Renewable Energy Laboratory, NREL/TP-6A20-79444, Executive Summary, p. 14, available at: https://maps.nrel.gov/la100/report.
[35] Long et al., "Clean Firm Power is the Key to California's Carbon-Free Energy Future," Issues in Science and Technology, March 24, 2021, available at: https://issues.org/california-decarbonizing-power-wind-solar-nuclear-gas/.
[36] Ibid.
[37] Blanton et al., "Investing in the US Natural Gas Pipeline System to Support Net-Zero Targets," Columbia Center on Global Energy Policy, p. 6, April 2021, available at: https://www.energypolicy.columbia.edu/sites/default/files/file-uploads/GasPipelines_CGEP_Report_081721.pdf.

In effect, the Columbia study explains that scale-up efforts supported by policy initiatives for decarbonizing fuels can and should follow the successful pathway for developing and scaling up approaches and tools for decarbonizing the electric grid, which have been underway since the turn of the century.

The American Gas Foundation highlights the resiliency value of the gas system, emphasizing that it is important to differentiate between the gas system, which is the pipeline and storage infrastructure, and the natural gas molecules that flow through it. Today, the gas system is mostly used to transport traditional gas, but it can be leveraged to transport clean fuels. An underground system, less exposed to physical disruption, has greater inherent operational flexibility and resiliency. Therefore, the gas network provides a form of resilient energy storage, with long duration and seasonal storage capabilities.[38]

The Rocky Mountain Institute highlights the critical role hydrogen plays in decarbonizing industry: "When considering what a global energy system on a 1.5°C or 2°C pathway will look like by 2050, hydrogen consistently plays a critical role as an energy carrier. The industrial processes used in the production of things like steel, cement, glass, and chemicals all require high temperature heat. For these hard-to-abate sectors, there is essentially no way to reach net-zero emissions at the scale required without using hydrogen."[39]

The International Renewable Energy Agency, the Energy Transitions Commission, and the Hydrogen Council expect that by 2050 as much as 18% of final energy consumption will be provided by hydrogen.[40] [41] [42] Given the high potential for CO2 abatement and the large-scale offtakers such as industrial steel producers and shipping companies, demand can be achieved at scale and significantly accelerate the learning curve for electrolysis, bringing technology costs down.

With the trend of declining costs of carbon neutral hydrogen production over the next decade and beyond, the Hydrogen Council highlighted the significant potential of carbon neutral hydrogen to decarbonize over 22 end-uses including industry, heavy duty-trucking, and blending of hydrogen into existing gas pipelines. The competitiveness of green hydrogen would stem from a total cost of ownership (TCO) perspective as well as other drivers such as environmental regulations, customer demand, and lower cost of capital for Environmental Social and Governance (ESG)-compliant investments.

[39]Rocky Mountain Institute, "Hydrogen's Decarbonization Impact for Industry: Near-term challenges and long-term potential," January 2020, available at: https://rmi.org/wp-content/uploads/2020/01/hydrogen_insight_brief.pdf.
[40]International Renewable Energy Agency, "Global Energy Transformation: A Roadmap to 2050," 2019, available at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Apr/IRENA_Global_Energy_Transformation_2019.pdf.
[41]Hydrogen Council, "Hydrogen Scaling Up: A Sustainable Pathway for the Global Energy Transition," p. 21, November 2017, available at: https://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-scaling-up-Hydrogen-Council.pdf.
[42]Energy Transitions Commission, "Mission Possible: Reaching Net-Zero Carbon Emissions From Harder-to-Abate Sectors by Mid-Century," November 2018, available at: https://www.energy-transitions.org/publications/mission-possible/.
[43]Hydrogen Council, "Hydrogen Insights: A perspective on hydrogen investment, market development and cost competitiveness," pp. 26-40, February 2021, available at: https://hydrogencouncil.com/wp-content/uploads/2021/02/Hydrogen-Insights-2021-Report.pdf.

This study examines three key questions that need to be answered when evaluating the role of a clean fuels network in California's path to full decarbonization:

1. How can full carbon neutrality be achieved, and what are important considerations in defining preferred pathways?
2. What is the potential role of clean fuels and a clean fuels network?
3. How could a clean fuels network be established in California?

The next chapters address these critical questions. First, Chapter 2 details the study approach and modeling methodology and starts to lay out the important considerations of question 1. Chapter 3 presents the results of different modeled pathways and how they compare across important criteria and trade-offs. Chapters 4 and 5 present a more detailed view into what a clean fuels network would entail, and then discuss the value of clean fuels and of a clean fuels network in California's decarbonization effort. Chapter 6 considers what it would take to establish a clean fuels network in Southern California. Chapter 7 discusses the potential impacts of the network transition on residential and commercial customers, and Chapter 8 answers question 3 by laying out a high-level roadmap for SoCalGas's prospective role in establishing a clean fuels network in California.

2.1 Overall Methodology

California's target of carbon neutrality requires a new level of economy-wide systems modeling that tackles the complexity of 100% emissions reductions (as opposed to lower percentages which are less complex to model and achieve), enables cross-sector optimization coupling across electric, fuels and transport, and appropriately accounts for the cost and value of gas transmission and distribution infrastructures – which, as far as we are aware, has previously not been sufficiently analyzed.

The technical analyses described here are among the first of their kind and aim to model these system impacts, thus helping to account for the following critical features of a decarbonized California:

- **Full carbon neutrality:** The importance of a clean fuels network becomes clearer when solving for full carbon neutrality, not just carbon reduction. Overall, economy-wide models have a good grasp and tend to largely align on the initial set of levers critical to achieving deep levels of decarbonization (e.g., deploying significant renewables to decarbonize power generation, transitioning vehicle fleets off of petroleum products, etc.). However, achieving full carbon neutrality is significantly harder and the pathway is more uncertain. This less-understood, last 20% of emissions is where this analysis finds that fuels and carbon management play a particularly critical role.

- **Cross-sectoral integration:** This analysis comprehensively integrates the electricity, transport, and fuels systems – the full energy picture. It considers all energy demands including transportation, residential and commercial buildings, and the industrial sector. Fuel production (e.g., electrolysis/ power-to-gas) represents an opportunity not only as a large new flexible load to balance the electric system but also for displacing traditional fuels with decarbonized fuels, especially for hard-to-electrify segments of the transportation and industrial sectors.

- **Fuels system infrastructure and flexibility:** The complex transmission and distribution infrastructure needs for both the fuels and electric systems have historically not been assessed with sufficient granularity to quantify the real tradeoffs between moving electrons and moving clean molecules. Serving energy demand with weather-dependent renewables compels more granular analyses due to inherent renewable variability and the consequent need for flexibility, as currently provided by natural gas, as a system attribute. In order to better represent the costs of transitioning the fuels system, this work includes an initial analysis of the key investments needed to build out a clean fuels network: retrofits/upgrades required to accommodate higher hydrogen blends; infrastructure for hydrogen and carbon management; decommissioning with associated costs and savings, and downstream infrastructure requirements, such as fuel cells and hydrogen refueling stations.

- In addition, the analysis also considers necessary investments in electric transmission and distribution. Transmission of electricity is modeled to expand between regions by a maximum of ten times the present-day capacity over the study horizon. Expanding transmission has an associated cost per additional megawatt of capacity that is specific to each modeled transmission corridor. For distribution, the model tracks the peak load across sectors (including residential, commercial, and industrial), and scales capital costs for electric distribution according to load increase, while scaling operation and maintenance cost with the number of customers, at an assumed rate of 1% per year. This analysis, considering costs for both gas and electric infrastructure investments, provides insights into the opportunities and challenges, and also identifies areas where additional research and analysis is needed. Further details are included in the Appendix.

- **Assessing other critical factors:** Many factors beyond cost, such as customer impacts and system resiliency, are important to consider. Scenarios must be carefully defined and infrastructure costs appropriately included to also consider system designs that can deliver against a broader set of goals beyond reliability, decarbonization, and costs.

Accounting for the full complexity and costs of both the electric power and fuels infrastructures is critical to evaluate possible pathways and chart the most beneficial path forward more accurately. Joint planning and careful evaluation among and between electric power and fuel supply systems are needed to understand system and local resiliency and reliability tradeoffs. The methodology used in this study consisted of three major steps:

1. Defining modeling objectives and relevant decarbonization scenarios: the key objective was to test different pathways to reach California climate goals of carbon neutrality by 2045. The optimization was based on least cost, and then a qualitative analysis that layered in other important considerations beyond costs was conducted to compare scenarios more holistically.

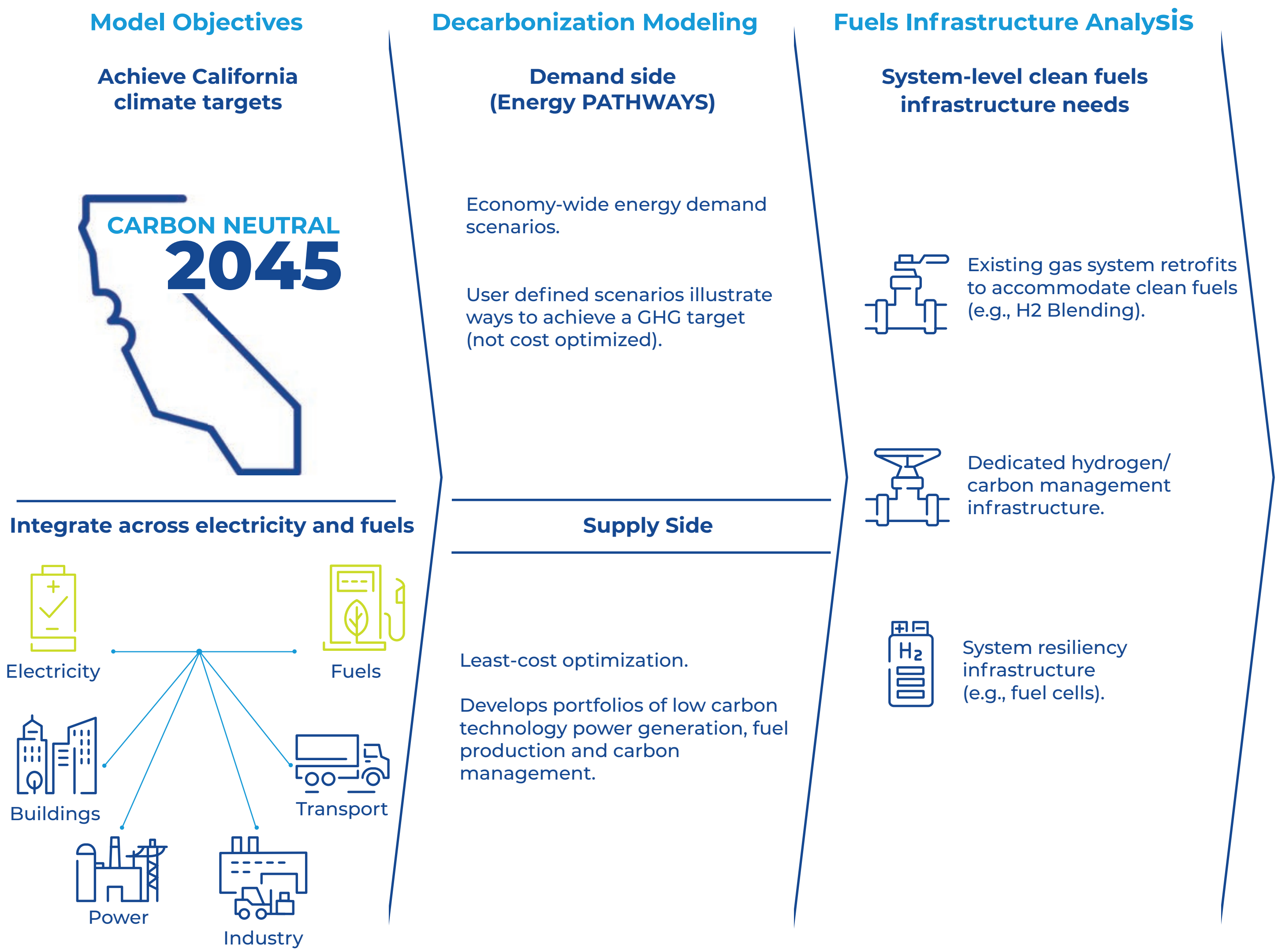
2. Conducting decarbonization modeling: this study is anchored on detailed decarbonization modeling that integrates demand-side end-use accounting and supply-side capacity expansion modeling, similar to the modeling done to support other California decarbonization studies, including those conducted by CARB, the CEC, and Southern California Edison. One key aspect of this modeling exercise is that all tested scenarios target 100% carbon neutrality. This effort did include some simplifying assumptions to account for emissions driven by non-energy and non-CO2 gases to attempt to align the modeling to achieve full GHG neutrality in California. However, there are significant studies and active ongoing scientific debate that could change the fundamentals of greenhouse gas emissions accounting of different technologies. Some examples of active scientific investigation include the true lifecycle emissions across all greenhouse gas sources (e.g., methane and CO2) of blue hydrogen, the amount of CO2 emissions that could occur from land-use accounting for climate driven events like drought and wild-fires in California, and the pace of phasing out “bunkering”[44] in sectors like aviation.

3. Conducting clean fuels infrastructure analysis: layered on top of the decarbonization analysis was a system-level analysis, conducted to determine the costs associated with different potential configurations of a clean fuels network. This exercise has not been previously done for California (or for other US jurisdictions) as far as we are aware.

[44]Bunkered aviation emissions include both international and inter-state flights that are not currently included as part of California's current inventory but for which jet-fuel sales occur within the state.

Through this multi-step process, the end-to-end analysis can inform potential implications for SoCalGas (Exhibit 2.1).

Exhibit 2.1 Overall study methodology



2.2 Decarbonization scenarios and assumptions

A path to full decarbonization will employ a range of different decarbonization levers, likely including a portfolio of solutions such as energy efficiency, renewable energy, electrification of transport and buildings, and clean fuels such as carbon-neutral hydrogen, biogas, and carbon capture, utilization, and sequestration.

To consider a realistic range of pathways, this analysis evaluates a set of scenarios that pull each of these levers to different degrees (Exhibit 2.2). The respective scenarios are designed to highlight distinctions for evaluation and provide for modeling conclusions that are directional in nature, as no scenario analysis can reliably predict and forecast all future developments. In this regard, they are best described as modeled "corner cases."[45] The four primary decarbonization corner cases evaluated are: High Clean fuels; High Carbon Sequestration; Resilient Electrification; and No Fuels Network. There are several largely common assumptions across all scenarios: All scenarios evaluated meet the target of carbon neutrality by 2045. All scenarios assume the same net-zero target across the west and, more broadly, throughout the country. U.S. wide net-zero targets are implemented to appropriately reflect competition for limited clean-fuel feedstocks within and outside of California. Scenario assumptions inside California are mirrored in the rest of the U.S.

- All scenarios except for the "No Fuels Network" (differences discussed below) assume that fuels are delivered to industrial customers for those uses that cannot be directly electrified.
- All scenarios except for the "No Fuels Network" (differences discussed below) assume that fuels consumed by electric generators are delivered by fuel networks.
- All scenarios assume that 85% of light duty vehicles sales are battery electric vehicles (BEVs) by 2035 and 15% of light duty vehicles sales by 2035 are fuel cell electric vehicles (FCEVs).
- Fuel cells or other fuel-flexible distributed generation to critical loads and vulnerable areas is assumed across all scenarios, excluding the "No Fuels Network" scenario.

Exhibit 2.2 Key assumption differences between scenarios

Key Assumptions		**Resilient Electrification**	**High Clean Fuels**	**High Carbon Sequestration**	**No Fuels Network**
Clean electricity and economy-wide GHG policy		SB100 and B-55-18; Carbon Neutrality by 2045			
Building electrification		100% sales of gas appliances electrified by 2035	50% sales of gas appliances electrified by 2035		100% sales of gas appliances electrified by 2035
H2 pipeline blending cap (by Volume)		5%	20%	No cap	N/A: No remaining pipelines
Transportation sales by 2035	**Light Duty**	BEV: 85% FCEV: 15%			
	Medium Duty	BEV: 90% FCEV: 10%	BEV: 50% FCEV: 50%		BEV: 90% FCEV: 10%
	Heavy Duty	Short-haul and transit buses BEV: 100% FCEV: 0% Long Haul: BEV: 50% FCEV 50%	Short-haul and transit buses BEV: 50% FCEV: 50% Long Haul: BEV: 0% FCEV 100%		Short-haul and transit buses BEV: 100% FCEV: 0% Long Haul: BEV: 50% FCEV 50%
Carbon sequestration allowed[1]		YES	NO	YES	NO

BEV: Battery Electric Vehicle **FCEV:** Fuel Cell Electric Vehicle **SB100:** The law passed by the California Legislature and signed by then-Governor Brown that established a landmark policy requiring renewable energy and zero-carbon resources to supply 100 percent of electric retail sales to end-use customers by 2045. **B-55-18:** An Executive Order issued by former Governor Brown that established the statewide goal to "achieve carbon neutrality as soon as possible, and no later than 2045, and maintain and achieve negative emissions thereafter."
1. Though carbon sequestration is disallowed in some scenarios, some form of "carbon management" appears in all scenarios; this includes carbon that is captured and utilized or sequestered as well as carbon used in products (asphalt, plastics) and carbon offset through bunkering of emissions from other sectors.

[45] As "corner cases" designed to highlight distinctions, the scenarios were designed to test end-points for key variables. Pushing key variables to their end-points allows the model to identify and understand the impacts of and trade-offs across those variables.

There are some key differences among the four primary decarbonization scenarios evaluated:

- **High Clean Fuels:** This scenario is designed to understand the impact of high reliance on clean fuels for decarbonization. It is assumed in this scenario that roughly 50% of medium-duty vehicles and 50% of short-haul heavy-duty vehicle sales are FCEVs by 2035 with the balance of sales being BEVs. In this case, 100% of long-haul, heavy-duty vehicles are assumed to be FCEVs. These assumptions are driven by a hypothesis of the cost competitiveness for FCEVs in heavy- and medium-duty vehicles[46] [47], and are aligned with decisions on model inputs, such as the ultimate cost of electrolyzers, that would make hydrogen and other clean fuels cheaper.

  Buildings are decarbonized through two means – clean fuels and electrification. This scenario assumes that sales of electric appliances and equipment represent 50% of residential and commercial appliance and equipment sales by 2035; remaining energy demand in buildings is decarbonized through clean fuels. The scenario is designed to maintain the gas distribution system in regions where full electrification and decommissioning is more difficult and/or less cost effective. Non-electrified buildings are served by clean fuels (primarily hydrogen and biogas).

  In this scenario, it was assumed that no major upgrades are required to the current gas transmission and delivery infrastructure to carry 20% of hydrogen by volume in its existing infrastructure and that hydrogen can be extracted from pipelines at this blend level to serve dedicated end-uses (e.g., refueling stations). While testing is needed to verify that is possible on California's gas system, pilots and research on other systems composed of similar pipeline make-up have shown that up to 20% hydrogen blending could be potentially be feasible.[48] The remaining 80% of pipeline gas is composed of primarily biogas with comparatively smaller amounts of traditional natural gas offset by bunkering and carbon utilization in durable products (i.e., bio-asphalts). This scenario also notably disallows any carbon sequestration – which encourages more synthesis of drop-in fuels using any captured carbon in the system (e.g., power-to-liquids).

- **High Carbon Sequestration:** This scenario is designed to understand the impact of ongoing use of traditional fuels with the emissions directly captured or indirectly offset by carbon capture and sequestration. This scenario carries many similarities to the high clean fuels scenarios with a few notable exceptions: pipelines primarily carry traditional natural gas, which is offset by direct air capture and carbon sequestration, with some biogas; annual carbon sequestration limits are informed by current industry understanding of CO2 injection rates; and dedicated hydrogen pipelines deliver carbon-neutral hydrogen to industrial customers as both fuel and feedstock, and as fuel to a subset of the transportation sector. This scenario assumed that existing natural gas pipelines have limited ability to blend hydrogen without significant retrofits needed. This was done to test how that would impact costs to deliver hydrogen to direct end-uses (e.g., refueling stations and industrial customers with hydrogen demand), and how hydrogen could be delivered to buildings. The scenario assumes that a "hydrogen hub" is built to deliver hydrogen to specific end-uses to avoid incurring costs associated with blending across the entire gas system.

[46] Hydrogen Council, "Path to hydrogen competitiveness: A cost perspective," pp. 32-42, January 20, 2020, available at: https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf
[47] Heid et al., "How hydrogen combustion engines can contribute to zero emissions," McKinsey & Company, June 25, 2021, available at: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/how-hydrogen-combustion-engines-can-contribute-to-zero-emissions.
[48] Gas Technology Institute, "Review Studies of Hydrogen Use in Natural Gas Distribution Systems," Prepared for NREL, p. viii, October 2010, available at: https://www.nrel.gov/docs/fy13osti/51995.pdf (Appendix A to Melaina, M.W., "Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues," March 2013)

- **Resilient Electrification:** This scenario is designed to test the potential of electrification primarily in the buildings sector with a fuels backbone still in place to serve harder to electrify end-uses: generators, industrial, and transportation. It is assumed in this scenario that roughly 90% of medium-duty vehicles, 100% of short-haul heavy-duty vehicle sales, and 50% of long-haul, heavy-duty vehicles are BEVs by 2035, with the balance of sales being FCEVs. Buildings are decarbonized primarily through electrification. This scenario assumes the vast majority of residential and commercial buildings can feasibly and cost effectively electrify, with 100% new appliance and equipment sales electric by 2035, resulting in approximately 95% of building space and heating stock being fully electrified at the end of the study period.

  While significant portions of the gas distribution system could be decommissioned as a result, this scenario is designed with a portion of the distribution system remaining in operation to maintain or increase reliability and resiliency to disruptions on the electric power grid, on the premise that customers will continue to expect energy services to be enhanced over time and operation of the electric system will become increasingly complex (e.g., increasing incidences of extreme weather and wildfires). Example infrastructure includes fuel cells or other fuel-flexible distributed generation that provide resiliency to urban centers like Los Angeles or to communities in higher wildfire risk zones. In this scenario, dedicated hydrogen pipelines would deliver carbon-neutral hydrogen as a feedstock to industry and as fuel to long-haul heavy-duty transportation.

  This scenario assumed that existing natural gas pipelines have limited ability to blend hydrogen without significant retrofits needed. This was done to test how that would impact costs needed to deliver hydrogen to direct end-uses (e.g., hydrogen refueling stations and industrial customers with hydrogen demand). If the analysis were to instead assume that existing natural gas pipelines could accommodate up to 20% hydrogen with minimal retrofits – as is done in the High Clean Fuels case -- and that hydrogen could be cost effectively extracted for dedicated use cases, the difference in NPV for the total system costs over the period of 2020-2050 could be on the order of magnitude of ~$10-20 billion.

- **No Fuels Network:** To quantify the value a clean fuels network could provide, this scenario contemplates a fully decarbonized California without a fuels network and without gas-powered thermal generation. The key assumption is that the fuels network would be gradually and fully decommissioned and all gas plants would be retired. The assumptions in this scenario are similar to Resilient Electrification with a few very important differences, including: buildings are assumed to be fully electrified; heavy-duty transport and industry are assumed to rely on fuels trucked in or produced on-site; and battery storage, including long-duration battery storage, is needed to provide grid reliability instead of thermal generators using fuels. Furthermore, there is no fuels backbone.

Key scenario assumptions are listed in Exhibit 2.2. A more detailed view is provided in the Appendix, Table A-1. Where possible, assumptions were sourced from publicly available data sets by business development, strategy, and engineering experts at SoCalGas. Some assumptions were provided or informed by internal SoCalGas experts in instances where publicly available data sets did not exist or where SoCalGas experts had more applicable data (e.g., the costs of developing or retrofitting pipelines in Southern California).

While the analysis of these scenarios is based on thorough modeling and assumptions, more will be learned as California proceeds towards implementation and execution along decarbonization pathways. As new learnings are revealed and uncertain assumptions are better understood, the implications of these scenarios could evolve.

2.3 Decarbonization modeling and fuels infrastructure analysis

Demand-side and supply-side models with high temporal, sectoral, and spatial[49] resolution were integrated in this study to provide an economy-wide view on potential decarbonization pathways for California. This pair of models produces energy, cost, and emissions data over the 30-year study period, 2020 – 2050. This modeling approach is similar in architecture to those used in other California decarbonization studies, such as the 2018 report by the CEC.[50] Likewise, it is similar to the approach used in the 2020 CARB report[51], while also employing a dedicated capacity expansion model for supply-side optimization, (see details in Appendix).

The demand-side model estimates final energy demand in a bottom-up fashion, for each of the over sixty end-uses or subsectors of the economy, ranging from residential space heating to heavy-duty trucks. Demand estimates are based on user decisions about technology adoption and energy service activity levels. Energy efficiency and end-use electrification measures are incorporated in demand-side scenarios. The final energy demand for fuels along with time-varying (8760 hour[52]) electricity demand profiles are used as inputs to the supply-side model.

The supply-side model used for this analysis is a linear programming model that combines capacity expansion and sequential hourly operations to find least-cost supply-side pathways. It optimizes annual investments for the electricity and fuels sectors to meet carbon targets and other constraints. It incorporates estimated final energy demand in future years from the demand-side modeling, as well as the future technology and fuel options available (including their efficiency, operating, and cost characteristics), and clean energy goals such as Renewable Portfolio Standards (RPS), Clean Energy Standards (CES), and carbon intensity.

This model is able to reflect detailed interactions among sectors, represented by electricity generation, fuel production and consumption, and carbon capture. With high temporal granularity, the model allows for co-optimized (electricity and fuels) supply-side solutions while enforcing economy-wide emissions constraints. This is important for accurate representation of the economics when electricity is used to produce fuels, for example when renewable over-generation is used for hydrogen production.

The analysis then goes beyond what many other full decarbonization analyses have historically done, using the results of the economy-wide decarbonization modeling to assess the potential for investment in clean fuels infrastructure, additional potential costs associated with fuel-switching, and potential gas system decommissioning costs and savings.

---

[49] Spatial resolution refers to the model's approach for projecting electric transmission expansion, as discussed in Section 2.1 (Overall Methodology), above.
[50] California Energy Commission, "Deep decarbonization in a high renewables future", June 2018, available at: https://www.ethree.com/wp-content/uploads/2018/06/Deep_Decarbonization_in_a_High_Renewables_Future_CEC-500-2018-012.pdf.
[51] Energy+Environmental Economics, "Achieving Carbon Neutrality in California: Pathways scenarios developed for the California Air Resources Board", October 2020, available at: https://ww2.arb.ca.gov/sites/default/files/2020-10/e3_cn_final_report_oct2020_0.pdf.
[52] To cover all hours in a year.

Five key dimensions of clean fuels infrastructure formed the basis for this analysis: hydrogen blending, pure hydrogen delivery, hydrogen storage, carbon management, and decommissioning. Along these dimensions, high-level answers to critical questions effectively created parameters within which the clean fuels network architecture was designed. These questions included, but were not limited to, the following and had to be answered differently across each scenario:

- **Hydrogen blending:** To what extent can the existing SoCalGas infrastructure (e.g., transmission pipelines made of high tensile strength steel) handle hydrogen blends? How, where, and at what cost can new hydrogen infrastructure be used to minimize total system cost?

- **Pure hydrogen delivery:** Where and at what cost could renewable energy resources be leveraged to economically connect green hydrogen supply to FCEV refueling stations, an end-use of pure hydrogen? How and where will natural gas and hydrogen be separated before reaching those customers who are connected to a blended pipeline but cannot tolerate a blend? What investment will be needed to deliver pure hydrogen to industrial customers or in “concentrated hydrogen hubs” where needed?

- **Hydrogen storage:** Given hydrogen levels in specific areas of the system, where would storage ideally be located to minimize cost with adequate safety and reliability? What additional infrastructure, such as pipelines, would be required for the most feasible hydrogen storage options?

- **Carbon management:** Where are the “sources” and “sinks” of carbon located? How could pipeline mileage be minimized to lower total costs of carbon pipelines? What investment is required to build those pipelines?

- **Decommissioning:** What zones have the highest cost to serve, both for gas and electric? In what zones would electrification be most beneficial (e.g., most cost-effective) to California’s energy system? What are the full costs of decommissioning?

This analysis relied on historical SoCalGas data, research conducted by SoCalGas and by third parties (e.g., universities, national labs, other utilities, etc.), market forecasts from a range of sources, and learnings from other geographies. Whenever available, California-specific data were used to improve analytical accuracy; for example, global averages of pipeline costs would result in an underestimate of the total pipeline cost for California. More granular location-specific analysis is required for planning. Assumptions and methodology for calculating the associated infrastructure costs in this high-level analysis are included in Appendix B.

Finally, it is important to acknowledge that this modeling and the assumptions inherently involve conjecture, as they rely on projections over a 30-year time period of technology development, customer behaviors, and other large-scale trends. In addition, the chosen assumptions also are constructed to reflect a range of potential scenarios, and thereby represent modeled corner cases. Therefore, the results of this modeling are not forecasts; they are meant to directionally inform policy-making and high-level strategic approaches for capital allocation and energy system decarbonization planning.

2.4 Decarbonization scenarios evaluation framework

Decarbonization pathways can be evaluated against a set of criteria that enhance public welfare. These criteria include but are not limited to local and system environmental impacts (both carbon and criteria pollutants), reliability and resiliency, and affordability.[53]

This effort focused on five specific key criteria (Exhibit 2.3).[54]

- **Energy system reliability and resiliency** is a vital condition for a successful energy transition. As an intrinsic condition of the decarbonization scenarios modeling, reliability requirements are met for all scenarios at the same level using proxies for loss of load. System resiliency is also important. Resiliency is defined here as the ability of the system to avoid altogether or bounce back quickly and minimize the impact of system outages including in unforeseen events (such as extended periods of extreme weather), as well as to help improve public safety by enhancing local generation. This is enabled by distributed and local energy to provide backup on a local level with clean fuels and solar. Resiliency is dependent upon infrastructure design and thus differs across scenarios based on the assumed energy infrastructure. Resiliency was evaluated in this effort by understanding the proportion of customers that would receive energy from both a fuels and an electric network given a fuels system's potential ability to provide redundancy in the event of an electric outage.

- **Long-term solutions** for decarbonization need to address the hard-to-abate sectors (e.g., industry and heavy-duty transportation); the challenges associated with decarbonizing these sectors varies across scenarios. This analysis qualitatively assesses the ability for different scenarios to meet the needs of customers in hard-to-abate sectors as they decarbonize. Solutions are deemed more challenging where they either create new complications (e.g., requiring switching from receiving fuels via pipeline to fuels via trucks) or may confine the options for industrial customers or vehicles to decarbonize, leading potentially to higher expense and/or other commercial challenges for these customers.

- **Customer conversion challenges** also vary across scenarios both in the level of intervention and per-customer cost of conversion to new technologies on the customer-end, and in the number of customers that need to switch technologies.

- **Technical maturity** is critical in assessing different scenarios. Scenarios that rely upon technologies that have not been proven at-scale (e.g., multi-day duration energy storage) may encounter unforeseen implementation challenges. Furthermore, scenarios requiring significant scale up of technologies that to date have been only demonstrated at smaller scale could have more challenges than scenarios leveraging only technologies that have already experienced broad commercial deployment. While all scenarios rely to some extent on scaling of early technologies, some rely more heavily on these newer technologies.

- **Overall system costs (affordability)** vary across scenarios. Quantitative analysis was performed as discussed in Section 2.3 to determine the cost impacts of different scenarios.

---

[53] See Cal. Pub. Util. Code § 451 (requiring rates to be "just and reasonable").

[54] The study's evaluation criteria are intended to be informative and not exhaustive. Other key assessment criteria for further evaluation could include impacts such as safety, land-use, air quality, short-lived climate pollutants, and economic development.

Exhibit 2.3 Key criteria used to assess scenarios

KEY CRITERIA	DESCRIPTION
System reliability & resiliency	Ability of system to maintain or rapidly secure customer and public safety, both under normal operating conditions including expected rare events (reliability) and under major disruptions with unforeseen events, such as those driven by climate change, leading to periods of constrained energy supply (resiliency)
Solution for hard-to-abate sectors	Extent to which the system is able to address the needs of hard-to-abate sectors, including heavy-duty transportation, shipping, and aviation, as well as industry such as cement and steel, all of which today largely rely on traditional fuels
Customer conversion challenges	Extent of impact on customer behavior and choice; challenges associated with retrofits to homes and buildings
Technical maturity	Stage of development for key technologies, with increasing risk associated with more nascent technologies where performance, reliability, safety, etc., have not been proven as thoroughly
Affordability	Costs associated with the evolving energy system, including electric generation and storage, electric and gas system infrastructure, demand-side conversion costs, fuel and biomass costs, etc.

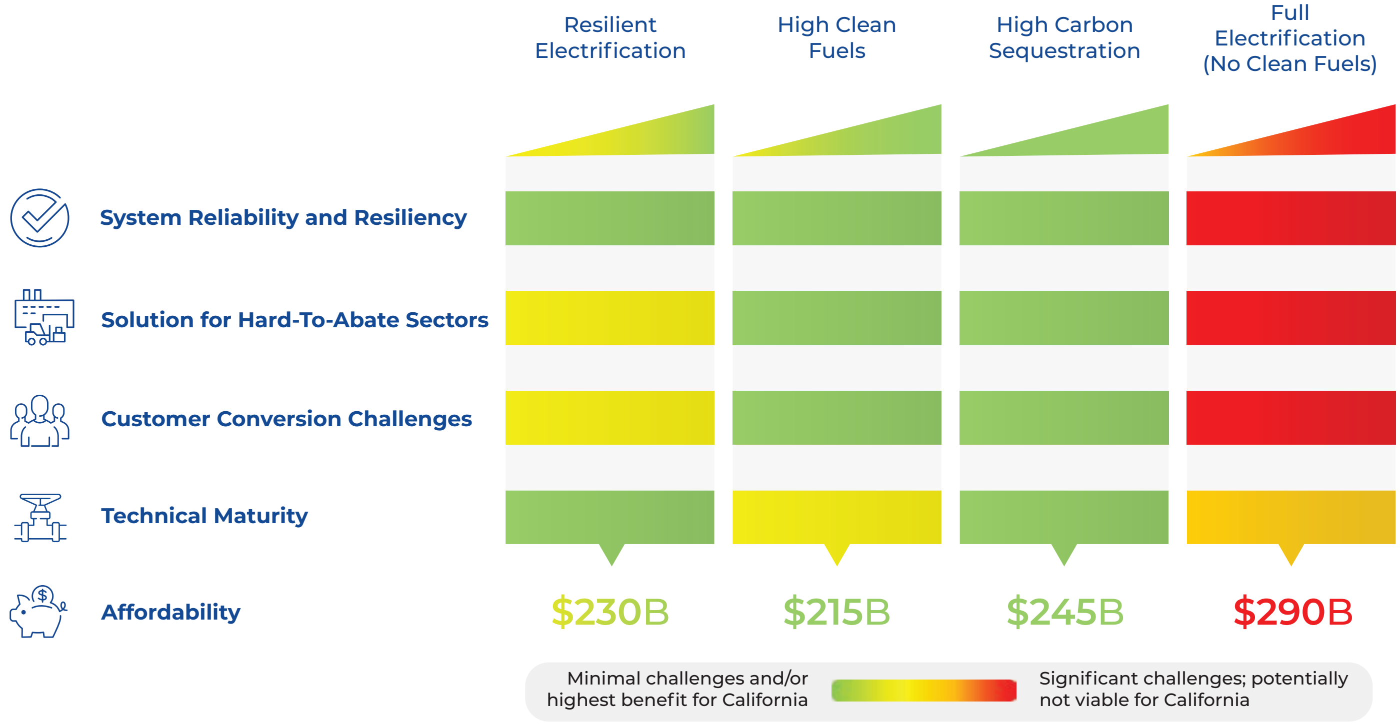
Least-cost, least-risk pathways and trade-offs

When different decarbonization scenarios are evaluated against the selected key criteria[55], one critical learning that emerges is that, in multiple ways, the presence of a clean fuels network minimizes challenges in and obstacles to California's energy transition.

The three scenarios that include a clean fuels network all perform better than a scenario with no clean fuels network across the criteria described above. Therefore, the three scenarios that include a clean fuels network are more plausible and logical for the state of California to pursue (see scenarios in Exhibit 3.1).

While all three scenarios that include a clean fuels network perform well in helping California reach its climate goals, there are important differences that highlight trade-offs for stakeholders to consider. For example, the Resilient Electrification scenario is evaluated as having a higher level of technical maturity because it relies less on emergent technologies such as clean fuels production as compared to the High Clean Fuels scenario; however, the Resilient Electrification system may not provide as clear a solution for substitution of traditional fuels in hard-to-abate sectors, and could also present end-customer challenges related to conversion given much higher levels of building electrification. A more detailed explanation of our evaluation across the selected key criteria follows below. The scenario without a fuels network is the most expensive, and also presents challenges in terms of resiliency and addressing hard-to-abate sectors. It will likely also necessitate the most effort from and cause the most disruption for customers.

Exhibit 3.1. Assessment of scenarios along selected key criteria



[55]Including resiliency, decarbonizing hard-to-abate sectors, customer conversion challenges, technical maturity, and affordability.

3.1 System reliability and resiliency

Reliability

In this analysis, reliability is modeled in each scenario by using hourly reserve margin constraints by zone. The dynamic reserve margins are based on the renewables capacity buildout, adoption of distributed energy resources (DERs), and load growth patterns. By being dynamic, as opposed to the traditional fixed percentage reserve margin based on gross-load peak, these constraints better represent future changing system reliability needs (e.g., moving from peak day to low renewable day).

Today's gas grid supports the reliability of California's electricity system. Thermal gas plants across the state help match supply with demand. In a decarbonized California, with high renewables penetration, the scenario analysis shows that thermal gas plants continue to play a role, though they run less frequently and at lower utilization (Exhibit 3.2). The analysis assumes thermal plants will eventually be flexible to run using net-zero fuels (e.g., hydrogen, biogas, and traditional natural gas offset by CCUS). This decarbonized thermal capacity would be an important source of reliability for California's power system in a decarbonized future.

Results of the modeling show that across scenarios a minimum of ~35 GW of gas capacity is expected in 2050 to provide system reliability (Exhibit 3.2). All scenarios meet the same levels of reliability per modeling constraints. Greater renewable electric capacity deployment, coupled with electrification of buildings and transport, corresponds to a need for more sustained peaking capacity, so more thermal generation capacity is needed in higher electrification cases. The modeled dynamic whereby thermal gas-fueled electric power plant fuel demand decreases on an annual basis, while concurrently peak daily and hourly fuel demand from power plants increases, has likewise been observed in modeling conducted by the California Public Utilities Commission Energy Division. (Exhibit 3.3).

With low capacity factors, the potential contribution of emissions from thermal generators is significantly reduced. Carbon-neutral fuels, like hydrogen, biogas, and traditional gas offset by carbon capture (through direct air capture [DAC] or biogenic sources) and sequestration can enable carbon-neutral generation capacity from these plants. This result demonstrates a role that a fuels network can play to enable high renewables penetration.[56]

[56]The analysis assumes that states beyond California also decarbonize. Thus, ensuring reliability across state boundaries is an important aspect of the model.

Exhibit 3.2. Gas plant capacity in California

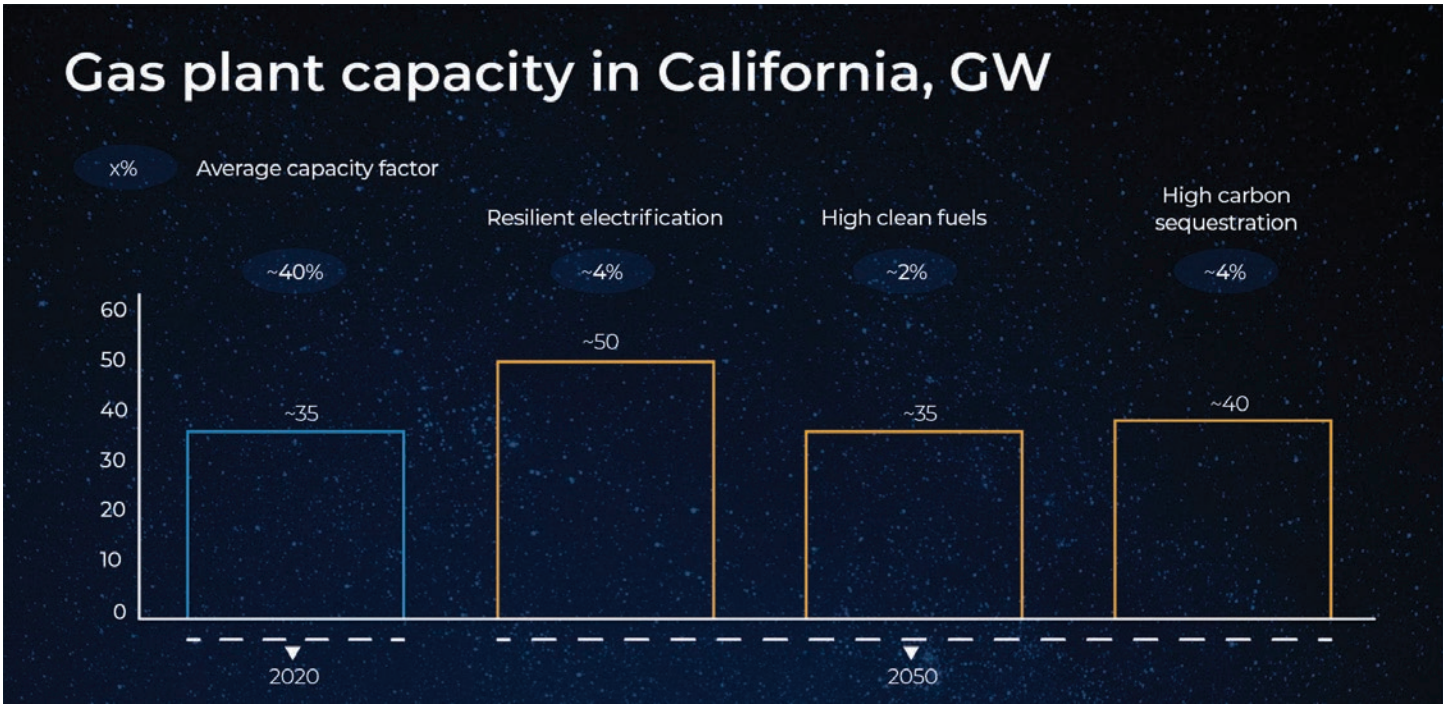
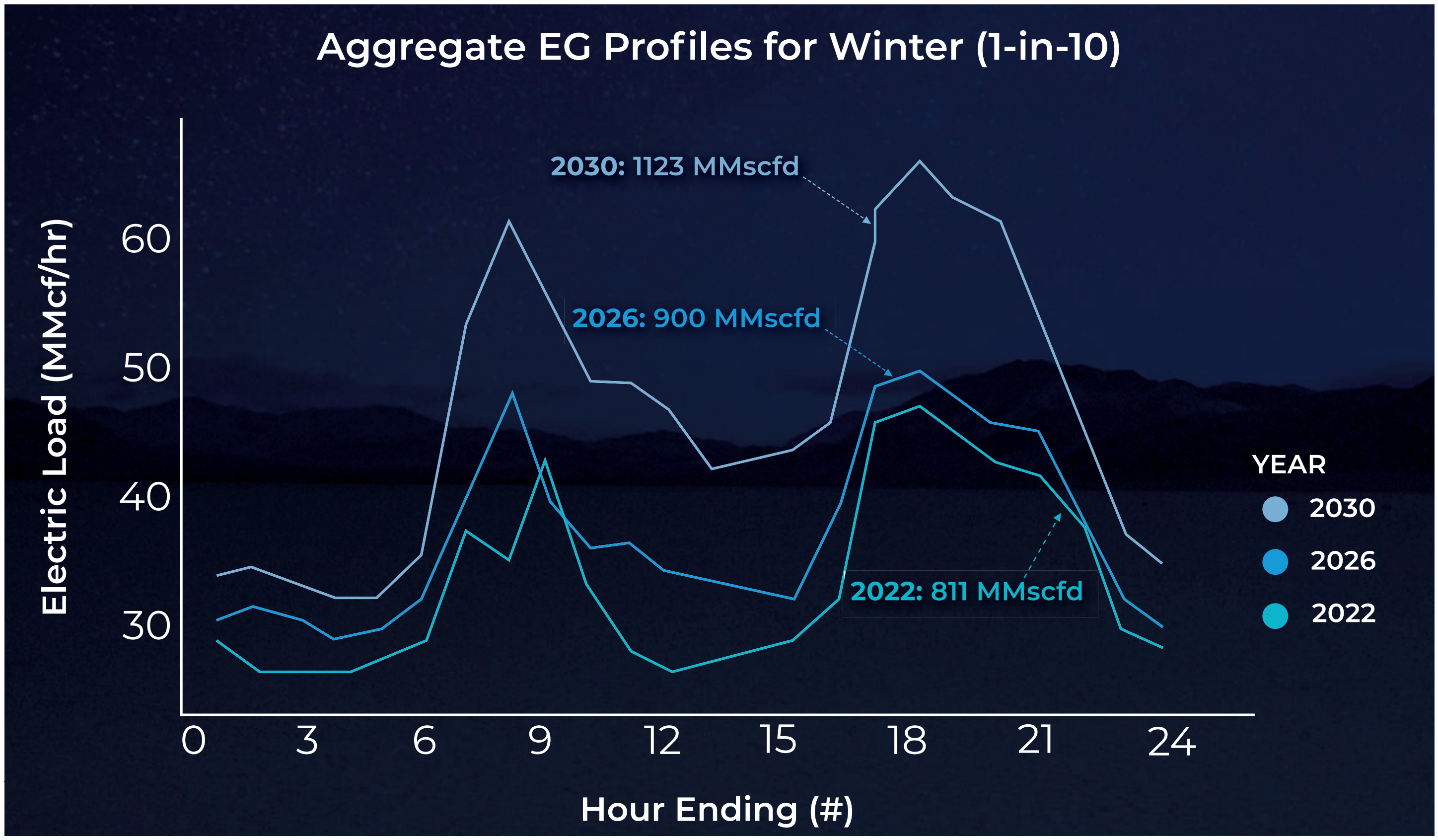


Exhibit 3.3. CPUC Projected SoCalGas Electric Generation Customer Fuel Burn Profiles[57]



[57]CPUC Energy Division Staff Presentation, Aliso OII I.17-02-002: Workshop 3 (July 28, 2020); available at: https://www.cpuc.ca.gov/-/media/cpuc-website/files/uploadedfiles/cpucwebsite/content/news_room/newsupdates/2020/session-4-hydraulic-modeling-updates-2020-workshop-3-slide-deck-final.pdf.

Resiliency

Energy resiliency is defined in this report as the ability of the system to avoid or bounce back quickly and minimize the impact of system outages including in unforeseen events (such as extended periods of extreme weather), as well as helping improve public safety by enhancing local generation. Today, the California economy is powered by electricity from a diverse mix of energy sources as well as fuels that enter the system from multiple points. This energy is delivered to customers through pipelines, across wires, and over road, rail, and ocean.[58] With diverse sources of supply and means of energy delivery, today's energy system – as a whole - does not have a single point of failure, increasing the resiliency of the system.

Power outages – particularly long-duration and system-wide – are costly. It was estimated that some of the large-scale power cuts in northern and central California in October 2020, which affected 2.7 million people, cost about $2.5 billion.[59] Power utilities have invested and will continue to invest heavily in wildfire mitigation programs; it is expected that $50 billion will be spent across the state by 2030.[60] However, as extreme weather events grow, outages are expected to increase in frequency, duration and severity.[61] Simultaneously, as transportation and building end-uses increasingly electrify, the economic and safety impacts of long-duration electric outages grow. The February 2021 Texas energy shortfall as a result of winter storm Uri, as well as the increase in the number of cyberattacks to America's energy infrastructure in recent years, are examples of the types of resiliency challenges to be addressed through properly designed and maintained energy infrastructure.

In addition to enabling reliable power generation through delivery of fuels to thermal gas plants, a clean fuels network can provide added resiliency, especially through fuels storage and local generation for microgrids, particularly in vulnerable risk zones, dense urban areas, and for critical loads (e.g., hospitals and emergency services).[62]

Fuel cells or other fuel-flexible distributed generation can be a critical resource to transition to a system with high hydrogen blends. These flexible dispatchable generators could use the existing natural gas infrastructure to provide resiliency now, and could also support a path to carbon neutral resiliency as the fuels grid becomes cleaner, using both biogas and carbon-neutral hydrogen.

There have been many attempts to quantify the value of reliability (or "lost load").[63] However, there is a significant range of values found for the value of lost load, and it is often context-specific (e.g., highly dependent upon type of customer, length of outage, recency of major resiliency events, and local customer behaviors). Resiliency is less understood. Increasing resiliency challenges, such as during extreme weather and/or public safety power shutoff (PSPS) events, impose societal and financial costs. Yet there is little empirical data regarding customer willingness to pay for enhanced energy resiliency.

---

[58] US Energy Information Administration, "California: State Profile and Energy Estimates," February 18, 2021, available at: https://www.eia.gov/state/?sid=CA.

[59] Stevens, P., "PG&E power outage could cost the California economy more than $2 billion," CNBC, October 10, 2019, available at: https://www.cnbc.com/2019/10/10/pge-power-outage-could-cost-the-california-economy-more-than-2-billion.html.

[60] California Public Utilities Commission, "Utility costs and Affordability of the Grid of the Future: An Evaluation of Electric Costs, Rates, and Equity Issues Pursuant to P.U. Code Section 913.1," February 2021, available at: https://www.voiceofsandiego.org/wp-content/uploads/2021/02/Feb-2021-Utility-Costs-and-Affordability-of-the-Grid-of-the-Future.pdf.

[61] U.S. Global Change Research Program, "Fourth National Climate Assessment, Volume II: Impacts, Risks, and Adaptation in the United States," p. 66, 2018, available at: https://nca2018.globalchange.gov/downloads/NCA4_2018_FullReport.pdf.

[62] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, "Fuel Cells for Stationary Power Applications," pp. 2-3, October 2017, available at: https://www.energy.gov/sites/prod/files/2018/01/f46/fcto_fc_stationary_power_apps.pdf.

[63] Schröder, T., Kuckshinrichs, W., "Value of Lost Load: An Efficient Economic Indicator for Power Supply Security? A Literature Review," Frontiers in Energy Research, December 24, 2015, available at: https://www.frontiersin.org/articles/10.3389/fenrg.2015.00055/full; London Economics, "The Value of Lost Load (VoLL) for Electricity in Great Britain," July 2013, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/224028/value_lost_load_electricty_gb.pdf.

This analysis assessed resiliency qualitatively based upon three factors:

- The portion of the California customer base that would continue to have access to both a fuels network and the electric network. Having two systems supporting energy delivery was deemed a more resilient pathway versus only having access to one.

- Proportion of end-use appliances that have both a fuels and electric network supporting them. In today's energy system, many end-use appliances are connected to either the gas delivery system or the electric system with relatively limited penetration of one system backing up the other for specific appliances. An example of support from two networks would be customers who have natural gas-fired generators backing up their home electric system in the event of an electric system outage.

- The difference in reliability of the fuels delivery system versus the electric delivery system. Electric delivery systems experience relatively higher amount of downtime as measured by outage metrics such as SAIFI/SAIDI and CAIFI/CAIDI versus the gas system that historically has rarely experienced significant unplanned outages in major portions of the network. This is largely related to the fact that gas systems, which are underground, are less exposed and subject to weather or physical interferences that may lead to outages, compared to electric delivery systems (especially legacy systems) that tend to be above ground.

The extent of resiliency varies across the scenarios evaluated. In the Resilient Electrification scenario, the electric system would support these customers much in the way it does today. This scenario additionally assumes investments in fuel cells for higher-risk, dense urban centers like Los Angeles. Therefore, these customers would also have the benefit of the fuels delivery system connected to fuel cells assumed to be sited in proximity of electric distribution substations and supporting of the electric system in the event of an upstream outage in the transmission system or generation system.

In the Resilient Electrification scenario, while the majority of residential and commercial end-uses are assumed to electrify by 2045, all end-uses in higher wildfire-risk areas would be supported by two energy delivery systems up to the distribution substation. Customers in dense urban areas and customers in higher wildfire risk areas accounts for roughly 60% of residential and commercial customers. Notably from the distribution substation to the home, there is only the support of one energy delivery system – the electric system. While the electric distribution system is known to have lower reliability and resiliency than the electric transmission and generation portions of the system, the outages in distribution system tend to affect fewer customers and pose less overall system risk versus upstream outages.

[64]SAIFI/SAIDI and CAIFI/CAIDI are reliability indices used to measure reliability for electric distribution service. See, National Association of Regulatory Utility Commissioners, "How is Reliability for Electricity Service Measured"; available at: https://www.naruc.org/servingthepublicinterest/about/reliability/.

Both the High Clean Fuels and High Carbon Sequestration scenarios assume a significant portion of the customer base (~65-70% by 2045) retain access to both the fuels and the electric delivery system in similar ways that they do today. In these scenarios, however, most appliances remain only supported by one system or the other – for example, space heating in a particular residence is either electrified with no fuel cell or fuels system back up or remains connected to the fuels system with no electric system back-up. Customers, though connected to both the electric and fuels system, are empowered with the options to choose to install on-site back-up equipment (e.g., a back-up fuel cell) that could support all appliances in the case of an outage event.

On the other end of the spectrum lies the No Fuels Network scenario, in which all customers would have to rely solely on electric power, without any network delivery of fuels. If there was an issue with the electric system in this scenario – either in generation, transmission, or distribution -- all end-uses without distributed generation and/or undergrounding of electric conduit (at a significant cost) would be without energy. This is considered to be the least resilient system, with considerably less resiliency than today's system.

The model includes the specific investment costs associated with delivering enhanced levels of resiliency in line with each scenario. For example, all three of the most plausible scenarios assume varying levels of fuel cell investment to vulnerable risk zones such as wildfire risk zones. However, this effort did not look at all costs associated with achieving resiliency which could include significant cost items such as undergrounding electric conduit. Enhancing resiliency requires significant investment to deploy known and proven resiliency options, along with the need to chart the path to carbon neutrality in the long term. In all three of the most plausible scenarios based on the selected key criteria, the fuels network could be leveraged to enable important resiliency measures.

3.2 Achieving full decarbonization including in hard-to-abate sectors

Achieving full carbon neutrality will require solutions to decarbonize traditionally hard-to-abate sectors. Industry and heavy-duty transportation account for approximately 33% of California's greenhouse gas emissions (Exhibit 1.1).[65] Across all scenarios evaluated, these hard-to-abate sectors require clean fuels – whether through biogas, hydrogen, or traditional gas offset by CCUS -- to most affordably achieve decarbonization.

Industry

The industrial sector accounts for approximately 21% of California's current emissions,[66] with carbon-emitting fuels used for both heating needs and as chemical feedstocks.

[65] California Air Resources Board, "California Greenhouse Gas Emissions for 2000 to 2019: Trends of Emissions and Other Indicators," p. 18, July 28, 2021, available at: https://ww3.arb.ca.gov/cc/inventory/pubs/reports/2000_2019/ghg_inventory_trends_00-19.pdf.
[66] Ibid.

Fuels for heating needs: Industrial heat applications are usually categorized according to the process temperature: very high-grade applications (above 1,000°C), high-grade applications (400 to 1000°C), medium-grade applications (100 to 400°C), and low-grade applications (less than 100°C). For the low- and medium-heat grade categories, electrification may be a potential way to reduce emissions, potentially with electric resistance or heat pumps, although active research on this topic is ongoing.[67] Electrification is less likely to be able to meet the requirements for higher grade heat applications.

Fuels as feedstock: Today, hydrogen is predominantly used in industry as a feedstock. In the US, >95% of hydrogen is directly used in the industrial processes of oil refining, ammonia production, and methanol, and other chemicals production. Other hydrogen users in the industrial sector are the cement, glass, rocket fuel, and food industries.[68]

Transportation

Approximately 40% of total greenhouse gas emissions in California today come from the transportation sector – the largest single emissions contributor.[69] The light-duty vehicle industry has started to shift towards zero emissions vehicles, currently dominated by battery EVs (BEVs) and complemented by hydrogen fuel cell electric vehicles (FCEVs). Other segments of the transport sector - including heavy-duty vehicles, aviation, and shipping - are more challenging to decarbonize.[70]

In the light-duty vehicle sector, BEVs and FCEVs could address different use cases. For vehicles with longer range requirements or higher utilization needs, such as taxis or ride-share fleet vehicles, FCEVs could be cost competitive in the 2020s, dependent on conditions and region.[71]

Comparison across scenarios

In all scenarios modeled, all sectors are modeled to achieve full decarbonization. The infrastructure needed to bring decarbonized electrons and molecules is built out to the affected customers in the Resilient Electrification, High Clean Fuels, and High Carbon Sequestration scenarios. In the No Fuels Network scenario, given the assumption that no gas pipeline remains, customers who continue to rely on molecules, because decarbonized electricity is not projected to meet their needs, must produce and store fuel on-site (e.g., on-site electrolysis) or truck in fuel.

In the High Clean Fuels and High Carbon Sequestration scenarios, a subset of residential and commercial buildings are assumed to continue to rely on a fuels network, transitioning to decarbonized clean fuels over time. This results in more customers utilizing the clean fuels network, as compared to the Resilient Electrification scenario where residential and commercial buildings are assumed to be fully electrified, presuming practical achievability, relying on the fuels system only for back-up power. Because of this, the costs of the clean fuels network are more widely shared in a High Clean Fuels or a High Carbon Sequestration scenario, as compared to a Resilient Electrification scenario, and the "hard-to-abate" sectors do not bear the entire system cost.

[67] McKinsey & Company, "Plugging in: What electrification can do for industry," May 2020, available at https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/plugging-in-what-electrification-can-do-for-industry.
[68] US Department of Energy, Office of Fossil Energy, "Hydrogen Strategy: Enabling a Low Carbon Economy," July 2020, available at: https://www.energy.gov/sites/prod/files/2020/07/f76/USDOE_FE_Hydrogen_Strategy_July2020.pdf.
[69] California Air Resources Board, "California Greenhouse Gas Emissions for 2000 to 2018, Trends of Emissions and Other Indicators," p. 5, 2020, available at: https://ww3.arb.ca.gov/cc/inventory/pubs/reports/2000_2018/ghg_inventory_trends_00-18.pdf.
[70] University of California Institute of Transportation Studies, "Driving California's Transportation Emissions to Zero," p. 12, April 2021, available at: https://escholarship.org/uc/item/3np3p2t0.
[71] Hydrogen Council, "Path to Hydrogen Competitiveness: a Cost Perspective," p. 35, January 2020, available at: https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf.

Additionally, more users relying on clean fuels for decarbonization will result in overall increased demand for those fuels. Therefore, the investment needed to catalyze and grow the market to produce clean fuels – e.g., investment in carbon sequestration and electrolysis – could scale more rapidly in a High Carbon Sequestration or High Clean Fuels where there are assumed to be more fuels consumers in 2050, as compared to a Resilient Electrification case, where it is presumed that energy consumers can electrify.

Because costs of a clean fuels network are more widely shared with high modeled demand, there is potential for increased investment to rapidly scale clean fuels. Consequently, the High Clean Fuels and High Carbon Sequestration scenarios are rated as green in the evaluation matrix above (Ex. 3.1), with the Resilient Electrification scenario rated as yellow specifically for the hard-to-abate sectors.

3.3 Customer conversion challenges

As decarbonization progresses, large scale energy transitions will likely require changes to many customers' homes and businesses – such as enhanced insulation, more energy efficient appliances, and fuel-switching from natural gas appliances to electric and/or hydrogen equipment. Some of these changes could be driven by customer choice, to technologies that are more cost effective, or that better support their lifestyle or business. Some of these changes will be driven by policy – local, state, or federal, accompanied by conversion costs.

Customer conversion challenges present prospective disruptions that could be experienced in homes or businesses to align their on-premise appliances and equipment to operate on the available energy sources for their particular premise. For example, this could include industrial customers switching to hydrogen-fueled processes (such as in the High Clean Fuels scenario), or installing carbon capture technologies (such as in the High Carbon Sequestration scenario), or necessary upgrades in homes and businesses to accommodate higher electric load (such as in the Resilient Electrification scenario). Managing this conversion is one of the most substantial implementation challenges associated with decarbonizing California's economy.

The Resilient Electrification scenario assumes levels of electrification that may result in higher customer conversion challenges, as 100% of residential and commercial appliance and equipment sales are assumed to be electric by 2035, compared to 50% in the High Clean Fuels and High Carbon Sequestration scenarios. While some customers may be able to convert to full electric, achieving 100% electric sales by 2035 will entail transitioning all buildings with the requisite electric supply and distribution capabilities. Achieving full customer conversions at such scale would require potentially complicated interventions, customer interruptions, and investment on the customer premise at unprecedented levels. For example, 100% electric sales by 2035 would require significant upgrades; in many instances, beyond simply upgrading to a heat pump. This is likely to include upgrading the distribution panel and the main switchboard (including some secondary components), as well as possibly working with the electric utility to upgrade the service connection.

Some installed existing HVAC systems are considerably more complicated and may even require a full internal retrofit of the circulation system requiring tenants to vacate the premise during portions of the upgrade. Residential systems can require upgrading the electric service panel (which may already be upgraded in some instances to handle EV charging). Some customers also may prefer one specific energy delivery source (e.g., gas for home cooking) over other energy sources. The process by which full electrification would occur such that a gas system is no longer used or needed in a specific area is unclear. Without targeted electrification of all end-uses of all customers in one area (which might require retiring appliances that are not yet ready to be replaced before end of life), the gaseous fuel distribution system would still likely be needed to support that specific area until its full electrification is complete. Where possible, customer costs for electrification were estimated and included in the analysis discussed in Section 4.5 on Affordability.

Similarly, and even more challenging, in the No Fuels Network scenario, given that the entire fuels network would be decommissioned, all customers – including residential, commercial and industrial -- would need to convert all appliances and equipment to electricity or truck in fuel, and would have no flexibility to use a piped mixed clean fuel as an alternative or back-up (as could still happen in the Resilient Electrification scenario). For these and other reasons, 100% electrification is therefore expressed in this analysis to be the most challenging. In comparison, the other scenarios which assume partial electrification (of 50% by 2035) provide greater flexibility and are therefore more manageable presuming electrification efforts could potentially focus on customers that are most feasible to electrify.

The High Clean Fuels scenario assumes that currently available customer appliances can tolerate a 20% blend of hydrogen. This assumption is informed by global literature review, although continued studies are ongoing in this area and need to be completed to maintain the safety and reliability of appliances. A balance of clean fuels replacing existing natural gas combined with electrification solutions could prove easier to implement on the customer premise as compared to full electrification.

3.4 Technical maturity

All technologies considered in the decarbonization scenarios modeling are either currently in development or have been deployed, though some are at more nascent stages. To appropriately compare the scenarios, it is important to consider which scenarios rely more heavily on technologies that are less developed, and therefore have greater uncertainty around their long-term viability and/or their long-term costs.

The implications of varying degrees of technical maturity are three-fold. First, the costs and performance of these technologies should be monitored to continuously refine the assumptions that inform decarbonization pathways. Second, given uncertainty of evolving technologies, it is important to pursue pathways that provide more technology options to enable long-term optionality to de-risk the route to decarbonization. Third, investments in nascent technologies could help accelerate market transformation. The High Clean Fuels scenario relies upon hydrogen blending in pipelines, which shows promise across many demonstrations in other jurisdictions on similar pipeline materials.

The High Clean Fuels scenario presumes that 20% blending by volume can be achieved in the existing California infrastructure with relatively low additional investment required to accommodate and that hydrogen can be extracted from blended pipelines with sufficient purity to serve dedicated end-uses (e.g., refueling stations). This level of hydrogen blending in natural gas pipelines has not been tested directly in California's infrastructure. Research suggests that up to 20% blending of hydrogen generally can be blended into the gas distribution system without significant risk[72], though the cost required to safely blend hydrogen through the California gas system is still uncertain. The High Clean Fuels scenario also relies upon a large scale-up and cost-down of renewably powered electrolysis. Recent scaleup and funding commitments, including the European Union initiative to deploy 40 gigawatts of electrolyzer capacity by 2030, bode well for prospective scaleup.[73] While all modeled scenarios rely on electrolysis to some extent, the High Clean Fuels scenario involves the greatest ramp up of electrolysis.

Even more challenging, the No Fuels Network scenario assumes no gas-fired and thermal generation, and therefore, in the decarbonization modeling, relies on long-duration battery storage to meet system needs after multi-day events with low renewable generation. While battery storage technologies to meet these long-duration requirements are in development, they are in early stages and have yet to be demonstrated at even pilot scale.[74] Because the No Fuels Network" scenario relies on unknown or yet proven resources to provide electric system reliability, it is rated and presented as the most challenging case when it comes to technical maturity.

Finally, the Resilient Electrification and the High Carbon Sequestration scenarios have a more favorable rating on technical maturity, as the uncertainty around their feasibility is smaller. Increased electrification in urban areas and installation of fuel cells at large scale, although technically challenging, are better known and understood technologies, notwithstanding uncertainties for scaling electrification to 100% of buildings by 2035. Carbon capture and sequestration are less uncertain technologies having been in use for industrial purposes, although they still have inherent technological risk and ultimate cost is uncertain in a California-specific context.

[72]United Kingdom Health and Safety Executive, "RR1047 Injecting hydrogen into the gas network - a literature search," p. v, 2015, available at: https://www.hse.gov.uk/research/rrpdf/rr1047.pdf; see also Gas Technology Institute, "Review Studies of Hydrogen Use in Natural Gas Distribution Systems," p. 1, December 2010, available at: https://www.nrel.gov/docs/fy13osti/51995.pdf (Appendix A to Melainaet al., "Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues," March 2013)

[73]Electrolyzer cost curves in "High clean fuels" scenario are in line with the European Commission's Advanced System Studies for Energy Transition ("ASSET") Project; see Capros et al., "Technology pathways in decarbonisation scenario," July 2018, available at: https://ec.europa.eu/energy/sites/ener/files/documents/2018_06_27_technology_pathways_-_finalreportmain2.pdf.

[74]Tuttman, M. and Litzelman, S., "Why Long-Duration Energy Storage Matters," ARPA-E, April 01, 2020, available at: https://arpa-e.energy.gov/news-and-media/blog-posts/why-long-duration-energy-storage-matters.

3.5 Affordability

The economy-wide modeling of California decarbonization, coupled with an assessment of the clean fuels infrastructure investment needs, projects that a clean fuels network is a part of the most affordable (least cost) scenarios to help achieve full carbon neutrality while enabling system resiliency, decarbonizing hard-to-abate sectors, and preserving optionality along California's path to decarbonization. Exhibit 3.3 shows a comparison across scenarios of the net present value of total California costs from 2020 to 2050, incremental to a reference case representing business as usual.[75]

Based on this analysis, the three most plausible scenarios that incorporate a clean fuels network are more affordable than the No Fuels Network scenario and therefore offer more affordable (and achievable) ways to enable California decarbonization and provide resiliency. Thermal generation and clean molecules are the lowest-cost approach for backing up the high-renewables system. Without a clean fuels network, a significantly larger buildout of renewables and storage is needed. Alternative forms of long duration storage would need to be scaled up from a nascent level and would need to reach low price targets to avoid a high cost burden.[76]

While considerable investment is needed to achieve full decarbonization, in all scenarios it is partially offset by reductions in spending on traditional fuels, including petroleum products and traditional natural gas. Based on this analysis, the reduced traditional fuel spending could amount to more than $600B in NPV from 2020 to 2050. If ramped down cost effectively and safely, this reduction in spend could help fund investments in clean technologies and fuels, supporting a more affordable energy transition.

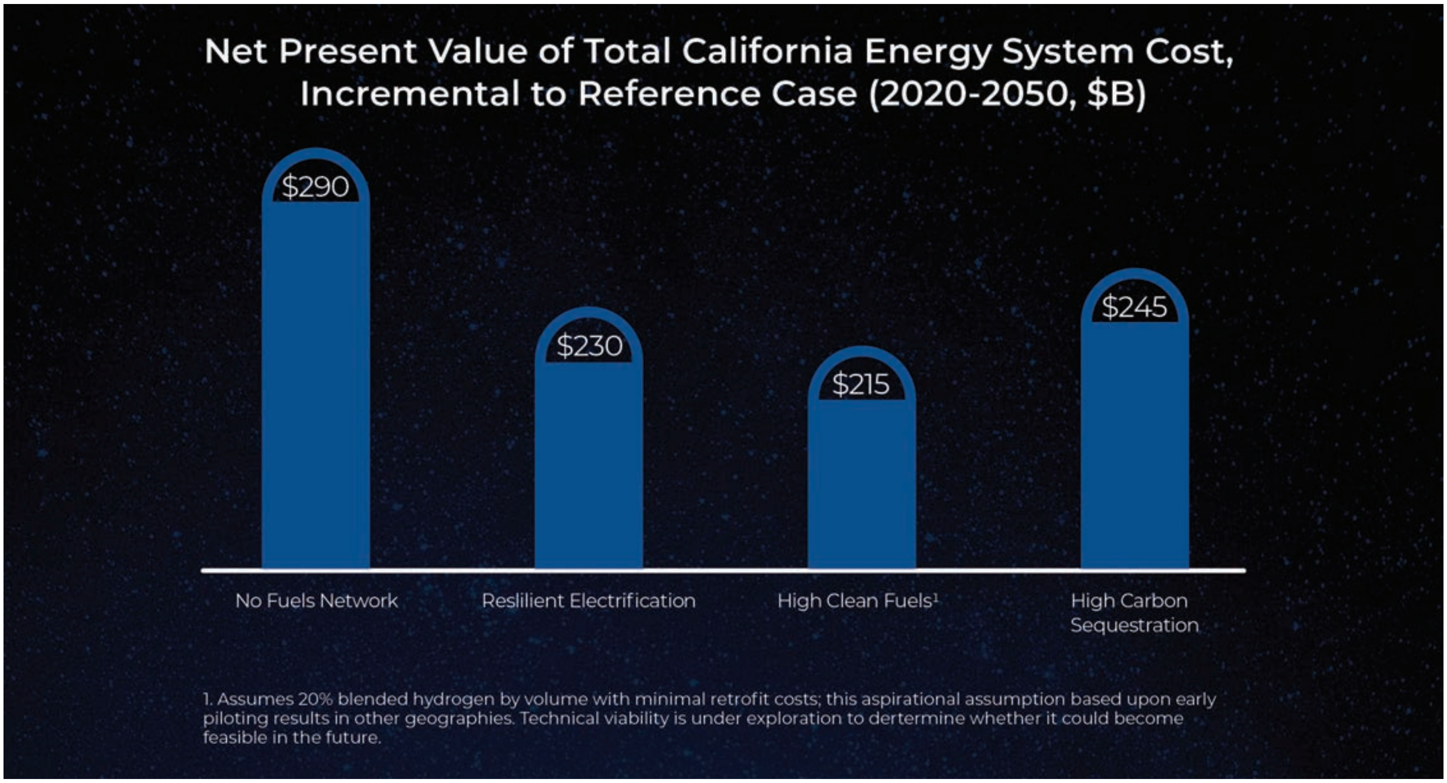
It should be noted that across the reference case and all scenarios modeled, the total net cost estimates are uncertain given variations in actual technology costs from forecasts and given unknowns around implementation and adoption. Total costs are based on cost projections over a 30-year timeframe, with assumptions around nascent technologies, customer behaviors, global fuel production and demand, etc. Although they must be considered with these uncertainties in mind and alongside other key criteria, total projected system costs still are an informative and critical consideration.

System costs are modeled through 2050. Beyond 2050, uncertainty continues to increase and the relative costs across scenarios could change. For example, annual savings associated with reduced traditional consumption and with reduced maintenance and sustaining capital investments resulting from gas infrastructure decommissioning will likely be ongoing beyond 2050. Additionally, beyond 2050 new capital investments will be needed to replace assets as they reach the end of their useful life; the future technology cost curves and real lifetimes will influence the cost to replace. Customer choices and behaviors that influence demand, such as vehicle miles travelled and building efficiency, will continually evolve. Regularly evaluating these and other critical trends over time can help maintain a long-term outlook on relative costs across pathways.

[75]The reference (business as usual) case represents a baseline of California total energy system spend, in a scenario where the state does not meet its decarbonization targets. This modeling suggests the 30-year present value of the reference case is ~$2.6T. The net present value across decarbonization scenarios is incremental to that reference value; it represents the additional costs incurred to fully decarbonize the system (e.g., renewables, storage, clean fuels, etc.) and the related savings (e.g., reduced spend on traditional fuels).
[76]Sepulveda et al., "The design space for long-duration energy storage in decarbonized power systems," 6 Nature Energy 506 (2021), available at: https://www.nature.com/articles/s41560-021-00796-8.pdf?proof=t.

Decarbonizing the system without the fuels network is significantly more expensive compared to alternative pathways. The other three scenarios with varying focus on different decarbonization levers – Resilient Electrification, High Clean Fuels, and Carbon Sequestration -- all fall within a similar range of costs, all lower than the No Fuels Network scenario.[77]

Exhibit 3.4 Net present value of costs incremental to reference case by scenario, 2020 – 2050[78]



In conclusion, the scenarios modeling coupled with an assessment of the investment required in a clean fuels network shows that a range of distinct energy infrastructure end-states could enable California to meet its decarbonization goals reliably. The analysis indicates that a clean fuels system with a blend of hydrogen, biogas, and traditional natural gas offset by CCUS, can enable reliable and resilient decarbonization, decarbonize hard-to-abate sectors, and reduce overall cost while preserving optionality of the energy transition.

The extent to which different decarbonization levers are applied varies across scenarios; the implications for the total system and for the supporting fuels infrastructure are explored in other sections.

[78]Cost estimates do not factor in the relative resiliency value, such as societal costs incurred due to outages from a system unable to withstand unexpected or extreme weather events, which costs would be greatest in the No Fuels Network scenario.

A clean fuels network assists in the production, transmission, distribution, consumption, and storage of clean fuels including hydrogen, biogas, synthetic natural gas, biofuels and synthetic fuels (defined in Section 1). Additionally, because direct decarbonization of traditional fuels involves carbon capture, this network also assists with the secure transport and sequestration or utilization of carbon dioxide.

Developing a clean fuels network will require a shift from transporting pure fossil-based methane today to a system that will need to be able to transport new clean fuels and enable carbon management. Some of those fuels (such as biogas and syngas) are "drop-in fuels" requiring no change in the current infrastructure to support their transport. Transporting hydrogen can take significant advantage of leveraging the existing system but will also require new investments to achieve hydrogen readiness, adequate hydrogen storage, and delivery of significant hydrogen volumes to new use cases (e.g., heavy-duty, long-haul vehicles).

4.1 A Potential clean fuels network in Southern California

The scenario modeling demonstrates that prospective pathways rely on a diverse blend of fuels including hydrogen, biogas, and traditional natural gas with carbon management. All viable scenarios reach net-zero and require investments in both new and existing infrastructure to deliver clean fuels to industry, transportation, thermal generation and other sectors as well as manage carbon.

A clean fuels network in Southern California that meets the needs of the viable scenarios could be composed of several key elements (Exhibit 4.1):

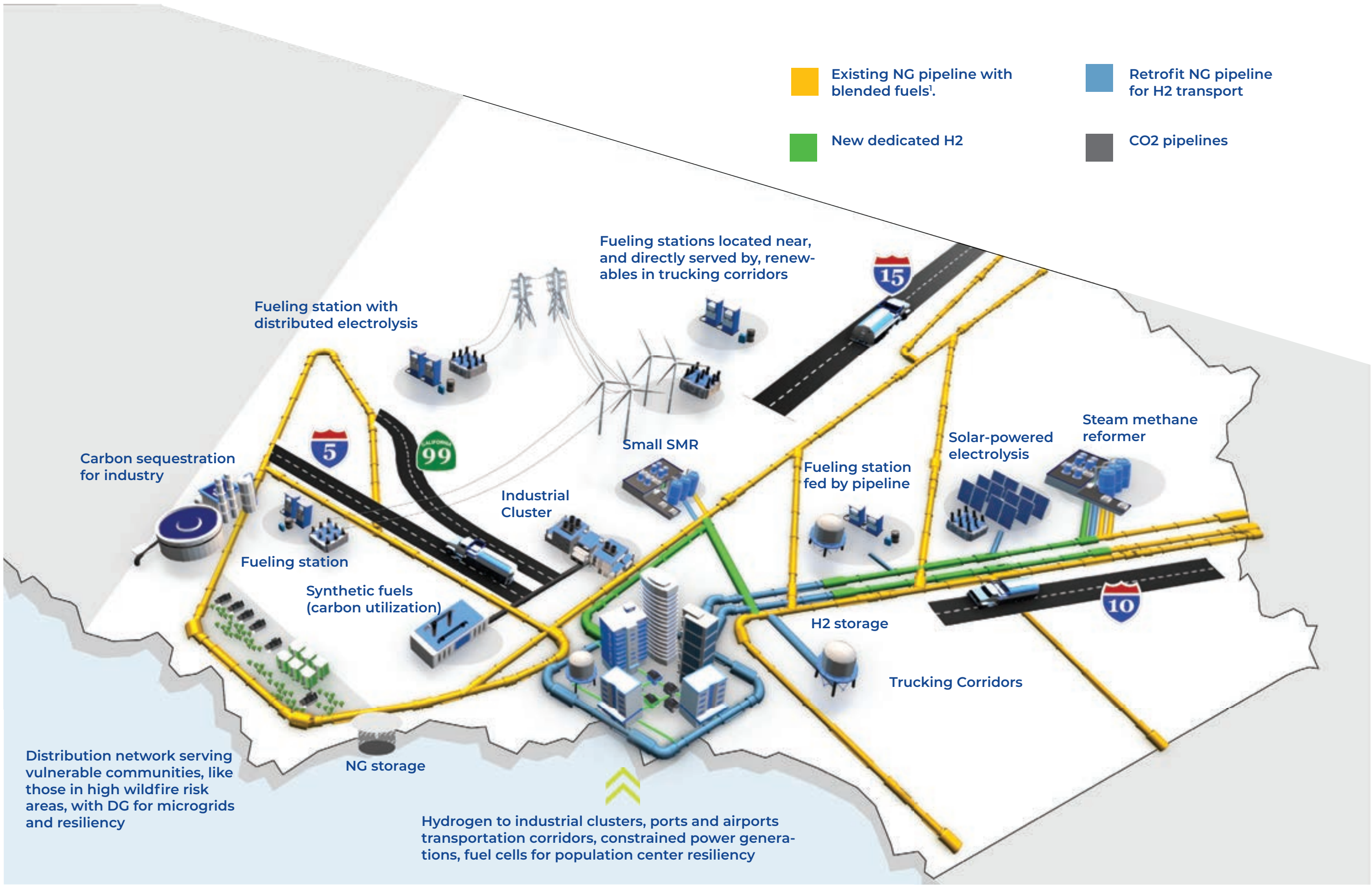
- **A clean fuels transmission backbone system** serving thermal generators, trucking routes, and connecting industrial hydrogen demand with hydrogen supply. This backbone system will likely require coordination across states as well. This network could potentially link the important industrial hubs of Los Angeles all the way to Houston connecting through the renewable-rich states of Arizona and New Mexico. In the case of substantial hydrogen volumes, multiple natural gas transmission pipelines would need to either blend hydrogen alongside natural gas or be retrofitted for hydrogen transport. Parallel pipelines, such as those found in southeastern California, would facilitate this retrofit process, similar to Europe where hydrogen pipeline retrofits will generally occur where parallel pipelines exist. The parallel pipelines in southeastern California are located near two other key facets of the clean fuels network: (1) renewable energy resources, unlocking a potential interconnect opportunity with green hydrogen production, and (2) the I-10 Freeway and trucking corridor, where hydrogen refueling stations could be built.

- CO2 could need to be captured, transported, and sequestered from industrial clusters such as those in San Bernardino County and Kern County. In the instance of significant carbon capture and utilization or sequestration, CO2 pipelines would likely be needed to transport the quantities of CO2 to sequestration or utilization sites.

- In scenarios where hydrogen concentration in the pipelines across the state far exceeds the technical blend limits, hydrogen could be concentrated into one region to create a "hydrogen hub". Compared to several other regions that were considered for this hydrogen hub, the Los Angeles Basin is a highly attractive candidate due to its high natural gas consumption, potential for industrial offtake (e.g., ports, airports, refineries, logistics centers, etc.), and proximity to renewable energy resources. By concentrating hydrogen adoption in one region, the remainder of the gas transmission and distribution system could undergo minimal retrofitting given blending thresholds in other parts of the system would not be exceeded. Hydrogen hubs could also deliver hydrogen via fuel cells that provide baseload power to electrified appliances. This could potentially result in higher end-use electrification: clean molecules are delivered to fuel cells, converted to clean electrons that then power homes and buildings.

- Other critical elements include:
  • Hydrogen refueling stations potentially placed along key transit corridors to provide clean fuels to long-haul trucks supported by hydrogen pipelines or on-site hydrogen production.
  • Steam methane reformers (SMRs) and electrolyzers to produce hydrogen.
  • Fuel cells and fuel-flexible distributed generation powered by today's natural gas system and transitioned over time to be fueled by a clean fuels network – whether biogas, hydrogen, or traditional natural gas offset by CCUS and deployed especially in high wildfire risk areas so customers have the back-up power they need in case of electric outage.

Exhibit 4.1. Illustrative Vision of a Potential Clean Fuels Network in Southern California



1. Pipelines containing a blend of fossil natural gas offset by CCUS; biogas; hydrogen up to safe blending standards

4.2 Clean fuels use cases

Clean fuels such as biogas (also frequently referred to as Renewable Natural Gas or RNG), hydrogen, and traditional gas supported by carbon capture can serve a number of different use cases in support of achieving California's carbon neutral goals:

Industry

The industrial sector accounts for approximately 21% of California's current emissions[79], with fuels used for both heating needs and as chemical feedstocks. Carbon-neutral hydrogen, biogas, and CCUS[80] are likely to play a key role in decarbonizing the industrial sector as discussed in the scenario analysis in subsequent sections.

- Fuels for heating needs: Industrial heat applications are usually categorized according to the process temperature: very high-grade applications (above 1,000°C), high-grade applications (400 to 1000°C), medium-grade applications (100 to 400°C), and low-grade applications (less than 100°C).[81] Many industrial heating needs today are powered by traditional fuel combustion. The high-grade heating category includes the iron, steel, chemicals, and petrochemicals industries, and is where hydrogen has the most promising application. To remain viable and competitive in a decarbonized future, industrial customers with high temperature heat demands are likely to need access to a reliable, low-cost decarbonized fuel. Replacing traditional fuels with carbon neutral hydrogen as a source of high-grade heat could be a cost-effective option. Some industries could retrofit gas-fired furnaces to run on hydrogen, while others could combine hydrogen with biogas or traditional natural gas offset by CCUS.
- Fuels as feedstock: Today, hydrogen is predominantly used in industry as a feedstock. In the US, more than 95% of hydrogen is directly used in the industrial processes of oil refining, ammonia production, methanol and other chemicals production.[82] Hydrogen used as a feedstock in these industrial applications will need to transition to net-zero-carbon in order to meet California's decarbonization goals. This transition could involve producing hydrogen from biomass, using SMR plants with carbon capture, or expanding hydrogen production through electrolysis powered by renewable energy.

Transportation

Approximately 40% of total greenhouse gas emissions in California today come from the transportation sector – the largest single emissions contributor. The light-duty vehicle industry has started to shift towards zero emissions vehicles, currently dominated by battery EVs (BEVs) and complemented by hydrogen fuel cell electric vehicles (FCEVs). Other segments of the transport sector - including heavy-duty vehicles, aviation, and shipping - are more challenging to decarbonize.

- Long-haul, heavy-duty transportation requires significant range while towing heavy loads which may favor the higher energy densities and faster refueling times of FCEV, resulting in significant hydrogen demand. These vehicles will also cross state-lines and will therefore require infrastructure in neighboring states as well.

---

[79]California Air Resources Board, "California Greenhouse Gas Emissions for 2000 to 2019, Trends of Emissions and Other Indicators," p. 18, July 2021, available at: https://ww3.arb.ca.gov/cc/inventory/pubs/reports/2000_2019/ghg_inventory_trends_00-19.pdf.
[80]Peridas, G., "Permitting Carbon Capture & Storage Projects in California," Lawrence Livermore National Laboratory (LLNL-TR-817425), February 2021, available at: https://www-gs.llnl.gov/content/assets/docs/energy/CA_CCS_PermittingReport.pdf.
[81]McKinsey & Company, "Plugging in: What electrification can do for industry," May 2020, available at: https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/plugging-in-what-electrification-can-do-for-industry.
[82]US Department of Energy, Office of Fossil Energy, "Hydrogen Strategy: Enabling a Low Carbon Economy," July 2020, available at: https://www.energy.gov/sites/prod/files/2020/07/f76/USDOE_FE_Hydrogen_Strategy_July2020.pdf.

- Shipping and aviation: these sectors have the most significant direct electrification challenges but have a variety of clean fuel options. Drop-in fuels (e.g., biofuels) are alternatives for fossil-derived fuels to serve these sectors. As "drop-in" fuels, they require no change in infrastructure or in vehicle make-up. Drop-in fuels can come from a variety of carbon feedstocks based on either organic material, such as vegetable oil, or captured CO2. Among the possible pathways to produce these alternative fuels, all require hydrogen as a primary feedstock to be combined with a carbon source, in the case of synthetic hydrocarbons, or nitrogen, in the case of ammonia. In both cases, hydrogen can contribute to lowering the carbon emissions of aviation and shipping.
- Light-duty vehicle sector: both BEVs and FCEVs could be needed to address different use cases.

Thermal Generation

As discussed in previous sections, thermal generation will be important to provide reliability, resiliency, and resource adequacy in a future decarbonized California to support weather-dependent intermittent renewable resources and fluctuations in demand. The key value these plants will ultimately provide is focused on the capacity backup they deliver to support different types of reliability events (e.g., multi-day periods where renewable production is significantly lower than demand). Thermal generation could be supported by a range of fuels including biogas, traditional natural gas supported by CCUS and hydrogen which could be used in thermal generation plants. The Los Angeles 100% Renewable Energy Study by LADWP highlights the need for "renewably fueled combustion turbines" in the LA Basin.[83] Those renewably fueled combustion turbines are built primarily to support reliability of the power system and provide capacity backup for times with low renewable output for multiple days. Having in-state and in-market generation reduces the risks associated with relying solely on transmission lines to bring wind and solar energy to the Los Angeles area given natural disaster risks (e.g., fire, earthquakes) and would allow the state to reduce expensive transmission upgrades. Additionally, the Los Angeles 100% Renewable Energy Study critically highlights the role renewably fueled generators can play in supporting local resource adequacy by providing multi-day load balancing support particularly during periods with low wind and solar resource availability. Resource adequacy helps ensure that utilities like LADWP have adequate generation supply that is at the right location and adequate availability so that even during a transmission or generation outage there is adequate backup capacity – optimally, this spare capacity is located "locally" to provide backup to transmission related outages. The LA100 study concluded that "Maintaining sufficient in-basin firm capacity resources allows the future systems to continue uninterrupted operation during infrequent but impactful long-duration transmission outages."[84]

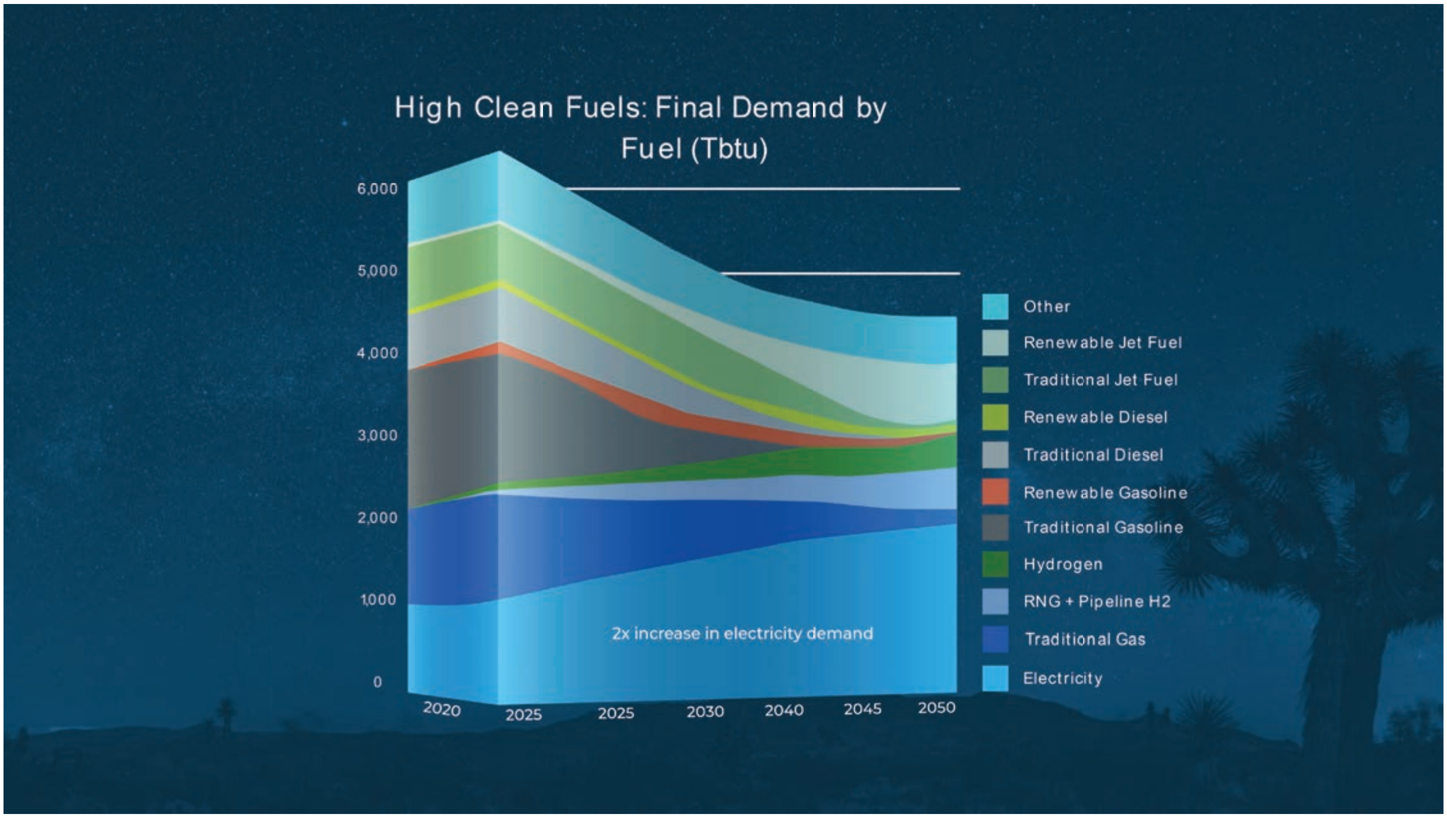
---

[83] Cochran et al., "LA100: The Los Angeles 100% Renewable Energy Study," National Renewable Energy Laboratory (NREL/TP-6A20-79444), p. 29, March 2021, available at: https://www.nrel.gov/docs/fy21osti/79444-ES.pdf. Renewable fuels include biofuels and green hydrogen.
[84] Id. at p. 34.

- **Decarbonizing residential and commercial buildings:** Today, SoCalGas customers overwhelmingly use natural gas from the pipeline network for heating and cooking needs in their households and businesses. Biogas, carbon-neutral hydrogen, and even traditional natural gas coupled with direct air capture (DAC) elsewhere could enable resilient decarbonization of the broader building sector while continuing to use the existing gas infrastructure. In addition to clean fuel replacement, electrification of end-uses will play a role. It is expected that end-uses such as space and water heating in buildings will be electrified; at this point, the feasibility and costs of full electrification and decommissioning are still being examined. Collaboration to assess the benefits of each solution as well as ways to enhance the local reliability and resiliency with substation-level clean fuel backup can create better solutions for customers. Electrification and clean fuels can work in concert to drive decarbonization, provide resiliency, and minimize cost impacts (e.g., lower transmission and distribution electric infrastructure investment by using fuel appliances during times of peak electric demand).

- **Fuel cell resiliency support:** As the reverse reaction of electrolysis, fuel cells convert hydrogen and oxygen into electricity and water. Some of them can run on pure hydrogen as a feedstock, although most of those commercially available today first reform methane – including synthetic or renewable methane – into hydrogen. Fuel cells that run on hydrogen can be particularly useful in a clean fuels network where hydrogen, rather than being disseminated and combusted in individual buildings, is sent to fuel cells in electric substations for decentralized electricity production, providing back-up power in case of an electric transmission failure.

Exhibit 4.2 High Clean Fuels: Modeled Demand by Fuel



4.3 Producing and transporting biogas

Biogas supply

Biogas can be produced from different feedstocks:

- Waste gases – gas emitted from landfills, wastewater treatment plants, and dairy farms. Waste gases are already in the form of methane, and thus require only cleaning to be ready for pipeline injection. The California legislature, through enactment of SB 1440 (Hueso 2018), expressed and codified the critical role biogas plays in mitigating methane emissions from California's waste streams. As noted by the CPUC Energy Division staff, "CARB's SLCP Reduction Strategy" notes that a significant amount of GHG emissions come from waste streams and an optimal way to reduce emissions from waste streams is to capture them. Those captured emissions, in the form of biomethane or Bio-SNG, become a pipeline injectable gas interchangeable with traditional natural gas. This Staff Proposal marks a substantial and important next step toward decarbonizing waste streams, an overlooked and underestimated source of carbon emissions and fuel that will be an essential component in helping California meet its climate goals moving forward.[85]

- Wet biomass – algae or crop residue is a relatively inefficient feedstock to gasify due to high water content. Wet biomass can more efficiently be turned into biogas via anaerobic digestion.

- Dry biomass – forest residue, which is typically gasified and the syngas mixture is then used to make liquid fuels through the Fischer-Tropsch process. Because biofuels are overall more valuable than biogas, and the scale and capital required for biomass gasification is high, it is usually more economic to use dry biomass as a feedstock for biofuels, as opposed to biogas.

The decarbonization scenarios modeling considers the US-wide supply of biomass and biogas, based respectively on the DOE's Billion Ton Study[86] and the American Gas Foundation's study "Renewable Sources of Natural Gas."[87] The potential supply of biogas is likely such that it will form a part of a larger mix of clean fuels necessary to support the decarbonization of California's gas grid. It is likely that other states will also demand biogas and biomass; thus the decarbonization scenarios modeling assumed that all US states meet the same decarbonization targets as California.

Biogas Transport

Biogas requires no changes to gas delivery infrastructure or customer end-uses given the same molecule properties as traditional methane. It is already used today to reduce carbon emissions not only from the gas system but from mobile sources which have historically relied on the liquid fuels system (e.g., gasoline and diesel).

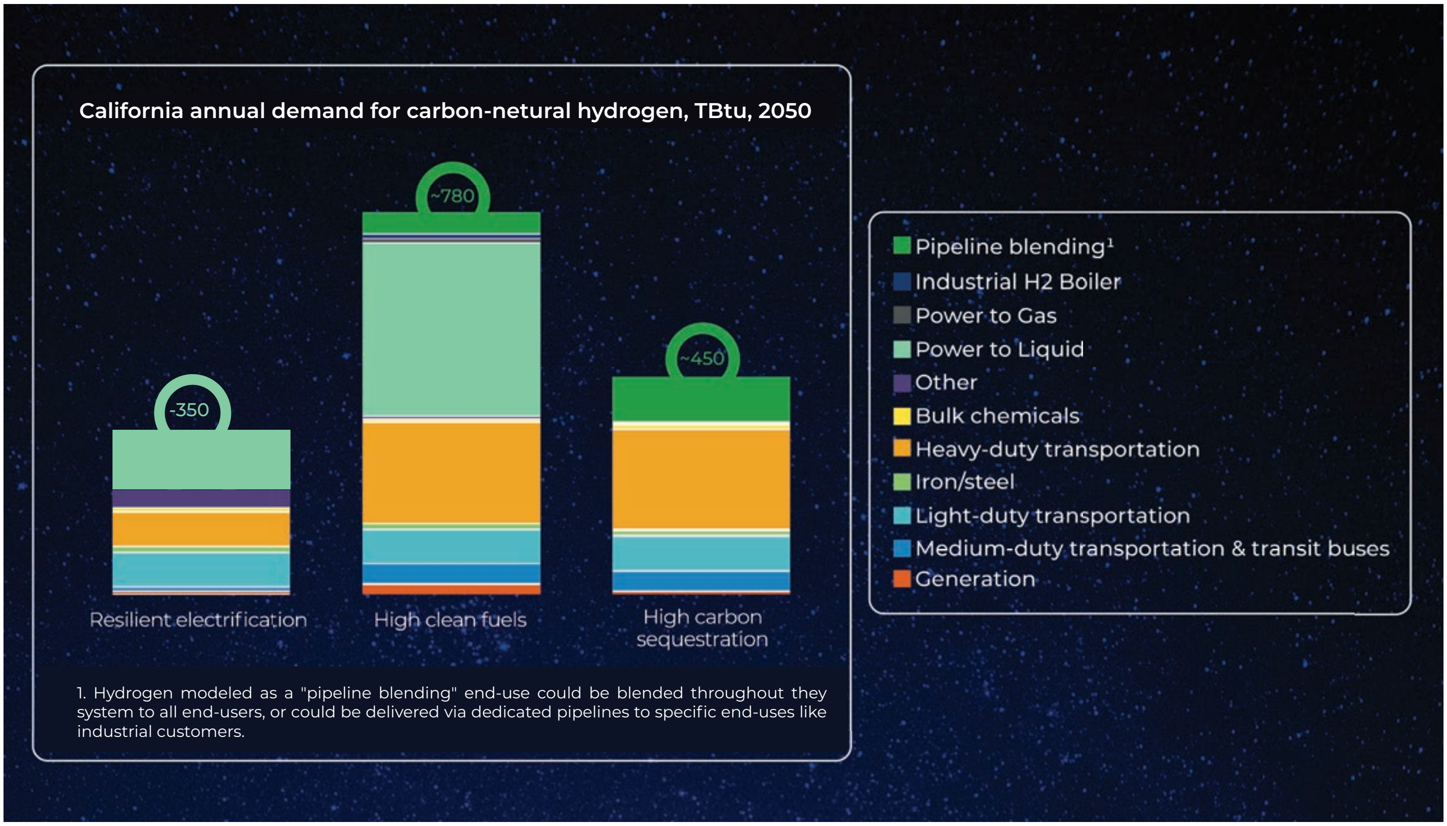
---

[85] California Public Utilities Commission, Energy Division, "R.13-02-008 Phase 4A Staff Proposal (DRAFT)," p. 56, June 2021, available at: https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M386/K579/386579735.PDF.
[86] Department of Energy, "2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy," July 2016, available at: https://www.energy.gov/sites/default/files/2016/12/f34/2016_billion_ton_report_12.2.16_0.pdf.
[87] American Gas Foundation, ICF, "Renewable Sources of Natural Gas: Supply And Emissions Reduction Assessment", December 2019, available at: https://www.gasfoundation.org/wp-content/uploads/2019/12/AGF-2019-RNG-Study-Full-Report-FINAL-12-18-19.pdf.

4.4 Producing and transporting carbon-neutral hydrogen

Both new and existing infrastructure is needed to produce and deliver carbon-neutral hydrogen to industry, transportation, and other sectors. Across the modeled scenarios, demand for and supply of hydrogen are modeled to increase to 100 - 235 TBtu by 2035 and 350 – 780 TBtu by 2050 (Exhibit 4.3).

Exhibit 4.3: California demand for carbon-neutral hydrogen



Hydrogen supply

- SMR: Steam methane reformation (SMR) produces the vast majority of hydrogen in California today and is a fossil fuel-intensive process with carbon emissions. SMR-based hydrogen can have a lower carbon footprint when coupled with CCUS, producing what is often referred to as "blue" hydrogen.[88] For it to be carbon-neutral, this blue hydrogen would have to be produced from methane that is free from fugitive emissions along the value chain. Given that SMR capacity is already built out in California today and the technology is mature and proven to be viable, SMR will likely play a role in the ramp up of hydrogen production across California.

[88]Department of Energy, Office of Energy Efficiency and Renewable Energy, "Hydrogen Production: Natural Gas Reforming," available at: https://www.energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming.

- Electrolysis: Over time, renewably powered electrolysis, often referred to as "green" hydrogen, becomes an increasingly important contributor to carbon-neutral hydrogen supply. Electrolytic hydrogen is expected to come down the cost curve - especially in this decade- driven both by forecasted reductions in electrolyzer capex and by very low marginal cost of electricity from increasing renewables. Assuming electrolyzers have access to wholesale electric rates or are directly co-located with by renewables, low-cost hydrogen – reaching values below approximately $2/kg - could be produced.[89]

  Additionally, the results of the decarbonization scenarios modeling demonstrate that electrolysis could become an important resource for integration of renewables into the electric system. Electrolysis is able to quickly ramp up and down to meet electric system needs – consuming electricity when supply is high and demand is low, and thus reducing curtailment, and shutting down when demand increases from less flexible end-uses.[90] If operated in a system-optimized way, electrolyzers' value as a flexible load is significant; as a result, least-cost optimization modeling selects an increasing proportion of hydrogen to be produced from electrolysis over time.

- Other hydrogen supply technologies: More recent technologies could play an important role in carbon-neutral hydrogen production including: (1) Bioenergy with carbon capture and storage (BECCS) wherein biomass is converted into hydrogen with the resulting carbon emissions captured and stored, potentially resulting in net negative carbon; (2) Methane pyrolysis: a high-temperature process through which methane is converted into hydrogen and solid carbon; and (3) Autothermal reforming (ATR): ATR converts traditional natural gas to syngas, a combination of hydrogen and carbon monoxide, which can then be separated to produce pure hydrogen.[91] Given the recent scaling up of hydrogen, the scale of innovation has been dramatically accelerating with many new approaches and technologies to produce hydrogen on the horizon. Monitoring technical developments for these and other clean fuel technologies to continuously refine the assumptions that can inform California's path to decarbonization will be important.

Hydrogen transportation and storage infrastructure

Hydrogen transportation has an advantage of being able to use existing infrastructure by either blending in hydrogen alongside natural gas or potentially retrofitting existing infrastructure to carry hydrogen. Blending could be a potential solution where the percentage of volume of hydrogen needing to be transported alongside methane remains relatively low. Where higher concentrations of hydrogen are needed, delivery infrastructure will either need full retrofits or new infrastructure. Additionally, new delivery infrastructure could be needed to deliver hydrogen at significant volumes to industrial customers and long-haul trucking refueling stations where adequate pipeline capacity does not exist today, or if separation technologies cannot produce pure enough hydrogen for dedicated end-uses.

---

[89] Bloomberg New Energy Finance, "Hydrogen Economy Outlook," p. 4, March 2020, available at: https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf.
[90] International Renewable Energy Agency, "Renewable Power-to-Hydrogen: Innovation Landscape Brief," 2019, available at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Power-to-Hydrogen_Innovation_2019.pdf.
[91] Air Liquide, "Autothermal Reforming (ATR) - Syngas Generation," 2021, available at: https://www.engineering-airliquide.com/autothermal-reforming-atr-syngas-generation.

Blending: Hydrogen can leverage the current natural gas system through blending hydrogen alongside natural gas in existing gas transmission and delivery infrastructure. Significant research and pilots are underway across the industry to determine the level of hydrogen blending that can safely occur within different components of current natural gas transmission and delivery infrastructure:

- National Renewables Energy Laboratory (NREL)[92] and other gas and transmission and delivery infrastructure studies have indicated that softer steel transmission pipelines could potentially tolerate 20% hydrogen blending (by volume) whereas plastic distribution pipelines have relatively high blending tolerances.

- In Germany, a technical standard sets the hydrogen blending limit at 10% by volume; however, several trials have tested higher admixture rates.[93]

- Italy's Snam successfully completed a trial in December 2019 carrying 10% hydrogen via transmission pipelines to two industrial customers; the utility is assessing the condition of its grid in order to blend hydrogen more broadly.[94]

- In Australia, a government-endorsed study found that 10% hydrogen by volume could be blended with no modifications to pipelines or appliances. Australian Gas Infrastructure Group plans to blend 5% hydrogen into the gas supply of 700 homes.[95]

Based upon literature review and the latest pilot findings, the analysis tests the impact of different pipelines blending tolerances ranging from 5-20%, with variation across the scenarios. Investment requirements were estimated for required upgrades to other components of the gas transmission and delivery system, like compressor stations.[96] There are also technologies that could be needed to manage the complexity of transporting blended hydrogen:

- Blending stations: These facilities extract natural gas from a pipeline, mix it with hydrogen, and inject the blended gas back into the pipeline. This process helps avoid uneven mixing and acute pockets of hydrogen that could cause pipeline embrittlement.

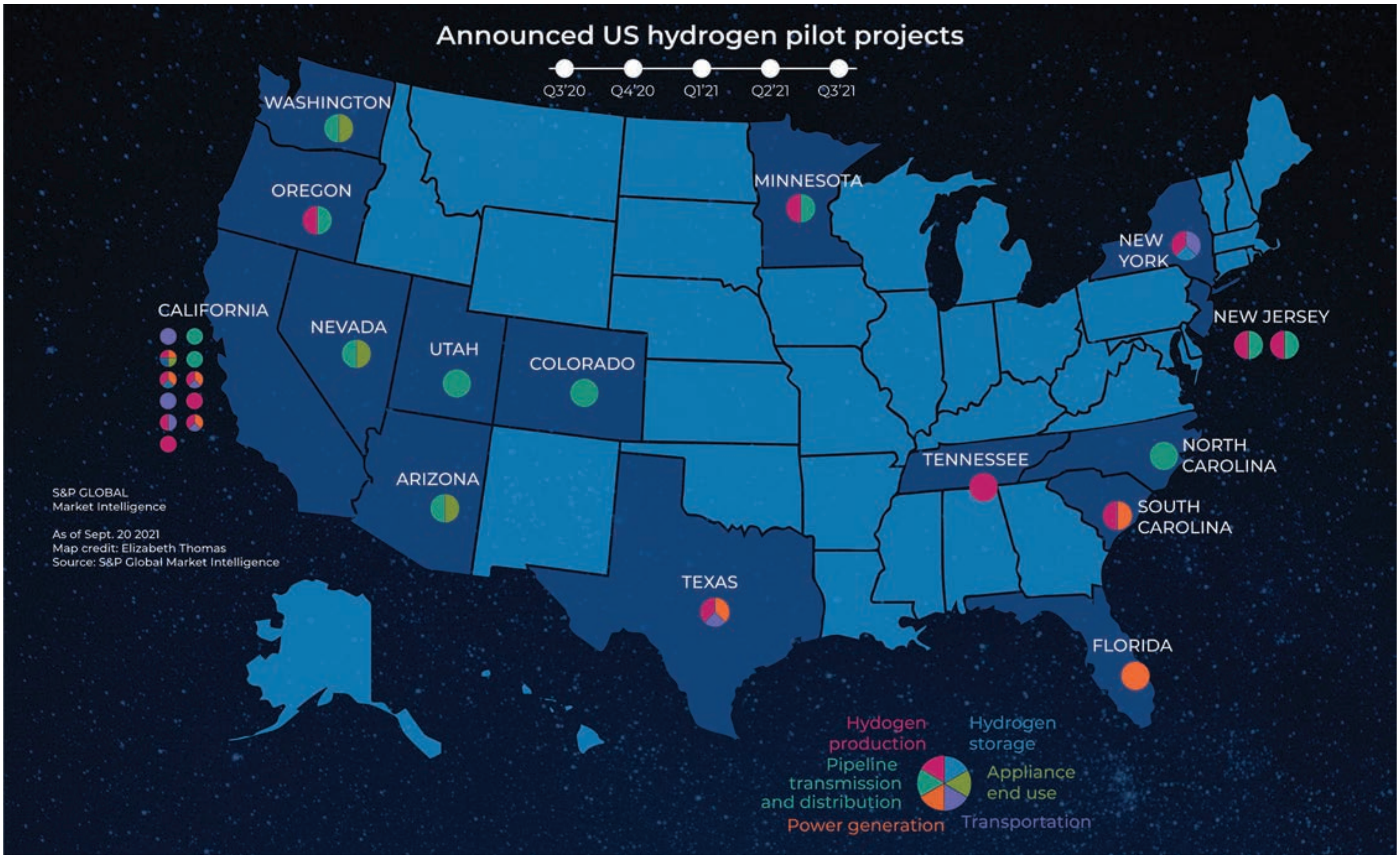
- Separation technology: Technologies such as pressure-swing adsorption (PSA), membranes, and electrochemical hydrogen purification and compression (EHPC) can separate hydrogen from natural gas. Pressure-swing adsorption is an established, widely used process in industry today, although its large size and gas volume requirements do not necessarily make it the optimal solution for all potential hydrogen end-users within California. The costs of membranes and EHPC equipment are rapidly coming down the cost curve as deployment and testing ramps up. Whether separation technologies can produce sufficiently pure hydrogen for dedicated end uses, like FCEVs, has yet to be tested at scale.

---

[92] Melaina et al., "Blending Hydrogen into Natural Gas Pipeline Networks; A Review of Key Issues," National Renewable Energy Laboratory (NREL/TP-5600-51995), March 2013, available at: https://www.nrel.gov/docs/fy13osti/51995.pdf.
[93] Radowitz, B., "E.ON to convert natural gas pipeline to carry pure hydrogen," Recharge News, November 2020, available at: https://www.rechargenews.com/transition/e-on-to-convert-natural-gas-pipeline-to-carry-pure-hydrogen/2-1-910119.
[94] Jewkes, S., "Italy drafts guidelines for national hydrogen strategy, document shows," Reuters, November 2020, available at: https://www.reuters.com/article/us-italy-hydrogen-idUKKBN27W1VI.
[95] "Australia's Gas Infrastructure Owners Test Hydrogen Blending," Journal of Petroleum Technology, February 2021, available at: https://jpt.spe.org/australias-gas-infrastructure-owners-test-hydrogen-blending.
[96] Siemens Energy, "Hydrogen infrastructure – the pillar of energy transition: The practical conversion of long-distance gas networks to hydrogen operation," 2020, available at: https://assets.siemens-energy.com/siemens/assets/api/uuid:3d4339dc-434e-4692-81a0-a55adbcaa92e/200915-whitepaper-h2-infrastructure-en.pdf; HyGrid, "Flexible Hybrid Separation System for H2 Recovery from NG Grids," August 2016; IEA Greenhouse Gas R&D Programme, "Reduction of CO2 Emissions by Adding Hydrogen to Natural Gas," Report No. PH4/24, October 2003, available at: https://ieaghg.org/docs/General_Docs/Reports/Ph4-24%20Hydrogen%20in%20nat%20gas.pdf.

With further research, testing, and innovation that is already underway there could be opportunities to further increase the amount of hydrogen currently blended into the natural gas system which would lower the overall costs of transporting and delivering hydrogen and further usage of existing infrastructure. SoCalGas is testing and demonstrating the viability of hydrogen blending[97], and is collaborating with California's other gas utilities, research institutions and the California Energy Commission to develop a hydrogen blending standard for regulatory review.[98] The research, testing, and demonstration efforts that are currently under way will inform the viability assessment and cost estimates of the scenarios in this analysis.

Exhibit 4.4 – Announced U.S. hydrogen pilot projects[99]



Pure hydrogen transmission and delivery

Given the challenges and potential limitations of retrofitting existing natural gas infrastructure and end-uses to accommodate high hydrogen concentrations, it is likely that a dedicated hydrogen transportation network is a more cost-effective means of delivering large volumes of hydrogen to dedicated end-uses, such as industrial customers and transportation hubs. Accordingly, the hydrogen for pipeline blending shown in Exhibit 4.3 in the High Carbon Sequestration scenario was assumed to be delivered via dedicated pipeline to specific parts of the gas network, rather than blended across the entire system.

[97]See, https://newsroom.socalgas.com/press-release/socalgas-among-first-in-the-nation-to-test-hydrogen-blending-in-real-world.

[98]CPUC, "Joint Application of Southern California Gas Company (U 904 G), San Diego Gas & Electric Company (U 902 G), Pacific Gas and Electric Company (U 39 G), and Southwest Gas Corporate (U 905 G) regarding hydrogen-related additions or revisions to the standard renewable gas interconnection tariff," November 2020, available at: https://www.socalgas.com/sites/default/files/2020-11/Utilities_Joint_Application_Prelim_H²_Injection_Standard_11-20-20.pdf.

[99]Authorized for republication and use by S&P Global Market Intelligence.

Creating infrastructure capable of delivering pure hydrogen could still leverage existing infrastructure. For example:

- In the UK, the H21 project seeks to convert gas grids across the North of England (e.g., the city of Leeds) to pure hydrogen between 2028 and 2035; this includes converting natural gas distribution pipelines, appliances, and 3.7 million meter points for 100% hydrogen use.[100]

- Utility E.ON has announced it will retrofit a natural gas pipeline to carry 100% hydrogen.[101]

However, where infrastructure does not exist today, or capacity is inadequate for delivery of pure hydrogen, new infrastructure will need to be developed. To that end, SoCalGas can evaluate investments in dedicated hydrogen pipelines; for example, in order to provide hydrogen to industrial clusters. As the cost of hydrogen declines and demand increases, this initial dedicated hydrogen infrastructure to industrial clusters could be built up to meet growing demand for decarbonized fuel over time. This concept is described in greater detail in a later section.

There are two other options for delivering pure hydrogen outside of using pipeline infrastructure:

- On-site hydrogen production: for relatively small volumes this could be feasible. At larger volumes, siting constraints near areas of consumption (e.g., hydrogen refueling stations or power plants) become considerable given the size of the electrolyzer, electric delivery infrastructure, and hydrogen storage needs (e.g., a tank).
- Hydrogen trucking: For shorter distances and low volumes of hydrogen, trucking may be an economic transportation option. The results of the analysis supporting this work found that large volumes of hydrogen exceed levels where hydrogen trucking would be cost-effective.

Hydrogen storage

With hydrogen produced from intermittent renewables, hydrogen storage becomes a needed investment for a clean fuels system. The amount of hydrogen storage needed will be largely dependent on the fluctuations in green hydrogen production and the amount of hydrogen needed for grid reliability and local resource adequacy. Grid reliability and local resource adequacy will rise in importance in a fully decarbonized California when low solar and wind energy production may periodically occur for long periods of time. Hydrogen storage is a critical tool to address these needs. Seasonal demand volatility for hydrogen may be less significant than what is experienced by the natural gas system today, given that transportation demand is less seasonal.

There are several solutions for hydrogen storage including aboveground storage tanks, ammonia storage, and salt caverns such as those found in Delta, Utah. SoCalGas' underground storage facilities are all depleted reservoirs. If hydrogen were blended and stored in these existing facilities, issues such as biomethanation and hydrogen sulfide formation may arise, even at hydrogen concentrations less than 10% by volume. However, if further research and development reduced those technical barriers, existing underground gas storage facilities could provide a more cost-effective storage solution. SoCalGas will also study other storage alternatives such as ammonia and hard rock caverns to better understand a full spectrum of hydrogen storage options, capable of meeting needs of our customers in a decarbonized future.

---

[100] H21, "H21 North of England," available at: https://h21.green/projects/h21-north-of-england/.

[101] Radowitz, B., "E.ON to convert natural gas pipeline to carry pure hydrogen," Recharge News, November 2020, available at: https://www.rechargenews.com/transition/e-on-to-convert-natural-gas-pipeline-to-carry-pure-hydrogen/2-1-910119.

4.5 Carbon management

All scenarios discussed herein reach net-zero carbon, relying to some degree on carbon management through carbon capture and utilization or sequestration (Exhibit 4.3).

Carbon sources: Even in a fully decarbonized end-state, across all scenarios, CO2 continues to be emitted from: (a) industry; (b) biofuels production; and (c) aviation. Additionally, in some of the scenarios modeled, there is further CO2 emitted from (d) steam methane reformation; (e) remaining natural gas in buildings; and (f) natural gas-powered thermal generation plants. The carbon can be captured more efficiently from high CO2 concentration waste gases at large stationary carbon sources or from the ambient atmosphere using direct air capture (DAC).

Carbon sinks: Carbon can be sequestered via permanent geologic storage in saline reservoirs or oil and gas reservoirs. While most carbon sequestration today occurs in the process of enhanced oil recovery (EOR), long-term carbon sequestration in saline aquifers or oil and gas reservoirs would be necessary in high sequestration pathways. Research shows that the potential for saline aquifer sequestration in California is significant and likely adequate to meet the levels of carbon sequestration needed in California.[102]

Different saline aquifers have different potential injection rates and associated costs of injection. This analysis assumes a "supply curve" of carbon sequestration: initial, smaller volumes of carbon can be sequestered at relatively lower cost; as volumes of sequestered carbon increase, higher-cost sequestration sites are needed.[103]

Alternatively, carbon can be captured and used as a feedstock to produce carbon-neutral fuels via power-to-liquids processes in combination with hydrogen. These fuels then enable decarbonization of the transportation sector.

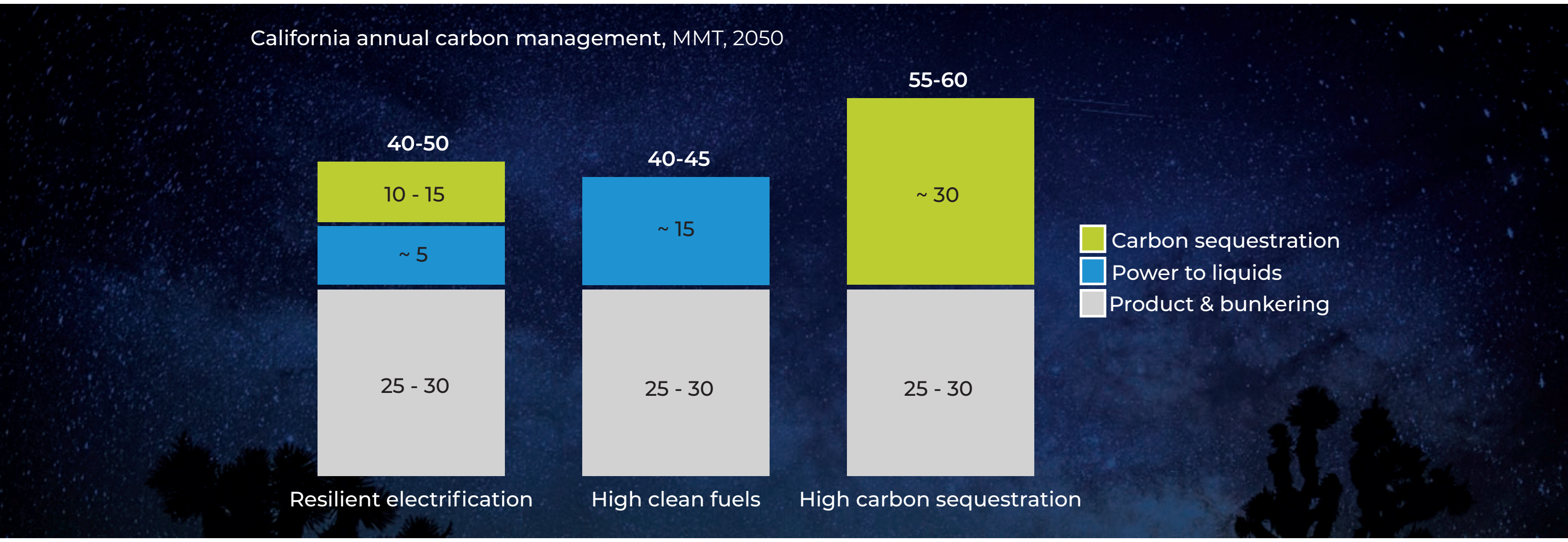
Beyond carbon sequestration and power-to liquids, emissions can be abated in two additional ways:

1. Products, like asphalt and plastics, use carbon as a feedstock. If this carbon comes from traditional fuels, the emissions and capture of those emissions within the product nets to zero.[104]

2. Bunkering, as defined in this analysis, refers to the reduction of emissions from parts of the economy that otherwise would not be required to reduce emissions under the California Air Resource's Board most recent emissions inventory. Today, aviation and shipping-related emissions are only accounted for if they come from intra-state travel.[105] These scenarios assume that over time, inter-state aviation and shipping emissions will be regulated and required to decarbonize. Therefore, in the near term, bunkering emissions from inter-state travel are relatively high. As the assumed potential for bunkering declines over time, the remaining bunkering that occurs comes only from international shipping and aviation.

[102] Stanford Energy Futures Initiative, "An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions," p. 52, October 2020, available at: https://static1.squarespace.com/static/58ec123cb3db2bd94e057628/t/5fda383062e28f00961c98db/1608136765723/EFI-Stanford-CA-CCS-FULL-rev2-12.11.20.pdf.
[103] US Department of Energy, National Energy Technology Laboratory, Carbon Storage Program; NETL CO2 Saline Storage Cost Model; available at: https://netl.doe.gov/energy-analysis/details?id=2403.
[104] Oliveira et al., "Achieving negative emissions in plastics life cycles through the conversion of biomass feedstock," 15 Biofuels, Bioprod. Bioref. 430, March 2021.
[105] California Air Resources Board, "California Greenhouse Gas Emissions for 2000 to 2019, Trends of Emissions and Other Indicators," p. 9, July 2021, available at: https://ww3.arb.ca.gov/cc/inventory/pubs/reports/2000_2019/ghg_inventory_trends_00-19.pdf.

Exhibit 4.5 Carbon management[106]



Carbon distribution/transportation

A clean fuels network could also be used for carbon management linking sources of CO2 emissions (thermal generation, industry, DAC) to consumers or sinks of CO2 (synthetic fuels production facilities and storage sites) with investment as a catalyst to help accelerate regional decarbonization and create an innovation engine to export new technologies. In addition, investing in the infrastructure to meet these customers' needs early on is key to helping maintain affordability and viability for these critical parts of the California economy.

Carbon can be moved from sources to sinks in one of three ways:

1. CO2 pipelines: CO2 pipelines are likely most applicable to cost-effectively transport CO2 molecules at scale over long distances. Additionally, pipelines are likely needed for emitters who cannot co-locate with sequestration or utilization sites. When building new pipelines, high pressure allows for a dense phase state and can reduce overall transport cost per ton CO2.[107] It is likely that new pipelines and associated infrastructure (compressors, pumps) to transport CO2 would need to be built, or, alternatively, direct pipeline retrofits will transport CO2 at lower pressures and higher subsequent operational cost.

2. Co-location: Carbon emitters may in certain cases co-locate with carbon sequestration sites to minimize costs associated with transporting carbon to its ultimate sink. For example, Direct Air Capture facilities are likely to be developed directly proximate to sequestration sites to eliminate carbon transportation costs, as well as proximate to high quality renewables to minimize energy costs. Similarly, power-to-liquid facilities and other consumers of carbon could co-locate near emitters for low-cost access to carbon or co-locate near high quality renewables for lower cost hydrogen, ideally both.

3. Carbon trucking: For shorter distances and very low volumes of carbon, trucking may be an economic transportation option.

[106] As discussed above, note that the High Clean Fuels scenario did not allow carbon sequestration.

[107] Doctor et al., "IPCC Special Report on Carbon Dioxide Capture and Storage, Chapter 4, Transport of CO2," p. 184, March 2018, available at: https://www.ipcc.ch/site/assets/uploads/2018/03/srccs_chapter4-1.pdf

4.6 California efforts underway to create a clean fuels network

In addition to the aforementioned conversion of the Intermountain Power Plant, the Request For Information (RFI) recently issued by LADWP (August 5, 2021), and the studies commissioned by the California Air Resources Board and the California Energy Commission, stakeholders across the state have been laying the groundwork for California's clean fuels network. Notably, LADWP has stated its intent to convert many of its plants to be hydrogen-ready. Plants are expected for an estimated 30% blend by 2025 with plans to fully convert several plants to be capable of handling 100% hydrogen by 2045.[108]

The state has a goal of 200 hydrogen stations by 2025, in addition to 250,000 electric vehicle chargers. [109] As of October 1, 2021, there were 47 hydrogen stations available in California, with 80 additional stations in various degrees of development.[110] Most of those stations are supplied by trucks today given relatively low volumes compared to what would be required in a decarbonized California, with one Shell station in Torrance supplied by a hydrogen pipeline.[111] A broader network of hydrogen pipelines could catalyze the expansion of hydrogen refueling stations.

SoCalGas is collaborating with California's other gas utilities and with research institutions to develop a hydrogen blending standard for regulatory review. The research, testing, and demonstration efforts that are currently underway inform the viability assessment and cost estimates of the modeled scenarios.[112] In December 2020, SoCalGas announced a partnership with HyET Hydrogen to test EHPC technology for extracting hydrogen from a blended gas stream.[113] Additionally, SoCalGas expects to break ground on its H2 Hydrogen Home project in late 2021, as a state-of-the-art demonstration of a hydrogen-powered house.[114]

On the biogas front, the California Department of Food and Agriculture (CDFA) sponsors a Dairy Digester Research and Development Program (DDRDP), with funding coming from California Climate Investments.[115] Entities that install dairy anaerobic digesters in California, thereby reducing greenhouse gas emissions, can receive financial assistance for those investments. SoCalGas is a stakeholder in the adoption of biogas, having committed to 5% RNG being delivered in its system for core customers by 2022 and 20% RNG by 2030.[116]

---

[108] Tucker, C., "Transforming LA's Last Coal Plant to Help Reach 100% Renewable Energy," available at: http://www.ladwpintake.com/the-future-of-ipp-is-green/.

[109] California Governor's Executive Order B-48-18, January 2018, available at: https://www.ca.gov/archive/gov39/2018/01/26/governor-brown-takes-action-to-increase-zero-emission-vehicles-fund-new-climate-investments/index.html

[110] California Fuel Cell Partnership (CAFCP), "By the Numbers – FCEV Sales, FCEB, & Hydrogen Station Data," available at: https://cafcp.org/by_the_numbers.

[111] PR Newswire, "Air Products Selected for Technology Upgrade at Shell Hydrogen Fueling Station in Torrance, California," November 2016, available at:https://www.prnewswire.com/news-releases/air-products-selected-for-technology-upgrade-at-shell-hydrogen-fueling-station-in-torrance-california-300363279.html.

[112] Modeling and analysis performed in this document relies upon assumptions currently available from broader literature, expert interviews, and SoCalGas experts.

[113] PR Newswire, "SoCalGas to Test Technology that Could Transform Hydrogen Distribution and Enable Rapid Expansion of Hydrogen Fueling Stations," December 2020, available at: https://www.prnewswire.com/news-releases/socalgas-to-test-technology-that-could-transform-hydrogen-distribution-and-enable-rapid-expansion-of-hydrogen-fueling-stations-301194342.html.

[114] Sempra, "Hydrogen's Role in Clean Energy to Take the Spotlight in SoCalGas' 'H2 Hydrogen Home,'" December 2020, available at: https://sempra.mediaroom.com/index.php?s=19080&item=137866. The demonstration project includes natural gas blending for appliances.

[115] California Department of Food and Agriculture, Dairy Digester Research & Development Program, https://www.cdfa.ca.gov/oefi/ddrdp/.

[116] SoCalGas, "Imagine the Possibilities," p. 4, April 2019, available at: https://www.socalgas.com/sites/default/files/2020-02/VisionPaper_Executive_Summary.pdf.

SoCalGas is unequivocally supportive of electrification as one important implement for decarbonizing. This analysis demonstrates the viability and need for a future clean fuels network, as a complement to electrification, to allow California to achieve full decarbonization. A clean fuels network provides multiple benefits, especially through the last 20% of emissions, and so that the decarbonization transition is affordable, provides reliability and resiliency, reduces reliance on nascent technologies, and helps mitigate potential customer conversion issues.

The value of clean fuels and a clean fuels network can be measured and evaluated in several different ways. A clean fuels approach is projected by this analysis to save energy customers between $45 billion and $75 billion over the course of the next 30 years in avoided costs, including for infrastructure, operations and customer equipment, that would otherwise be needed without a clean fuels network.[117] Furthermore, the additional value of providing a clear pathway to address hard-to-abate sectors and an affordable, proven path to resiliency is hard to measure in monetary terms. This study did not attempt to put a monetary value on increased resiliency, nor did it quantify the economic impact of industrial customers potentially having less access to a fuel pipeline for processes that cannot be electrified.

The three most affordable, resilient, and technologically proven deep decarbonization pathways require clean fuels and a supporting clean fuels network. The No Fuels System scenario also relies more heavily upon unproven technologies such as multi-day storage solutions. In addition, clean fuels will be required to reach full net-zero in hard-to-abate sectors such as industry with high temperature heat processing that is unlikely to be cost effectively electrified.

Today, the existing natural gas infrastructure supports the reliability and affordability of California's energy system. In the future, clean fuels (e.g., hydrogen, biogas, carbon management) have the potential to decarbonize up to a significant portion of California's energy supply in a clean, resilient, and affordable energy system.

Under the more cost-effective scenarios modeled, clean thermal generation (i.e., hydrogen combustion, biogas combustion, methane combustion with carbon capture) is critical to maintain the affordability and resilience of the electricity network in a net-zero future. A clean fuels network to support clean thermal generation is the most economical solution modeled. All scenarios studied highlighted a significant increase in renewable energy from ~30 GW today to ~225 - 300 GW of wind and solar in 2050. Our analysis also found that alternative sources of energy are needed to meet demand in instances of multi-day 'flexibility' events where renewables cannot meet demand because of a combination of peaking demand and lower renewable resources. Current commercially proven battery storage solutions cannot presently meet the needs of those long-duration flexibility events. Across the plausible scenarios modeled, roughly 35-50 GW (vs. 35 GW of natural gas generation today) of thermal generation capacity is projected to be needed in California to affordably support a reliable and resilient electric system.

[117]This study estimates California's economy-wide cost to produce, deliver, and consume energy from 2020-2050. Costs vary depending on the demand side inputs and supply side assumptions and constraints applied to each scenario. Additional details can be found in the Appendix.

A clean fuels network supports decarbonization and electrification. Clean fuels and a clean fuels network fill several valuable roles in a decarbonized world:

- Resiliency: Underground gas networks are less susceptible to fire risk, climate risk, and public safety power shutoffs than the electric system in California. A clean fuels network can enable critical resiliency by delivering clean fuels directly to customers and by enabling resiliency in the electric network by providing clean fuels to distributed generation (e.g., fuel cells) in wildfire risk areas or critical portions of the network, such as downtown Los Angeles, which is particularly important in the high electrification scenario.

- Supporting electricity decarbonization: Clean fuels and a clean fuels network can further support the electric grid by providing flexible peaking capacity particularly in constrained zones, like the Los Angeles Basin, where it is more challenging to expand electric infrastructure to support the additional load that will result from vehicle and building electrification.

- Providing decarbonized energy for customer end-uses: While building electrification is presumed to provide an affordable decarbonization pathway for numerous buildings and applications in California, even with ~60-95% of building space heating assumed to be electrified by 2050 across the three most plausible scenarios— there is still a role for a clean fuels infrastructure to support buildings in decarbonizing. In buildings where electrification is not cost effective or feasible, appliances that currently rely upon natural gas could in the future use clean fuels. Biogas, synthetic natural gas, natural gas offset by carbon sequestration, utilization, product or bunkering, and a limited amount of hydrogen blended with natural gas could provide these customers with decarbonized fuels that work with today's appliances.

- Providing infrastructure for carbon management: Pipelines to enable carbon management could be a critical part of a clean fuels network that enables California carbon neutrality goals. All scenarios highlighted a need for carbon capture and utilization, sequestration or both. The scale of carbon management ranges from 15-30 MMT of CO2 that is captured and either used (e.g., through "power-to-liquids" conversion) or sequestered. Given the significant volume of carbon and the distance between potential carbon capture sites to where it would be used or sequestered, pipelines become a potentially effective option to transport the carbon from "source" to "sink.

- Enabling diversification that helps lower risk: Pursuing a diverse set of decarbonization levers reduces the risk of over-dependence on any one technology or set of technologies, so continuing to scale different technologies and decarbonization tools can de-risk California's decarbonization pathways in an uncertain environment. Diversification also minimizes other risks such as "single points of failure." For example, multiple infrastructure options to deliver energy (e.g., both molecules and electrons) could reduce risk versus a system reliant upon one method of energy delivery.

Several public studies have highlighted the importance of clean fuels and a supporting clean fuels network.

- **LA100:** The Los Angeles 100% Renewable Energy Study by produced under the direction of the Los Angeles Department of Water and Power (LADWP) by the National Renewable Energy Laboratory (NREL) highlights the need for "renewably produced and storable fuels" to maintain reliability in the power sector.[118]

- **The Rocky Mountain Institute** highlights the critical role hydrogen plays in decarbonizing industry: "When considering what a global energy system on a 1.5°C or 2°C pathway will look like by 2050, hydrogen consistently plays a critical role as an energy carrier. The industrial processes used in the production of things like steel, cement, glass, and chemicals all require high temperature heat. For these hard-to-abate sectors, there is essentially no way to reach net-zero emissions at the scale required without using hydrogen." [119]

- **The Columbia Center on Global Energy Policy**, expresses that "for many of the needs natural gas currently meets, the eventual replacement may be zero-carbon gaseous fuels (e.g., hydrogen, biogas)."[120] It notes that "[t]hese fuels may play a significant role in supporting reliability and making the energy transition more affordable—but they, too, will require a pipeline network for efficient delivery to markets and end users."

- **The American Gas Foundation** highlights the resiliency value of a gas system that provides a form of energy storage with long duration and seasonal storage capabilities, that is underground and so less exposed to physical disruption, and has operational flexibility designed into it.[121]

- **The Hydrogen Council** has highlighted the significant potential of decarbonized hydrogen to decarbonize over 22 end-uses including industry and heavy duty-trucking. It also emphasized the potential for blending of hydrogen into existing gas pipelines.[122] [123]

---

[118]Cochran et al., "LA100: The Los Angeles 100% Renewable Energy Study," National Renewable Energy Laboratory, NREL/TP-6A20-79444, Executive Summary, p. 14, available at: https://maps.nrel.gov/la100/report.
[119]Rocky Mountain Institute, "Hydrogen's Decarbonization Impact for Industry: Near-term challenges and long-term potential," January 2020, available at: https://rmi.org/wp-content/uploads/2020/01/hydrogen_insight_brief.pdf.
[120]Blanton et al., "Investing in the US Natural Gas Pipeline System to Support Net-Zero Targets," Columbia Center on Global Energy Policy, April 2021, available at: https://www.energypolicy.columbia.edu/research/report/investing-us-natural-gas-pipeline-system-support-net-zero-targets.
[121]American Gas Foundation, "Building a Resilient Energy Future: How the Gas System Contributes to US Energy System Resilience," January 2021, available at: https://gasfoundation.org/wp-content/uploads/2021/01/Building-a-Resilient-Energy-Future-Full-Report_FINAL_1.13.21.pdf.
[122]Hydrogen Council, "Path to hydrogen competitiveness: A cost perspective," January 20, 2020, available at: https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf.
[123]Hydrogen Council, "Hydrogen Insights: A perspective on hydrogen investment, market development and cost competitiveness," February 2021, available at: https://hydrogencouncil.com/wp-content/uploads/2021/02/Hydrogen-Insights-2021-Report.pdf.

Scenarios resulting in the most successful economy-wide decarbonization highlight the importance and value of a clean fuels approach. Establishing a clean fuels network in Southern California will require a combination of existing infrastructure and developing new infrastructure. While much of the technology necessary is generally established, research will be needed to confirm viability and drive continued cost reduction. To achieve this level of investment, near-term market transformation will likely be required to meet the necessary timeline of having adequate clean fuels capacity in place to enable California's decarbonization. Achieving the clean fuels vision requires near-term action, including investment that should occur between now and the end of the decade, piloting and testing to continue to confirm viability of different approaches and to drive down the cost curve in the future, and market activation. It is worth noting that all decarbonization pathways also require use of existing and development of new electric transmission and distribution infrastructure. The focus of this study is only on infrastructure directly related to clean fuels.

6.1 Building the infrastructure

Based on high-level estimates, unlocking the benefits of clean fuels and a clean fuels network in SoCalGas territory could require approximately $60 billion of investment across four areas: (1) hydrogen transportation, storage, and distribution, (2) carbon management transportation, (3) hydrogen production, and (4) downstream clean fuels investments (e.g., fuel cells and refueling stations).[124] These projected energy supply chain investments could be driven by a combination of utility and energy market participants. Creating a clean fuels network should leverage existing infrastructure where feasible to keep overall system costs lower. According to this analysis, an estimated $9-13 billion of the investment in Southern California would be needed between now and 2031 to achieve the most plausible pathways. As discussed in section 4, this level of investment results in a lower overall cost system than the scenario that does not include a clean fuels network (the "No Fuels Network" scenario) as well as provides a higher level of resiliency, solutions for hard-to-abate sectors, reliability and resource adequacy, optionality and diversification.

Hydrogen transportation: Building the infrastructure required to transport hydrogen would likely require approximately $35 billion of investments over the next 30 years primarily to develop new hydrogen pipelines, hydrogen storage and some system upgrades to enable hydrogen blending in the existing infrastructure.[125]

Clean fuels transportation can take significant advantage of reusing existing infrastructure to accelerate clean fuels adoption. Biogas, synthetic natural gas, and potentially hydrogen blending all provide tools to achieve decarbonization goals without major changes in infrastructure. Biogas and synthetic natural gas are "drop-in fuels" which, when cleaned, can be immediately used wherever traditional natural gas is used today. These zero- or even negative-carbon fuels could therefore be transported by today's infrastructure.

[124] Based on high level estimates based on the High Carbon Sequestration scenario

[125] Based on high level estimates for SoCalGas territory based on the High Carbon Sequestration scenario

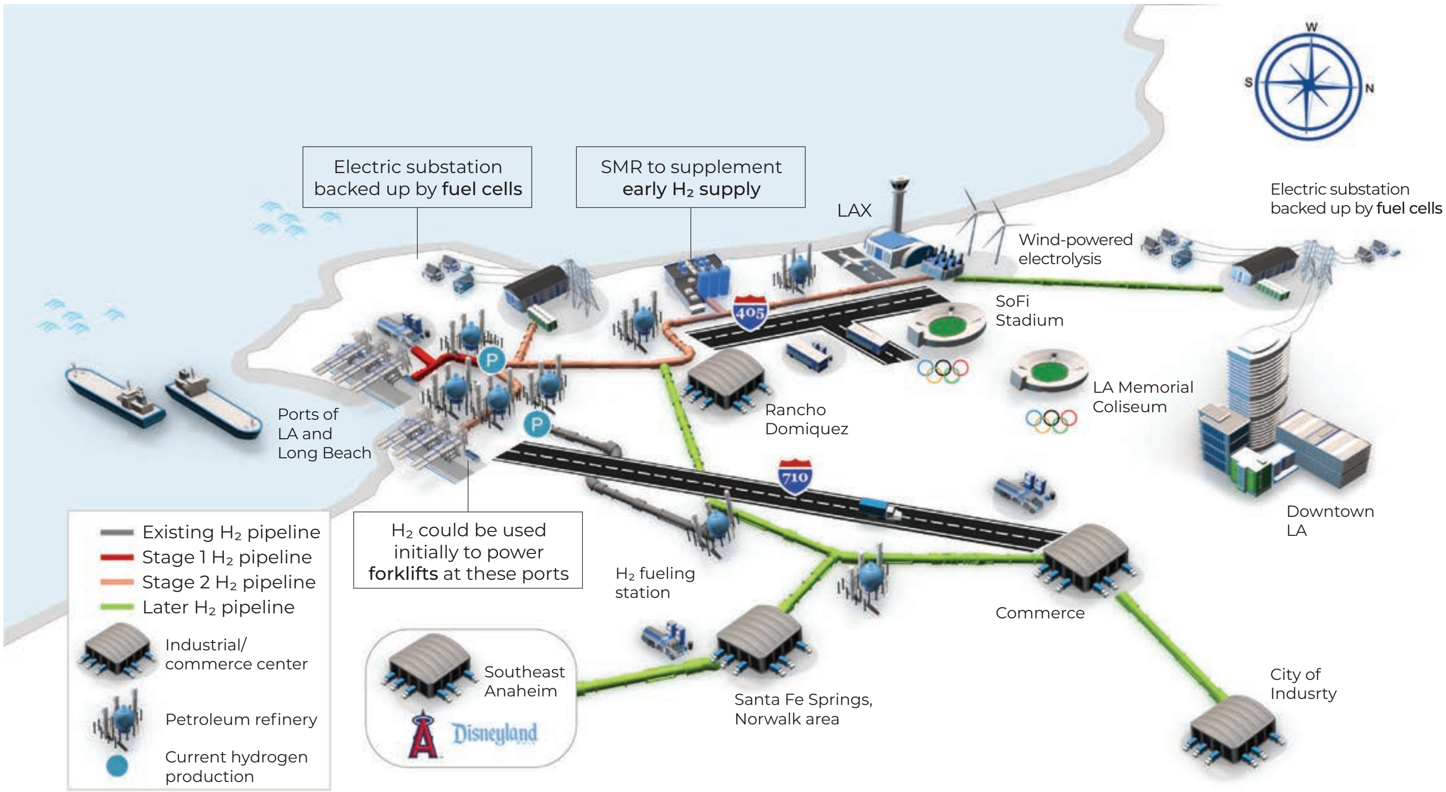
Biogas and synthetic natural gas are “drop-in fuels” which, when cleaned, can be immediately used wherever traditional natural gas is used today. These zero- or even negative-carbon fuels could therefore be transported by today’s infrastructure. Furthermore, international studies performed on pipelines and related infrastructure show that that existing natural gas infrastructure can be leveraged to transport hydrogen.[126] For example, 69% of the pipelines needed to build a European Hydrogen Backbone can come from re-purposing existing natural gas pipelines.[127] Other studies on US systems such as the April 2021 report from the Center on Global Energy Policy at Columbia University highlights that “the US has 2.5 million miles of natural gas pipeline infrastructure across the country, which, with investment, could be upgraded to cut emissions and be retrofitted for future transport of cleaner fuels.” Studies on California’s infrastructure are already underway to determine the viability of safely blending hydrogen in the existing infrastructure at varying volumes. Repurposing the existing infrastructure can provide significant cost savings if feasible – for example, according to our analysis, using existing infrastructure to blend 20% of hydrogen could reduce infrastructure costs in California by an order of magnitude of up to $20 billion over 30 years.

Dedicated hydrogen pipeline infrastructure could also be needed. For example, dedicated end-uses, such as hydrogen refueling stations, may not find it feasible to extract hydrogen from a blended pipeline cost effectively or at the purity needed. Additionally, if hydrogen cannot be blended into existing pipelines without significant retrofits to infrastructure and/or end-use appliances, a specific region with concentrated hydrogen consumption may be more cost effective than a system with hydrogen blending throughout. Additionally, if retrofits are needed to accommodate hydrogen blending, large transmission pipes that deliver natural gas today may be unable to be shut down for the time it takes to fully retrofit, necessitating building new parallel hydrogen pipelines. The end-states modeled show that the use of hydrogen to facilitate decarbonization of industry and heavy-duty transportation, aviation, and shipping ramps up in the 2030s timeframe. Based on these projections, infrastructure to deliver that hydrogen safely and reliably would need to be in place over the next decade.

Hydrogen delivery infrastructure could be scaled incrementally, starting with geographically concentrated clusters of demand where hydrogen is more cost effective in the near-term. For example, the Ports of Los Angeles and Long Beach may serve as a near-term source of demand for hydrogen for heavy-duty drayage trucks and forklifts and potentially for marine fueling, as well as for industrial needs near the ports. A concentrated network of hydrogen pipelines to serve the ports could be gradually built up to serve a wider geographic area, meeting the needs of more industrial customers and power generation stations in the Los Angeles basin, providing resiliency to the electric system through combined heat and power or fuel cells, and providing fuel to hydrogen refueling stations.

[126]United Kingdom Health and Safety Executive, “RR1047 Injecting hydrogen into the gas network - a literature search,” 2015, available at: https://www.hse.gov.uk/research/rrpdf/rr1047.pdf; see also Gas Technology Institute, “Review Studies of Hydrogen Use in Natural Gas Distribution Systems,” December 2010, available at: https://www.nrel.gov/docs/fy13osti/51995.pdf (Appendix A to Melaina et al., “Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues,” March 2013).
[127]Gas for Climate 2050, “Extending the European Hydrogen Backbone,” p. 4, April 2021, available at: https://gasforclimate2050.eu/wp-content/uploads/2021/06/European-Hydrogen-Backbone_April-2021_V3.pdf.

Exhibit 6.1. Illustrative build-out of hydrogen delivery network in Los Angeles



There are already active players in the Southern California region, such as LADWP, that have indicated they plan to provide hydrogen to some of their electric generation facilities by as early as 2025.[128] LADWP recently issued a request for information ("RFI") seeking support "in technologies related to four main areas of hydrogen: production, transportation, storage, and electricity generation, all of which are to support the future electricity generating needs of the City of Los Angeles."[129] In that RFI, LADWP highlights hydrogen capacity needs as early as 2025-2030. It will be important that there is critical infrastructure in place to transport that hydrogen to those facilities when it is needed.

[128]Smith, C., "America's Largest Municipal Utility Invests in Move from Coal to Hydrogen Power," April 2020, available at: https://www.governing.com/next/americas-largest-municipal-utility-invests-from-coal-to-hydrogen-power.html.
[129]Los Angeles Department of Water and Power, "Green Hydrogen Pathways for Supporting 100% Renewable Energy," RFI No. 8.5.21-Power-SAL, August 2021, available at: https://www.ammoniaenergy.org/wp-content/uploads/2021/09/Green_Hydrogen_RFI_-_8.5.21-Power-SAL.pdf.

Carbon management transportation: An estimated $5 billion in investment across the SoCalGas territory through 2050 is needed to develop carbon pipelines to transfer carbon from "source" to "sink."[130] Across the plausible scenarios CO2 pipelines can more cost-effectively transport CO2 molecules at scale over long distances, particularly for emitters who cannot co-locate with sequestration or utilization sites. It is likely that new pipelines to transport CO2 would need to be built, though further innovation might reveal ways to retrofit existing pipelines safely and reliably. Carbon will likely be captured at several sources across industrial sites, thermal generators, and potentially direct air capture (DAC) locations. According to the Stanford Center for Carbon Storage [131], carbon sinks are expected to predominantly be in the form of carbon sequestration, with initial sites in the Central Valley. While industrial sites and thermal generators are sometimes in close proximity of each other, there is less flexibility to move those sites close to carbon "sinks" and, therefore, their decarbonization would require some form of carbon transportation. DAC location is more flexible and could be co-located in close proximity to carbon "sinks" such as sequestration sites, thus minimizing transportation costs.

Hydrogen production: Approximately $10 billion of investment is needed to produce hydrogen through electrolysis and steam methane reformation paired with carbon capture and sequestration. [132] The most plausible scenarios show 350 – 780 TBtu of annual hydrogen demand, with production ramping as early as 2025 and significant scaling up in the 2030s. Some electrolysis could be grid connected (leveraging electricity from the grid to produce hydrogen), while some could also be directly connected to solar or wind projects. This analysis assumed a significant portion of electrolyzers would be located in eastern California to capitalize on being co-located with renewable resources to minimize electric transmission costs and thus, could reap benefits on existing transmission pipelines, creating an overall lower cost of delivered energy.

Downstream clean fuels investments: Approximately $10 billion will be required through 2050 to develop refueling stations for hydrogen vehicles and deployment of fuel cells (e.g., in wildfire zones, urban centers, etc.) to address critical resiliency needs.[133] Fuel cells and associated microgrids provide opportunities to help improve customer safety and resiliency today. Refueling stations to support hydrogen fuel cell electric vehicle transportation would need to be established. To minimize costs and position refueling stations with maximal benefit for heavy-duty transport needs, refueling stations were assumed to be positioned along major transportation / interstate corridors in California. The likely capacity of each refueling station eventually could reach capacities of 26 tons/day based upon the analysis in this study. Given the volume of hydrogen needed at the refueling stations, it is anticipated the hydrogen would be delivered by pipeline instead of depending on on-site electrolysis, or delivering the hydrogen to the station by truck, given cost, siting, and other considerations (e.g., additional electric capacity needed to support on-site electrolysis).

---

[130]Based on high level estimates for SoCalGas territory based on the High Carbon Sequestration scenario.
[131]Energy Futures Initiative and Stanford University. "An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions." October 2020; available at:https://static1.squarespace.com/static/58ec123cb3db2bd94e057628/t/5f96e219d9d9d55660fbdc43/1603723821961/EFI-Stanford-CA-CCS-FULL-rev1.vF-10.25.20.pdf.
[132]Based on high level estimates for SoCalGas territory based on the High Carbon Sequestration scenario.
[133]Based on high level estimates for SoCalGas territory based on the High Carbon Sequestration scenario.

6.2 Critical piloting, testing, and research

A reliable, sustainable transition to a net-zero carbon California and a supporting clean fuels network will require further analysis, research, piloting, and testing. Careful analysis and pilot design could address many unanswered questions, and thus reduce the risk of negative consequences, in the following areas:

- Hydrogen blending: As referenced elsewhere in this document, hydrogen blending is critical to driving affordable decarbonization. Significant testing, piloting, and research are underway across the globe to understand the potential for blending in existing infrastructure, with continuous new advances and innovations driven by the pace of hydrogen development. Given similar chemical properties and material properties across different gas systems, much of that research can be applied to the Southern California fuels delivery network. However, to help ensure reliability and safety, it is important to conduct testing on the specific systems where hydrogen will be blended in California. Given the lead times, timing of when hydrogen blending will be needed, and potential significant cost savings by achieving higher blending percentages in existing infrastructure, it is important to begin testing in existing hydrogen infrastructure in order to understand the impact of blended hydrogen on California customers' equipment, and where necessary how certain customers would transition to "hydrogen-ready" equipment.

- Dedicated hydrogen pipelines and delivery: Hydrogen delivery at large scale and short distances to certain industrial assets is well understood. Dedicated hydrogen delivery and infrastructure will position California to deliver carbon-neutral hydrogen to industrial users and refueling stations and better enable California to complete new pure hydrogen delivery pipelines (e.g., Stage 1 and Stage 2 pipelines in Exhibit 6.1 as potential examples) to be developed later in this decade. Providing clarity and certainty on how hydrogen infrastructure would be developed is also critical to allow industrial companies and vehicle owners the time to plan and make informed decisions around driving towards net-zero. Furthermore, ensuring adequate hydrogen transportation capacity will be key to unlocking more hydrogen production capacity.

- Hydrogen refueling stations: Initial demonstrations and deployments for hydrogen refueling stations for heavy-duty vehicles will be important to help surface and rectify issues and challenges early, particularly given California's zero-emission vehicle Executive Order targeting 100% zero emission vehicle sales by 2035.[134] Ahead of that order, heavy-duty trucking fleets owners (and other hydrogen vehicle owners) will need to plan for their eventual transition, which will require an understanding of what infrastructure will be in place. Also, it is unlikely that all heavy-duty trucks will wait until 2035 to convert and therefore it is anticipated that hydrogen refueling stations would be needed well in advance of that timeline. Given the typical lengthy timeline of changing over and developing infrastructure of that magnitude, it is important to start deployments soon.

[134] California Governor's Executive Order N-79-20, September 2020; available at: https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf.

- **Carbon capture, utilization, sequestration:** There are several aspects of at-scale carbon capture, utilization, and sequestration that merit further testing, research, and piloting. Given the potential scale of sequestration across the plausible pathways – in particular the high carbon sequestration pathway – there will need to be clear understanding of the viability of different sequestration sites. This analysis relied on research by the Stanford Center for Carbon Storage and Energy Future Institute and studies conducted for SoCalGas to understand sequestration potential in California.[135] Tests will need to be done, for example to understand performance and potential under different injection rates, potential leakage, and leakage mitigation mechanisms. Furthermore, some carbon sequestration options (e.g., saline aquifers) are newer and therefore less understood. Other technologies such as direct air capture (DAC) have yet to see significant commercial deployment and would likely benefit from broader piloting and testing to confirm viability before they are relied upon at-scale.

- **Hydrogen production:** The amount of hydrogen needed varies across plausible scenarios. However, all three plausible pathways call for significant amounts of hydrogen, from 350 to 780 TBtu per year in 2050 across scenarios. Identifying, piloting, and testing green and blue hydrogen production in California will be important to enable carbon-neutral hydrogen production which could be needed at scale as early as the end of the decade.

- **Process of potential building electrification:** There is a need for a cross-stakeholder study on building electrification, in order to inform long-term system planning, maintenance, and investment by developing more granular understanding of where, when, and how electrification may scale up and gas system utilization may decrease. Such a collaborative study would also be helpful to better understand the extent to which end-uses (e.g., space heating or water heating) would most likely be electrified, as well as to quantify the potential value of maintaining the fuels infrastructure in specific areas and to specific end-users. In addition, it could develop a set of scale up "signposts" to inform gas system planning and energy market regulatory considerations such as the need to evolve cost allocation approaches (discussed below). Even in cases where buildings are fully electrified, there could be some benefits that were not directly quantified in this study, but were considered qualitatively – e.g., providing resiliency backup and maintaining "option" value of having clean fuels available should challenges arise in building the supporting infrastructure for electrification. SoCalGas in partnership with the CEC and RAND Corporation is conducting a pilot study to explore some of these questions and work in concert to assess these deeper considerations on the road to achieving carbon neutrality in buildings.

Additional efforts are likely needed to drive further research, testing, and analysis, including testing new equipment in Southern California. There is also a need for customer side research, including refining initial analysis done across the globe on the ability of existing appliances to tolerate different levels of hydrogen. Given the lead time associated with this research, pilot, demonstration, and analysis, it is critical to move quickly.

---

[135] Energy Futures Initiative and Stanford University. "An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions." October 2020; available at: https://static1.squarespace.com/static/58ec123cb3db2bd94e057628/t/5f96e219d9d9d55660fbdc43/1603723821961/EFI-Stanford-CA-CCS-FULL-rev1.vF-10.25.20.pdf

6.3 Transforming the market and scaling up clean fuels

The models indicate a need to urgently stimulate clean fuels technologies to ramp up and achieve economies of scale. Ensuring that a clean fuels network is in place in time to meet the levels of clean fuels called for in the most plausible scenarios likely means rapidly scaling up activity today:

- Significant lead times are driven by the need to conduct more testing, pilots and demonstrations before unlocking the ability to re-purpose significant amounts of infrastructure or develop new infrastructure needed for clean fuels. Given those lead times, expeditious action is required to enable proper system planning, testing, safety and reliability, regulatory alignment to avoid downstream implementation challenges.

- Certain hard-to-abate sectors such as shipping, industry, and aviation that are making long-term investments today will need to know if the fuels and fuels delivery network will be in place before they make those investments. Tackling the hard-to-abate sectors early on is important as industry and transportation emissions represent the majority of the remainingemissions that California will ultimately need to tackle. Investment in infrastructure will be needed to help enable industry and heavy-duty transport to decarbonize in order to manage costs and bring more stability to the sectors that are particularly exposed to the energy transition.

- There is a clear need for interstate coordination (e.g., to develop an I-10 corridor between California and Texas for heavy-duty fuel cell electric trucks that will need hydrogen refueling infrastructure) and even international cooperation which further suggests the need for early solutions.

- Taking a leadership position in developing a clean fuels network is expected to create an opportunity for California to be a leader in the clean fuels energy transition, by fostering innovation and early involvement in the potential development of successful technologies and aiming to become a “hub” of clean fuels activity.

- Having a clean fuels network in place will enable more rapid scaling of hydrogen producers who are more likely to build scaled systems where the capability exists to transport hydrogen at scale to the broadest set of end-users. Without the ability to transport hydrogen at scale, hydrogen producers will be more prone to develop sub-scaled projects that serve a more localized need. Accordingly, early investments in hydrogen delivery infrastructure will play a critical role in catalyzing clean fuels development.

Investments will be needed to drive clean fuel technologies down the cost curve, pilot their use in California's specific context, and build the supporting infrastructure to deliver these fuels. The basic regulated utility framework in the US allows for cost recovery mechanisms that enable regulated utilities to make investments in infrastructure deemed necessary and prudent by their regulators. Industry, policymakers, and regulators could plan to work together to accelerate a clean fuels sector that is poised to play an important role in helping California achieve a decarbonized, resilient, and affordable energy system. In doing so, they could learn from lessons derived in renewable electric generation deployment on how to drive cost reduction in decarbonization technologies. It is well noted that costs for wind and solar energy production over the last decade have come down nearly a full order of magnitude. According to the National Renewable Energy Laboratory, "From 2010 to 2020, there was a 64%, 69%, and 82% reduction in the residential, commercial rooftop, and utility-scale (one-axis) PV system cost benchmark, respectively."[136] Much of this cost reduction was driven by the scale of deployment, which was in large part enabled by state renewable portfolio standards where California had one of the most ambitious targets as well as specific incentives such as production tax credits for wind as well as investment tax credits for solar. These learnings can and should be applied to clean fuels.

Critically, cross-sector energy system planning and integration could help ensure a more orderly energy transition to a net-zero energy system. Over the next three decades, decarbonization is anticipated to drive major shifts in end-uses and supply of energy with significant cross-sector shifts. The gas system can work in concert with the electric system to provide a more resilient energy supply. Finding the right paths, market constructs, and rate and tariff structures can help drive an integrated, resilient, decarbonized, and more affordable energy system.

[136] Feldman et al., "U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020," National Renewable Energy Laboratory (NREL/TP-6A20-77324), p. vi, January 2021, available at: https://www.nrel.gov/docs/fy21osti/77324.pdf.

7.1 Overview of impacts of the transition on gas customers

The scenario analysis highlights that a clean fuels network is key to delivering affordable, resilient and diversified economy-wide decarbonization. The shift towards a clean fuels future, and decarbonization more broadly, is expected to affect different end-users in distinct ways - by changes in the origin and type of fuel they consume, the amount they consume, or when and how flexibly they need those fuels. These effects are challenging to model as they implicate consumer behavior and scale up of various abatement approaches, such as the rate of electrification penetration and costs for doing so. Over time, with a transformation of fuel usage for building thermal purposes, there will also come challenges on customer rates, given the way customers have been historically charged and are charged today. Considerations of an evolving utility revenue requirement and its impact on cost allocation methodologies should be evaluated in order to minimize undesirable incentives or unduly burden any specific customer class.

For many SoCalGas customers, clean fuels may fuel their industry or their vehicle, their home and business, or may provide back-up resiliency. Some customers may see no changes to their buildings, but the electrons and molecules that power their appliances and equipment become decarbonized further upstream, or their emissions may be offset by carbon management. Many homes and businesses are expected to convert to fully electrified buildings. To help make the overall energy transition more affordable, SoCalGas and other stakeholders can and should coordinate and effect a process around customer transitions. Decarbonization pathways likely require multiple actions across all major energy market participant segments, including energy consumers and utilities.

One key learning of the decarbonization modeling study is that reduction of traditional gas pipeline throughput is a common outcome across the three more likely scenarios modeled, with future throughput reduction by energy ranging from 55% to 80% across scenarios – much of which is driven by a decline in the utilization of thermal generation.[137] Increasing demand for hydrogen to new dedicated hydrogen end-uses such as transportation and industrial feedstock could help partially offset throughput reduction if that hydrogen is transported through existing gas pipelines; nevertheless, an overall decline of gas throughput is expected. This change in throughput will impact rates for customers who continue to use the gas system. The analysis herein focuses on the core residential and commercial customers, but also connects the impacts analyzed and the potential mitigation levers to important changes and trends happening to other customer classes and the system as a whole, namely:

[137] Annual thermal gas generation demand goes down as thermal generator utilization decreases. However, as discussed in section 4.1, the capacity of thermal generation will potentially increase in the viable scenarios to provide reliability including peak hourly demands.

- An important and major current user of the gas system, electric generators would increasingly shift from demanding natural gas at high volumes on a daily basis to needing a high capacity of gas for use during peak periods, a trendline which is already occurring as electric capacity is increasingly comprised of weather dependent renewable resources. This dynamic implies a shift in value that is derived from the gas system to the electric system: from providing volume for base load power generation to providing adequate capacity for critical periods when gas (or in the future, clean fuels) is needed, especially when renewables are unavailable (i.e., when the sun does not shine and wind does not blow). The decline in gas demand for electric generation accounts for the most significant proportion of throughput reduction. Not withstanding the projected decreased annual demand, increased peak hourly demand coupled with the reliability/resiliency need for thermal generation (as highlighted in Section 3.1) requires a more capable fuels network to supply peak hourly demand. In other words, annual throughput reduction is not directly correlated to a decline in the size of the fuels network or thermal generation capacity as necessary to supply at peak.
- Beyond changes for existing customers, a transition to a clean fuels network will also likely imply an expansion of the current gas customer base. There are several new potential users of a clean fuels network that are not served by today's natural gas network, e.g., fuel cell electric vehicles (or their hydrogen refueling stations), carbon capture and sequestration assets (acting as source and sinks for CO2), etc. New customer classes would imply an adaptation on the utility's cost allocation methodology to fairly apportion gas prices for all classes involved.

7.2 The transition for core (residential and commercial) customers

There is a range of different end-states across viable scenarios for commercial and residential customers that has potentially significant implications. The possible outcomes include a range from customers using clean fuels (e.g., biogas and blended hydrogen), to customers continuing to use natural gas that is captured later on through direct air capture technologies, to customers electrifying their appliances and homes.

To date, publications and studies have highlighted the important potential of and need for electrification of residential and commercial buildings.[138] This scenario analysis examined a range of building electrification levels with electric sales of residential and commercial appliances and equipment ranging from 50% to 100% of total sales by 2035.

As described in previous sections, in all of the analyzed and feasible decarbonization scenarios a clean fuels network plays an important role. In partial electrification scenarios, such as the High Clean Fuels and High Carbon Sequestration scenarios, a clean fuels network directly delivers clean fuels for customers or communities for whom electrification is not a cost-effective measure or where it is precluded based on other system considerations. In the Resilient Electrification scenario, the clean fuels network plays the same role for the smaller percentage of customers for whom barriers prevent direct electrification. In addition, in all scenarios the clean fuels network can provide back-up resiliency through dispatchable clean distributed generation (e.g., fuel cells) for critical loads (hospitals, emergency services, etc.), and vulnerable areas such as wildfire risk zones.

[138] See Synapse Energy Economics, Inc., "Decarbonization of Heating Energy Use in California Buildings," October 2018, available at: https://www.synapse-energy.com/sites/default/files/Decarbonization-Heating-CA-Buildings-17-092-1.pdf; Billimoria et al., "The Economics of Electrifying Buildings: How Electric Space and Water Heating Supports Decarbonization of Residential Buildings," 2018, available at: https://rmi.org/insight/the-economics-of-electrifying-buildings/.

At-scale electrification raises several critical questions, including: what will be the process of driving electrification? Which areas will be cost-effective to fully electrify and potentially decommission parts of the gas distribution system? The variables that primarily impact where these areas might be located and how much of the system they could represent include customer conversion cost of end-use electrification[139], cost of increasing electric grid capacity, and cost of decommissioning the existing gas network. Other criteria, such as local resiliency and reliability needs, are also important, as is considering the potential adverse impacts to vulnerable customers and communities.

At this point, the feasibility and costs of full electrification and decommissioning are still being examined, as are the parameters for and extent to which it will be in the public interest to decommission gas distribution systems, including even in high electrification scenarios. Thus, it will be important to consider potential impacts of decommissioning and large gas demand declines that are implied by decarbonization scenarios, considering the rate and extent of electrification. As part of this study, SoCalGas undertook a qualitative assessment of the spectrum between and among electrification and decommissioning to inform preliminary planning. The analysis identifies specific land use and system topographic conditions that may inform and influence decommissioning (Exhibit 7.1).

Exhibit 7.1. Factors influencing decommissioning and electrification

Factors weighted most heavily due to (1) customer vulnerability, and (2) relative magnitude of impact on cost

Factor	Bias towards maintaining gas infrastructure	Bias towards full electrification with gas decommissioning	Rationale
Current High or Very High wildfire risk, in non-urban areas	✓		Resiliency benefits; underground elecrification still an option for urban areas in significant wildfire risk zones
Industrial customers	✓		Electrification not viable for many industrial applications due to highthermal requirements
Population density	High	Low	Higher total customer costs and complications associated with fuel-switching due to higher number of end-uses
Average pipeline replacement costs	High	Low	High replacement costs are indicative of higher decommissioning costs
Future wildfire risk	Very High	Low	Gas system provides resiliency benefits through dual-fuel system, with gas remaining on even when electricity is off
Electric capacity	Low	High	Low capacity relative to peak load increases likelihood that T&D upgrades will be required for full electrification
Topography complexity	High (mountainous)	Low (flat)	More complex terrain may increase costs to build up electric T&D capacity and to decommission pipelines
Diversity of end-uses	High	Low	May lead to more complications associated with fuel-switching due to wider range of appliance/equipment and building types to convert
Fraction of small-diameter pipe	Low	High	More expensive to remove large-diameter pipelines, making decommissioning more expensive
Pipeline O&M costs	Low	High	High cost to maintain pipelines - more cost effective to take out of service

[139] Recent analysis by the City of San Francisco estimates the costs of electric appliance retrofitting for San Francisco residences to range from $14,363 per housing unit at the low end, up to $19,574 for multi-family units and $34,790 for single family homes at the higher end. It estimates the citywide cost to retrofit all residential units currently using natural gas-fueled appliances with those fueled by electricity ranges from $3.5 to $5.9 billion. See City and County of San Francisco Board of Supervisors "Budget and Legislative Analyst Policy Analysis Report", April 2021, available at: https://sfbos.org/sites/default/files/BLA.ResidentialDecarbonization.042221.pdf.

In order to optimize planning, a set of data-driven measures for the external environment, focused primarily on electrification uptake and scaleup, will be useful for strategic decision-making for decommissioning, cost allocation and rate design. These signposts may include:

- Energy customer sentiment around electrification
- Average customer conversion cost, current and projected
- New build electrification market share
- Electric appliance sales and gas appliance displacement
- Annual rate of building electrification conversion
- Decrease in gas throughput to core customers
- Increase in peak hourly demand from electric generation customers
- Existing and new building stock energy efficiency gains realized

In this vein, SoCalGas is participating in and gathering data to assess community preferences and to pilot decommissioning and electrification, in collaboration with the CEC, RAND Corporation, the Gas Technology Institute and the Los Angeles Regional Collaboration. On an ongoing basis, the analysis will illuminate and help optimize interaction between electrification and deployment of clean fuels infrastructure to decarbonize. It is expected that such data-driven analysis and modeling will help inform infrastructure and operational planning for achieving a decarbonized end state while maintaining safe, reliable, and affordable energy supply.

7.3 Average core customer gas rates

For all decarbonization end-states modeled, gas rates of core customers (residential and core commercial/industrial) are likely to increase over time under the current cost allocation and regulatory construct, commensurately with the rate of electrification displacing core customer gas use. This analysis assumes the application of the current cost allocation factors across customer classes into the future. While the rate and penetration of utilization of thermal gas plants and building electrification over time would impact the magnitude of this increase, the trendline is clear in all of the modeled scenarios.

The current cost allocation framework, which has been in place mostly unchanged for decades, was designed to reflect a system of which residential and small commercial customers were the core beneficiaries, for whom access to gaseous fuels is delineated as an essential service. Therefore, most of today's system costs are borne by core residential and commercial customers, even though they are not the largest consumers on a volumetric basis. As the gas system transitions to complement and foster decarbonization, there could be a shift in value among existing gas utility's customers; and new customer classes may also be added to the mix (e.g., FCEVs).

Moreover, due to the need for reliability and resiliency services, the value of gas transportation and delivery services will increasingly provide benefit to electric customers, insofar as gas use in homes and businesses is displaced by electrification. Increasing electrification amplifies the need for and value of peak hourly and firm dispatchable energy delivery provided by the gas grid today, and a clean fuels network in the future. Presuming a large portion of residential and commercial customers electrify, electric generators and large industrial customers would increasingly become the major users of the gas system. Core customers that remain connected to the fuels network could be unduly burdened by increasing fuels rates and bearing the costs of infrastructure and services that maintain reliable and resilient electric service thereby benefitting those who have left the gas system. This shift would impact the regulatory and cost allocation framework as between core and non-core customers.

New and updated cost allocation mechanisms should therefore be employed so this shifting value is more equitably allocated across customers classes (residential, commercial, industrial, electric generators, wholesale, new customers, etc.) consistently with bedrock rate design principles of cost causation and beneficiary pays principles.[140] In this case, allocation metrics and rate design should adapt to assign costs to the beneficiaries from the reliability and resiliency benefits provided to the energy system as a whole, and costs should also be shared with new users of a clean fuels system.

The study explored several cost-allocation levers that could potentially mitigate some adverse rate impacts for the average core gas customer and more equitably assign costs:

- **Adapting cost allocation methodologies:** With shifting energy needs and daily/intra-daily variability of gas demand expected to increase, metrics that more closely reflect the nature and value of the service provided by the fuels network could be employed. The implication would be that customers that more heavily rely on the capacity and flexibility provided by the system, e.g., electric generators and large industrial customers, would over time share more of the burden with smaller core customers.
  It is important to note that the impact of increased fuels rates to electric generators are expected to be muted in a world where there is a declining percentage of fuels in the overall electric generation mix and where thermal generators are assumed to be compensated for the capacity they provide.

- **Expanding cost allocation to new end users:** Costs associated with new hydrogen infrastructure can be partially allocated to new users of the system if the gas utility serves these consumers. For example, hydrogen vehicles or refueling stations could potentially become a new customer class. In this model, costs associated with dedicated infrastructure to serve this new customer class could be added to the revenue requirement, and these customers would bear the costs of both their dedicated infrastructure and part of the shared hydrogen infrastructure, which would in turn partially alleviate the burden on core customers of the system.

- **Securitization and accelerated depreciation:** For assets to be decommissioned, securitization of the stranded value may be one approach to partially offset customer rate increases. Accelerated depreciation of assets to be decommissioned may also be another approach to mitigate the impact of rate increases on future customers.

---

[140]Cost causation means revenues should be recovered from those who cause costs to be incurred. Beneficiary pays is the concept that those benefiting from infrastructure, or a utility service should bear its costs.

Further analyses into the impacts on low-income customers, bills and share of wallet, and possible ways to mitigate those impacts are needed. To lay the groundwork for an equitable energy transition, further elements of cost allocation and rate design would need to be evaluated, particularly as the expected fuel switching pathways are developed and materialize.

In addition to updating the existing cost allocation construct, other broader market structures could be adapted. The prevalent gas market construct, from which electric generators, large commercial and industrial customers purchase gas supply, is premised on “ratable take provisions”, which assume a uniform constant hourly flow over the day. As the needs for gaseous fuels become more variable over the course of a day or even hours in a future with higher renewables penetration, some form of shaped flow service, allowing for “non-ratable provisions” (i.e., variable flow over a day) could be established, accounting for the value of just-in-time delivery to customers.

To more cost-effectively decarbonize, cost allocation policies and rate design structures should evolve to complement the changing commercial environment. Utility investment and access to capital markets, combined with the ability to deploy cost-sharing mechanisms to protect disadvantaged customers, could create several levers to help to manage the energy transition.

SoCalGas set the goal to achieve carbon neutrality for scope 1, 2, and 3 emissions no later than 2045. The company's Aspire 2045 ambition demonstrates SoCalGas's commitment to California's decarbonization goal and positions us to be the cleanest, safest, most innovative energy infrastructure company in America. At SoCalGas, we are dedicated to being a leader in the transition to a decarbonized energy system by achieving net-zero greenhouse gas emissions in both our operations and delivery of energy by 2045, by reducing the carbon intensity of the molecules that flow through our system, and by building the infrastructure for new fuels, such as hydrogen, that will enable the energy transition.

This study highlights the value a clean fuels network can play in decarbonizing California. According to the analysis, a clean fuels network provides reliability, resilience, and resource adequacy, enables building decarbonization, transports carbon from source to sink, provides decarbonization pathways to hard-to-abate sectors, and is a critical element of the most affordable decarbonization pathways. There is significant opportunity and work to be done to capture this opportunity and establish a clean fuels network in California.

As discussed in Chapter 5, a clean fuels network can play an important role in the state's decarbonization plan for an affordable, resilient, reliable, and safe energy transition. A clean fuels network is essential to:

- Enabling electrification by supporting increased renewable generation with peaking and intermittency solutions needed to provide a resilient electric supply, and providing the resiliency for buildings that continue to require energy and fuel diversification
- Supporting the decarbonization of hard-to-abate sectors (e.g., industry, heavy-duty transportation, chemical processing)
- Providing the carbon neutral or carbon negative fuels (e.g., biogas and carbon neutral hydrogen) that customers require where electrification may be challenging or inequitable to implement
- Ensuring decarbonization can be achieved in an affordable and equitable manner for all customers

A clean fuels network can provide pathways for reaching the State's decarbonization goals that lead to a more affordable, more resilient, and more equitable future for California.

See SB 1371; available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140SB1371 .

A clean fuels network will rely on three critical components (as outlined in Chapter 4 of this study):

1. Continuing to invest in the safety and reliability of existing infrastructure to transport lower carbon intensity fuels in order to accelerate the energy transition while also maintaining energy resiliency and affordability.

2. Supplying energy customers with the clean, renewable and/or carbon neutral fuels theydemand (such as, for example, green hydrogen, RNG and syngas) and incorporating increasing levels of clean fuels.

3. Building and deploying vital new infrastructure for breakthrough solutions such as transporting and delivering carbon-neutral hydrogen to customers; facilitating carbon storage and sequestration through developing carbon dioxide transportation systems; and supporting the development of distributed energy resources by investing in microgrids and fuel cells, as detailed in Chapter 6 of this study.

To achieve the benefits of a clean fuels network, which is necessary to decarbonize reliably and affordably, several distinct regulatory responses are required:

- **Clean Fuels Procurement Standard:** Procuring and blending RNG, hydrogen, and other carbon neutral/negative fuels into the clean fuels network is essential for lowering the carbon intensity of fuels. A procurement standard like the renewable standard used by electric utilities would accelerate clean fuels deployment. The CPUC recently issued a staff report (SB 1440 Report) recommending a renewable gas procurement program for residential and small commercial customers.

- **Investing in Infrastructure:** Investments to modernize the gas infrastructure for hydrogen and for distributing all clean fuels are vital to realizing the cost-savings offered by a clean fuels network.

- **Energy Efficiency Solutions:** Customer incentives to increase energy efficiency (furnace replacement, window/insulation upgrades, etc.) and demand response programs like smart thermostats that reduce throughput are powerful levers for lowering emissions while also economical for customers.

- **Research, Development and Demonstration (RD&D):** Breakthrough technologies are essential to developing decarbonization solutions and scaling them quickly. Accelerated RD&D for clean hydrogen production, hydrogen fuel cells, distributed energy resources (including hydrogen hubs), industrial hydrogen clusters, national hydrogen blending standards and carbon management will advance a clean fuels network.

- **Carbon Capture, Utilization, and Sequestration (CCUS):** The International Panel on Climate Change (IPCC), the International Energy Agency, and other global climate experts agree that carbon capture, utilization, and sequestration is needed alongside – not instead of – other mitigation tools to meet Paris Climate Agreement's targets. Gas utility infrastructure and expertise can contribute greatly to CCUS deployment.

- **Modern Rate Structures:** As discussed in chapter 7 of this study an updated rate structure is needed to modify the approach to cost recovery allocation to account for the change in customer usage of the clean fuels network over time (e.g., declining residential and commercial volumes and increasing reliance of power plants and large industrial customers on a reliable and resilient clean fuels network for high-heat technical processes that are hard to electrify.)

Integrated energy system planning

The increasing interdependencies between the gas and electric systems compel a new approach to infrastructure planning in order to optimize resource deployment and achieve operational and infrastructure synergies to reach decarbonization goals. Building from the resource planning approach for the electric grid, a thorough and transparent approach which takes a clean fuels network into account, will more effectively and efficiently utilize capital and investment required to decarbonize.

SoCalGas has already established significant goals to facilitate decarbonization:

- Target of 20% RNG (biogas) by 2030; SoCalGas aspires to both reach and exceed the target by incorporating ever-increasing levels of biogas into the system, as enabled by supportive policies.
- Net-zero carbon emissions across all operations, including elimination of 100% vented gas during planned transmission pipeline work, operating a 100% zero emission over the road fleet and achieving net-zero energy for 100% of all SoCalGas buildings.
- Exceed California targets for methane leak reductions by finding and eliminating leaks in the system. SoCalGas is on track to exceed California's goal to reduce fugitive methane emissions 40% by 2030[141]. SoCalGas will simultaneously use this opportunity to ready the system for the future by using hydrogen-ready materials as part of our integrity management programs.
- Testing the hydrogen blending capacity of the SoCalGas system as well as running several pure hydrogen pilot projects to start developing scale hydrogen solutions and help propel California to be a leader in the hydrogen space globally.

Beyond these actions, more clean fuels and new infrastructure will need to be incorporated into the energy system. SoCalGas looks forward to working with our current and future customers, policymakers, regulators, our peer utilities, the academic and research communities, and other stakeholders to jointly develop an integrated plan for a cost-effective, equitable, and sustainable decarbonization of the California economy. Together, we can develop the solutions and technologies we need to achieve carbon neutrality by 2045.

[141]See SB 1371; available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140SB1371 .

SoCalGas

TODAY

Delivering gas to our customers, safely, reliably, and affordably

Investing in system modernization, safety, and reliability

Energy Efficiency solutions

RNG blending and vehicle fueling stations

Smart meters

Exceed the state requirements to demonstrate a reduction of fugitive methane emissions 20% by 2025

2022

Diversifying the decarbonized energy system while increasing resiliency and reliability benefit

Legislative and Regulatory framework to advance the role of clean fuels network in decarbonization of California economy

Modified cost recovery and cost allocation to support evolution of clean fuel network

Demonstrate technical capability for gas distribution to safely support up to 20% hydrogen blend by 2030

RD&D in hydrogen delivery and syngas

Fuel cells for customer resiliency

Planning for carbon management

Develop hydrogen infrastructure solutions for the 2028 Olympics

2030

Adaptation and expansion of clean fuels network evolving in line with technology, customer needs, and policy direction

Invest in infrastructure to deliver clean molecules, build hydrogen hubs, and support carbon management

Deliver 20% RNG to core customers

Streamline customer decarbonization

Demonstrate higher % blend of clean fuels

Advance clean hydrogen, RNG, syngas, and CCUS infrastructure

Complete five hydrogen pilot projects

2045

Innovating to deliver clean energy that enables a safe, reliable, affordable, and decarbonized California

Net zero emissions goal across all operations (ASPIRE 2045)

THE GOAL TO 2045

Cautionary Statement Regarding Forward- Looking Information

This study contains statements that constitute forward-looking statements within the meaning of the Private Securities Litigation Reform Act of 1995. Forward-looking statements are based on assumptions with respect to the future, involve risks and uncertainties, and are not guarantees. Future results may differ materially from those expressed in any forward-looking statements. These forward-looking statements represent our estimates and assumptions only as of the date of this study. We assume no obligation to update or revise any forward-looking statement as a result of new information, future events or other factors.

In this study, forward-looking statements can be identified by words such as "believes," "expects," "anticipates," "plans," "estimates," "projects," "forecasts," "should," "could," "would," "will," "confident," "may," "can," "potential," "possible," "proposed," "in process," "under construction," "in development," "target," "outlook," "maintain," "continue," “goal,” “aim,” “commit,” or similar expressions, or when we discuss our guidance, priorities, strategy, goals, vision, mission, opportunities, projections, intentions or expectations.

Factors, among others, that could cause actual results and events to differ materially from those described in any forward-looking statements include risks and uncertainties relating to: decisions, investigations, regulations, issuances or revocations of permits and other authorizations, renewals of franchises, and other actions by (i) the California Public Utilities Commission (CPUC), U.S. Department of Energy, and other regulatory and governmental bodies and (ii) states, counties, cities and other jurisdictions in the U.S. in which we do business; the success of business development efforts and construction projects, including risks in (i) completing construction projects or other transactions on schedule and budget, (ii) the ability to realize anticipated benefits from any of these efforts if completed, and (iii) obtaining the consent of partners or other third parties; the resolution of civil and criminal litigation, regulatory inquiries, investigations and proceedings, and arbitrations, including, among others, those related to the natural gas leak at the Aliso Canyon natural gas storage facility; actions by credit rating agencies to downgrade our credit ratings or to place those ratings on negative outlook and our ability to borrow on favorable terms and meet our substantial debt service obligations; actions to reduce or eliminate reliance on natural gas, including any deterioration of or increased uncertainty in the political or regulatory environment for local natural gas distribution companies operating in California; weather, natural disasters, pandemics, accidents, equipment failures, explosions, acts of terrorism, information system outages or other events that disrupt our operations, damage our facilities and systems, cause the release of harmful materials, cause fires or subject us to liability for property damage or personal injuries, fines and penalties, some of which may not be covered by insurance, may be disputed by insurers or may otherwise not be recoverable through regulatory mechanisms or may impact our ability to obtain satisfactory levels of affordable insurance; the availability of natural gas and natural gas storage capacity, including disruptions caused by limitations on the withdrawal of natural gas from storage facilities; the impact of the COVID-19 pandemic on capital projects, regulatory approvals and the execution of our operations; cybersecurity threats to the storage and pipeline infrastructure, information and systems used to operate our businesses, and confidentiality of our proprietary information and personal information of our customers and employees, including ransomware attacks on our systems and the systems of third-party vendors and other parties with which we conduct business; volatility in inflation and interest rates and commodity prices and our ability to effectively hedge these risks; changes in tax and trade policies, laws and regulations, including tariffs and revisions to international trade agreements that may increase our costs, reduce our competitiveness, or impair our ability to resolve trade disputes; and other uncertainties, some of which may be difficult to predict and are beyond our control. These risks and uncertainties are further discussed in the reports that the company has filed with the U.S. Securities and Exchange Commission (SEC). These reports are available through the EDGAR system free-of-charge on the SEC's website, www.sec.gov, and on Sempra’s website, www.sempra.com. Investors should not rely unduly on any forward-looking statements.

This study may include market, demographic and industry data and forecasts that are based on or derived from third-party sources such as independent industry publications, publicly available information, government data and other similar information from third parties. We do not guarantee the accuracy or completeness of any of this information, and we have not independently verified any of the information provided by these third-party sources. In addition, market, demographic and industry data and forecasts involve estimates, assumptions and other uncertainties and are subject to change based on various factors, including those discussed above. Accordingly, you should not place undue reliance on any of this information. This study also contains links to third-party websites that are not hosted or managed by Sempra or its family of companies, including SoCalGas. We are not responsible for, nor do we recommend, endorse or support, any information contained on any such third-party websites.

Sempra Infrastructure, Sempra LNG, Sempra Mexico, Sempra Texas Utilities, Oncor Electric Delivery Company LLC (Oncor) and Infraestructura Energética Nova, S.A.B. de C.V. (IEnova) are not the same companies as the California utilities, San Diego Gas & Electric Company or Southern California Gas Company, and Sempra Infrastructure, Sempra LNG, Sempra Mexico, Sempra Texas Utilities, Oncor and IEnova are not regulated by the CPUC.