ANGELES LINK PHASE 1

PRODUCTION PLANNING & ASSESSMENT

FINAL REPORT – DECEMBER 2024

SoCalGas commissioned this Production Planning & Assessment from Burns & McDonnell. The analysis was conducted, and this report was prepared, collaboratively.

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List of Abbreviations

Abbreviation	Term/Phrase/Name
AEM	Anion Exchange Membrane
ALMA	Angeles Link Memorandum Account
BESS	Battery Energy Storage System
BOP	Balance of Plant
CPUC	California Public Utilities Commission
DOE	Department of Energy
GHG	Greenhouse Gases
LCOH	Levelized Cost of Hydrogen
MSW	Municipal Solid Waste
OEM	Original Equipment Manufacturer
PEM	Proton Exchange Membrane
POI	Point of Interconnect
RNG	Renewable Natural Gas
SOC	State of Charge
SoCalGas	Southern California Gas Company
SOEC	Solid Oxide Exchange Membrane

1.0 Executive Summary

1.1 Production Assessment Overview

On December 15, 2022, the California Public Utilities Commission (CPUC) adopted Decision 22-12-055 (Decision), which authorized Southern California Gas Company (SoCalGas) to establish the Angeles Link Memorandum Account to record the costs of performing Angeles Link Phase 1 feasibility studies. The Decision requires SoCalGas to identify potential sources of hydrogen generation for Angeles Link and its plans to ensure the hydrogen quality meets the clean renewable hydrogen standard set forth in the Decision. Accordingly, this Hydrogen Production Planning & Assessment (Production Study) analyzes clean renewable hydrogen production potential focused on SoCalGas's service territory through 2045.

SoCalGas does not intend to own or operate hydrogen production facilities. This assessment was conducted to evaluate potential sources of clean renewable hydrogen and assess the techno-economic feasibility of various options that may be available to third-party producers. The production from renewable energy resources such as solar and wind, input requirements, and estimated cost of production are presented in this report.

1.2 Stakeholder Feedback

The input and feedback from stakeholders, including the Planning Advisory Group (PAG) and Community Based Organization Stakeholder Group (CBOSG), has played an important role in the development of this Production Study. Key feedback received related to the Production Study is summarized in Section 12.0 below. All feedback received is included, in its original form, in the quarterly reports submitted to the CPUC and published on SoCalGas's website.[1]

For example, in response to stakeholder input, the Production Study assesses hydrogen produced via electrolysis but also includes other potential technology pathways (e.g., biomass/biogas) that could meet the CPUC's definition of clean renewable hydrogen[2] (included in Sections 3, 4, and 5). Additionally, in consideration of feedback received, the current SoCalGas used a conservative assumption is that renewable power requirements would be incremental and met with power generation that is not grid connected (i.e., does not tie into high voltage transmission lines), along

[1] https://www.socalgas.com/sustainability/innovation-center/angeles-link

[2] Decision (D).22-12-055 specifies use of clean renewable hydrogen, which is hydrogen produced with emissions less than 4 kg CO2 for each kg H2 and not derived from fossil fuels.

with local utility distribution power for minimum power needs to enable startup and shut down (Sections 2 and 9). The study further explores the role of hydrogen storage that can help balance clean renewable hydrogen production and demand profiles (Section 8).

1.3 Key Findings

- Solar power paired with electrolyzers is expected to be the primary renewable energy source and technology used for hydrogen production at scale for transport by Angeles Link. This considers that solar irradiance in most of SoCalGas's territory (Central and Southern CA) is some of the best in the country. Solar is also a mature technology, among the least expensive renewable energy generation options available, and can be co-located near hydrogen production.
- Proton Exchange Membrane (PEM) electrolyzers are expected to be a suitable technology to pair with intermittent and variable power supplies such as solar. This is due to the operational attributes of PEM electrolyzers such as startup times (process to turn on and activate the electrolyzer that is in an off state), ramp rates (ability to adjust hydrogen production rate), and turndown ratios (the ability to operate over different production rates). Third-party producers may also employ other electrolyzer technologies (e.g., Alkaline, Solid Oxide Electrolyzer Cell), in combination with renewable sources of power, depending on various design and operational requirements.
- Other renewable energy sources are expected to be utilized on a smaller scale than solar due to their resource limitations in Central and Southern California. Small-scale biomass hydrogen production facilities are anticipated to be sited near opportunistic fuel supply sources found throughout the region.
- Based on preliminary analysis, approximately 2 million acres of potentially available land for energy development was identified in three primary production locations within the SoCalGas service territory. Potential production locations include San Joaquin Valley (SJV), Lancaster, and Blythe. These locations could alone, or in some combination (depending on the throughput levels), meet the 0.5 million – 1.5 million metric tonnes per year (MMTPY) Angeles Link throughput range. The land required to support a production volume of 1.5 MMTPY is estimated to be 240,000 acres, which represents approximately 12% of the land identified as potentially available for hydrogen production from all three production areas. For the 1.5 MMTPY case, just under 15% of the land area within the Lancaster and SJV production areas would be required in a scenario assuming production from only those two production areas.

- As the hydrogen market develops, hydrogen storage could play an important role in balancing hydrogen supply with demand, primarily due to the intermittent nature of renewables and the expected demand profiles of the power generation, mobility, and industrial sectors. Angeles Link could support the transportation of hydrogen from production, in and out of third-party storage, and to demand locations. Storage volumes would be dependent on various factors, such as the type of renewable power source used to make hydrogen, the anticipated hourly demand profiles for power generation, mobility, and industrial sectors, and the system hydrogen demand volumes. Depending on the volume required, storage could be provided in a number of manners, including line pack (e.g., storage within the pipeline), construction of a parallel pipe in a portion or portions of the pipeline system, on-site storage at third-party clean renewable hydrogen producers or end users, and/or dedicated above-ground or underground storage.
- System curtailments will likely be sporadic and seasonal. If production facilities were grid-connected, curtailed energy could be used opportunistically to produce hydrogen that Angeles Link could transport, resulting in additional hydrogen production capacity beyond that addressed in this Study.

2.0 Introduction

2.1 Background

Today, there are approximately 10 million metric tons of hydrogen produced in the United States each year, with petroleum refining and ammonia production currently driving the primary demand.[3] As California's decarbonization goals to achieve carbon neutrality by 2045 or earlier are considered, it is important to understand various hydrogen production pathways and technologies, including their suitability to support local, state, and national decarbonization goals. This report aims to analyze potential hydrogen production that meets the California Public Utilities Commission's (CPUC) clean renewable hydrogen specifications in D.22-12-055 (see Section 2.2 for more details).

Hydrogen has potential applications across multiple sectors and could enable zero or near-zero emissions, such as in transportation, power generation, and other chemical and industrial processes. As the CPUC has recognized, "Clean renewable hydrogen is one of the only few viable carbon-free energy alternatives for the hard-to-electrify industries and the heavy-duty transportation sector in the Los Angeles Basin."[4] Similarly, the Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES) has identified clean renewable hydrogen as "the most scalable zero-carbon alternative to natural gas for use in gas power plants required by state planning to remain operational to ensure reliability."[5]

In California today, the increasing emphasis on reaching a net-zero carbon future is catalyzing the development of projects focused on clean renewable hydrogen that could begin to transform California's hydrogen economy. Several technologies are commercially available for the industrial production of hydrogen from biomass gasification, to steam methane reforming of renewable natural gas, to the electrolysis of water to produce pure hydrogen. While electrolysis of water to produce hydrogen dates back to the 1920s, deploying clean renewable hydrogen technologies at scale is not without challenges, including the need to lower clean renewable hydrogen production

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[3] Department of Energy U.S. National Clean Hydrogen Strategy and Roadmap, pg. 14, available at: https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/us-national-clean-hydrogen-strategy-roadmap.pdf?sfvrsn=c425b44f_5.

[4] CPUC, Decision (D).22-12-055, see Summary, page 2 at https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M500/K167/500167327.PDF.

[5] ARCHES H2, Frequently Asked Questions (March 2024) at 2, available at: https://archesh2.org/wp-content/uploads/2024/03/ARCHES-FAQ-Basic-1.pdf.

costs. This is expected to occur as the clean hydrogen economy matures, with technical advancements and larger scale deployments of hydrogen production.

This report aims to capture the status of clean renewable energy-based hydrogen production technologies that are anticipated to be commercially available through 2045.

2.2 Purpose and Objectives

On December 15, 2022, the CPUC adopted Decision (D).22-12-055 (Decision), authorizing Southern California Gas Company (SoCalGas) to establish the Angeles Link Memorandum Account (ALMA) to record the costs of performing Angeles Link Phase 1 feasibility studies. The Decision requires SoCalGas to identify potential sources of hydrogen generation for Angeles Link and its plans to confirm the quality meets clean renewable hydrogen standards set forth in the Decision.[6] The Production Study is one of the Angeles Link feasibility studies being performed as part of Phase 1 and analyzes clean renewable hydrogen production potential focused on SoCalGas's service territory through 2045. This study evaluates potential sources of clean renewable hydrogen production from renewable energy resources such as solar and wind, inputs such as land and the supporting auxiliary infrastructure components (i.e., balance of plant (BOP)) required for hydrogen production, and the estimated cost of production. This report sets forth the scope, methodology, and results of the study.

2.3 Definition of Clean Renewable Hydrogen

The objective of Angeles Link is to develop a non-discriminatory pipeline system that is dedicated to public use and aims to facilitate transportation of clean renewable hydrogen[7] from multiple third-party sources to various end users in Central and Southern California, including the Los Angeles Basin. While the CPUC may consider future modifications to the definition adopted by the Decision, for the purposes of this Angeles Link feasibility study, "clean renewable hydrogen" is defined as:

"Hydrogen which is produced through a process that results in a lifecycle (i.e., well-to-gate) GHG emissions rate of not greater than 4 kilograms of CO2e per kilogram of

[6] Refer to Section 2.3 for the applicable clean renewable hydrogen definition.

[7] The Angeles Link Phase 1 studies are restricted to studying the transport of only clean renewable hydrogen as directed by the Commission in D.22-12-055 at 73 (OP 3(a)) ("…carbon intensity equal to or less than four kilograms of carbon dioxide-equivalent produced on a lifecycle basis per kilogram and does not use any fossil fuel in the production process").

hydrogen produced and does not use fossil fuel as either a feedstock or production energy source."[8]

This definition is consistent with other CPUC decisions, policies, and directives, including Order Instituting Ratemaking R. 20-01-007 (Long-Term Gas Planning Order Instituting Ratemaking) and R.13-02-008 (Biomethane Standards and Requirements and Pipeline Open Access Rules Order Instituting Ratemaking).

2.4 Clean Renewable Hydrogen Standards

On September 22, 2022, the U.S. Department of Energy (DOE) released draft guidance for a Clean Hydrogen Production Standard (CHPS)[9] developed to meet the requirements of the Infrastructure Investment and Jobs Act of 2021, also known as the Bipartisan Infrastructure Law (BIL), Section 40315.[10] The initial proposal of the CHPS establishes a target for well-to-gate lifecycle greenhouse gas emissions of less than or equal to four kilograms of carbon dioxide-equivalent produced on a lifecycle basis per kilogram of hydrogen (≤4.0 kgCO2e/kgH2). The term well-to-gate generally includes emissions created at and upstream of the production facility (e.g., emissions to bring feedstocks to the production location as well as at the production facility).[11] The establishment of a well-to-gate target aligns with statutory requirements to consider not only emissions at the site of production but also technological and economic feasibility, and to support clean hydrogen production from diverse energy sources.

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[8] The term "fossil fuel" is consistent with the definition found in Pub. Util. Code § 2806. The prohibition on the use of fossil fuel does not apply to an eligible renewable energy resource that uses a de minimis quantity of fossil fuel, as allowed under Pub. Util. Code § 399.12 (h)(3).

[9] https://www.hydrogen.energy.gov/library/policies-acts/clean-hydrogen-production-standard.

[10] https://www.congress.gov/bill/117th-congress/house-bill/3684/text. https://www.congress.gov/117/plaws/publ58/PLAW-117publ58.pdf.

[11] The Department of Energy defines well-to-gate as "the aggregate lifecycle GHG emissions related to hydrogen produced at a hydrogen production facility during the taxable year through the point of production. It includes emissions associated with feedstock growth, gathering, extraction, processing, and delivery to a hydrogen production facility. It also includes the emissions associated with the hydrogen production process, inclusive of the electricity used by the hydrogen production facility and any capture and sequestration of carbon dioxide (CO2) generated by the hydrogen production facility." (https://www.energy.gov/sites/default/files/2024-05/45vh2-greet-user-manual_may-2024.pdf).

On December 22, 2023, the U.S. Department of the Treasury released a proposed rulemaking for the clean hydrogen production tax credit (45V) under the Inflation Reduction Act (IRA).[12] The IRA offers a production tax credit of up to $3 per kg of hydrogen produced based on carbon intensity. Electrolytic hydrogen, produced by using electricity to split water into hydrogen and oxygen, could be eligible for the highest-level tax credit if zero-carbon electricity is used. In addition, the DOE released the 45VH2-GREET model,[13] which was adopted by the U.S. Department of the Treasury, to determine emissions rates for purposes of the Clean Hydrogen Production Tax Credit. In April 2024, the Treasury Department issued draft guidance for producers to meet "clean hydrogen" standards to be eligible for 45V tax credits.[14] The draft guidance includes a discussion of three elements commonly referred to as the "three pillars" (temporal matching, additionality, and deliverability). As of the date of this report, the Treasury Department has not issued final 45V tax credit guidance, and it is unknown whether the" three pillars" will be a requirement in the final guidance.

While the CPUC definition of clean renewable hydrogen does not currently require adherence to the three "pillars,"[15] further discussion of these terms and how the concepts are being considered with respect to potential clean renewable production that could be served by Angeles Link are provided below.[16]

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[12] https://www.federalregister.gov/documents/2023/12/26/2023-28359/section-45v-credit-for-production-of-clean-hydrogen-section-48a15-election-to-treat-clean-hydrogen.

[13] https://www.energy.gov/eere/greet and https://www.energy.gov/sites/default/files/2024-05/45vh2-greet-user-manual_may-2024.pdf.

[14] "Assessing Lifecycle Greenhouse Gas Emissions Associated with Electricity Use for the Section 45V Clean Hydrogen Production Tax Credit." DOE. December 2023. https://www.energy.gov/sites/default/files/2023-12/Assessing_Lifecycle_Greenhouse_Gas_Emissions_Associated_with_Electricity_Use_for_the_Section_45V_Clean_Hydrogen_Production_Tax_Credit.pdf

[15] Some stakeholders submitted comments supporting making the three pillars a requirement for Angeles Link. SoCalGas is committed to transporting clean renewable hydrogen that meets the applicable regulatory requirements set for by the CPUC.

[16] *Temporal matching* refers to the requirement to match the amount of electricity being used in hydrogen production to the amount of zero-carbon electricity being produced within a specified time period. Treasury's proposed guidance requires annual matching up to 2027 and phases-in hourly matching from 2028 onwards. This study assumes standalone clean, renewable resources will be used to meet the requirement of

Although the CPUC and the DOE have established working definitions for “clean renewable hydrogen” and “clean hydrogen,” it is anticipated that these standards will continue to evolve as the industry matures and as the U.S. progresses towards goals laid out in the U.S. National Clean Hydrogen Strategy and Roadmap.[17] Several European regulatory standards have already set lifecycle emission targets for clean hydrogen ranging from 2.4-3.4 $kgCO_2e/kgH_2$.

While official regulatory guidance on how to certify well-to-gate emissions of hydrogen projects in CA has not been determined, the CPUC Decision calls for SoCalGas to consider plans to confirm hydrogen that is transported by Angeles Link meets its clean renewable hydrogen standards. Section 2.5 explores details of potential plans/methods that demonstrate transported hydrogen meets the Decision requirements. Finally, the Greenhouse Gas Emissions Evaluation captures an analysis of associated emissions of different hydrogen production pathways.

2.5 Plans to Confirm Adherence to Clean Renewable Hydrogen Standards: Clean Renewable Hydrogen Certification and Other Measures

Identical hydrogen molecules can be produced and combined from sources that have different carbon intensities. Accounting standards for different sources of hydrogen along the supply chain are required to create a market for clean renewable hydrogen.

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temporal matching, and grid-supplied electricity will not be allowed to support hydrogen production during hours when zero-carbon electricity is not available.

Incremental Generation (“Additionality”) requires that electricity used for electrolytic hydrogen production is new and explicitly dedicated to hydrogen production. The proposed Treasury guidance requires new renewable generation or new carbon capture and storage (CCS) installed at existing fossil fuel power plants within three years of hydrogen production. In the Angeles Link Decision, the CPUC does not allow for consideration of fossil fuel-based production for Angeles Link. This study assumes all renewable energy supply options will be considered “additional” to projects already installed or planned to support the bulk electric system.

Geographic Matching (“Deliverability”) – focuses on the geographic boundaries, e.g., how close hydrogen production needs to be located to renewable electricity generation. The proposed guidance requires renewable energy supply to be in the same region as defined by DOE’s National Transmission Needs Study, which is mapped to balancing authorities. For Angeles Link, all renewable electricity generation is assumed to be built within SoCalGas’s service territory and delivered to a co-located hydrogen production facility that is not connected to the transmission electric grid.

[17] https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/us-national-clean-hydrogen-strategy-roadmap.pdf?sfvrsn=c425b44f_5.

Currently, there is no industry-wide standard for certification of "clean renewable hydrogen" under the CPUC's definition. There are several agencies developing "green hydrogen" guidelines to address emissions associated with the hydrogen production supply chain.[18] However, producers and consumers can generally choose to participate and adopt any method that aligns with their goals. Nonetheless, an appropriate certification framework is an important component to create a set of common and standard practices to measure the carbon intensity of different types of hydrogen production methods. Over time, as certification policies, procedures, and practices mature, confidence will increase that hydrogen produced meets the applicable standards as set by regulatory and/or legal requirements. As Angeles Link continues to develop, potential measures SoCalGas could take to confirm that hydrogen transported by Angeles Link meets applicable clean renewable hydrogen standards include:

1. *On-going Monitoring:* Monitor industry guidance or regulatory requirements from applicable regulatory agencies that define standards for "clean renewable hydrogen" or establish certification standards.
2. *Tariffs:* As authorized by the CPUC, consider developing appropriate tariffs and/or interconnection with quality-specific requirements for the hydrogen that would be injected into Angeles Link.
3. *Contractual Arrangement with Third-Party Certification Agencies:* SoCalGas does not intend to become an accrediting body and would likely rely on third-party certification body(ies) to certify hydrogen producers as a contractual condition of access to the Angeles Link pipeline. Currently, certification of hydrogen qualified to receive Section 45V credit for the production of clean hydrogen requires the production and sale or use of such hydrogen to be verified by an unrelated party. To the extent such certifications, which have been established in the proposed federal regulation,[19] meet or exceed CA regulatory requirements of "clean renewable hydrogen," they could be relied upon. SoCalGas envisions using certification and accreditation agencies that would typically define the measuring, monitoring, reporting, and verification procedures to confirm clean renewable hydrogen meets the governing requirements.
4. *Contractual Terms and Conditions:* To the extent authorized by the applicable regulators, SoCalGas procurement of hydrogen from third-party producers would have terms and conditions in the contracts that require hydrogen to be produced according to the applicable standards.
5. *Other Measures:* Various controls such as inquiries, surveys, examination of records, and inspections could further be implemented as determined necessary

[18] Example: https://www.gti.energy/OHI/

[19] Section 45V(c)(2)(B)(ii).

to help confirm that hydrogen produced meets the clean renewable hydrogen standards.

SoCalGas plans could involve a combination of the various measures identified above. SoCalGas will continue to assess other potential measures that could further confirm that the hydrogen quality meets applicable clean renewable hydrogen standards.

2.6 Scope of Study

This Production Study identifies (1) the potential sources of hydrogen generation for transport via Angeles Link and (2) potential measures to confirm the produced hydrogen meets the clean renewable hydrogen standards set forth in the Decision. The main objectives include:

1. Evaluate potential renewable energy sources such as solar and wind to provide clean, renewable electricity for hydrogen production.
2. Evaluate land for potential clean renewable hydrogen production facilities that could be supported by the proposed Angeles Link system.[20]
3. Assessment of potential clean renewable hydrogen production volumes.
4. Estimate costs of clean renewable hydrogen production.

2.7 Statement of Limitations

Information to support the Production Study was provided by vendors where possible. Professional judgement was used to select parameters to characterize each production technology. As such, the information contained in this report does not represent a particular Original Equipment Manufacturer (OEM) within the technology class. Where vendor data could not be obtained, publicly available data was relied upon.

This report is screening-level and includes a comparison of the technical features, cost, performance, and operating characteristics of commercially available “clean renewable hydrogen” production technologies. This report is not intended to conclude on a specific technology for future clean renewable hydrogen production that Angeles Link could transport; however, a hydrogen production technology is selected to serve as the basis of design for study purposes. It is also assumed third-parties would be responsible for hydrogen production, which would be outside the scope of Angeles Link.

[20] While this analysis focuses on potential production locations in SoCalGas’s service territory, production locations (such as projects included as part of ARCHES hydrogen hub application) that are outside the territory could still potentially benefit from an interconnected, open access pipeline system.

3.0 Overview of Hydrogen Technologies

3.1 Hydrogen Production Technology Pathways

Several pathways currently exist to produce clean renewable hydrogen, some of which involve producing hydrogen from fossil fuels and capturing carbon emissions for storage or usage. Under the CPUC's "clean renewable hydrogen" definition, these fossil fuel-based pathways are omitted from this study. The following summarizes the various hydrogen technology pathways that have the potential to meet the CPUC's definition of "clean renewable hydrogen." Information in this section was provided by vendors where possible, and publicly available data for information not directly obtained through vendor solicited requests.

3.1.1 Electrolysis

Electrolysis is based on splitting water (H2O) into hydrogen and oxygen, which can be powered by zero-carbon energy sources such as wind and solar. Various technologies, including low-temperature Alkaline and Proton Exchange Membrane electrolyzers as well as higher-temperature Solid Oxide electrolyzers, are seeing cost reductions associated with conversion efficiency and scale up. Electrolyzer technologies are commercially available and provide the most near-term potential for electrolytic hydrogen at scale. The status, applicability, and selection of electrolyzer technology for the basis of the Production Study assessment is presented in this report. Renewable energy technologies for electrolysis power supply are evaluated in Appendix A – Renewable Energy Technology Assessment for Hydrogen Production.

3.1.2 Thermal Conversion

Thermal conversion processes use heat as a primary energy source to drive chemical reactions that convert carbon-based feedstocks into hydrogen and other byproducts. Examples include reforming, gasification, and pyrolysis processes. Under the definition of "clean renewable hydrogen," only renewable, biomass fuels are considered for thermal conversion into hydrogen. See Section 5 for further details on biomass pathways that leverage thermal energy to convert biomass directly or indirectly into hydrogen production.

3.1.3 Advanced Pathways

Clean renewable hydrogen can also be produced through a variety of new and advanced pathways including photoelectrochemical and thermochemical processes facilitating direct solar H_2O splitting that does not require electricity, and biological processes that can convert biomass or waste streams into hydrogen with value-added co-products. While these technologies provide promise, they remain at the laboratory-scale development stage and more information needs to be understood on these hydrogen pathways' performance and cost trajectories.

Accelerating technological breakthroughs will be key to reducing hydrogen production costs and reaching net-zero carbon emission goals. To achieve national carbon emission reduction goals, the DOE has launched a "Hydrogen Shot" Initiative, as part of the National Clean Hydrogen Strategy and Roadmap, to help advance clean hydrogen technologies. While each of these advanced pathways is not discussed in detail in this assessment, further information on the status of electrolytic hydrogen production technologies can be accessed in the DOE Hydrogen Shot Technology Assessment report.[21]

[21] "Hydrogen Shot Technology Assessment," December 5, 2023. https://netl.doe.gov/projects/files/HydrogenShotTechnologyAssessmentThermalConversionApproachesRevised_120523.pdf

4.0 Electrolysis[22]

4.1 Technology Overview

Various electrolyzers are explored in this assessment, including Alkaline, Proton Exchange Membrane (PEM), Solid Oxide Electrolyzer Cell (SOEC), and Anion Exchange Membrane (AEM) technologies. In general, electrolysis is the method of using electricity to split water molecules into hydrogen and oxygen. The electrical current drives chemical reactions at each of the two electrodes – the anode and cathode. Hydrogen gas (H_2) is produced at the cathode, and oxygen is produced at the anode. An electrolyte spans between the two electrodes to facilitate the exchanging of ions. The ions transferred are OH^-, H^+ or O_2^- depending on the type of electrolyzer. The three most common electrolyzer technologies are Alkaline, Proton Exchange Membrane, and Solid Oxide Electrolyzer Cell. Anion Exchange Membrane is a novel electrolyzer technology that is commercially available only at small (<1 MW) scale. Large scale AEM electrolyzer design is currently under development. There continues to be global interest in electrolyzer technologies, and the number of patents being issued suggest technology is being developed to make electrolyzers "more efficient, cheaper and scalable up to market needs."[23]

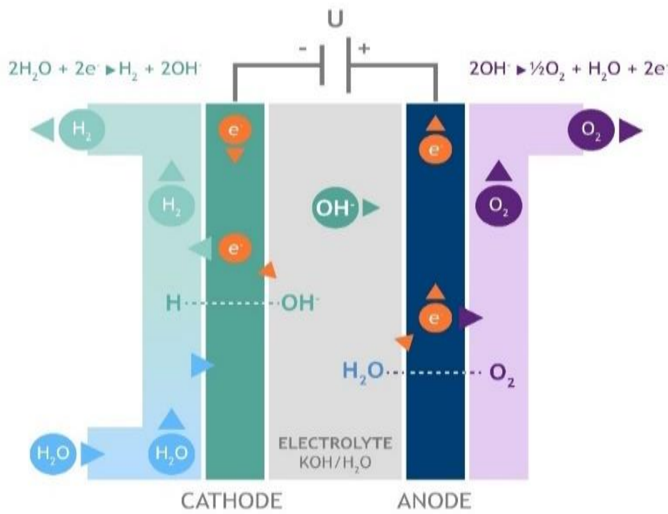
4.1.1 Alkaline

Alkaline electrolysis is the oldest and most well-established technology for producing hydrogen from water. As shown in Figure 4.1, liquid Alkaline electrolysis uses two metal electrodes submersed in a liquid electrolyte, typically a 20% to 30% potassium hydroxide (KOH) solution. At the cathode, electricity causes water to convert to a hydrogen molecule and two hydroxide ions. At the anode, the hydroxide ions transform into oxygen and water molecules. Hydrogen and oxygen molecules are the net reaction products. The two electrodes are separated by a membrane that is permeable to hydroxyl ions (OH^-) but is impermeable to hydrogen (H_2) and oxygen (O_2). The electrodes for Alkaline electrolyzers are typically nickel-plated steel (anode) and steel (cathode) and contain primarily nickel-based catalysts.

Cathode: $2H_2O_{(l)} + 2e^- \rightarrow H_{2(g)} + 2OH^-_{(aq)}$
Anode: $2OH^-_{(aq)} \rightarrow \frac{1}{2}O_{2(g)} + H_2O_{(l)} + 2e^-$
Overall: $H_2O_{(l)} \rightarrow H_{2(g)} + \frac{1}{2}O_{2(g)}$

[22] Information in this section was provided by vendors where possible, and publicly available data for information not directly obtained through vendor solicited requests.
[23] https://www.irena.org/publications/2022/May/Innovation-Trends-in-Electrolysers-for-Hydrogen-Production

Figure 4.1 Alkaline Process Diagram



The main advantage of Alkaline electrolysis is the maturity of the technology, being used for more than a century.[24] Alkaline electrolyzers require approximately 52-60 kWh of energy per kg of hydrogen produced (see Section 4.2 for electrolyzer efficiency comparisons). In addition, Alkaline electrolyzers may also have lower capital cost at larger scale (see Section 4.3.1 Electrolyzer Technology Comparison Table), depending on system requirements. Potential drawbacks include having to dispose of a caustic waste stream and turndown limitations. Alkaline electrolyzers are typically restricted in their ability to operate at low turndown conditions and have slower ramp times, making it challenging to integrate Alkaline electrolyzers with intermittent renewable electricity sources without a grid connection. At lower power availability, the gas mixture within the electrolyzer becomes more impure, and are typically shut down below certain power levels to maintain safety. Alternate electricity sources and power storage solutions must be considered when evaluating Alkaline electrolysis to produce clean renewable hydrogen.

4.1.2 Proton Exchange Membrane

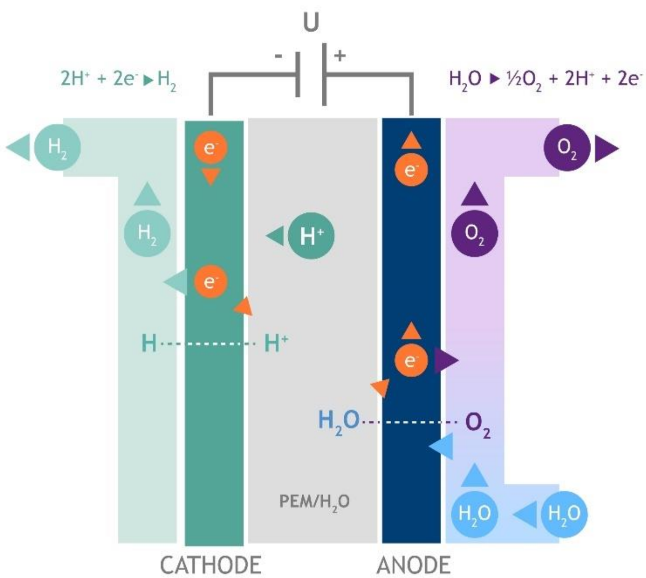
Proton Exchange Membrane (PEM) technology is one of the fastest growing clean renewable hydrogen electrolysis technologies. PEM was developed to address the

[24] Alkaline electrolyzers: Powering industries and overcoming fundamental challenges - ScienceDirect https://www.sciencedirect.com/science/article/abs/pii/S2542435124000953#:~:text=Alkaline%20electrolysis%20is%20the%20most%20mature%2C%20being%20used,in%20the%20production%20of%20ammonia%20fertilizers%20and%20explosives

partial load (turndown) restrictions associated with Alkaline electrolyzers. As shown in Figure 4.2, PEM electrolysis uses two metal electrodes separated by a membrane. PEM contain catalysts such as platinum and iridium and uses a solid polymer electrolyte which is the membrane that conducts protons. The intermediate reactions in a PEM electrolyzer differ from an Alkaline electrolyzer in that a hydrogen ion (H+, proton) is exchanged rather than a hydroxyl (OH-).

Anode: $H_2O_{(l)} \rightarrow ½O_{2(g)} + 2H^+_{(aq)} + 2e^-$
Cathode: $2H^+_{(aq)} + 2e^- \rightarrow H_{2(g)}$
Overall: $H_2O_{(l)} \rightarrow H_{2(g)} + ½O_{2(g)}$

Figure 4.2 PEM Process Diagram



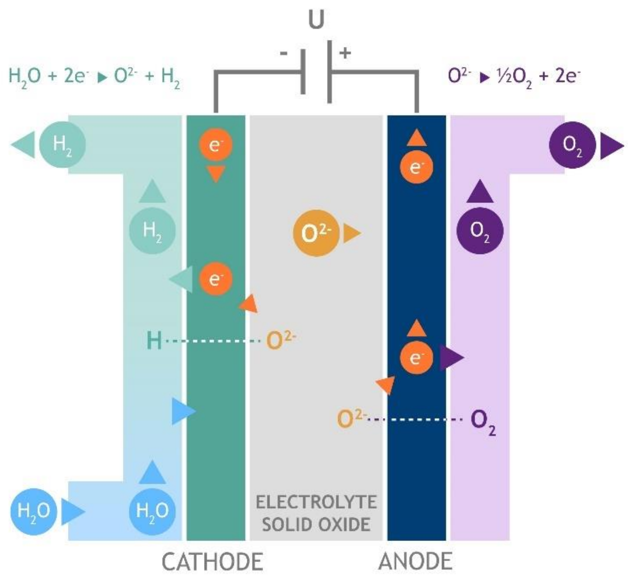
Significant advancements have been made in recent years in terms of the scale and capacity of PEM electrolyzers. The main advantage of PEM electrolysis is the ability for low turndown ratios (the ability to operate over different production rates) and quick ramp rates (ability to adjust hydrogen production rate), making it a complementary pairing for fluctuating power supplies such as intermittent renewable electricity sources. It also does not have a caustic waste stream (in contrast to Alkaline electrolyzers). Potential drawbacks include a modestly higher capital cost than Alkaline (see Section 4.3 for cost details) with today's technology. Another challenge facing PEM electrolyzers is the availability, cost, and supply chain for raw materials such as titanium, nickel, gold, platinum, and iridium.

4.1.3 Solid Oxide Electrolyzer Cell

Solid Oxide Electrolyzer Cell (SOEC) technology is an efficient, emerging technology in the electrolyzer space. With only one U.S. manufacturer, it is the newest electrolyzer technology to reach the market. As shown in Figure 4.3, SOEC uses two porous electrodes and a dense ceramic electrolyte. The intermediate reactions in an SOEC electrolyzer differ from Alkaline and PEM electrolyzers.

Cathode: $H_2O_{(l)} + 2e^- \rightarrow O^{2-}_{(aq)} + H_{2(g)}$
Anode: $O^{2-}_{(aq)} \rightarrow ½O_{2(g)} + 2e^-$
Overall: $H_2O_{(l)} \rightarrow H_{2(g)} + ½O_{2(g)}$

Figure 4.3 SOEC Process Diagram



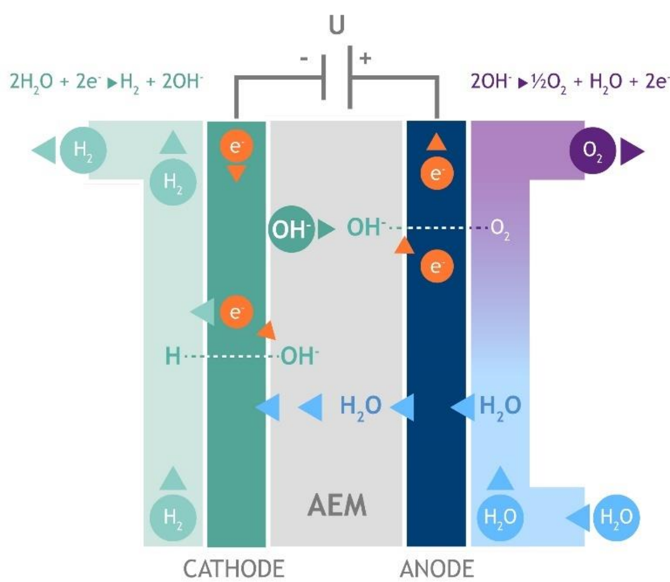
Based on vendor information, an advantage of SOEC is the potential 20-30% improvement in efficiency versus Alkaline and PEM electrolyzer technologies. This can further take advantage of waste heat or waste steam streams available to be utilized by the electrolyzer. SOEC also does not require any rare metals. One key potential drawback to current SOEC designs is the lack of flexibility to quickly adjust to operating ranges as compared to PEM. While SOEC stacks are efficient near their full capacity, efficiency significantly declines at low turndown. Also, SOEC electrolyzers have a relatively slower start time than PEM and often require energy for “hot standby” (i.e., keeping the electrolyzer running during periods of low demand to facilitate faster ramp up of the electrolyzer when called on). Overall, these factors make SOEC challenging to pair with intermittent renewable electricity sources unless also supplemented by additional electricity.

4.1.4 Anion Exchange Membrane

Anion Exchange Membrane (AEM) electrolyzers were developed to combine some of the benefits of both Alkaline and PEM electrolyzers. As shown in Figure 4.4, Like Alkaline electrolyzers, AEM electrolyzers exchange a hydroxide ion (OH^-) across a membrane. Since the reaction occurs across a membrane, it can be kept at higher pressures similar to PEM. With PEM electrolysis, the protons (H^+) create an acidic environment, which necessitates platinum group metal catalysts and titanium bipolar plates. Since the AEM reaction occurs in a slightly alkaline environment, no noble metals are required. Therefore, the AEM stacks can be built for lower cost than PEM.

Cathode: $2H_2O_{(l)} + 2e^- \rightarrow H_{2(g)} + 2OH^-_{(aq)}$
Anode: $2OH^-_{(aq)} \rightarrow ½O_{2(g)} + H_2O_{(l)} + 2e^-$
Overall: $H_2O_{(l)} \rightarrow H_{2(g)} + ½O_{2(g)}$

Figure 4.4 AEM Process Diagram



Currently, AEM electrolyzers have smaller hydrogen production capacities than other technologies, and their manufacturing and production rates make them difficult to use for projects larger than 1 MW.

4.2 Electrolyzer Technology Comparison

4.2.1 Energy Requirements

The efficiency of an electrolyzer can be measured by the amount of electrical energy required to produce a certain amount of hydrogen. The electrolyzer efficiency considers the energy losses in the entire process of producing hydrogen. Advancements in technology have improved the energy efficiency of electrolyzers. Table 4.1 below shows the anticipated energy requirements provided by technology suppliers. Vendors typically state energy required for the electrolyzer scope, which excludes Balance of Plant (BOP) auxiliary loads and electrical losses.

Table 4.1 Comparison of Electrolyzer Efficiencies

	Alkaline	PEM	SOEC	AEM
Electrolyzer Power Requirement per Kilogram of hydrogen	52-60 kWh	50-58 kWh	37.5-42 kWh	54 kWh

4.2.2 Operational Flexibility

The various electrolyzer technologies differ in their operational flexibility, especially regarding start-up times (required to bring the electrolyzer from off status to minimum production capacity), ramp rates, and turn-down ratios.

PEM electrolyzers boast the quickest startup times, ramp rates, and have favorable turndown capabilities. This makes them the most suitable technology to pair with intermittent and variable power supplies such as PV solar. PEM can be turned down to 10-20% of nameplate capacity while achieving better-than-published efficiencies. It takes less than 5 minutes to cold start a PEM electrolyzer and once warm, it can ramp at 1% per second. This means that a PEM electrolyzer can go from completely shut down to full rate in less than 7 minutes.

Alkaline electrolyzers can be turned down to 15-20% of nameplate capacity and have a cold-start time of approximately 10 minutes. It takes an additional 10 minutes to ramp from minimum rates to full capacity. Constant ramping and frequent starts/stops make Alkaline electrolyzers a more challenging pairing with behind-the-meter renewables without increased investment in batteries or another form of energy storage.

SOECs have a cold upstart time of 15 hours, which is much longer than PEM or Alkaline. Once warm, SOECs can ramp up to full rates within minutes. SOECs complement existing industrial facility co-location where waste heat or steam can be utilized to improve electrolyzer efficiencies. However, SOEC electrolyzers are best suited for stable operating conditions. Compared to PEM, SOEC electrolyzers are not as capable of operating with load variations and frequent starts/stops that come with behind-the-meter renewables. SOECs can be turned down to 10-20%. However, efficiency declines quickly below 40% capacity and declines severely below 20% capacity. If paired with renewables, SOECs would best be used in applications where they are able to be supplemented by other, more stable, energy sources such as grid power or stored renewable energy (hydroelectric, geothermal, etc.) to keep the SOEC at steady operating conditions near nameplate capacity.

4.2.3 Maintenance

Electrolyzers are complex systems and performance will degrade over time due to kinetic, electrochemical, and thermophysical phenomena. As electrolyzer stacks are a significant cost component of an electrolyzer production facility, the speed of performance degradation (and therefore need for stack replacements to regain new and clean performance) can be a significant factor in lifecycle hydrogen production costs.

Given the lack of electrolyzer operating data tied to highly variable renewable power and the relatively early maturity of PEM, SOEC, and AEM technologies, the effect of operations on stack degradation is not well understood. Vendors are projecting a range of stack replacement intervals of approximately 80,000 hours for Alkaline and PEM, 50,000 plus hours for SOEC, and likely shorter lifespans for AEM.

In addition to stack replacements, vendors recommend quarterly and annual inspection and maintenance requirements for water treatment and electrolyzer equipment. Quarterly maintenance/inspection is expected to take a few hours, while annual maintenance is expected to take less than a day.

4.2.4 Water / Wastewater

The electrolysis reaction requires approximately 9 kg (9 liters or 2.4 gallons) of water to create 1 kg of hydrogen. This water must be pure, demineralized quality water. In addition to the water needed for conversion to hydrogen, water is also required to support balance of system cooling requirements. Refer to the Water Study for additional information on water required for hydrogen production.

4.2.5 Compression

Alkaline and SOEC electrolyzers discharge hydrogen near atmospheric pressure. PEM and AEM electrolyzers discharge hydrogen at 30 to 40 barg (or 435 to 580 psig). Hydrogen from Alkaline or SOEC electrolyzers would therefore need more compression (and therefore more auxiliary power requirements) for transportation via pipeline and storage.

4.2.6 Land Requirements

The land required for electrolyzers and related equipment will be much smaller than the land required for the renewable power used to supply the electrolyzer. The land required for PV solar power to support an electrolyzer facility will be approximately 200 times the land required for the electrolyzer facility itself. Additionally, electrolyzers can be stacked vertically, saving space, and reducing the overall land footprint further. While the plot space required for the electrolyzer facility will not significantly vary between electrolyzer technologies, the efficiency difference between technologies will impact total land requirements due to differences in power requirements.

4.3 Cost Comparisons

The Alkaline electrolyzer technology is the most mature technology and is currently the lowest capital cost option on a nameplate capacity basis. However, other technologies may be lower on a levelized cost basis in certain applications depending on power profiles and other factors. See Section 4.3.1 Electrolyzer Technology Comparison Table for cost comparisons between different electrolyzer technologies.

PEM technology uses rare minerals in the electrode design which are found in low concentrations. While PEM efficiencies and manufacturing capabilities have improved over recent years, the availability and cost of critical metals continue to put upward pressure on costs. The price and availability of iridium and nickel alloys contribute to higher PEM price volatility as compared to Alkaline electrolyzers. Nonetheless, overall PEM costs are expected to decline as manufacturing and technological developments progress.

PEM operating capabilities allow for a close time match of intermittent renewable power supply and hydrogen production. This flexibility is becoming increasingly important in determining the levelized cost of hydrogen production. Even with higher capital costs, PEM technology should be evaluated against Alkaline to determine the most economically beneficial technology for each specific potential project.

SOEC electrolyzers are currently more expensive than Alkaline and PEM electrolyzers. SOEC technology is newer than Alkaline and PEM and is expected to have improved cost efficiencies as the technology matures. SOEC electrolyzers have the best efficiency and economics for applications with a constant electrical supply.

Electrolyzers manufactured in China offer lower price points than electrolyzers manufactured in North American and European countries, primarily due to differences in manufacturing labor costs, material and sub-supplier sourcing standards, national, state, and local code requirements, and typical U.S. owner-driven technical and commercial requirements. The costs referenced in this study rely on prices obtained from North American and European suppliers.

4.3.1 Electrolyzer Technology Comparison Table

The table below summarizes the techno-economic comparison of the electrolyzer technologies.

Table 4.2 Electrolyzer Technology Comparison

	Alkaline	Proton Exchange Membrane (PEM)	Anion Exchange Membrane (AEM)	Solid Oxide Electrolysis Cell (SOEC)
Costs				
Capex ($M /tpd H_2) – Installed Plant	4 – 6	5 -7	Note 1	6 – 8
Opex ($k /tpd H_2)	50	50	Note 1	50
Stack/Electrode Replacement Cost ($M /tpd H_2)		1.2	Note 1	0.8
Stack/Electrode Life Expectancy	8-10 years	8-10 years	Note 1	5+ years
Operating Parameters				
System Power Consumption (kWh/kg H_2)	52 – 60	50 – 58	~54	37.5* - 42
Demin Water Consumption (gal / kg H_2)	2.7	2.7	2.7	2.7
% Turndown	15 – 20%	10 – 20%	3%	10-20%
Cold Start Time (0-min rate)	~10 minutes	<5 minutes	30 minutes	15 hours+
Warm Ramp Rate	Full Rate in <10 minutes	1% per second	Full Rate in 10 Minutes	Full Rate in Minutes
Operating Temperature (°C)	30 – 80	50 – 220	55	600 – 1000
Hydrogen Pressure at Site Boundary (barg)	0 – 10	30 – 40	35	0 – 2
Hydrogen Purity (%)	99.998%	99.1 – 99.9995%	99.9900%	85% - 99.8%
Technology Readiness				

Commercial Status	Commercially Operational	Commercially Operational	Developing	Commercially Operational
TRL Level	9	9	5	9**
Size of Largest Operating Facility (tpy H_2)	20,338	2,920	0	876
Size of Largest Operating Facility (MW)	150	20	0	4
2023 Existing Ez Mfg Capacity (MW/yr)	2,840	4,700	2.9	2,000

Note 1: Technology still in development status, costs and life expectancy pending commercial operation status

* Assumes steam

**Reached Commercial Operation in 2023

4.4 Electrolyzer Manufacturing and Supply

4.4.1 Commercialization and Deployment Plans

Most of the electrolyzer facilities constructed over the last 50 years have been 25 MW or smaller and mostly concentrated in Europe. In the last 10 years, electrolyzers have received a significant increase in global interest and the total manufacturing capacity of electrolyzers has rapidly increased worldwide from 100 MW per year in 2000 to 25 GW per year in 2023. The rapid scale-up in electrolyzer capacity is expected to continue in the coming years as announced projects suggest an installed electrolyzer capacity reaching 230 GW globally by the year 2030. However, only 8% of these announced projects have reached a Final Investment Decision (FID).[25]

In the United States, current installed capacity of electrolyzers is approximately 67 MW, with electrolyzer plants ranging from 120 kW to 40 MW in size. Planned capacity is approximately 3.6 GW with sizes ranging from 120 kW to 1.25 GW.[26] Table 4.3 below shows the top 11 planned electrolyzer projects in the United States ranked by size as of Q1 2024:

[25] See full report: https://www.iea.org/reports/global-hydrogen-review-2024

[26] https://www.energy.gov/eere/fuelcells/articles/electrolyzer-installations-united-states

Table 4.3 Top 11 Planned Electrolyzer Projects in the United States

No.	Location	Power (MW)	Status
1	Corpus Christi, TX	1,250	Planned
2	LaSalle, IL	320	Planned
3	Amarillo, TX	240	Planned
4	Laramie County, WY	240	Planned
5	Lubbock County, TX	240	Planned
6	Pueblo County, CO	240	Planned
7	Delta, UT	220	Planned
8	Alabama, NY	200	Planned/Under Construction
9	Nederland, TX	120	Planned/Under Construction
10	Young County, TX	120	Planned/Under Construction
11	Yuma, AZ	120	Planned

Source: https://www.energy.gov/eere/fuelcells/articles/electrolyzer-installations-united-states

Focusing on California projects, Table 4.4 below shows the top 10 planned/installed electrolyzer projects by size (MW):

Table 4.4 Top 10 Planned/Installed Electrolyzer Projects in California

No.	Location	Power (MW)	Status	Estimated Total Hydrogen Production (tpd)
1	Fresno, CA	80	Planned	32
2	Ontario, CA	5	Planned/Under Construction	2
3	Mountain View, CA	4	Installed/Operational	2
4	Palm Springs, CA	2	Installed/Operational	1
5	CA	1.25	Planned/Under Construction	<1
6	Borrego Springs, CA	1	Planned/Under Construction	<1
7	CA	0.9	Planned/Under Construction	<1
8	Sonoma, CA	0.5	Installed	<1
9	CA	0.25	Installed/Commissioning	<1
10	CA	.18	Installed	<1

Source: https://www.energy.gov/eere/fuelcells/articles/electrolyzer-installations-united-states[27]

4.4.2 Manufacturing Capacities

Electrolyzer manufacturers have responded to the anticipated demand by investing heavily in new manufacturing facilities. The global electrolyzer manufacturing capacity, based on manufacturers projections, could reach 165 GW/year by 2030 with Europe and China accounting for 50% of the growth.[28] North America is expected to expand its electrolyzer production capacity from 550 MW (2022) to an estimated 2 GW of electrolyzer manufacturing capacity by 2030. Nel, a Norwegian-based supplier, is currently planning to expand manufacturing capacity in Connecticut by adding 500 MW

[27] Other announcements include Element Resources planned 20,000 tonnes per year electrolyzer plant in Lancaster, CA (https://www.elementresources.com/element-resources-awards-lancaster-clean-energy-center-feed/).

[28] See full report: https://www.iea.org/reports/global-hydrogen-review-2024

of PEM capacity by 2025.[29] Nel also has recently announced plans to build a 4 GW capacity manufacturing facility in Michigan.[30] Bloom Energy is projecting 4-5 GW of future electrolyzer cell capacity at their facilities in California and Delaware. Accelera by Cummins has recently completed a PEM electrolyzer manufacturing facility in Minnesota with an annual production capacity of 500 MW and plans to scale up to 1 GW of capacity in the future.

Overall, it is projected by electrolyzer suppliers that the manufacturing capacity will outpace the electrolyzer demand over the next 5-10 years.

4.4.3 Supply Chain Considerations

By the end of 2022, Alkaline electrolyzers comprised approximately 60% of the worldwide installed electrolyzer capacity, while PEM electrolyzers represented approximately 30% of installed capacity. Based on announced projects, PEM appears to be gaining market share as technology costs decline and the value of operational flexibility increases as intermittent renewable capacity increases.

Nickel, steel, and aluminum are the main raw materials for Alkaline electrolyzers. Nickel is the world's fifth-most common element on earth and Australia, Indonesia, South Africa, Russia, and Canada account for more than 50% of the global nickel resources. Today, nickel is primarily used for making stainless steel and batteries and has well established resources and supply chain. Based on 2022 metal prices, nickel, steel, and aluminum account for approximately 4% of total Alkaline electrolyzer production costs. Platinum and iridium are the key raw materials for PEM technology electrolyzers. Platinum and iridium production is largely concentrated in South Africa and Russia. Since these two countries account for ~80% of global supply, the prices for platinum and iridium can be volatile. Analyzing 2022 metal prices, platinum, and iridium account for approximately 12% of total PEM costs.[31]

Over the past few years, precious metal price increases have contributed to an increase in the supply cost of electrolyzers. This cost increase is occurring at a time when suppliers are attempting to ramp up production while maintaining or lowering production costs. Electrolyzer prices will likely continue to fluctuate based on a variety of factors, including, but not limited to, supply and demand, mining capacity, environmental

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[29] https://nelhydrogen.com/articles/in-depth/expanding-production-capacity-in-wallingford/

[30] https://nelhydrogen.com/articles/in-depth/nel-plans-gigafactory-in-michigan/

[31] "2022 Global Hydrogen Review." International Energy Agency (IEA). https://www.iea.org/reports/global-hydrogen-review-2022/executive-summary

regulations, economic conditions, and geopolitical events. Reducing critical metal use is a priority focus of ongoing electrolyzer R&D and commercialization efforts.

4.4.4 Electrolyzer Emissions

Electrolytic hydrogen that uses renewable electricity is expected to have zero associated greenhouse gas emissions as would be considered clean renewable hydrogen. Please refer to the GHG Study Report Appendix for information regarding a summary of carbon intensity values compiled based on a review of existing literature.

5.0 Biomass Derived Hydrogen Technologies

5.0 Biomass in California

Biomass is organic materials "utilized as fuels for producing energy. Examples include forest slash, urban wood waste, lumber waste, agricultural wastes, etc." [32] Biomass has been a subject of interest in California's transition to a zero-carbon future for some time. In 2022, the CPUC implemented California Senate Bill 1440 by setting renewable natural gas (RNG[33]) procurement targets and goals for each Investor-Owned Utility in California. The California Energy Commission (CEC) executed a study of potential sources and volumes of RNG production within California and the carbon intensities for different sources. Figure 5.1 summarizes the results of this study, showing various sources of RNG and the respective potential to displace traditional natural gas.

Woody biomass as a source of RNG may be a key pathway as the removal and use of forest material in overly dense ecosystems increases habitat potential for many species and decreases the risk of catastrophic forest fires. Using woody biomass for fuel generation could create market demand to offset a forests landowner's cost of forest thinning.

An additional benefit to the production of RNG from woody biomass is that this RNG can be further converted into renewable hydrogen. After considering existing uses of woody biomass in the state of California, the remaining available amount is estimated to be 14.3 million bone dry tons per year (MBTDT/year).[34] If these resources were converted to renewable hydrogen, just under 1 million tons of hydrogen would be produced each year. Following woody biomass, RNG produced from municipal solid waste, landfills, and agricultural residues are the next largest biomass resource in California, with a collective potential to produce another approximately 1 million tonnes

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[32] https://www.energy.ca.gov/data-reports/california-power-generation-and-power-sources/biomass/biomass-energy-california

[33] Renewable Natural Gas (RNG) is a combustible gas produced from the anaerobic decomposition of organic materials (i.e., biogas) that is captured and then purified to a quality suitable for injection into an IOU-operated gas pipeline. Major sources of biomethane include non-hazardous landfills, wastewater treatment facilities, organize waste, and animal manure. Biomethane can capture methane emissions from the waste sector and be used as a direct replacement for fossil natural gas to help California reduce its GHG emissions. Biomethane also includes woody biomass as described in California Public Utilities Code section 650.

[34] California Biomass Consortium, 2013 projections. https://ucdavis.app.box.com/s/ke4a3us8gtkmffmo2l2gkfrmhad8d654

of hydrogen annually. Further studies would be needed to address biomass availability specifically within SoCalGas's service territory.

Figure 5.1 Comparison of Renewable Natural Gas Sources[35]

	Livestock	WRRF	Landfills	Biomass	HSAD
Potential Displacement of California's Natural Gas Consumption	• Production Potential: 1 - 3% • Technical Potential: 4%	• Production Potential: <1% • Technical Potential: <1%	• Production Potential: 6 - 10% • Technical Potential: 15%	• Production Potential: 1 - 3% • Technical Potential: 11%	• Production Potential: 3 - 7% • Technical Potential: 17%
Cost to Produce RNG [$/MMBtu]	$25.50	$16.75	$13.00	$23.25	$30.75
Carbon Intensity Compared to the Baseline (Flaring or Venting) [gCO2e/MJ]*	-341	+28	+42	+13	-23
Reduction in Carbon over Natural Gas [gCO2e/MJ]	417	47	34	62	99
LCFS Incentive [$/MMBtu]	$53.85	$6.12	$4.40	$8.06	$12.79

Notes: WRRF is water resource and recovery facilities.
HSAD is high-solids anaerobic discharge (green waste from municipal sources, food processing plants etc.)

5.1 Biomass to Hydrogen Technologies

Biomass to hydrogen pathways can be generally divided into two categories: 1) direct production routes and 2) conversion of storable intermediates (indirect routes). Direct production routes have the benefit that they are the most simplistic. Indirect routes have the advantage that they can store and distribute production of the intermediate "biogas," which could minimize transportation costs of the biomass.[36] Biogas can be transported by pipelines to centralized larger-scale hydrogen production facilities. This section describes the most common pathway for both indirect and direct biomass to hydrogen technologies.

5.1.1 Steam Methane Reforming (Indirect) of Biogas/Biomethane

Steam methane reforming (SMR) is the most common hydrogen production method in the U.S. The raw biogas is typically produced from anaerobic digesters, which requires

[35] Renewable Natural Gas in California: Characteristics, Potential, and Incentives: 2023 Update. Verdant. August 2023. https://www.energy.ca.gov/sites/default/files/2023-08/CEC-200-2023-010.pdf

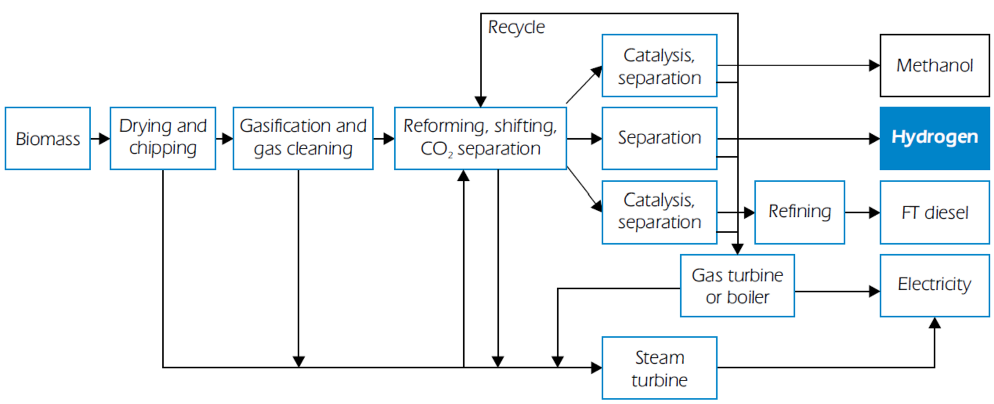
[36] https://www.nrel.gov/docs/legosti/old/36262.pdf

cleaning and upgrading, with the separation of impurities such as sulfur and siloxanes. This upgraded biogas (i.e., biomethane) is then sent to a SMR, where it is reacted with steam to produce a hydrogen-rich syngas, which is then processed through a water-shift-reaction to separate the hydrogen. Since converting RNG to hydrogen involves an extra processing step to separate the CO2, the cost to produce hydrogen from raw biogas is higher compared to the cost of producing pipeline quality RNG. Renewable natural gas and biogenically derived hydrogen will compete for the same feedstocks.

5.1.2 Biomass Gasification (Direct)

A more efficient and cost-effective approach to convert solid biomass to hydrogen involves directly converting the fuel stock to hydrogen without creating RNG as the intermediary fuel. Biomass can be converted to hydrogen using various thermal conversion processes which use heat as the energy source to drive chemical reactions releasing (or capturing) the carbon byproduct. Gasification conversion technologies have been commercially proven to convert coal and solid biomass to renewable fuels. To date, there are no pathways that have reached a demonstration phase using biomass gasification to produce hydrogen. Gasification coupled with water-gas shift is a widely practiced process that involves the reaction of carbon monoxide and water vapor to form carbon dioxide and hydrogen. This process has the highest technology readiness level (TRL) to convert biomass to hydrogen.[37] Figure 5.2 below shows the conversion process.

Figure 5.2 Biomass Gasification to Hydrogen Process Diagram



Source: "Hydrogen Production and Storage: Research Priorities and Gaps." IEA 2006

[37] Hydrogen Production and Storage: Research Priorities and Gaps. IEA 2006. https://iea.blob.core.windows.net/assets/e19e0c2a-0cef-4de6-a559-59d0342974c3/hydrogen.pdf

Direct hydrogen production from biomass has challenges from a commercialization perspective. At present, there are only a few sustainably sourced biomass to renewable fuel demonstration plants in California, and there are no demonstration plants producing hydrogen from forested biomass operating today.[38] The components of biomass gasification to hydrogen (gasification, gas cleaning and upgrading) are all based on the utilization of developed and technologically proven operation units. It is the process chains of integrating these components to produce hydrogen that still need to be tested to mature the market for biomass to hydrogen production. Because the technology components themselves have been proven, it is possible there will be a faster path to market maturity once further testing and development is completed.

5.1.3 Biomass Conversion to Electricity for Electrolysis

There are three ways to release biomass energy to produce power for electrical generation: burning in a conventional steam generation plant, bacterial decay (anaerobic digestion) to create a biogas for powering a gas turbine, and chemical conversion to gas or liquid fuel which can be used to power a turbine or engine. Each of these biomasses to electricity conversion pathways have been commercially demonstrated, and there are currently utility scale plants using these methods operating in California. Biomass power plants in operation are further discussed in Appendix A, Renewable Energy Technology Assessment. As compared to intermittent renewable resources, biomass is able to provide dispatchable, baseload generation. However, biomass to electricity is currently reliant on a constant supply of a homogenous feedstock. Biomass must be supplied to a single facility within a narrow fuel quality range, meaning that a power plant designed to accept forested biomass to produce hydrogen requires homogenous forested biomass sources that can be economically delivered to the power plant. This constraint currently limits biomass to electricity facilities to a smaller size relative to other power supply options.

The potential for biomass as a renewable energy source for electrolyzer based hydrogen production is evaluated in the Renewable Energy Technology Assessment provided in Appendix A. In the near term, biomass to electricity to power electrolyzers is the only commercially available hydrogen production technology and is considered to be a more feasible biomass to hydrogen pathway (as compared to other biomass to hydrogen pathways) for future hydrogen production.

5.2 Biomass Emissions

Hydrogen created from biomass generates greenhouse gas emissions during harvesting, transporting, and conversion to electricity or directly to hydrogen. Because

[38] https://www.energy.ca.gov/data-reports/california-power-generation-and-power-sources/biomass/biomass-energy-california

growing biomass removes carbon dioxide from the atmosphere, the net carbon emissions can be neutral or low. In addition, concerns about the impacts of forest waste currently burned in wildfires can be mitigated by the collection of forest waste for productive use. Carbon emissions can be further reduced to the extent biomass hydrogen production is coupled with carbon capture and storage. The use of carbon capture will depend on the biomass feedstock and the final regulations that determine the lifecycle well-to-gate GHG emissions rate associated with biomass to hydrogen production. For additional information regarding a summary of carbon intensity values compiled based on a review of existing literature, please refer to the GHG Study Report Appendix.

5.3 Conclusions

Biomass is a potential feedstock source for hydrogen that could provide several environmental benefits, including support of forest restoration. Currently, biomass to hydrogen technology is still in its early stages, with research and development efforts focused on improving efficiency of direct biomass to hydrogen technology and reducing costs.

Biomass to electricity for electrolysis is considered the most feasible biomass to hydrogen pathway based on current technology status. Biomethane and biomass projects in SoCalGas's service territory are currently limited by the costs to transport the biomass to processing facilities, resulting in a smaller scale of these renewable resources. It is anticipated biomass may play an important role for clean renewable hydrogen production to support hydrogen production in the future, with increasing opportunities once direct hydrogen conversion technologies mature and cost and efficiency improvements are realized.

6.0 Hydrogen Production Technology

6.0 Hydrogen Production Technology and Size

Electrolyzers for dedicated hydrogen production have traditionally been built in small volumes for niche markets. Larger sized production facilities are expected to meet the higher demand volumes anticipated in a decarbonized California economy (see Demand Study for projected market demand in SoCalGas's service territory) and reduce electrolyzer investment costs through design optimization and economies of scale. Research and development are currently focused on improving the design and performance of electrolyzer technology and the associated BOP equipment, which is expected to further reduce total costs. For the purpose of the Study, an electrolyzer technology was selected to develop a reference design to approximate hydrogen production technical requirements and costs. PEM technology was currently selected based on commercially available designs indicating PEM electrolyzers offer suitable operating flexibility across a wide range of hydrogen production volumes expected when using intermittent and variable renewable energy.

The highest capacity commercially available PEM electrolyzer units are between 10 – 18 mWe (the term mWe is referring to the consumed electrical power), depending on the supplier. Multiple units can be installed at a single production facility to increase total facility hydrogen production. The size, technology, and renewable energy supply source for hydrogen producers in the Angeles Link system is expected to vary due to several factors including locational constraints, renewable resource availability, technological improvements, future policy drivers, and economic factors. A 20 x 10 mWe PEM electrolyzer (200 mWe nominal total) industrial scale production facility is assumed as the design basis for this production study.

6.1 Renewable Energy Technology

The Renewable Energy Technology Assessment included in Appendix A summarizes a range of viable renewable energy resources to support electrolytic hydrogen production. The report concludes that solar is the most widely suitable power resource for SoCalGas's service territory, which serves Central and Southern California. Solar irradiance in most of SoCalGas's territory is some of the best in the country and is the lowest cost source of renewable energy in the area. On-shore wind is also suitable for serving hydrogen production. However, above average locations for wind speed are not abundant in SoCalGas's service territory. Other renewable power resources, including biomethane, biomass, geothermal, hydroelectric, and offshore wind, are expected to support total hydrogen production on a smaller scale than solar due to their resource limitations in Southern California.

While solar was selected as the design basis for this production study, additional analysis to assess whether solar should be paired with lithium-ion batteries from an optimization standpoint is further explored in Section 6.3 and 6.4.

6.2 Renewable Energy Resource Profiles

Burns & McDonnell utilized the System Advisor Model (SAM) toolkit available via the National Renewable Energy Lab (NREL) website to develop annual hourly (8760) solar profiles. The Renewable Energy Assessment concluded that capacity factors for solar varied from 28-34% among sites evaluated across the SoCalGas service territory. For purposes of design optimization and energy estimation, a representative average solar profile near Bakersfield, CA was selected with a capacity factor of 30%.

6.3 Hydrogen Production Optimization

Due to the intermittent nature of renewables, there may be periods where supply exceeds demand, resulting in the curtailment of renewable generation. There will also be periods of demand where the renewable energy source cannot supply electricity for hydrogen production. To meet a steady hydrogen demand when using intermittent resources, three options exist:

1. Store intermittent electricity in periods of excess generation, and discharge from battery storage in times of renewable energy supply shortage.
2. Store excess hydrogen in periods of excess generation, and withdraw it from storage in times of hydrogen production shortage.
3. A combination of options 1 and 2

To evaluate the impact of electricity storage, an analysis of adding various amounts of solar and 4-hour Li-ion battery energy storage system (BESS) was performed to increase the hydrogen production capacity factor. High ratios of solar and solar+BESS energy capacity relative to the peak electrolyzer capacity were analyzed. The results showed the potential impact of increasing annual electricity production compared to the need for increasing pipeline capacity and volumes of annual hydrogen storage. The following section describes the analysis and outcomes of adding batteries to the solar facility to increase electrical production.

6.3.1 Configuration

The solar and BESS can be configured in either a DC coupled or an AC coupled arrangement. In an AC coupled system, the BESS and solar are co-located but do not share an inverter. An AC coupled system is inherently more reliable than a DC coupled system since the solar and BESS systems do not share common inverters. In an AC coupled system, the BESS is centralized into a single container or building next to the solar array, which reduces footprint and simplifies DC cabling.

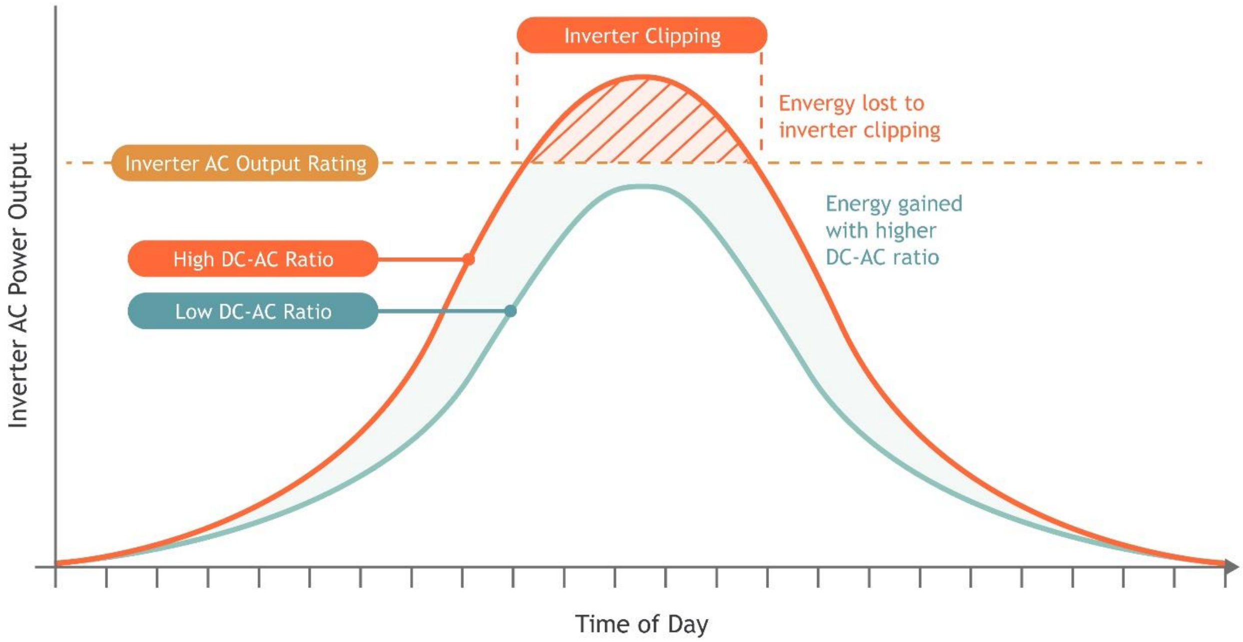
In a DC coupled system, the solar and BESS are coupled on the DC side and share a bi-directional inverter. This system eliminates the need for a set of inverters, switchgear, and other BOP costs. Electrical losses through the inverter are also eliminated. In this arrangement, single BESS containers will be co-located next to inverters throughout the solar array, which may increase the solar facility footprint.

For the purposes of this study, the solar and BESS facility was assumed to be AC coupled. A medium voltage (MV) AC tie to the hydrogen production facility MV switchgear is assumed, where a rectifier will convert the AC power to DC power for the electrolyzers. Additional analysis considering site layout, costs, reliability, operating requirements, and potential grid connection options could be performed to further refine configurations for a potential hydrogen production facility.

6.3.2 Solar and Battery Sizing

It is common for solar energy facility design to include some amount of solar “clipping,” which refers to the situation where the amount of solar energy produced by the PV system exceeds the capacity of the inverter to convert it to usable electricity. This happens when the PV system is exposed to high levels of sunlight, such as during peak daylight hours. When this happens, the excess energy cannot be utilized by the system. However, over-sizing solar increases the amount of usable electricity during times of earlier solar ramp up or decreasing ramp down, which may improve the overall design optimization. Figure 6.1 below conceptually shows the impact of designing a solar system with a higher DC-AC ratio to increase energy output).

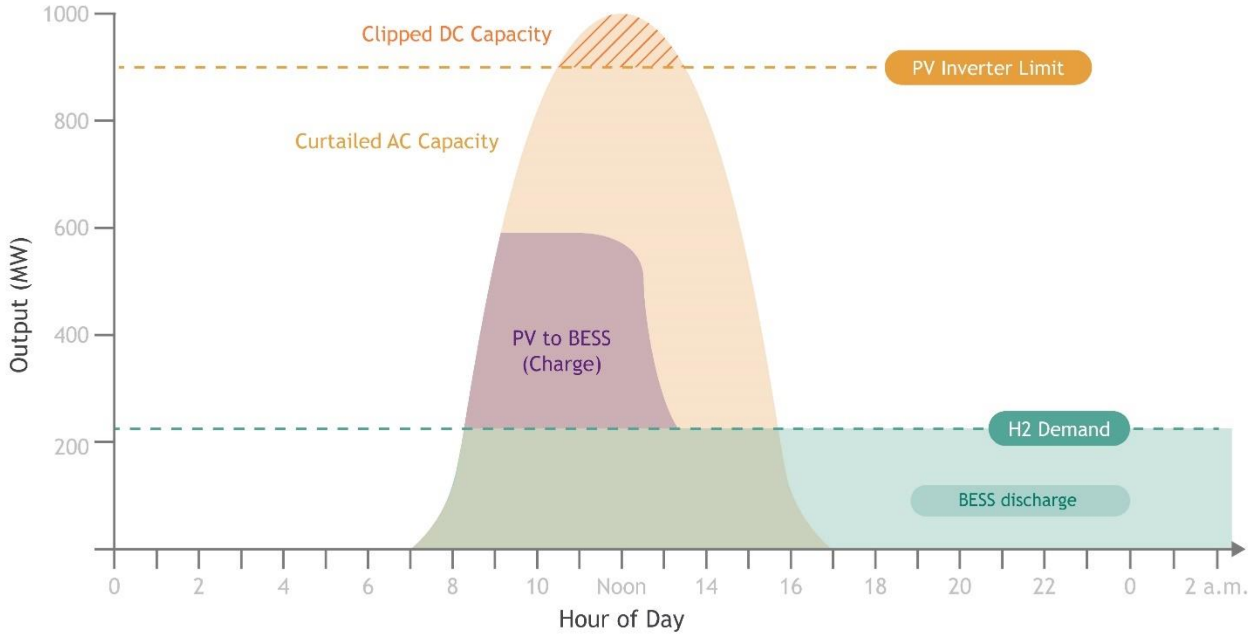
Figure 6.1 Impact of Solar Sizing – AC to DC Ratios



When a solar facility is directly connected to a hydrogen production facility, the usable solar output is further “curtailed” to the maximum electrical demand of the electrolyzers. This creates a second point of electrical capacity limitation at the facility point of interconnect (POI). While it may not intuitively seem reasonable to build a solar facility that can deliver more AC power than required by the electrolyzers, this design will increase the electricity sent to the hydrogen production facility during early and late times of the day when there is less sunlight. Annual hydrogen production output can therefore be increased.

Using BESS to take advantage of unused solar is an efficient way to increase the benefits of the solar panels. The batteries can charge with the extra solar capacity during peak hours, and discharge during periods of cloudiness or nighttime hours to level out electricity sent to the electrolyzers and increase hydrogen production. Figure 6.2 illustrates this concept.

Figure 6.2 Conceptual Solar + BESS Facility Sizing Comparison



Note that the maximum power sent to the hydrogen facility is limited by the hydrogen facility's electricity demand. Therefore, if the PV rated power is above approximately 226 MWac at the solar and BESS facility POI, then the PV facility will clip energy production during peak production hours. If the BESS rated power is above approximately 226 MWac at the POI, the BESS will discharge a maximum of approximately 226 MWac for a longer duration than its nominal rating of 4 hours.

6.3.3 Methodology

Burns & McDonnell used a proprietary in-house modeling tool to analyze hourly hydrogen production from electrolyzers with hybrid solar (PV) and lithium-ion BESS to evaluate the various solar and BESS configurations. Each configuration and logical inputs are used to generate a hybrid facility hourly production profile in MWh at the hydrogen production facility POI for all 8,760 hours in Year 1. The model begins by establishing the following inputs:

- BESS power and energy ratings for each case
- Solar PV power ratings for each case
- AC BESS coupling configuration
- Hourly solar generation profile
- Hourly electrolyzer load profile (constant hourly demand)
- BESS charge / discharge logic
- Maximum electrolyzer plant energy requirement

Using the assumptions and configurations above, the modeling process begins with the solar energy available each hour from the solar profile. Each hour, the model determines the behavior of the BESS using coded logic that dictates the BESS' operational behavior based on the load-following use case and system technical characteristics during that hour. The BESS' sole operation is to meet the hydrogen load every hour.

During hours where the PV energy generated will go directly to the hydrogen production facility, the model applies the proper system losses and constraints as the energy traverses the electrical system to the POI at the production facility. During BESS charging events, the model applies charging losses and considers the state of charge and other technical constraints to determine the amount of DC energy charged during a particular hour. Similarly on the discharge side, the model applies losses to the BESS energy alongside applying discharging losses to PV energy while also considering load constraints at the hydrogen facility.

6.3.4 Optimization Input Parameters

The following 2023 cost projections, inputs, and assumptions in Table 6.1 and Table 6.2 were used to build the CAPEX and OPEX estimates for the purpose of developing an economic comparison of PV + BESS options. A discount rate of 7% was assumed, consistent with projected costs of generating electricity (IEA 2020).

Table 6.1 Optimization Cost Parameters

Solar Facility			
CAPEX	$/kW	$1,080/kWac	2021 NREL ATB, escalated to 2023 USD
OPEX	$/kW/yr	$19/kWac	
BESS Facility			
CAPEX	$/kW	$330/kWac	2021 NREL ATB, escalated to 2023 USD
Replacement Cost	$/kW	38% of Initial CAPEX	
OPEX	$/kW/yr	$33/kWac	
Electrolyzer Facility			
CAPEX Electrolyzer Facility	$/kW	$3,000/kWac	In-house estimating for optimization purposes
Replacement Cost	$/kW	19% of Initial CAPEX every 9 yrs	Vendor provided data
OPEX	$/kW/yr	0.7% of Initial CAPEX	Vendor provided data

Table 6.2 Modeling Inputs and Assumptions

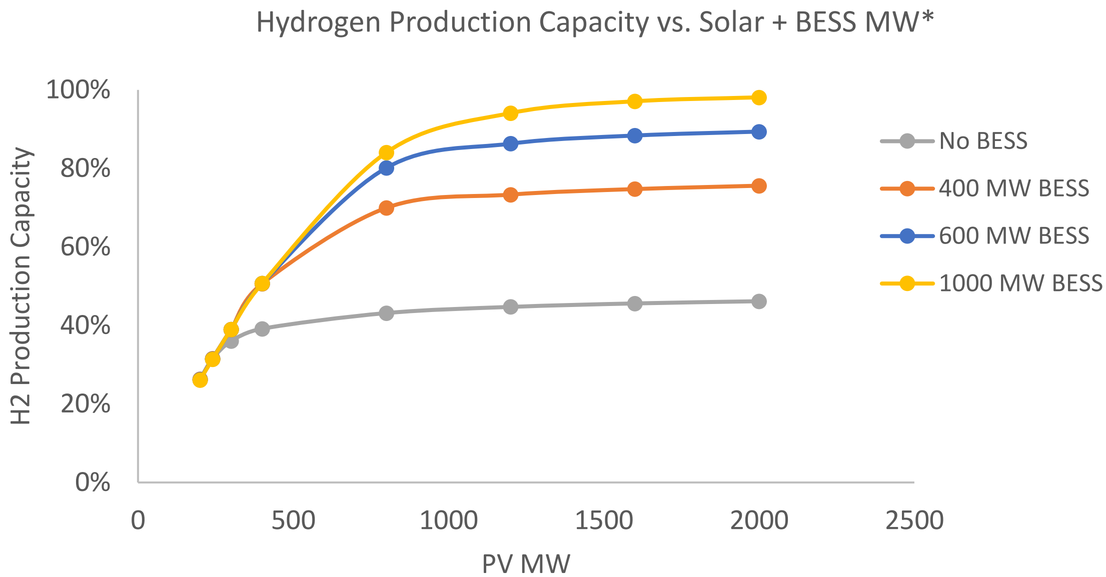
Parameter	Value
Project Life (PV, BESS, and Hydrogen Facility)	35
Solar Installed Power (MWdc)	Optimization Parameter
Solar Rated Power (MWac)	Optimization Parameter
Solar DC:AC Ratio @ PV/BESS POI	1.25
Solar MWac Maximum @ PV/BESS POI	226 MWac
Solar Panels	550 Wp monofacial w/ tracking
Annual Solar Production Degradation	0.5%/yr for Years 2-35
BESS Rated Power (MW)	Optimization Parameter
BESS Rated Energy Capacity (MWh)	4 * BESS Rated Power
Minimum state of charge	0%
Maximum charge rate	BESS Rated Power
Maximum discharge rate	226 MWac
Number of Electrolyzer Stacks	Optimization Parameter
Electrolyzer plant efficiency (@ Ez plant POI)	60 kWh / kg H2
Efficiency degradation	Excluded from model
Stack replacement frequency	9 years

Note that the installed BESS energy capacity would be larger than the rated energy capacity to accommodate for electrical losses, inefficiencies, and aux loads. This allows the minimum state of charge to be 0% from a BESS rated power perspective.

6.3.5 Optimization Results

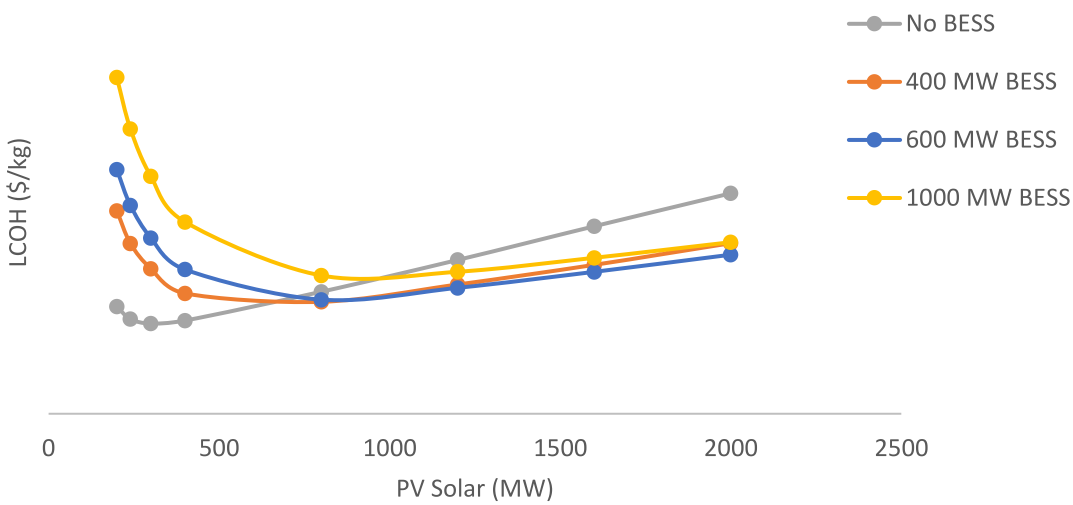
The result of the modeling is an hourly hybrid energy output at the hydrogen POI. Multiple cases of varying solar and BESS sizes were analyzed for a 200 MW hydrogen production capacity. Assuming a constant hourly electric demand is required at the hydrogen facility to produce hydrogen at full output, the graph below shows what percentage of the hydrogen facility's electricity requirement can be met with various solar and solar + BESS configurations. The hydrogen production capacity is expressed as the total tonnes per hour that can be generated by the electrolyzers (the maximum tonnes per hour that could be generated by the electrolyzers * 8760). The graph shows that as PV solar and BESS sizes increase, more of the hydrogen facility's load will be met by the solar and BESS facility.

Figure 6.3 Solar + BESS Configuration Impact on Hydrogen Production Capacity



In order to understand the economic benefit associated with increasing the hydrogen capacity from a single production facility, a preliminary economic model was developed. A simplified 35-year cash flow was used to quantify lifetime projected costs across the solar, BESS, and hydrogen facilities against hydrogen facility load coverage. The intent of the analysis was not to determine the absolute levelized cost of hydrogen (LCOH), but rather to assess the comparative impact of renewable energy capacity and configuration on the total cost of hydrogen produced.

Figure 6.4 Solar + BESS Configuration Impact on LCOH



At each BESS size, the lowest cost is the minimum point on the curve. The table below describes the lowest levelized costs for a solar-only scenario and a solar + BESS scenario.

Table 6.3 Lowest LCOH Cases

Facility Rating	Unit	Solar Only	Solar + BESS
BESS Rated Power	MWac	0	400
BESS Rated Energy Capacity	MWhdc	0	1,600
Solar Installed Power	MWdc	375	1,000
Solar Rated Power	MWac	300	800
Renewable Energy POI limit	MWac	226	226
Electrolyzer Size (EZ)	MWac	200	200

Two factors that significantly affect project economics are hydrogen production capacity and capital costs. As each curve in Figure 6.3 reaches an asymptotic maximum potential production, the electrolyzer experiences diminishing marginal returns for the incremental hydrogen produced. The BESS charging limits prevent capturing additional clipped solar energy, which reduces the value of oversized solar at such high solar capacities. For capital costs, a constant $/kW capital cost value was used for all projects to show that utility-scale PV and BESS project costs at this size are linear in nature.

When considering these two factors, the minimum point on each curve in Figure 6.4 approximately corresponds to the point on each curve in Figure 6.3 where slope starts to decrease e.g., the beginning of diminishing marginal returns. Levelized cost curves begin to increase in Figure 6.4 because the additional cost incurred by building larger solar and BESS sizes grows faster than the additional hydrogen production capacity.

6.4 Conclusions

Adding BESS to the solar energy facility increases the electrolyzer capacity factor, reducing the storage volumes of hydrogen and pipeline size requirements to meet modeled demand for this use case. However, continuing to add incremental BESS to increase the hydrogen production capacity factor beyond 50-80% in all cases has significantly diminishing returns. With today's commercially available technology, Li-ion BESS alone may not economically support solar production to provide a steady supply of hydrogen due to limitations on the technology's duration and technology costs.

Based on the analysis performed, increasing the solar capacity relative to the power demand of the electrolyzer increases hydrogen production during the "shoulder hours" and improves hydrogen production economics to a point. Beyond a sizing philosophy of around 1.75 MW of DC solar capacity to 1 MW of DC electrolyzer capacity, adding solar does not improve hydrogen production economics. If BESS is included, the system is improved if solar size is increased to 8 MW of DC solar capacity to 1 MW of DC electrolyzer capacity along with 1.6 MWh of BESS DC capacity to 1 MW of solar DC capacity.

Considering the economic impacts of using: 1) only solar or 2) solar with BESS, the solar only option has the lowest potential economic configuration. The narrow margin in comparative costs is highly sensitive to economic inputs, particularly tax incentives (which were excluded from evaluation), discount rate, and future pricing and efficiency projections. Furthermore, the optimization results do not consider pipeline, compression, and storage impacts, which could change total system design costs.

Two options – a solar only and solar + BESS option – were selected for further evaluation of potential hydrogen storage volumes and required pipeline capacities.

- **Solar only** - 375 MWdc Solar / 200 MWdc Electrolyzer
- **Solar + BESS** - 1,000 MWdc Solar / 400 MW (1600 MWh) BESS / 200 MWdc Electrolyzer

7.0 Hydrogen Production to Meet Demand

7.1 Hydrogen Demand Assessment

As part of the Angeles Link Phase 1 Studies, the Demand Study projected demand for clean renewable hydrogen across the mobility, power generation, and industrial sectors in SoCalGas's service territory through 2045. Three scenarios were modeled over the time period of 2025-2045 with the results indicating 1.9 MMTPY of hydrogen demand by 2045 in its conservative scenario, 3.2MMTPY in the moderate scenario, and 5.9 MMTPY in the ambitious scenario.

As noted in the Demand Study, the proposed Angeles Link system would transport a portion of that overall projected demand, with a proposed throughput of approximately 0.5 MMTPY under a low case scenario (1.9 MMTPY total demand in the conservative scenario) and up to 1.5 MMTPY under a high case scenario (5.9 MMTPY total demand in the ambitious scenario).

7.2 Matching Production to Meet Demand

Hydrogen production from renewable energy resources such as solar and wind is inherently variable. Demand for hydrogen in end-use applications such as heavy industry and transport is generally consistent and predictable (albeit only partially constant). However, hydrogen demand for the power sector is expected to be highly variable and less predictable.[39]

One method of meeting demand in times when the solar facility is not producing adequate energy for hydrogen production is to supplement the electricity supply with grid-supplied power. This option was not the focus of this report as grid electricity currently relies on some fossil fuel sources and therefore is assumed not to meet CPUC clean renewable hydrogen requirements.

To assess the hydrogen production requirements needed to serve the anticipated market, an hourly demand profile was analyzed against the hourly production profile utilizing both a solar-only profile and solar + BESS profile.

7.2.1 Industrial Sector Hydrogen Demand

Petroleum refineries typically decrease output during the spring and fall for maintenance. Food and beverage industries typically decrease output during the summer months (e.g., tomato processing) while other industries have no other seasonal

[39] Based on work performed for the Demand Study.

variations. For other industrial sectors, no seasonal variations are anticipated.[40] For the purposes of the study, a constant annual demand was assumed for the industrial sector.

7.2.2 Mobility Sector Hydrogen Demand

Hydrogen demand throughout the year for the mobility sector is assumed to vary like current gasoline retail fuel sales. Historical data shows slightly higher demand in late summer months and slightly lower demand in the winter, although demand does not vary significantly from month to month.[41] Additional phases of analysis can evaluate displacement at a more granular level across mobility applications and fuel types. For the level of detail of the analysis conducted in this phase of analysis, a constant annual demand was assumed for the mobility sector.

7.2.3 Power Sector Hydrogen Demand

The Demand Study assessed the role clean renewable hydrogen could play in providing a zero-carbon pathway for power generation to maintain necessary grid reliability. The growing amount of variable renewable resources is not expected to provide the consistent, dispatchable, and firm generation needed to balance supply and demand on the grid at both the daily level – when the sun sets at night – and at the seasonal level – when sunlight decreases during wintertime. Hydrogen for power generation is projected to be used in peak situations that will require high flow rates of hydrogen to the units to fill the need for generation when wind and solar cannot generate. Subsequently, hydrogen will need to ramp quickly to make up for power lost as wind and solar go offline. This demand will be most significant when events such as extreme weather or net load ramps are widespread across SoCalGas's service territory and beyond.

To assess potential long term storage volumes to support the power generation sector in the future (described below in Section 8), a hypothetical power sector annual hourly demand profile was developed considering the trends from LA100[42] and Burns & McDonnell integrated power resource planning knowledge. An assumed power sector demand profile with a 15% capacity factor was created as shown in Figure 7.1. The

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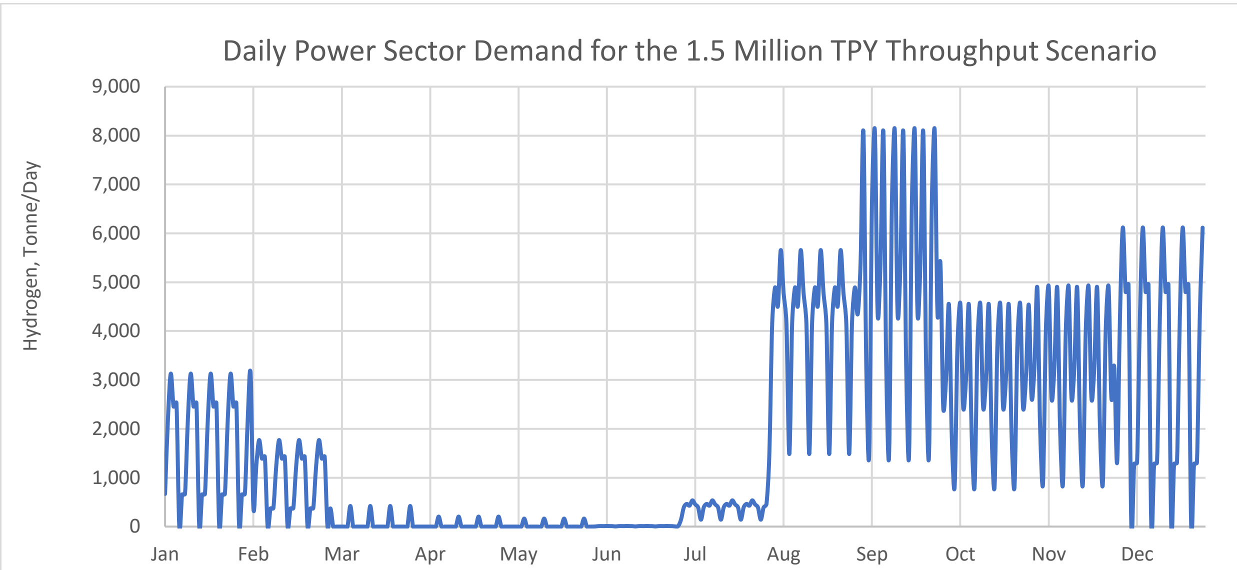
[40] Based on discussions with the consultant who performed the Demand Study.
[41] Based on discussions with the consultant who performed the Demand Study.
[42] Using the NREL LA100 Study Data Viewer, generation dispatch for hydrogen combustion turbine trends were examined across each of the scenarios, with the following trends noted:

- Peak generation occurs between July and October, peaking in September.
- Minimal or no generation anticipated between March through June.
- Moderate generation required from October through February.
- Hourly peak demand varies significantly by scenario. Most scenarios assume generation coming online at 5 am and offline around 4 pm at Peak Summer.

analysis was conducted using an hourly basis. While hydrogen turbine operation forecasts are challenging to accurately project given the hydrogen industry market maturity, the complex power market forecast modeling work required, and the numerous and highly variable set of assumptions, the chart below shows illustrative daily power sector demand for one hypothetical use case scenario.

Figure 7.1 Power Sector Demand Profile



In summary, this section establishes the evaluation of the potential production facilities that could produce the hydrogen that Angeles Link would transport to meet potential demand.

8.0 Evaluation of Potential Hydrogen Storage

Hydrogen has the ability to provide energy flexibility and security as it can be stored in large volumes for long periods of time. Accordingly, it is important to examine how storage interacts with the variable production[43] and demand of clean renewable hydrogen, which could be effectively transported by the connective infrastructure of Angeles Link.

A wide range of drivers can influence how various storage options may support the balance of supply and demand, including:

[43] Referring to hydrogen supplied via solar/electrolyzers (and solar + BESS / electrolyzers).

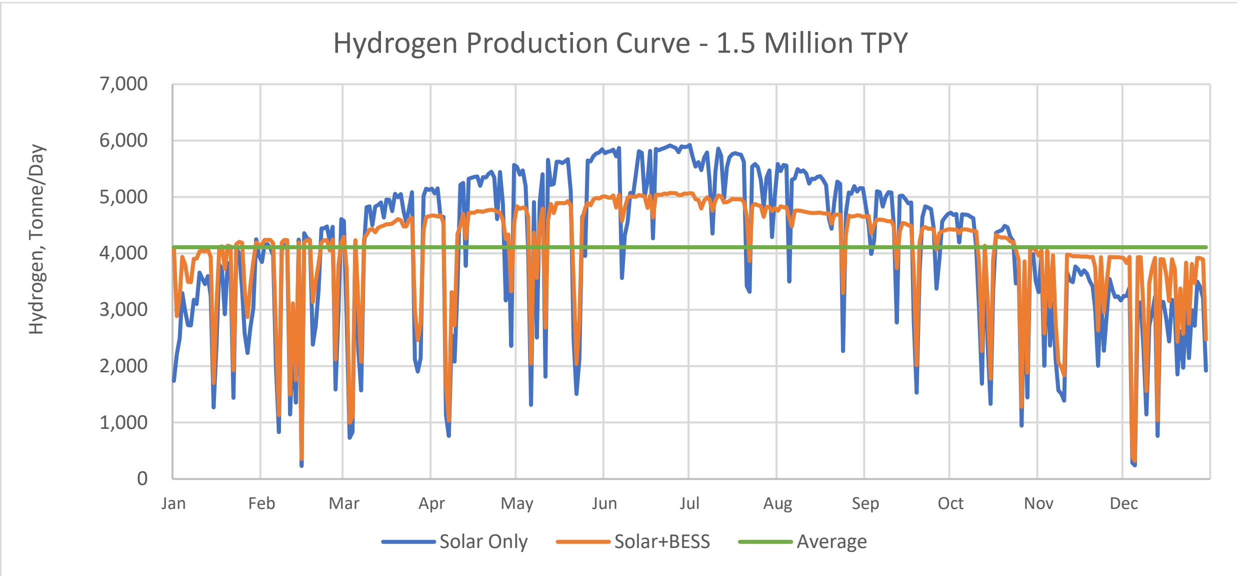
- Projected supply and demand, including the specific timing (e.g., hourly profiles) of supply, the type of clean renewable hydrogen production (e.g., electrolytic, biomass, SMR of RNG), and the specific demand for different sectors
- Production facilities configurations (e.g., availability of on-site storage, role of the grid, the extent batteries are utilized, degradation and outage considerations)
- Attributes of the connective pipeline infrastructure such as the size and compression
- End-use facilities configurations (e.g., availability of on-site end user storage, location of end-use relative to upstream connective infrastructure)
- Other factors such as the potential role of demand response, the ability to use other technologies during times of potential supply/demand imbalances, and potential reliability requirements for outages

Clean hydrogen production and aboveground and underground storage is not currently part of Angeles Link. As Angeles Link is further designed and, in alignment with the development of system requirements, the role of storage to support regional hydrogen producers and end users should be considered. Distributed storage equipment located at third-party production and end user sites, along with line pack (storing and then withdrawing gas supplies from the pipeline), can provide storage capacity while larger scale storage technologies are developed over time to support regional requirements.

To assess the potential long-term role and scale of storage in 2045, two potential production configurations were evaluated: 1) a solar PV only and 2) a solar PV with BESS. The evaluation conservatively assumed no end user facility storage, no on-site production storage, and no line pack. In addition, the potential role of demand response or the use of back up fuels were also excluded. It is important to highlight that these two scenarios are intended to be illustrative only, and actual conditions will depend on a number of factors, including the type of renewable power source used to make hydrogen, the anticipated hourly demand profiles for power generation, mobility, and industrial sectors, and the system hydrogen demand volumes. Depending on the volume required, storage could be provided in various ways, including line pack, construction of a parallel pipe in a portion or portions of the pipeline system, on-site storage by clean renewable hydrogen producers or end users, and/or dedicated above-ground or underground storage.

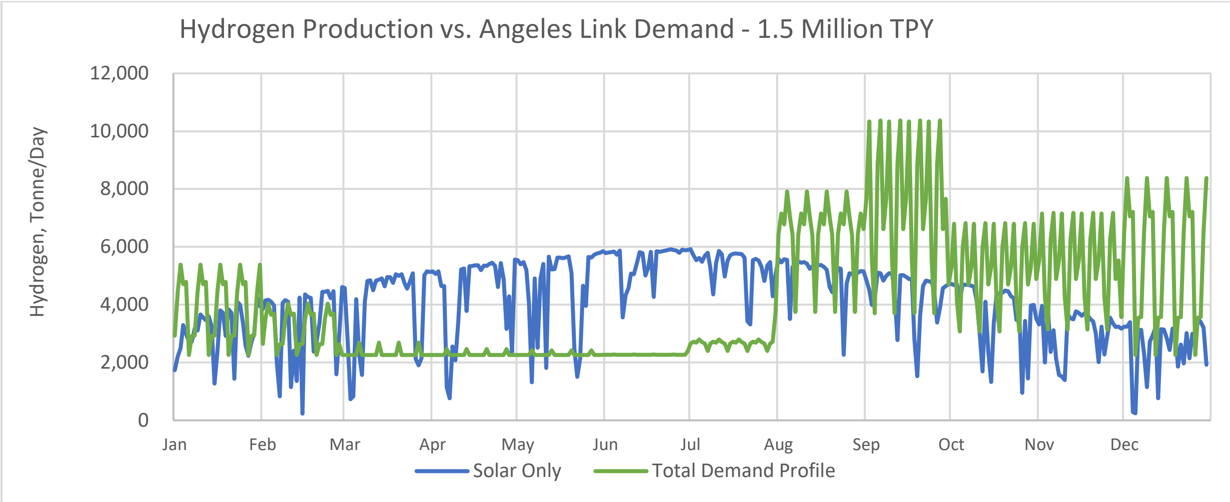
Hydrogen Production Profile: The evaluated hydrogen supply is based on the renewable energy generation profiles for solar PV only and solar PV + BESS as described in Appendix A. Figure 8.1 shows the hydrogen production profiles for the solar and solar + BESS configurations for the 1.5 MMTPY Angeles Link throughput scenario. The production profile assumes the same solar profile for the cumulative of all production facilities. The same hourly production profile was assumed for the other Angeles Link throughput scenarios of 1 MMTPY and 0.5 MMTPY cases.

Figure 8.1 Illustrative 2045 Hydrogen Production Profiles for Solar Only and Solar + BESS Scenarios



Hydrogen Demand Profiles: Section 7 describes assumptions for hydrogen demand for the mobility, power, and industrial sectors. The composite demand profile is shown in Figure 8.2 below. The total demand by sector varies in each Angeles Link throughput scenario (.5MMTPY, 1MMTPY, 1.5MMTPY), and varies across the projected years. Potential storage volumes were analyzed for the year 2045, and demand volumes were adjusted accordingly based on the assumed demand sector volumes under each scenario. In 2045, the power sector is expected to make up 45% of demand in the ambitious case, 51% in the moderate case, and 38% in the conservative case. The 1.5 MMTPY Angeles Link throughput scenario, conservatively assuming solar-only production (no batteries) is shown below for illustrative purposes.

Figure 8.2 Illustrative 2045 Ambitious Demand Profile vs Production Profiles



Storage Cycles: For both Solar Only and Solar+BESS production profiles, the difference between the amount of hydrogen produced in each hour versus the amount of hydrogen required to meet potential demand in the same hour was analyzed. Where production values exceed demand, the difference represents a hydrogen surplus that can be stored for later use. When demand exceeds production, the difference indicates a need for the demand to be met by withdrawing hydrogen from storage inventory (whether from line pack or dedicated storage). The cycles used in the analysis to estimate total storage sizing were set on an hourly basis. For illustrative purposes, Figure 8.3 and Figure 8.4 below show the daily storage inventory drawn and built for the Solar Only and Solar+BESS production cases. The second figure below shows the daily build and draw for storage as well as the total storage inventory. The withdrawal and injection cycles for the Solar+BESS case is slightly dampened compared to the Solar Only case, resulting in a slightly lower need for storage working capacity.

Figure 8.3 Illustrative 2045 Hydrogen Storage Cycles

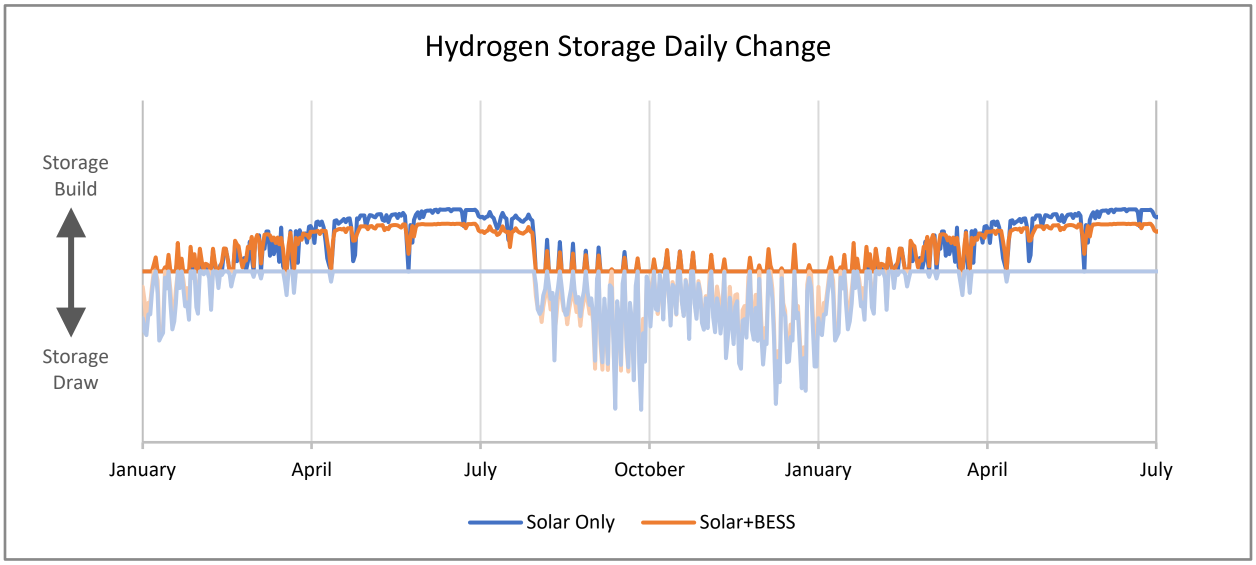
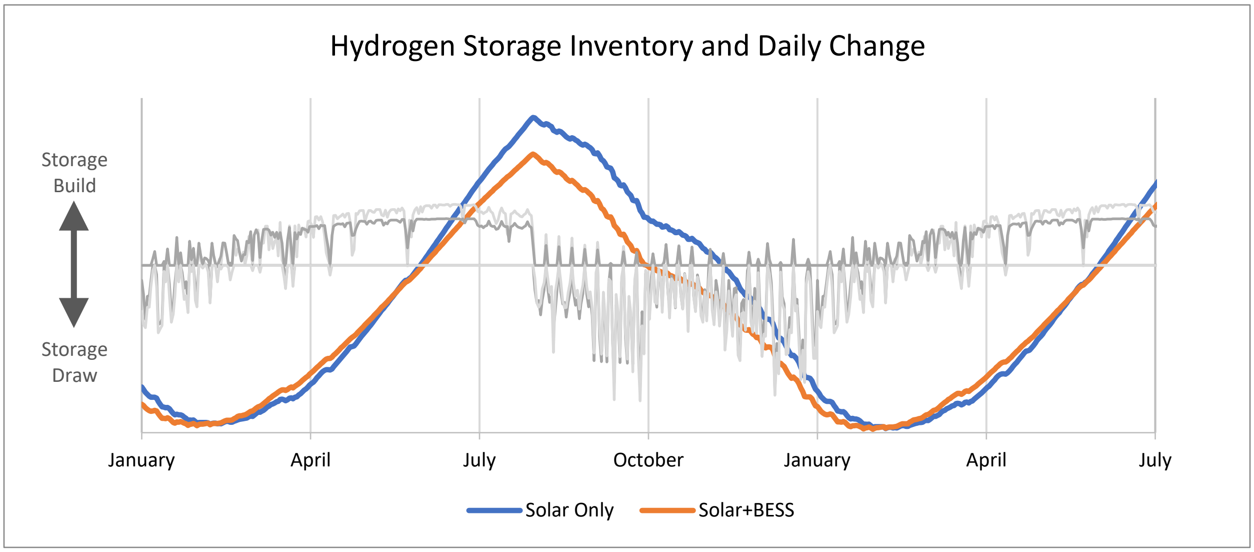


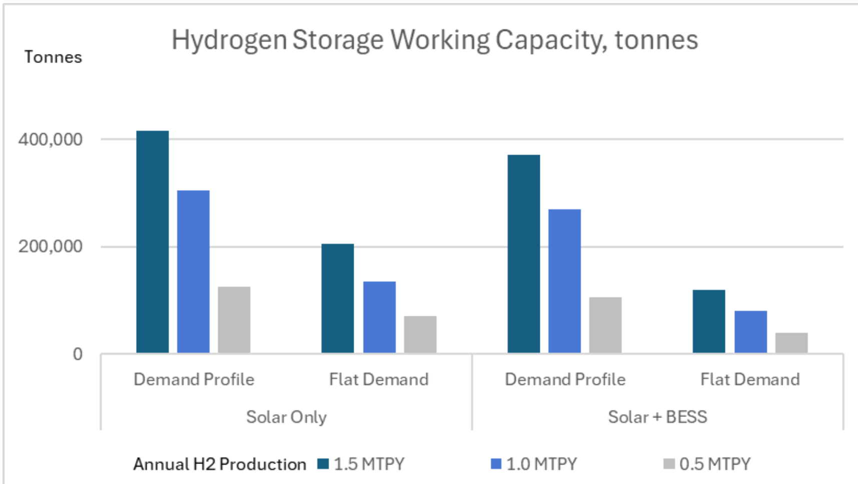
Figure 8.4 Illustrative 2045 Hydrogen Storage Cycles – Solar and Solar + BESS Production



Potential Long-Term Role of Hydrogen Storage for Two Illustrative Production Configurations: (1) Solar and (2) Solar + Bess

As described above, illustrative hydrogen production and demand profiles were assessed to develop an assumption on the potential role of storage to help balance supply and demand. Table 8.1 shows the storage working capacities that could support the assumed solar and solar + BESS production scenarios to meet: 1) a constant flat demand for mobility, industrial, and power sectors and 2) a demand profile based on the more variable power sector.

Table 8.1 2045 Hydrogen Storage Sizing



This analysis is highly dependent upon the initial analysis of the power sector demand profiles. While the solar + BESS option reduces the overall storage volume to meet the assumed demand profile, the results illustrate the importance of further analyzing the potential for storage options to support production and demand balancing as more detailed information is developed. This information could include:

- Detailed projections of production supply forecasts, including technology(ies), mix of renewable energy hourly supply projections, outages, and degradation considerations
- In-depth market/end-user analysis and hourly demand forecasts
- Storage characteristics such as sizing for reliability requirements for planned and unplanned outages
- Other factors such as end-use facility configurations, location of end use, potential role of demand response

8.1 Hydrogen Storage Operating Assumptions

It is assumed that the hydrogen production facilities will supply hydrogen to demand centers, supplemented by storage if demand exceeds the production rate at any given time. Hydrogen can be stored at various points in the supply chain, including the demand locations (e.g., ports, refueling stations, power plants), production facilities, or any point on the pipeline in the form of line pack or process equipment (e.g., pressure vessels and cylinders) between production and demand. For discussion on how hydrogen may be stored and accessed within the pipeline system using pack and draft, refer to the Pipeline Sizing and Design Criteria study.

A discussion of aboveground and underground storage technologies is detailed in Appendix B – Hydrogen Storage. This section provides a summary of those options.

- **Storage Technologies**
    - Commercially available aboveground storage technologies include compressed gas, liquid hydrogen, metal hydride and iron oxide storage systems
    - Depleted oil and gas fields are promising candidates to provide local underground storage in California[44]

Aboveground storage. While aboveground hydrogen storage technologies are technically viable, storing hydrogen aboveground comes with significant costs at limited capacities, making it challenging to use as a means of steadying the energy production from renewable sources at large volumes in a centralized location. More likely, aboveground hydrogen storage will be used by producers and end users in a distributed fashion. Some technologies, like compressed gas and liquid hydrogen storage, require high initial investment and ongoing operating expenses. Despite these challenges, ongoing research and development efforts are focused on improving the efficiency and cost-effectiveness of these storage methods.

Underground Storage. Underground Hydrogen Storage (UHS) in geologic formations can support deploying clean renewable hydrogen at scale due to its volumetric capacity and low-cost relative to aboveground storage technologies. Appendix B examined three options for underground storage of hydrogen in geologic formations in the Area of Interest (AOI) which include California, Arizona, Nevada, and Utah – salt caverns, porous rocks, and abandoned mines. While underground natural gas storage is commonplace, underground hydrogen storage is in the early phases of technological adaptation. UHS in solution-mined salt caverns is the most active commercially, with three projects currently operating and at least one under construction. Two field-scale pilot studies in Austria and Argentina for hydrogen storage in depleted oil and gas reservoirs are under way. Research in this area is ongoing; for example, the CEC has

[44] While existing SoCalGas facilities were evaluated for geologic adequacy because they are located within the study area, they are not currently being considered as storage options for Angeles Link.

issued a solicitation to fund a project that will evaluate the feasibility of using existing underground gas storage facilities to store clean renewable hydrogen in California.[45]

Potential UHS sites to support regional hydrogen producers and end users include depleted reservoirs in oil and gas fields, salt caverns, and abandoned underground mines. The analysis in Appendix B considers a dataset of identified potential UHS sites across California, Arizona, Nevada, and Utah. Evaluation criteria for adequacy of hydrogen storage were developed for all three storage types. However, due to a lack of data regarding abandoned mines and saline aquifers, only oil and gas fields within California and salt basins across the 4-state area could be evaluated using these criteria.

Six salt basins within the Angeles Link project area were evaluated for confidence of adequacy to support solution-mining of caverns capable of hydrogen storage. The Sevier Valley, Luke Basin, and Red Lake basins yielded the highest composite in geologic confidence of adequacy value, primarily due to salt thickness and salt purity.

A total of 297 oil and gas reservoirs were evaluated to assess the technical geologic feasibility of the reservoirs to provide UHS and identify candidate reservoirs for further analysis. In addition to the geologic conditions needed for viable storage in depleted reservoirs, other factors were considered, such as population density, land designation, and proximity to seismic faults.

[45] https://www.energy.ca.gov/solicitations/2024-04/gfo-23-503-feasibility-underground-hydrogen-storage-california.

9.0 Hydrogen Production Facility Design Basis

9.1 Production Facility Design Basis

The basis of design conveys the assumptions for hydrogen production such as the production rates and cost estimates that support other Phase 1 studies, such as the High-Level Economic Analysis & Cost Effectiveness study and the Pipeline Sizing & Design Criteria. Table 9.1 summarizes the assumptions further described in this section.

9.2 Production Facility Scope

An illustrative diagram of a hydrogen production facility is show below in Figure 9.1:

Figure 9.1 Hydrogen Facility Flow Diagram

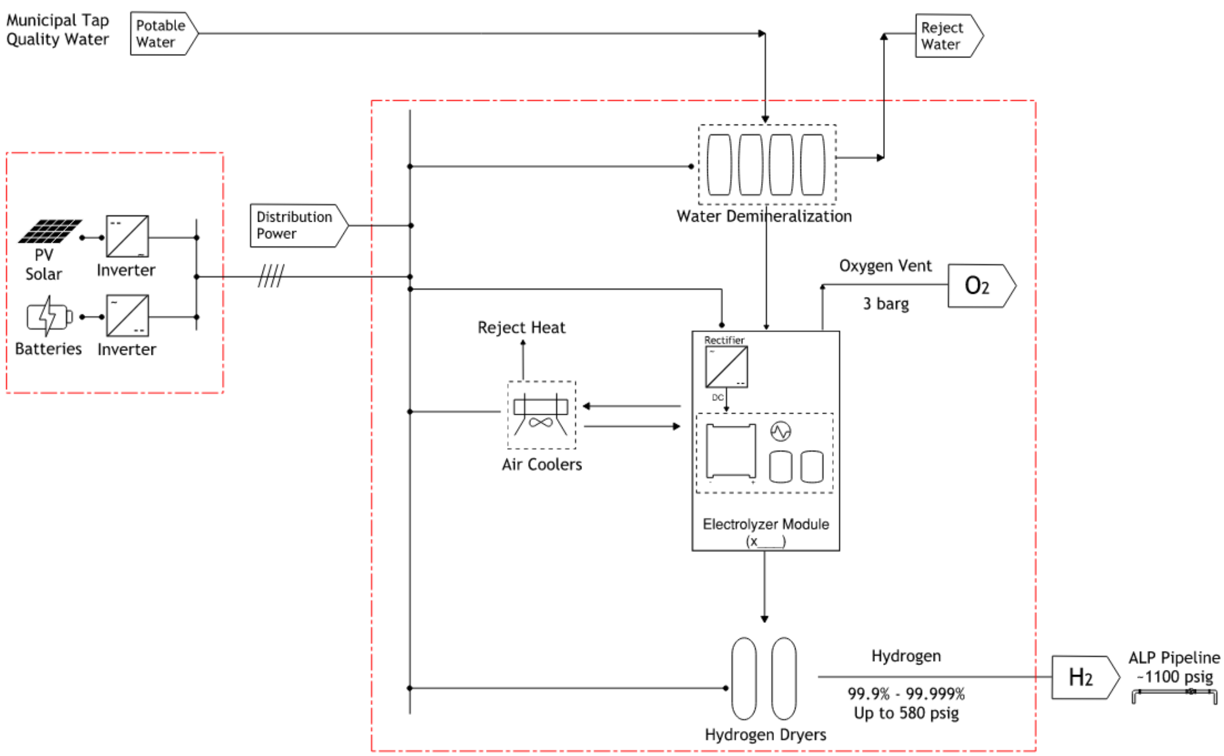


Table 9.1 Hydrogen Facility Scope Assumptions

Production Facility Major Scope Assumptions	
Hydrogen Production Technology	PEM Electrolyzers
Power Source	Co-located direct tie Solar PV (tracking) with no battery storage
Site Condition	Flat, greenfield land, no demolition or extensive earthwork
Water Supply	Delivered as municipal water quality to fenceline
Waste Water Disposal	Water discharge to fenceline
Hydrogen Compression	Excluded from Scope
On-site Hydrogen Storage	Excluded
Bulk Power Grid Interconnect	Interconnect from the local utility is assumed to service loads required for start-up and safe shutdown operations.
Land Area Required per Production Facility	1800 acres for production and solar facility
Production Facility Design Basis	
Assumed Production Facility Size Basis	226 MW Gross Facility Load (accounting for BOP auxiliary loads)
Configuration of Electrolyzer Modules	20 x 10 MW Electrolyzer Modules
Max (Design) Hydrogen Throughput per Production Facility	180 kg/h max per electrolyzer module (3.6 tph total facility max)
Electrolyzer Efficiency	~60 kWh/kg, including BOP auxiliary loads and compression
Cooling	Process cooling via fin-fan air coolers
Oxygen	By-product oxygen vented to atmosphere
Enclosures	Electrolyzer modules in standard OEM enclosures
Electrolysis discharge pressure	30 barg
On-site hydrogen compressor discharge pressure to pipeline	Excluded from scope
H2 Purity at Fenceline	>99.999%
Switchgear	MV collection system
Production Facility Performance	
Annual Hydrogen Production per Facility	11,400 tpy

Max Hourly Hydrogen Production per Facility	3.6 tph
Hydrogen Facility Utilization Rate	36%
Turndown Ratio	10-100% per cell stack
Ramp Rate	<1 min from min to full load
Annual Production Related Water Required	Refer to Water Study
Co-Located Renewable Energy Supply Assumptions	
Assumed Solar Profile	NREL SAM San Bernardino, CA
Assumed Solar Facility Size Basis	375 MWdc / 300 MWac / 226 MWac at Solar Facility POI
Tracker Design	Single Axis Tracker
Solar Panel Design	550 Wp monofacial
Land Area Required per Solar Facility	6 Acres / MW
Interconnection	Substation to step-up from solar facility to production facility, 1 mi of T-line interconnect
Solar Facility Production	
Energy Yield (P50, Year 1)	694,000 GWh @ POI
Solar Facility Capacity Factor	26%

9.2.1 PEM Electrolyzer Unit

The electrolyzer scope consists of electrolyzer stacks, water separators, polishing tanks, circ pumps, plate & frame heat exchangers, gas dryers, and all interconnecting piping.

9.2.2 Hydrogen Compression

A PEM electrolyzer is capable of supplying hydrogen up to 30 or 40 bar. The Study assumes the minimum pressure requirement at the production facility fenceline will be 500-600 psig. Compression is excluded from the production scope and is included in the Angeles Link Pipeline Sizing & Design Criteria study.

9.2.3 Hydrogen Storage

Hydrogen storage volumes are assumed to be located between production and demand locations to handle daily and seasonal production/demand variations. For purposes of this study, no on-site storage is assumed in the production scope.

9.2.4 Closed Cooling Water

A 50% propylene glycol / 50% water mixture will be used to provide the adequate equipment cooling needs for the facility within a closed cooling water (CCW) system. The CCW system will include a CCW tank, circulating pumps, and an air-cooled heat exchanger.

9.2.5 Water Supply and Treatment

To achieve the required demineralized water quality, a two-pass reverse osmosis (RO) system followed by electrodeionization (EDI) will be required at the production facility. Municipal quality water is assumed to be received at the site boundary and will enter feedwater and firewater storage tanks. Chemicals will be stored on-site, including provisions for antiscalant upstream of the ROs and sodium bisulfite for de-chlorination of the municipal water to protect RO membranes from fouling.

The study assumes municipal water supplied at site boundary with 350 ppm total dissolved solids (TDS). Producing hydrogen through the process of electrolysis theoretically requires 9 kg (equivalent of 9 liters) of demineralized water per kg of hydrogen based on the stoichiometric values. Additional water is required to support balance of plant cooling requirements of the electrolyzer. Based on electrolyzer supplier quotes, 11 to 13 kg of municipal water is assumed to be required for every 1 kg of hydrogen production. Water to support pipeline compressor intercooling and aftercooling is also required but is beyond the scope of the Hydrogen Production Assessment. Information regarding the supply and treatment of raw water to the production site boundary is discussed in the Angeles Link Phase 1 Water Resources Evaluation.

9.2.6 Wastewater Collection and Discharge

This study assumes the wastewater from the water treatment would be collected in a network of plant drains located throughout the site and sent to a wastewater treatment facility or treated on-site (not included in scope). A sump in the water treatment building would collect wastewater from the demineralized water system, such as RO and EDI reject. A pump would transfer wastewater to the site boundary. Water treatment processes are discussed further in the Angeles Link Phase 1 Water Resources Evaluation.

9.2.7 Fire Protection

Fire protection is assumed to be fed from the municipal water tie-in and stored in a combined firewater / feedwater storage tank. Electric and diesel driven fire pumps are assumed to be required along with firewater piping, hydrants, and post indicators.

9.2.8 Auxiliary Electrical Supply

The electrical system will be fed by a single overhead medium voltage transmission line coming from the solar facility medium voltage collector system. Each electrolyzer train consists of medium voltage transformers and rectifiers to provide the regulated DC current required for the electrolysis process. Medium voltage switchgear will also feed station service transformers for BOP auxiliary power requirements.

The scope does not assume batteries or on-site generators are included for start-up/shutdown/upset conditions. A utility power feed is assumed to be required for minimum power needs to enable startup shutdown.

9.2.9 Development and Construction Timeline

The expected project duration to design, procure, and construct a nominal 200 MW electrolyzer and solar energy facility will depend highly on manufacturing lead times and local labor availability. A 200 MW hydrogen production facility from start of design to operation is expected to take 3 years in a supply chain balanced market. A 375 MWdc solar facility is anticipated to require the same construction timeline, and may be constructed concurrent to the electrolyzer facility. Site development activities including permitting and regulatory approvals are highly site-specific and would occur after land acquisition.

9.3 Limitations and Qualifications

Commissioning and operational modes such as start-up, shut-down, and upset requirements were not analyzed in determining required facility scope. Equipment design margins, spare parts philosophy, production make-up to support system losses, and production overbuild capacities to support facility outages, performance degradation, weather variability, etc. were not considered in this phase of study. Production design requirements to meet overall system reliability and resiliency needs could be evaluated in subsequent phases of study.

10.0 Production Land Assessment

10.1 Hydrogen Production Land Assessment

Burns & McDonnell conducted a production land assessment to determine if land in SoCalGas's territory can support development of enough renewables to support high levels of hydrogen production and expected electric system needs. The assumption was made that solar based energy requires the largest land area per MW and therefore is the most conservative assumption when assessing how much land is required for renewable based hydrogen production. An evaluation of land available to support only solar development is conservative because additional renewable resources may be used, at a scale much smaller than solar, to meet electricity demand in Southern California.

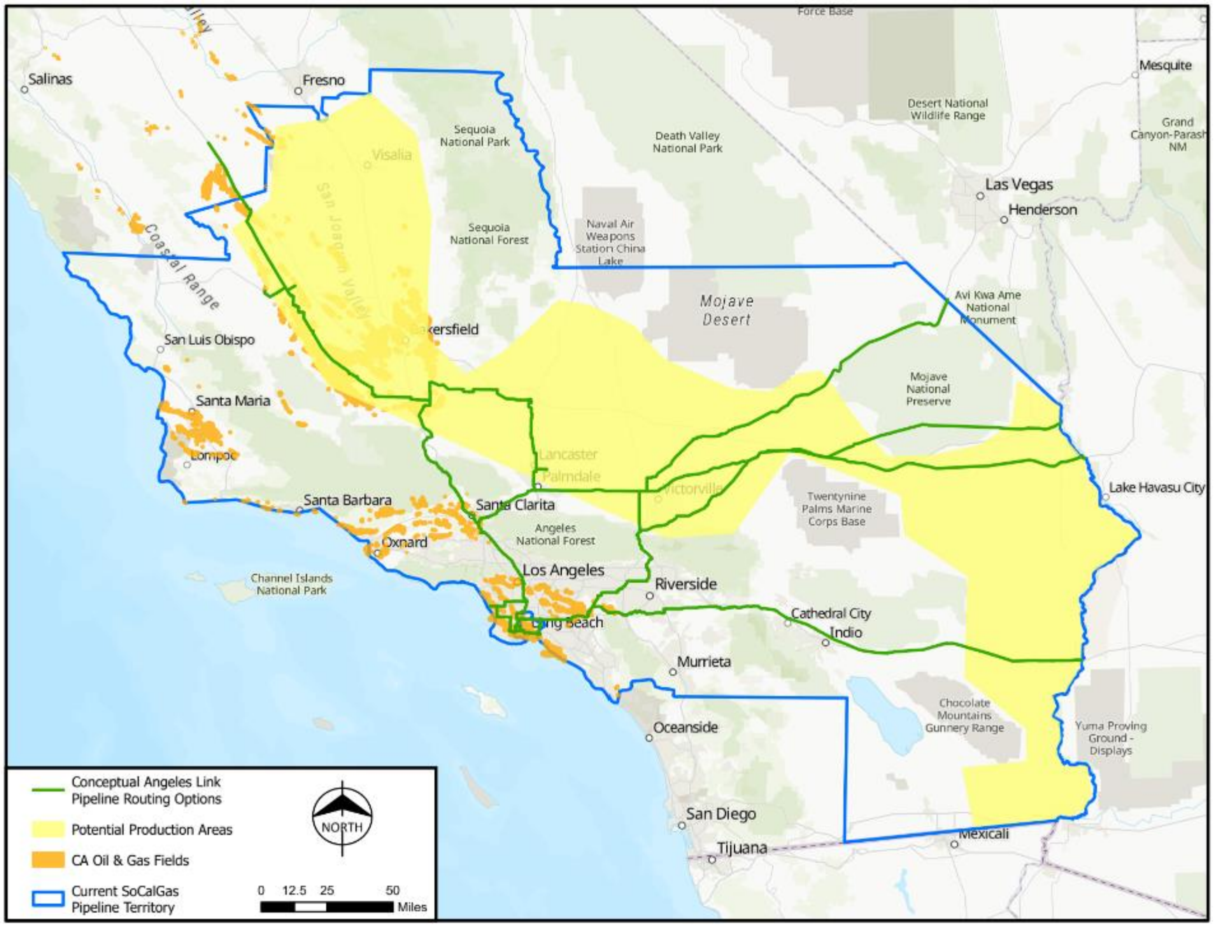
10.2 Land Assessment Methodology

The Phase I study land assessment scope was limited to desktop screening focused on SoCalGas's service territory to identify land areas suitable for hydrogen production. ArcGIS software was used to identify large, contiguous areas of land that met the following criteria:

- Areas devoid of significant urban/suburban development, areas in the lesser developed portions of Southern and Central California were identified
- National and state parks, government refuges, preserves, and military ranges were avoided
- Topography greater than 15% slope was avoided

For utility scale power projects, proximity to transmission lines with adequate line capacity is typically a critical requirement for siting. However, this study assumes that renewable power requirements would be incremental and met with power generation that is not grid connected (i.e., does not tie into high voltage transmission lines), along with local utility distribution power for minimum power needs to enable startup and shut down. This results in more potentially viable locations for hydrogen production. The yellow area shown in Figure 10.1 was identified as potentially suitable, large, contiguous land areas using this desktop screening criteria.

Figure 10.1 Broad Screening of Land Area Available for Production



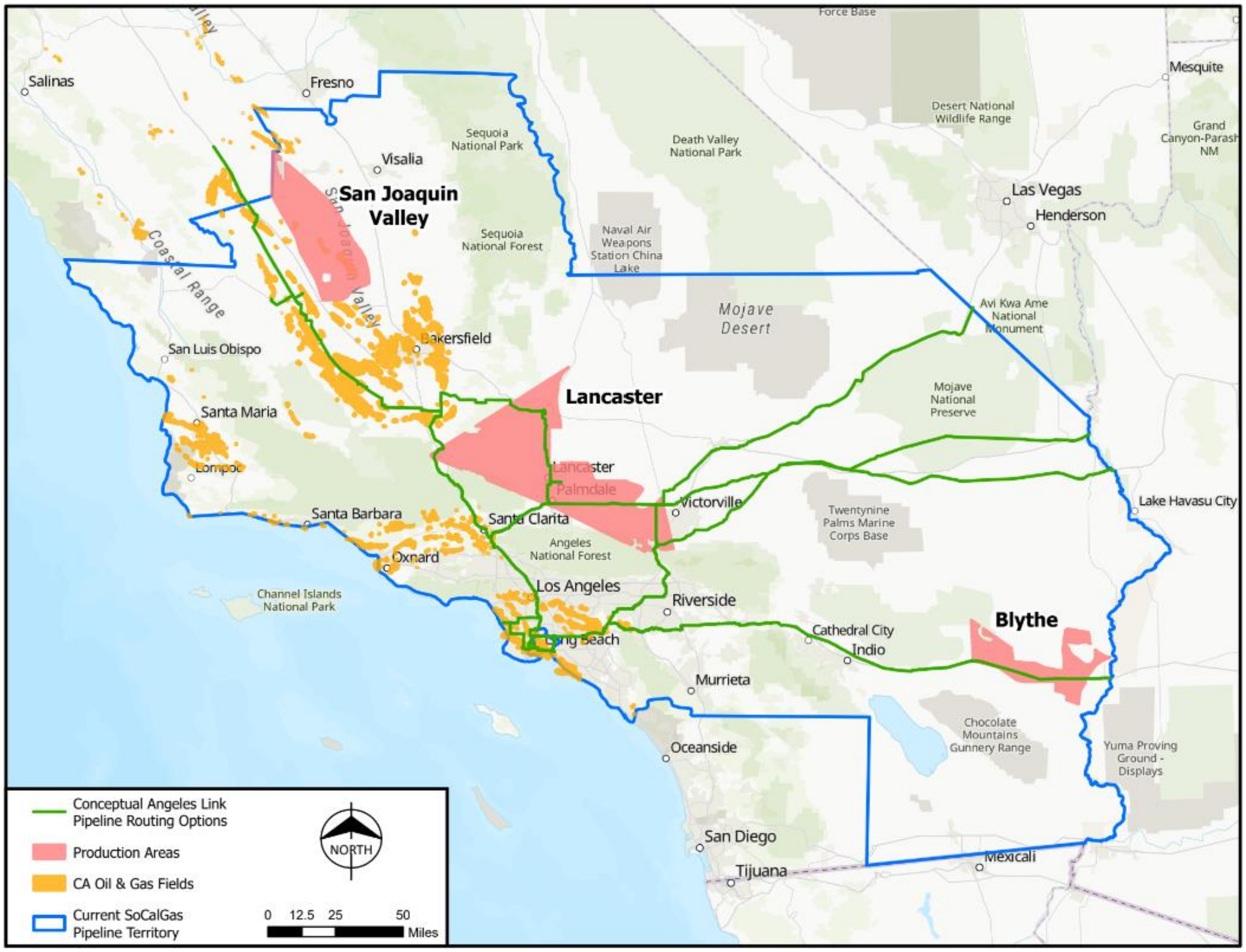
The potential land area was overlayed with conceptual pipeline routing options evaluated in the Pipeline Routing Assessment Study (which considered existing natural gas lines) to help identify potential pathways to deliver hydrogen to demand centers in the LA Basin. In addition, participation in ARCHES provided an understanding of potential production projects being considered[46] in California. Three production area boundaries were developed to further assess production land constraints and to define production areas for further production analysis. Within each production area, the following constraints were applied (see Figure 10.2) in addition to the constraint layers used in the broad land area assessment:

- 50 ft setback from Interstate and State Highways
- 50 ft setback from bodies of water, wetlands, and floodplains

[46] https://archesh2.org/wp-content/uploads/2023/10/Meet-Arches_October-2023.pdf

- 50 ft setback from culturally and environmentally sensitive areas
- 75 ft setback from transmission lines
- Buildings / structures excluded using Microsoft Buildings Footprints

Figure 10.2 Assumed Production Areas



10.3 Land Availability

Production of the maximum case of 1.5 MMTPY of clean renewable hydrogen throughput is assumed to require 39 GW of solar capacity assuming the solar only design. Assuming 6 acres per MWac of solar output, the land area required for this capacity is estimated to be 240,000 acres (375 square miles).[47]

Land area available within each Production Area after constraints were applied (see section 10.2) are below:

- San Joaquin Valley – 535,000 acres (836 square miles)
- Lancaster – 1,124,000 acres (1,756 square miles)
- Blythe – 273,000 acres (427 square miles)

The area required for solar represents 12%[48] of the total land area identified within the target production areas. In a scenario assuming production from only two production areas such as Lancaster and SJV, less than 15% of the land area within those production areas would be required. While the three production areas were identified due to their large available land areas, this does not preclude hydrogen production from other areas within the SoCalGas service territory.

10.4 Limitations and Qualifications

The available land area does not consider existing structures and buildings not identified in the source filter, contiguous land areas of minimum size adequate for large scale production, population densities, state and local zoning and land use ordinances,

[47] For comparative purposes, Environmental Defense Fund's (EDF) study "California needs clean firm power, and so does the rest of the world" reviews land requirements for decarbonized electricity systems with clean firm power and compares it to those without clean firm power in California. The study summarizes that electricity systems without clean firm power require 3-10 times as much land as compared to systems with clean firm power. See https://www.edf.org/sites/default/files/documents/SB100%20clean%20firm%20power%20report%20plus%20SI.pdf

[48] Stakeholder feedback included analysis that stated the overlay of additional CEC data onto the available land identified in the Production Study analysis would result in a reduction in available land for the different production areas. While SoCalGas did not validate the independent analysis performed, SoCalGas did consider the potential acreage and percentage impact on the three production areas. SoCalGas calculated the land available would be approximately 1.3 million acres with these additional constraints applied and that the land required to produce up to 1.5 MMTPY of hydrogen as a percentage of total land available across production areas using identified land available in this study compared to the land available suggested by this stakeholder feedback would increase from 12% to 18% across the three identified production areas (San Joaquin Valley, Lancaster, Blythe).

land purchase values, and other technical, environmental, or economic constraints which may further prohibit renewable energy and/or hydrogen production development.

11.0 Hydrogen Production Cost Estimates

11.1 Cost Estimate Methodology

Burns & McDonnell solicited high level budgetary cost information from electrolyzer technology providers to determine the electrolyzer equipment costs. Where technology provider information was limited or unavailable, Burns & McDonnell relied upon in-house information from other similar project quote requests or historical databases to develop high level cost estimates. BOP equipment and installation costs were prepared using similar project estimates and performing a “top down” Association for the Advancement of Cost Engineering (AACE) Class V cost estimate, adjusting for scope and scaling for size.

11.2 Cost Estimate Basis and Assumptions

The following assumptions and scope of supply forms the basis of the cost estimates:

- Estimated Project Cost (EPC) Basis of estimate including all overhead, profit, and contingency
- Overnight cost in 2023$, escalation excluded
- Construction estimates are based on factored estimates from Burns & McDonnell internal database and construction estimating knowledge
- Hydrogen compression and onsite storage excluded
- BOP Equipment: in-house information from similar projects

Major scope assumptions are shown in Table 9.1.

11.3 Cost Estimate Exclusions

- Water infrastructure and delivery to site
- Hydrogen delivery pipeline, storage, and compression costs
- Owner’s costs (e.g., project development, permitting, staffing, owner’s engineering, legal)
- Land costs
- Escalation, sales tax, financing fees, interest during construction
- Production and investment tax credits.

11.4 Capital and Operating Cost Estimates

Capital cost assumptions summarized in Table 11.1 for the .5 MMTPY, 1 MMTPY, and 1.5 MMTPY Angeles Link throughput scenarios. The estimated capital and operating costs for third-party producers to achieve the projected throughput scenarios are approximately $2,600/kW and $18/kW (annual operational expense calculated as 0.7%

of capital) annually for the electrolyzer facility, and approximately $1,100/kW and $20/kW annually for the solar facility, respectively.

Table 11.1 Hydrogen Production Facility Cost Estimates

Average Annual Hydrogen Production	Single Facility	0.5 MMTPY	1 MMTPY	1.5 MMTPY
Solar, MW	300	13,000	26,000	39,000
Electrolyzer, MW	200	8,800	17,600	26,400
Production Capital Costs				
Solar Facility, $MM	$320	$14,000	$28,000	$42,000
Hydrogen Production Facility, $MM	$520	$23,000	$45,000	$68,000
TOTAL $MM	$840	$37,000	$73,000	$110,000
Production Operating Costs				
Solar, $MM/yr	$5.8	$250	$500	$750
Electrolyzer, $MM/yr	$4	$170	$340	$520
Electrolyzer Stack Replacement, $MM @ Year 9	$100	$4,300	$8,600	$12,900

12.0 Stakeholder Feedback

SoCalGas presented opportunities for the Planning Advisory Group (PAG) and Community Based Organization Stakeholder Group (CBOSG) to provide feedback at four key milestones in the course of conducting this study: (1) the draft description of the Scope of Work, (2) the draft Technical Approach, (3) Preliminary Findings and Data, and (4) the Draft Report. These milestones were selected because they are critical points at which relevant feedback can meaningfully influence the study. Key milestone dates summarized in Table 12.1 below.

Table 12.1 Key Milestone Dates

Milestone	Date Provided to PAG/CBOSG	Comment Due Date	Responses to Comments in Quarterly Report
1. Draft Scope of Work	July 6, 2023	July 31, 2023	Q3 2023
2. Draft Technical Approach	September 7, 2023	November 3, 2023	Q3 2023/ Q4 2023
3. Preliminary Findings and Data	April 11, 2024	May 3, 2024	Q2 2024
4. Draft Report	July 19, 2024	August 30, 2024	Q3 2024

The input and feedback from stakeholders including the PAG and CBOSG has played an important role in the development of the Production Study. Table 12.2 below is a summary of some of the feedback received that was incorporated throughout the development of the Production Study. All feedback received is included, in its original form, in the quarterly reports submitted to the CPUC and published on SoCalGas's website.[49]

[49] https://www.socalgas.com/sustainability/innovation-center/angeles-link.

Table 12.2 Summary of Incorporation of Stakeholder Feedback

Summary of Incorporated Stakeholder Feedback	
Thematic Comments from PAG/CBOSG Members	**Incorporation of and Response to Feedback**
Production Study Assumptions and Criteria Stakeholders suggested specifying the assumptions used regarding production capacity for various technologies and projects and how those assumptions were determined. Stakeholders also suggested setting forth the criteria used to determine the locations of potential H2 and renewable energy production, in addition to when those projects would come online. Stakeholders also suggested clarifying whether the space requirements account for energy storage needs, what utilization rates have been assumed for the electrolyzers, and whether this utilization has been factored into the number of electrolyzers and solar needed.	Consistent with this feedback, the criteria and assumptions relied on in the study are detailed in various sections of the study (e.g., Section 9 describes production facility design basis assumptions, and Section 11.2 has cost assumptions). For the production locations specifically, factors that were considered included availability of land as described in Section 10, solar irradiance (Appendix A), existing pipeline and transportation corridors (Section 10), etc. Appendix A also has a market assessment of current and planned renewable projects and a discussion on storage technologies including lithium-ion battery storage. Section 9 describes potential measures that hydrogen producers may implement to reliably produce hydrogen (e.g., grid connection for safe start-up and shutdown).

Hydrogen Production Methods and Assumptions Stakeholders commented that the study should focus on hydrogen production through electrolysis using renewable electricity, adhering to the “three pillars” (temporal matching, additionality, and deliverability). Other feedback was received suggested further exploration beyond solar resources, such as geothermal resources, should be included in further analysis.	Consistent with this feedback, during development of this study, how the concepts of the three pillars could be considered with respect to potential clean renewable production that could be served by Angeles Link, is discussed further below. For Phase 1 design purposes, this study assumes renewable energy power requirements will be met with islanded power generation and potentially local utility distribution power for start-up/shut-down operations, which do not need to tie into high voltage transmission lines on the electric grid. The current assumption is that renewables would be incremental, as described in Section 2. The study also explores how renewables on the CAISO grid that are curtailed may potentially be reused for hydrogen production in Appendix A.8 (Renewable Curtailments). In addition, consistent with this feedback, while hydrogen produced via electrolysis is central to Angeles Link, a high-level analysis of other potential technology pathways (e.g., biomass/biogas) that could meet the CPUC’s definition of clean renewable hydrogen in Decision 22-12-055 (i.e., be produced with emissions less than 4kg CO2 for each kg H2 and not be from fossil fuels) are included in sections 3, 4, and 5. Until a final route is determined, SoCalGas will continue to assess where 3rd party producers are developing clean renewable hydrogen production as a factor for consideration.

Hydrogen Storage Stakeholders emphasized the need to understand the role of storage, highlighting potential risks related to underground and aboveground storage. Stakeholders requested consideration of competition with existing solar projects, the role of battery storage, land requirements for aboveground storage and other facilities, and the suitability of underground storage locations. Additionally, stakeholders requested that the production study describe and analyze the roles of storage and curtailed renewable generation.	Consistent with this feedback, Section 8 in this study evaluates the role of third-party hydrogen storage options that could help balance clean renewable hydrogen production and demand profiles. Potential third-party hydrogen storage options are discussed in Section 8 and Appendix B. As noted in those sections, Angeles Link could provide transportation of clean renewable hydrogen to or from future storage locations, if developed, and could also provide storage in the pipeline via line pack. Curtailed renewable generation is discussed in Appendix A and as noted, the curtailed energy is expected to be used opportunistically to produce hydrogen.
Hydrogen Production Costs Stakeholders requested clarity on production costs, including costs associated with building electrolyzers, electrolyzer facilities, additional renewable energy sources, and producing hydrogen.	Consistent with this feedback, capital and operating costs were estimated and are described in Section 11.
Land Requirements Stakeholders expressed concerns about potential competition for the land needed to produce enough hydrogen for the assumed throughput volume of 1.5 MMTPY. They requested specific details about the acreage calculation assumptions and what production and storage elements are included in the acreage calculations, like battery energy storage for electrolyzers and above-ground H2 storage. Stakeholders also suggested adding additional limitations on potential land availability, including applying data related to land constraints from the California Energy Commission (CEC).	Consistent with this feedback, Section 10 of this study discusses the assumptions supporting the analysis of land requirements for solar power coupled with electrolyzers to determine feasibility of hydrogen production for 1.5 MMTPY. In addition, in response to feedback related to data from the CEC, a footnote has been added to Section 10.3 considering the potential acreage impacts on the three production areas of the additional constraints suggested by this feedback.

Hydrogen Purity/Quality Some stakeholders recommended detailing purity specifications for different end uses, which could impact production	Consistent with this feedback, various electrolyzer technologies were evaluated to determine the expected hydrogen purity/quality for different technologies as described in section 4 (Electrolyzer Technology Comparison Table) and the expected purity at the production facility (see Hydrogen Facility Scope Assumptions in section 9).
Permitting/Land Use Some stakeholders requested that the production study identify whether there are any legal or land use policy limitations that would impact production	Consistent with this feedback, permitting and land use considerations for hydrogen production took into account various factors as described in section 10.2, which included the location of national and state parks, government refuges, preserves, and military ranges as well as setbacks from culturally and environmentally sensitive areas. Permitting considerations for Angeles Link more generally are discussed in the High-Level Feasibility Assessment and Permitting Analysis.

13.0 Appendices

13.1 Appendix A: Renewable Energy Technology Assessment for Hydrogen Production

Renewables Energy Assessment

The **Renewables Energy Assessment** provides an overview of various renewable power sources and applies various criteria to assess their potential suitability to support clean renewable hydrogen production in SoCalGas's service territory. The assessment also explores various operational characteristics and costs. Finally, potential hydrogen production that uses energy curtailed from the electric grid is evaluated. The analysis in this assessment is meant to inform the reader on how clean renewable hydrogen production may develop.

The Decision states on page 73, "…the Angeles Link Project shall be restricted to the service of **clean renewable hydrogen** that is produced with a carbon intensity equal to or less than four kilograms of carbon dioxide-equivalent produced on a lifecycle basis per kilogram and does not use any fossil fuel in its production process." Consequently, this assessment begins by considering renewable sources from the renewable technologies identified in the California Energy Commission's (CEC) RPS Eligibility Guidebook, Ninth Edition (see Table 13.1):

Table 13.1 CEC Defined Renewables

Technology	Special Requirements
Biodiesel	
Biomass	
Biomethane	Digester or landfill gas only; pipeline and fuel container restrictions
Fuel Cell	Use RPS eligible renewable energy source or hydrogen gas powered by RPS eligible renewable source
Geothermal	
Small Hydroelectric	Nameplate capacity of <=30 MW
Conduit Hydroelectric	Small hydroelectric using potential of an existing manmade conduit (e.g., pipe, canal, tunnel) built before January 1, 2008
Municipal Solid Waste	Combustion is not eligible; Conversion is dependent on technology
Ocean Thermal	
Ocean Wave	
Solar	
Tidal Current	
Wind	

Renewable Power Sources - Criteria Assessment

The analysis of renewable technologies considered criteria such as: maturity, feasibility, scale, and land requirements.

Mature technologies are considered commercially viable technologies with established equipment production cycles and established skilled development, operations, and maintenance labor forces.

Feasible technologies are those that can be developed to required sizes with manageable uncertainty around development timeline and costs.

Scalability of a technology considers how much a technology can be developed at project sizes large enough to satisfy electricity demand. Scalability of technologies in SoCalGas's territory, as an example, can be examined by considering renewable power generation that already exists in SoCalGas's service territory. See Table 13.2: SoCalGas Territory Renewable Project Counts and Sizes by Technology below shows the count, average size, and maximum size for various renewable projects.

Land requirements considers how much land is needed and available for development.

Another factor considered in determining the suitability of renewable resources was the ability to serve hydrogen production without interconnecting to an existing electric transmission system. This study assumes that some electricity produced from carbon-emitting resources would exist on all electricity systems without a firm mandate for zero emissions from any electric generating resource. Currently, California SB 100 calls for 100 percent clean, zero carbon, and renewable energy policy for California's electricity system by 2045. Thus, it is assumed that renewable resources must be able to serve hydrogen production without connection to a grid.

Table 13.2 SoCalGas Territory Renewable Project Counts and Sizes by Technology

Technology	Count of Projects	Average of Project Size (MW)	Maximum Project Size (MW)
Biomethane	18	8	26
Biomass	19	7	50
Geothermal	51	27	127
Hydro	5	529	903
Solar	296	44	395
Wind	82	59	272

Source: CPUC IRP Resource Cost & Build Workbook (June 2023 MAG) for SCE, IID and LADWP, included in file CPUC IRP Resource Cost & Build - - Draft 2023 I&A – v2.xlsx tab "Gen List," found at https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/zipped-files/supporting_materials_v2.zip.

Considering the criteria above, several renewable power technologies were screened for further analysis. Specifically, ocean thermal, ocean wave, and tidal current technologies are not as mature and do not appear able to produce electricity at a scale required for hydrogen production. Biodiesel and municipal solid waste (MSW) were excluded from further consideration because they emit CO2. MSW can qualify as a renewable resource if clean-burning gaseous or liquid fuel can be derived from waste with non-combustion thermal processes. However, the requirements on processing are very restrictive for clean fuel from MSW to qualify as renewable. One of the requirements of MSW to qualify as a renewable is to not use air or oxygen in the conversion process. This restriction eliminates pyrolysis as an option to produce clean fuels using MSW.

Biomass: Biomass renewable energy is produced when solid waste from wood, agricultural or other plant-derived processes is used as a fuel for electricity production. Like biomethane, biomass renewable technologies are mature and used throughout the country. Also, like biomethane, biomass projects in SoCalGas's service territory are smaller in size due to their resource limitation in Southern California. As a result, biomass may complement other renewable power sources to support hydrogen production but is not expected to be the primary power source.

Biomethane: Often referred to as biogas, biomethane is made from waste that produces primarily methane through digesters or landfills. Biomethane is used to fuel combustion processes that generate electricity. Biomethane-fueled electric generation is a mature renewable technology and is used throughout the country. However, biomethane-fueled electric generation relies on access to biomethane sources of significant quantity. Biogas projects are smaller in size due to their resource limitations in Southern California. As a result, biogas may complement other renewable power sources to support hydrogen production but is not expected to be the primary power source.

Geothermal: Geothermal generation resources can provide reliable baseload generation. However, geothermal resources must be sited in locations suitable for providing heat necessary for the geothermal process. Two categories of geothermal technologies exist currently – hydrothermal and enhanced geothermal systems (EGS). Hydrothermal involves the recovery of water or steam from deep below the earth's surface. EGS technologies exhibit naturally occurring zones of heat but lack sufficient fluid flow. EGS processes require engineering to enhance permeability. Geothermal resource development relies on the ability to locate and successfully access sub-surface heat sources. In addition, success of a hydrothermal resource relies heavily on water flow rate and minimum water temperatures. No EGS geothermal projects current exist in the U.S. and the technology is still in a research and development phase. Geothermal technologies were excluded from further analysis primarily due to project feasibility. Feasibility challenges related to geothermal projects include exploration and discovery efforts needed to locate project sites, uncertainty around access to adequate fluid temperatures and flows, uncertainty around project location relative to locations of energy need and uncertainty around technology and project costs.

Hydroelectric: Southern California currently benefits from significant hydroelectric generation throughout California. While hydro represent projects with the largest average size, there are few hydro projects in SoCalGas's service territory and the feasibility to scale is unlikely since for new hydroelectric to be considered renewable under the CEC's RPS standards, projects must be below 30 MW. This limitation results in a scalability issue for serving hydrogen production. In addition, new hydroelectric development faces locational challenges as most suitable locations have already been exploited**.**

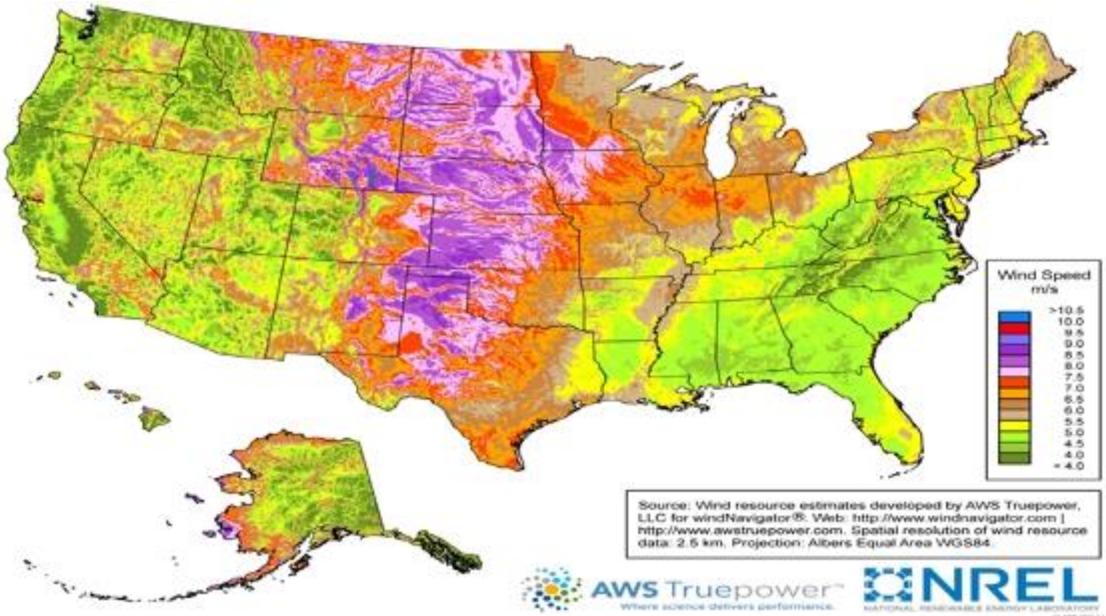
Hydroelectric power was not considered to support hydrogen production for this study.

Off-shore Wind: Off-shore wind technology is developing quickly, with fixed-bottom off-shore wind projects seeing the most development in the U.S. Because of water depths off the coast of Southern California, off-shore wind serving hydrogen production in SoCalGas's service territory would likely need to be floating, which would come at a higher cost than fixed-bottom offshore wind. Currently, there are no floating offshore wind projects off the California coast. Also, the infrastructure needed to develop and deploy offshore wind structure has not yet been developed in California. While floating offshore wind technology may prove to be a suitable renewable resource to serve hydrogen production, it is not expected to be the primary power source.

Solar and wind represent technologies considered to be more appropriate to support the production of hydrogen at levels contemplated by the Hydrogen Production Assessment Study due to the following:

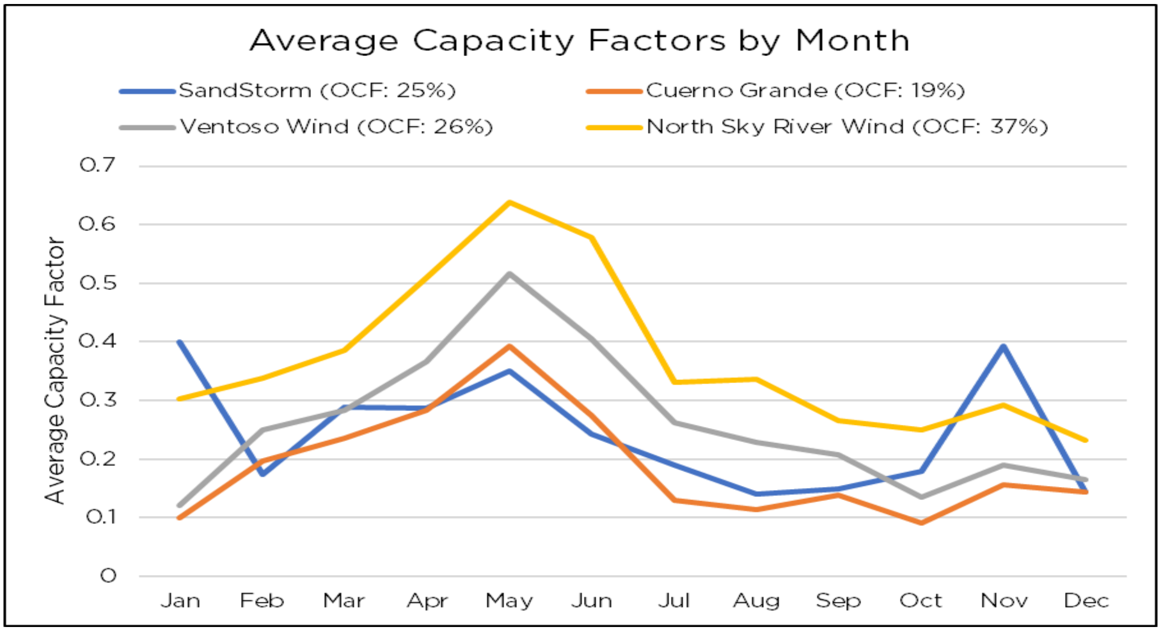
Wind: Wind renewable technology is proven worldwide and is a mature technology. Wind projects can be developed at a large scale given enough land and there is significant land available for wind projects in SoCalGas's service territory. Wind can also be developed without an interconnection to a grid and at capacity sizes that are relatively large compared to alternative renewable power sources. The potential for wind depends on the wind generation profiles, which vary throughout Southern California, with sites at higher elevations typically being the most efficient. However, relative to other parts of the U.S., the wind potential in SGC territory is weak to average depending on location. The figure below developed by AWS Truepower and NREL shows wind speed potential across the country.

Figure 13.1 U.S. Wind Speed Potential



As can be seen from Figure 13.1 above, the strong wind potential in the U.S. can be found in the center of the country. An NREL's SAM model was used to develop wind generation profiles for 42 sites in SoCalGas's territory. From these 42 solar generation profiles, generation outlooks for three (3) sites that represent low, average, and high generation performances for an average weather year were evaluated. Three projects, Cuerno Grande, Ventoso, and North Sky River are representative of low, average, and high wind performance, respectively. A fourth project, Sandstorm, was also evaluated to show that while average on an annual basis, projects can be significantly different monthly. The monthly capacity factors for these projects are shown in the figure below.

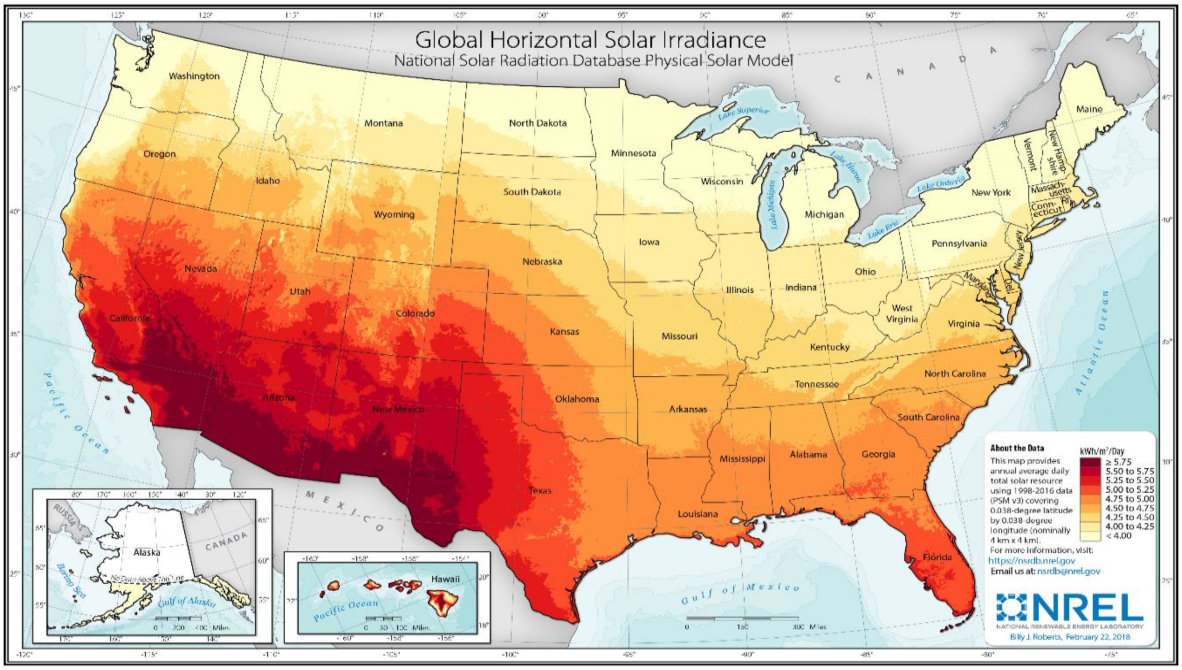
Figure 13.2 Range of Wind Capacity Factors in SGC Territory



As can be seen in Figure 13.2, Southern California sees the most wind in the spring. The highest performing project, North Sky River Wind, has a May capacity factor over 60 percent while the lowest performing project, SandStorm, has a May capacity factor of about 35 percent. This range demonstrates that wind performance across Southern California can vary significantly that could impact the feasibility of wind for large scale hydrogen production for Angeles Link.

Solar: Of the various renewable technologies evaluated, solar is considered the most suitable to provide clean renewable hydrogen production since the technology is proven, the solar irradiance is high in SoCalGas's service territory, and land is expected to be available for solar project development. There are more solar projects in SoCalGas's service territory than for any other technology and the scale is larger for solar than many alternatives. Solar can also be developed without an interconnection to a grid. Figure 13.3: NREL Solar Irradiance Across the U.S. shows relatively high solar potential in SoCalGas's service territory compared to the rest of the country.

Figure 13.3 NREL Solar Irradiance Across the U.S.



Burns & McDonnell used NREL's SAM model to develop solar generation profiles for 221 sites in SoCalGas's service territory. From these 221 solar generation profiles, generation outlooks for three (3) sites that represent low, average, and high generation performances for an average weather year were evaluated. The solar sites evaluated are Ariella Solar in Tulare County (representative low profile), Northern Orchard Solar in Kern County southwest of Bakerfield (representative average profile), and Chaparral Solar in Kern County north of Lancaster (representative high profile). The annual capacity factors for the solar projects evaluated range from 28 percent to 34 percent. Figure 13.4, Figure 13.5, and Figure 13.6 show low, average, and high monthly solar production profiles, respectively for the three sites evaluated.

Figure 13.4 Low Monthly Solar Capacity Factors

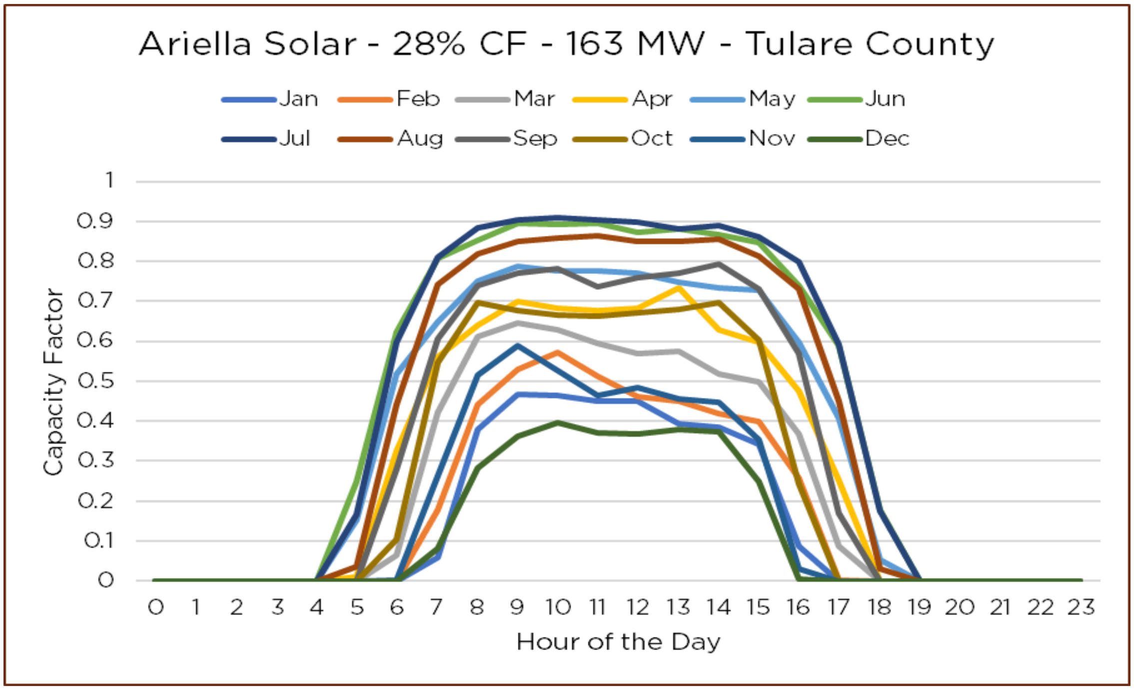


Figure 13.5 Average Monthly Solar Capacity Factors

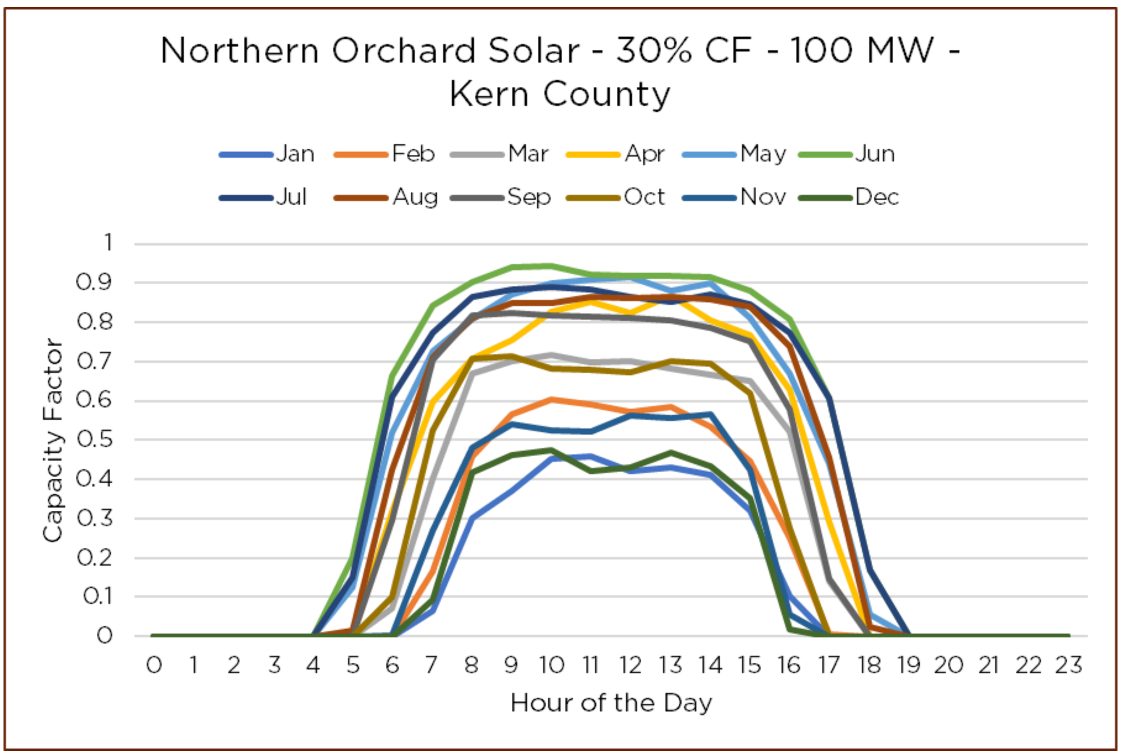
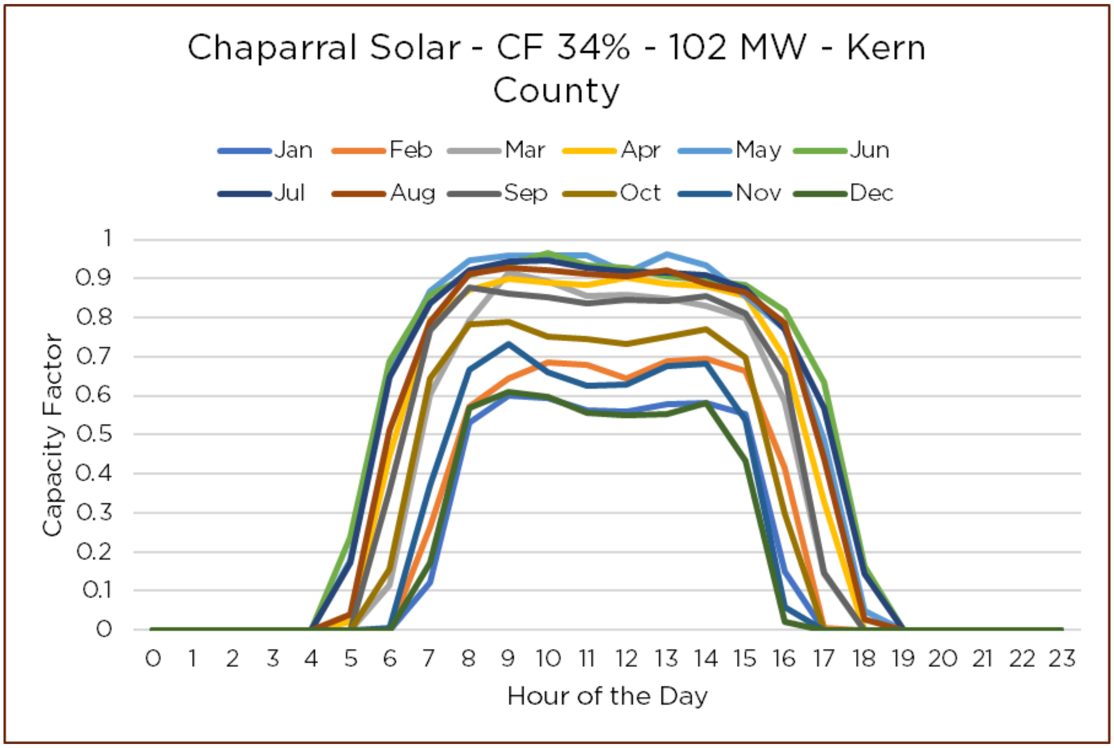


Figure 13.6 High Monthly Solar Capacity Factors



Each of the projects depicted in the figures above have very high summer capacity factors. However, the lowest production occurs in December, when peak capacity factors are 39 percent, 48 percent, and 61 percent for the low, average, and high profiles, respectively.

Conclusions

The renewable power source most suitable for serving hydrogen production in Central and Southern California is solar. Solar irradiance in most of SoCalGas's service territory is some of the best in the country. Other renewable technologies, including wind, biomethane, biomass, geothermal, hydroelectric, and offshore wind, may have roles supporting hydrogen production but are not expected to play the same role as solar generation.

Renewable Power Sources – Cost Assessment

Burns & McDonnell developed AACE Class 5 capital and operational cost estimates for renewable technologies that support the production of clean renewable hydrogen using publicly available information from NREL's ATB data, the Energy Information Administration (EIA) and Lazard. These sources are consistent with sources used for the CPUC 2022-2023 Integrated Resource Plan (IRP). Costs by resource type have been included in a financial pro forma model to allow for the calculation of renewable resource costs over the life of the resource. Renewable costs included in the pro forma model include costs to develop renewable resources and costs to operate renewable resources. Renewable resource costs include tax credits defined in the Inflation Reduction Act of 2022 (IRA).

Costs for renewable technologies included the compilation of renewable technology development costs, renewable technology operating costs, and renewable tax credits. Production tax credits and investment tax credits according to the IRA have been modeled to determine the optimal tax credit to apply to renewable resource costs.

A.4 Analysis of Renewable Technology Costs

NREL 2023 ATB provides estimates of levelized cost of energy (LCOE) for various renewable technologies. LCOE calculates discounted cashflow of technology's development and operations costs over the expected life of a technology and divides this total discounted cashflow by total expected energy from the technology. While LCOE is a simplified version of total renewable project costs, it does allow for an easy comparison of renewable technology costs across technologies.

Table 13.3 below includes NREL LCOE for various renewable technologies along with the primary inputs used to derive LCOE.

Table 13.3 Renewable Technology Characteristics and Costs

Item	Biomass	Geothermal	Hydro – Run of River	Solar PV	Wind – Onshore	Wind - Offshore
Assumed Useful Life (Years)	45	30	100	30	30	30
Capacity Factor	64%	80%	66%	28% - 34% 1/	19% - 37% 1/	52%
Construction Years	4	8	3	1	3	3
Recommendation - Earliest Start Year	2040	2040	2040	2040	2040	2040
Assumed Project Completion Year	2040	2040	2040	2040	2040	2040
CAPEX (2021 $/kW)	$4,186	$7,010	$7,553	$764	$1,299	$4,149
Fixed O&M Costs (2021 $/kW/year)	$157.22	$124.10	$47.00	$14.84	$25.90	$70.44
Variable O&M Costs (2021 $/MWh)	$5.04	$0.00	$0.00	$0.00	$0.00	$0.00
LCOE (2021 $/MWh)	$147.93	$81.01	$69.25	$19.25	$33.71	$72.40

Source: 2023 NREL Annual Technologies Baseline. Found at https://atb.nrel.gov/electricity/2023/data.
1/ Capacity factors ranges are based on NREL SAM's data for SoCalGas's territory.
Note: PVsyst Solar Model capacity factor of 26.4% for Bakersfield, CA is considered more accurate and is used in the detailed analysis.

As seen in Table 13.3, NREL is forecasting solar will be the lowest cost renewable technology, followed by onshore wind.

A.5 Electrical Storage Technologies and Costs

Several electricity storage technologies were considered that could support clean renewable hydrogen production, including:

- Utility Scale Lithium-ion Batteries
- Pumped Hydro Storage

- Utility Scale Flow Batteries
- Compressed Air Energy Storage

Of these technologies, lithium-ion batteries and pumped hydro are mature technologies with demonstrated operational success. Flow batteries and compressed air storage are developing technologies that have yet to achieve utility-scale commercial success. Thus, these technologies were not considered to support Phase 1 clean renewable hydrogen production. Pumped hydro storage, while a mature technology, faces feasibility and cost challenges in SoCalGas's service territory as suitable sites are not readily available, especially sites that could be tied directly to clean renewable hydrogen production facilities. Thus, pumped hydro storage was not considered to support Phase 1 hydrogen production. The storage technology considered suitable to support Phase 1 hydrogen production at utility scale is lithium-ion batteries. Lithium-ion battery technology is mature and lithium-ion battery projects can be scaled and co-located near renewable technologies such as solar and wind.

NREL also develops cost estimates for various storage technologies. Because storage technologies are transferring energy, it is not appropriate to develop LCOE's for storage resources. Table 13.4 includes estimated storage costs for various technologies based on assumed development and operations inputs.

SoCalGas

Table 13.4 Electrical Storage Technology Characteristics and Costs

Item	Utility Scale Lithium-Ion Battery 4-hour	Pumped Storage Hydro Energy	Utility Scale Flow Battery 1/	Compressed Air Energy Storage (adiabatic) 1/
Typical Project Size (MW)	60	879	10	100 – 1,000 2/
Assumed Useful Life (years)	15	100	12	60
Duration	2 - 10 hours	8 - 12 hours	10 hours	12 - 24 hours
Roundtrip Efficiency	85%	80%	65%	52%
Construction Years 3/	< 2 years 4/	3	2	5
Year Cost Basis	2021	2021	2022	2022
Year of Cost	2040	2040	2030	2030
CAPEX ($/kW)	$1,018	$2,250	$3,386	$1,639
Fixed O&M Costs ($/kW/year)	$25.46	$18.66	$10.63	$10.04
Variable O&M Costs ($/MWh)	$0.00	$0.54	$0.00	$0.00
Source (unless otherwise noted): 2023 NREL Annual Technologies Baseline. Found at https://atb.nrel.gov/electricity/2023/data. 1/ From PNNL 2022 Grid Energy Storage Technology Cost and Performance Assessment 2/ No projects currently exist. Reflects PNNL assumption (see footnote 1/). 3/ Excludes time for permitting and generation interconnection requirements. 4/ Construction years were not provided by NREL on its ATB. Construction times will vary depending on configurations.				

Utility-scale lithium-ion batteries are the least expensive of the storage technologies. In addition, there is less uncertainty around lithium-ion battery costs than there is around the other storage technologies. Pumped storage hydro costs are highly influenced by locations that can accommodate the technology, and thus costs for pumped storage hydro can vary significantly depending on a project is developed. Both utility scale flow batteries and compressed air energy storage are early in their development, meaning costs are likely to be uncertain until these technologies become commercially acceptable.

A.6 Renewable Power – CA Market Assessment

Analyses from public sources have been examined to form a view on the demand for renewables in Central and Southern California. Analysis from the CPUC in its 2022-

SoCalGas

2023 IRP was examined for a view of SoCalGas's service territory generation resource mix into the future. Generation resources in the electric service territories of Southern California Edison (SCE), Imperial Irrigation District (IID) and Los Angeles Department of Water and Power (LADWP) were assumed to be reflected of resources in SoCalGas's service territory.

Table 13.5 below shows the generation capacity outlook for SCE, IID and LADWP developed by the CPUC in its 2022-2023 IRP.

Table 13.5 WECC Generation Capacity Outlook by Technology

Technology Type	Capacity (MW)		
	2022	2030	2040
Coal	480	-	-
Geothermal	1,348	1,392	1,392
Hydro	4,303	4,303	4,303
Natural Gas Combined Cycle (NGCC)	9,160	10,609	10,609
Natural Gas Combustion Turbine (NGCT)	4,648	4,738	4,738
Battery Storage	3,193	5,636	5,636
Natural Gas Steam Turbines (NG Steam)	3,886	186	186
Nuclear	1,042	1,042	1,042
Other	2,759	2,076	2,041
Solar	11,533	13,161	13,161
Wind	4,654	4,828	4,828
Total	**47,005**	**47,971**	**47,935**
Source: CPUC IRP Resource Cost & Build Workbook (June 2023 MAG)), included in file CPUC IRP Resource Cost & Build - - Draft 2023 I&A – v2.xlsx tab "Gen List," found at https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/zipped-files/supporting_materials_v2.zip.			

The outlook shows coal generation as well as nearly all natural gas steam turbine generation retired by 2030. These retirements are expected to be offset primarily by additions to solar and battery storage. Nuclear (Palo Verde) is assumed to continue beyond 2040. The electric service territories of SCE, IID and LADWP already have significant renewable generation capacity, which is expected to continue to be augmented by natural gas combined cycle generation and nuclear generation out through 2040.

To gain insights on where existing and planned renewable projects are located within SoCalGas's service territory, Burns & McDonnell evaluated EIA Form 860 data, which includes county information for generation plants. Table 13.6 below shows existing and planned renewable projects by counties located in SoCalGas's service territory.

Table 13.6 Existing and Planned Renewable Capacity by Counties in SoCalGas Service Territory (MW)

County	Existing			Planned/Under Development			Total		
	Batteries	Wind	Solar PV	Batteries	Wind	Solar PV	Batteries	Wind	Solar PV
Kern	718	3,655	4,283	2,332	16	2,217	3,049	3,671	6,500
Riverside	1,545	590	3,089	2,060	27	1,682	3,605	617	4,771
Imperial	155	265	1,977	922	-	1,282	1,077	265	3,259
Los Angeles	376	2	1,286	841	-	497	1,217	2	1,783
Kings	225	-	1,319	360	-	917	585	-	2,235
San Luis Obispo	-	-	1,127	525	-	300	525	-	1,427
San Bernardino	80	7	752	641	-	22	721	7	773
Tulare	-	-	356	380	-	10	380	-	366
Orange	128	-	15	80	96	-	208	96	15
Ventura	113	-	9	89	-	20	202	-	29
Santa Barbara	10	-	67	-	-	2	10	-	69
Total	**3,350**	**4,520**	**14,278**	**8,228**	**138**	**6,948**	**11,579**	**4,658**	**21,226**
Source: EIA Form 860, 2022.									

As can be seen in Table 13.6 above, Kern County has the most existing and planned renewable resources, followed by Riverside County. The existing and planned resources in Kern and Riverside Counties account for over half of all existing and planned renewable resources in SoCalGas's service territory.

A.7 Summary of Projects in the CAISO Queue

Another indication of expected renewable project development in California can be provided by examining the proposed projects in CAISO's generation interconnection queue. Renewable developers must request a generation interconnection from CAISO prior to project development. CAISO studies projects in its interconnection queue to estimate interconnection costs as well as additional costs a project may impose on the CAISO system. Many projects in CAISO's generation interconnection queue may not be completed.

Table 13.7 summarizes the generation projects currently in CAISO's generation interconnection queue by number of projects, average project size, maximum project size and total capacity by technology.

Table 13.7 Summary of Renewable Projects in CAISO's Generation Interconnect Queue

Technology	Number of Projects	Average Project Size (MW)	Maximum Project Size (MW)	Total Capacity (MW)
Battery	194	270	1,434	52,296
Natural Gas	1	656	656	656
Other	2	516	520	1,032
Pumped-Storage hydro	3	1,108	1,417	3,324
Solar	118	243	1,182	28,677
Wind Turbine	12	574	1,518	6,890
Source: CAISO PublicQueueReport.xlsx, found at http://www.caiso.com/PublishedDocuments/PublicQueueReport.xlsx.				

Generation interconnection requests for batteries and solar make up the majority of request, with battery capacity reflecting 56 percent of the MW requested and solar reflecting 31 percent of the MW requested.

The expected demand for renewable generation resources is significant. The Energy Information Administration (EIA), in its Annual Energy Outlook for 2023 (AEO23), provides a forecast of generation needs by technology out through 2050. Table 13.8 below shows EIA's expected renewable resource needs for Southern California.

Table 13.8 EIA AEO23 Expected Capacity Additions - Southern California

Technology	Southern California (Net Summer Capacity GW)				
	2023	2030	2040	2050	% Change
Hydroelectric Power	1.8	1.8	1.8	1.8	0%
Geothermal	0.3	0.6	0.8	1.1	239%
Municipal Waste	0.2	0.2	0.2	0.2	57%
Wood and Other Biomass	0.0	0.0	0.0	0.0	0%
Solar Thermal	1.0	1.0	1.0	1.0	0%
Solar Photovoltaic	15.7	19.1	36.4	59.2	276%
Wind	5.1	4.8	4.5	6.1	20%
Offshore Wind	-	-	-	-	--
Total	**24.2**	**27.5**	**44.9**	**69.6**	**188%**
Source: EIA Annual Energy Outlook 2023.					

Table 13.8 above shows renewable resource demand is expected to result in the most growth in solar on a MW basis.

A.8 Renewable Curtailments

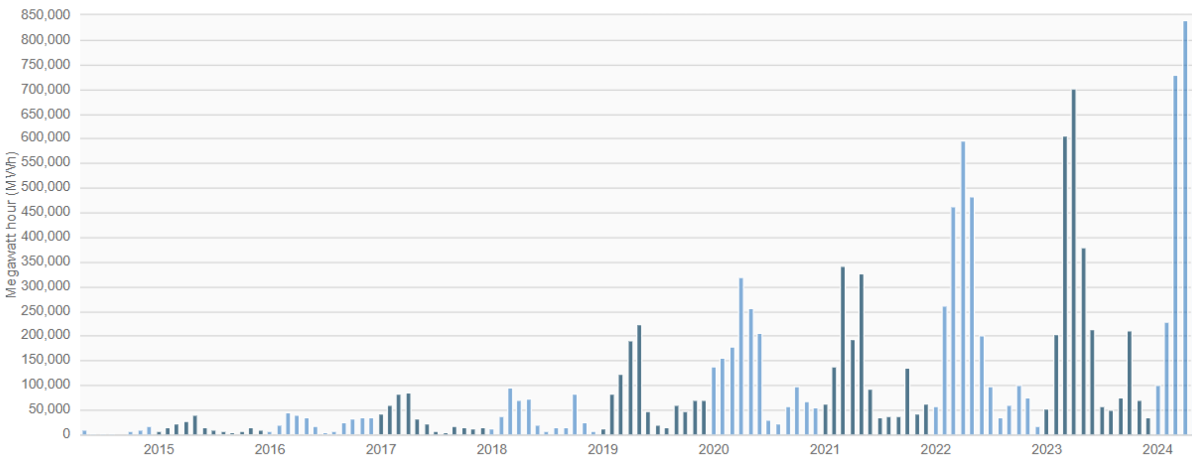
Electric curtailment occurs when a generating resource is turned down or limited because the electric system cannot take the energy as the transmission system is constrained or there is not enough demand for energy. In California, CAISO manages two types of curtailments that occur on the electric grid: 1) system and 2) local.

System curtailment occurs when energy supply is greater than demand, even if the curtailed resource is a least-cost resource. An example of a system curtailment would be when, on a sunny, cool summer day, there are more solar resources online than needed, even after backing down dispatchable generation. Local curtailments occur when energy is unable to flow from an area of oversupply to an area of need due to transmission constraints. Transmission constraints can occur due to transmission ties that are insufficient to handle certain flows, unit outages near areas of high demand, transmission line outages or any combination of the aforementioned.

Distinguishing between local and system curtailments is important because system curtailments represent the excess energy that could be used for hydrogen production.

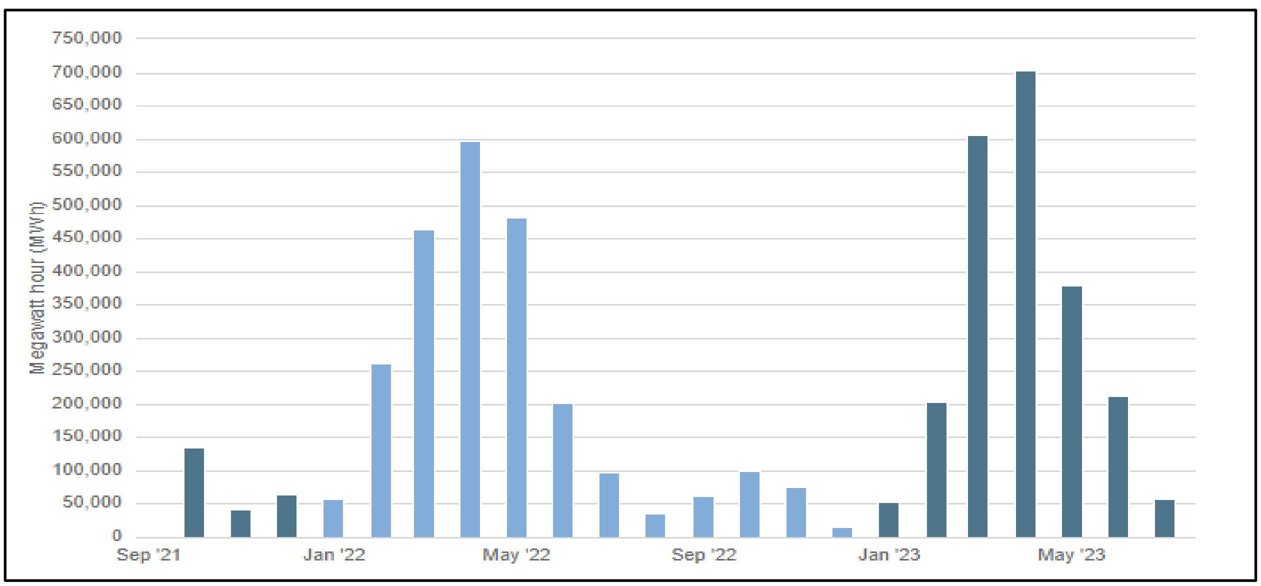
Figure 13.7 and 13.8: CAISO Solar/Wind Curtailments show curtailed energy for both the past 10 years ending May 2024 as well as the two years ending July 2023 and includes system and local curtailments.

Figure 13.7 CAISO Solar/Wind Curtailments – 10 Years Ending May 2024



Source: https://www.caiso.com/about/our-business/managing-the-evolving-grid

Figure 13.8 CAISO Solar/Wind Curtailments – 2 Years Ending July 2023

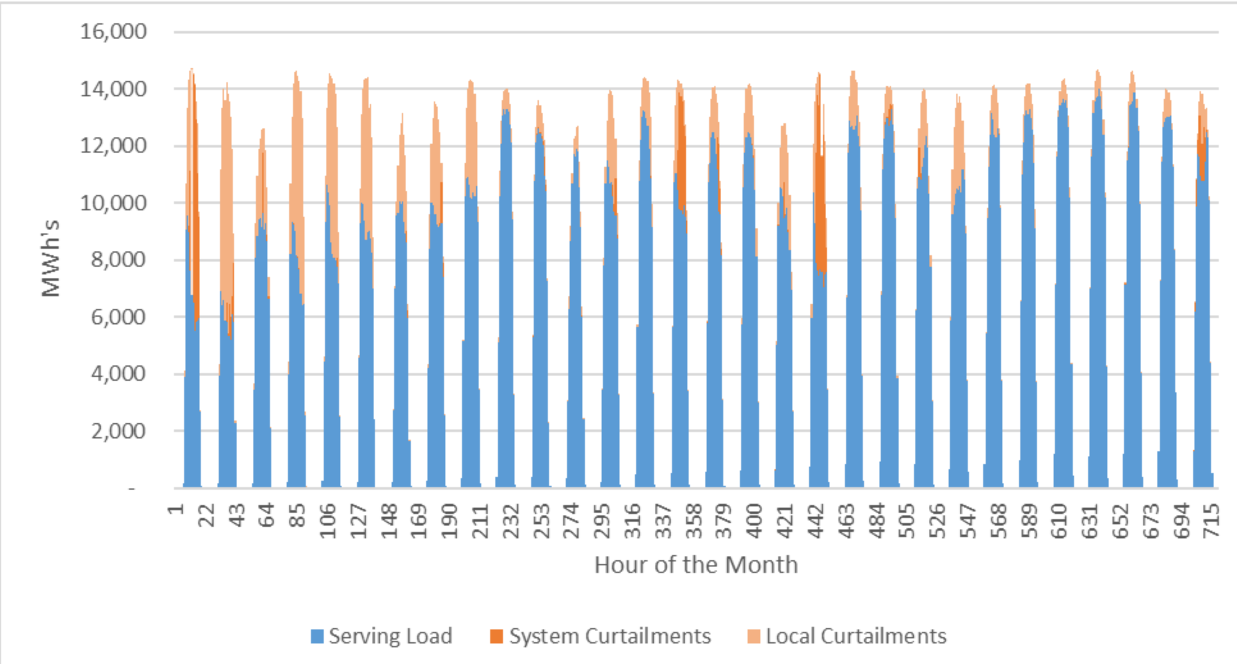


Figures 13.7 and 13.8 show that curtailed solar and wind energy amounts are generally more significant between March and May, with peaks in April. For instance, April 2023 saw 702,833 MWhs of solar and wind curtailments in CAISO, with 672,010 MWhs, or 96

percent related to solar generation. In April 2023, total solar generation serving load was 3,409,117 MWhs.

The next several figures show a breakdown of solar curtailments for April 2023. Figure 13.9 shows solar serving load, system solar curtailments and local solar curtailments, for all hours in April 2023. In Figure 13.9, 3,409,1117 MWhs of solar generation served load in April 2023. Of the total solar curtailment amount of 672,010 MWhs, 132,507 MWhs were system curtailments and 539,503 were local curtailments.

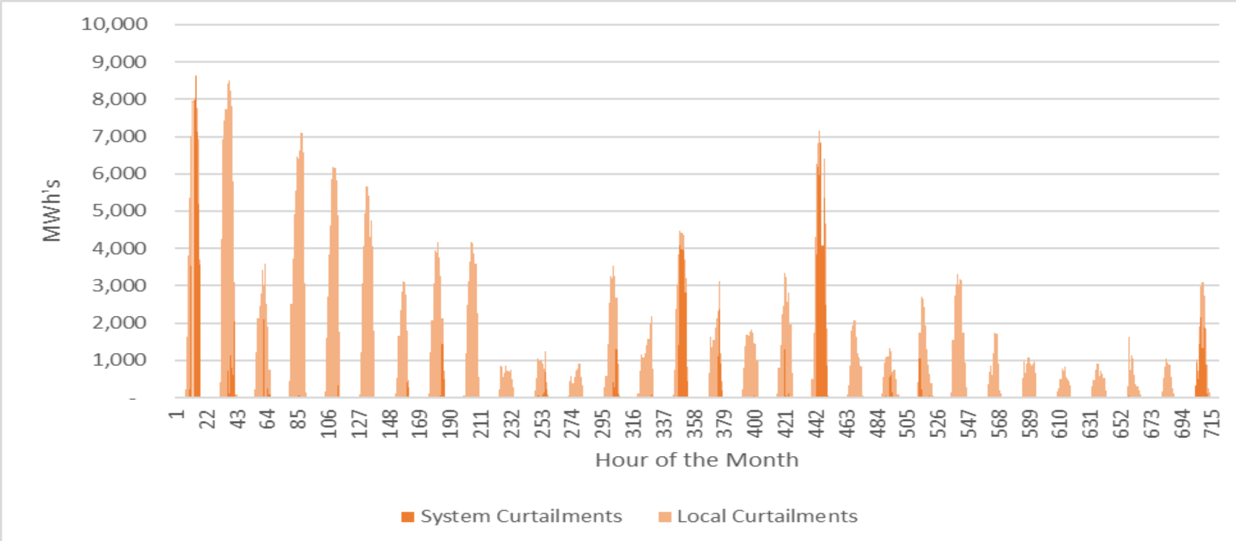
Figure 13.9 CAISO Solar Generation – April 2023



Source: CAISO, ProductionAndCurtailmentData_2023.xlsx, found at https://www.caiso.com/informed/Pages/ManagingOversupply.aspx

Figure 13.10 shows only solar curtailments for April 2023 on an hourly basis.

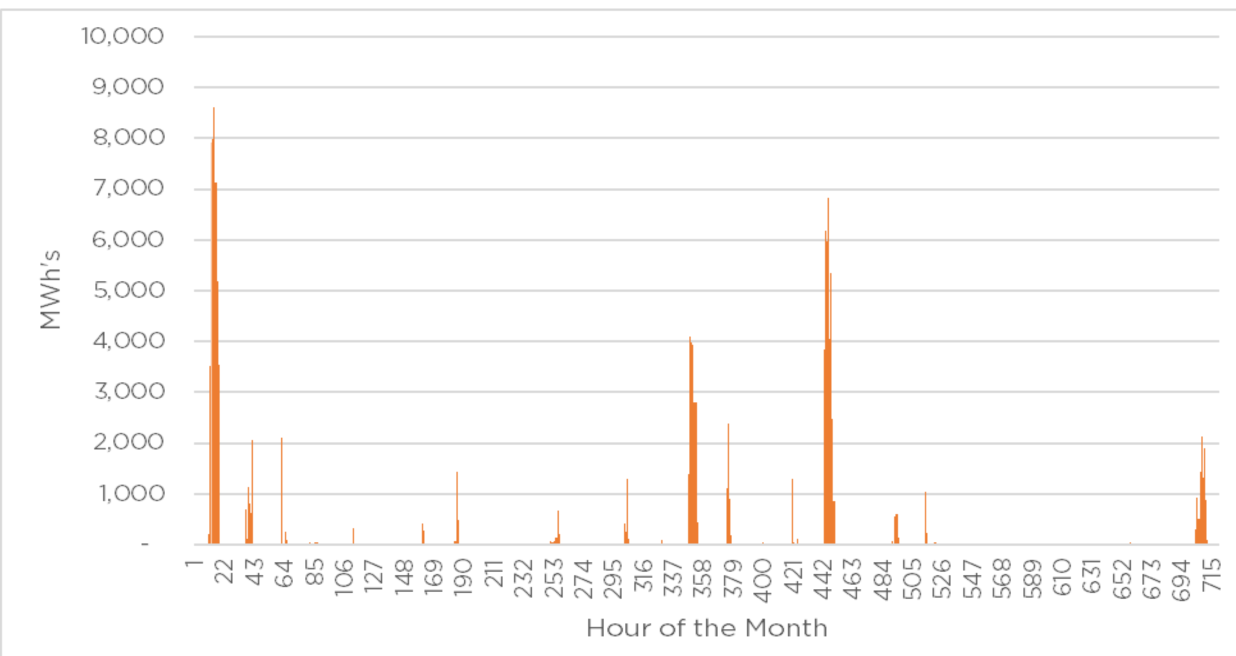
Figure 13.10 CAISO Solar Curtailments – April 2023



Source: https://www.caiso.com/informed/Pages/ManagingOversupply.aspx, ProductionAndCurtailmentData_2023.xlsx.

Significant local curtailments occurred every day in April 2023 while significant system curtailments occurred only a handful of days. Figure 13.11 shows only system solar curtailments for April 2023 on an hourly basis.

Figure 13.11 CAISO Solar System Curtailments – April 2023



Source: https://www.caiso.com/informed/Pages/ManagingOversupply.aspx, ProductionAndCurtailmentData_2023.xlsx.

In Figure 13.11, the three (3) largest days of system solar curtailments make up 75 percent of all system solar curtailments for the month of April 2023.

The previous several figures show during a month of high solar curtailments, system solar curtailments make up a minority of total solar curtailments (20 percent in April 2023) and occur sporadically during a month. System curtailments, while significant, are expected to continue to be sporadic and seasonal. As a result, the curtailed energy is expected to be used opportunistically to produce hydrogen.

13.2 Appendix B: Hydrogen Storage

B.1 Aboveground Storage

Commercially available aboveground storage technologies include compressed gas, liquid hydrogen, metal hydride and iron oxide storage systems. Each option provides distinct differences in terms of safety, capacity, and operational flexibility, catering to diverse applications across industries.

B.1.1 Compressed Hydrogen Gas Storage

Compressed hydrogen gas storage involves storing hydrogen at high pressures, typically between 350 to 700 bar (5,000-10,000 psi), in cylindrical tanks made of steel or composite materials. This method requires moderate to high capital expenditure due to the cost of high-pressure tanks and compression equipment. Operating expenses are moderate, primarily attributed to the energy required for compression and periodic tank inspections. The technology for compressed hydrogen storage is mature and widely adopted, with tanks typically lasting 15 to 20 years with proper maintenance. Auxiliary equipment such as compressors, pressure relief devices, and safety sensors are essential components of this storage system.[50]

B.1.2 Liquid Hydrogen Storage

Liquid hydrogen storage requires cooling hydrogen to cryogenic temperatures of -423 °F (-253 °C). This method incurs high capital expenditure mostly from the cost of cryogenic storage tanks and refrigeration systems. Operating expenses are also high, largely stemming from energy consumption for refrigeration and management of boil-off gas. Boil-off occurs when liquid hydrogen absorbs heat, typically from its surroundings, and must be reliquefied or vented.[51] To prevent hydrogen losses, energy-intensive reliquification is required. The technology for liquid hydrogen storage is mature and commonly utilized in space and specialized applications, like hydrogen fuel stored for NASA launches. Cryogenic tanks typically have a lifespan of 15-20 years with proper maintenance. Auxiliary equipment such as refrigeration systems, boil-off gas management systems, and insulation materials are integral to the storage system, which typically employs double-wall vacuum-insulated tanks. This technology is mature, with ongoing advancements in storage capacities and technology. The US Department of Energy is funding research through the Hydrogen and Fuel Cell Technologies Office to develop spheres up to 100,000 m^3 (6250 tonnes) in capacity (DOE H2@Scale, n.d.-

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[50] Eberle, Mueller, & von Helmolt, 2012.

[51] Gülzow, E., & Bohn, L. (2010). Cryogenic Storage of Hydrogen. Wiley-VCH Verlag GmbH & Co. KGaA.

a). Several commercially available options for liquid hydrogen storage vessels, capacities, and cost ranges are provided for reference.

B.1.3 Metal Hydrides Hydrogen Storage

Metal hydrides hydrogen storage involves the absorption of hydrogen into a metal alloy, creating a solid metal hydride. This method requires high capital expenditure due to the cost of metal hydrides and containment systems. Operating expenses vary from low to moderate, contingent upon the hydride material and the necessity for thermal management.[52] The technology for metal hydride hydrogen storage is still emerging, undergoing continuous development to achieve commercial viability. The lifespan of metal hydride storage systems depends on cycling stability but is shorter than compressed or liquid systems. Auxiliary equipment such as heat management systems is necessary to control the exothermic and endothermic reactions during charging and discharging processes. This is an emerging technology, with active development focused on efficiency and cost-effectiveness. A commercially available option for metal hydride hydrogen storage, capacity, and cost estimate is provided below for reference.

B.1.4 Iron Oxide Hydrogen Storage

The Iron Oxide Hydrogen Storage technology employs reduction and oxidation reactions of iron (Fe) for hydrogen storage. During the loading phase, hydrogen reduces iron oxide, releasing steam that can be utilized in electrolysis. Conversely, during discharge, steam is introduced to oxidize iron, yielding hydrogen. Commercial units have been available since early 2022, with plans to release 20-foot standard containers by 2024. Iron Oxide Hydrogen Storage demonstrates the highest storage density among energy storage systems, capable of storing over 2 kWh of hydrogen per liter, surpassing traditional methods such as pressure vessels or liquid hydrogen. Integrated with steam-driven electrolysis and fuel cells, Iron Oxide Hydrogen Storage achieves significantly higher long-term power storage efficiencies, thereby reducing hydrogen generation and storage costs. Moreover, this technology reduces the space requirement for hydrogen storage, increases capacity per truck, and lowers overall generation and storage expenses. While currently more costly than batteries for larger storage systems, Iron Oxide Hydrogen Storage remains competitive with the aid of investment subsidies and possesses potential for cost reduction in the medium term. Details for commercially available options for Iron Oxide hydrogen storage, capacity, and cost estimate are provided for reference.

[52] Züttel et al, 2010.

<u>B.1.5 Aboveground Storage Options Comparison</u>

Storage Type	Physical Storage	Physical Storage	Chemical Storage	Chemical Storage
	Compressed Gas	Liquid	Metal Hydrides	Compact Iron Oxide
Equipment Type	Cylinders, pressure vessels, tubes	Insulated spherical vessels, cylindrical tanks	Metal hydrides stored in containment systems	Proprietary containerized storage
Pressure Range	5,000-10,000 psi,	Up to 150 psi,	Varies depending on absorption process	400 - 1,400 psi
Temperature Range	-40 to 185 °F	-423 °F (cryogenic)	Ambient to 400+ °F	Ambient to 300 °F
Commercially Available Capacity per unit	Up to 20 tonnes	Up to 312 tonnes	Up to 0.25 tonnes	Up to 100 tonnes
	(20,000 kg) per cylinder	(312,000 kg) per sphere	(250 kg) per unit	(8300 kg) per unit

B.2 Underground Storage

Underground Hydrogen Storage (UHS) in geologic formations offers potential benefits to large-scale deployment of hydrogen as an energy source including storage capacity, low relative cost, and protection from natural hazards or anthropogenic threats. As part of Angeles Link Phase 1, evaluations were performed for the potential of UHS within an Area of Interest (AOI) that includes the SoCalGas service area within California as well as potential resources in Nevada, Utah, and Arizona, as indicated in Appendix C.1. UHS options evaluated included rock salt provinces capable of supporting solution-mined salt caverns, depleted reservoirs in oil and gas fields, abandoned underground hard rock mines, and saline aquifers.

Void space created in geologic rock salt formations by solution-mining techniques is the only commercially deployed UHS technology at present. Within the AOI, there are six geologic provinces with salt formations (salt basins) where solution-mining of salt caverns may be feasible. All six salt basins are outside of California. Solution-mined caverns are operational for fuel storage near Delta, Utah. Additionally, green hydrogen generation and storage projects were announced at Delta, Utah (ACES project) and near Kingman, Arizona (Mohave Green Energy Hub), both of which have stated intent to solution-mine salt cavern for underground storage of hydrogen.

Within the SoCalGas general service area in California, there is significant UHS capacity in existing depleted oil and gas reservoirs. There is a consensus among the scientific and engineering community that hydrogen storage in depleted oil and gas reservoirs is likely feasible,[53] but the community also acknowledges uncertainty in the commercial application of depleted oil and gas reservoirs for UHS. As such, there are many ongoing research projects in this area as stated below in Section B.2.3.2.1. These uncertainties are related to subsurface processes, cost, and permitting, including the following:

- Lack of an established regulatory framework for permitting and operating a UHS facility and associated project timeframes
- Lack of commercially operable projects and thus estimates of capital and operational costs
- Potential for loss of hydrogen by microbial activity
- Leakage through sealing rocks and/or wells penetrating the sealing rocks
- Environmental permitting and social considerations
- Site preparation
- Acquisition of land and/or pore space rights

A total of 297 oil and gas fields and 6 salt basins were evaluated using rubrics developed to assess certain geologic characteristics impacting the feasibility of utilizing the fields or basins as UHS facilities. The final evaluation of each oil and gas field are

[53] Foh, S., Novil, M., Rockar, E., and Randolph, P., 1979. Underground hydrogen storage. final report. [salt caverns, excavated caverns, aquifers, and depleted fields] (No. BNL-51275). Brookhaven National Lab., Upton, NY (USA).
Amid, A., Mignard, D. and Wilkinson, M., 2016. Seasonal storage of hydrogen in a depleted natural gas reservoir. International Journal of Hydrogen Energy, 41, 5549–5558, https://doi.org/10.1016/j.ijhydene.2016.02.036.
Heinemann, N., Alcalde, J., Miocic, J.M., Hangx, S.J., Kallmeyer, J., Ostertag-Henning, C., Hassanpouryouzband, A., Thaysen, E.M., Strobel, G.J., Schmidt-Hattenberger, C. and Edlmann, K., 2021. Enabling large-scale hydrogen storage in porous media–the scientific challenges. Energy & Environmental Science, 14(2), pp.853-864.
Muhammed, N.S., Haq, M.B., Al Shehri, D.A., Al-Ahmed, A., Rahman, M.M., Zaman, E. and Iglauer, S., 2023. Hydrogen storage in depleted gas reservoirs: A comprehensive review. Fuel, 337, p.127032.

presented on “stop-light” maps, where fields with the most favorable characteristics appear green, fields for which information is lacking or with certain unfavorable aspects were noted appear yellow, and fields that are inadequate appear red. These maps provide a scientific baseline assessment of the geologic feasibility of UHS in each field. In addition to maps showing the geologic feasibility of UHS within the oil and gas fields, maps showing population density and potential earthquake faults are included, as these aspects may impact the ability to permit a UHS facility in the AOI.

In addition to a review of oil and gas fields and salt basins, abandoned underground mines and saline aquifers were also considered. A comprehensive database of locations of abandoned underground mines was compiled and mapped. Other than location information, no data regarding depth, size, or host rock was identified in this phase of work for abandoned underground mines to screen their potential for UHS. Mine specific data is necessary to determine the potential feasibility of UHS at any abandoned mine.

There is UHS potential in saline aquifer systems in the AOI. However, subsurface investigations in the AOI, and in California in particular, have been focused on discovering, delineating, and producing oil and gas accumulations, not saline aquifers. Therefore, locating suitable structures in saline aquifers with the potential to contain hydrogen would require significant exploration and characterization activities. Due to the lack of available data, abandoned mines and saline aquifers, while having potential, are not considered prospective for UHS soon and therefore no evaluation frameworks were applied.

B.2.1 Technology Evaluation Approach

This UHS evaluation aims to screen the AOI for suitable geologic conditions for hydrogen storage. All methods of subsurface storage share the goal of safely meeting storage capacity needs with suitable injection and withdrawal rates to meet production and consumption needs. Available subsurface storage options are geologically distinct, and each has unique geologic characteristics and commercial limitations.

B.2.2 Statement of Limitations

This evaluation was completed utilizing publicly available data and published materials, and as such, the accuracy and completeness of the information presented herein are dependent upon the accuracy and completeness of the references cited. Except for salt caverns, the science and engineering aspects of UHS have not advanced to the commercial deployment stage. This assessment is therefore intended as a screening tool and any prospective UHS prospects will require further assessment in future Angeles Link phases.

B.2.3 Underground Hydrogen Storage in Geologic Formations: The State of the Practice

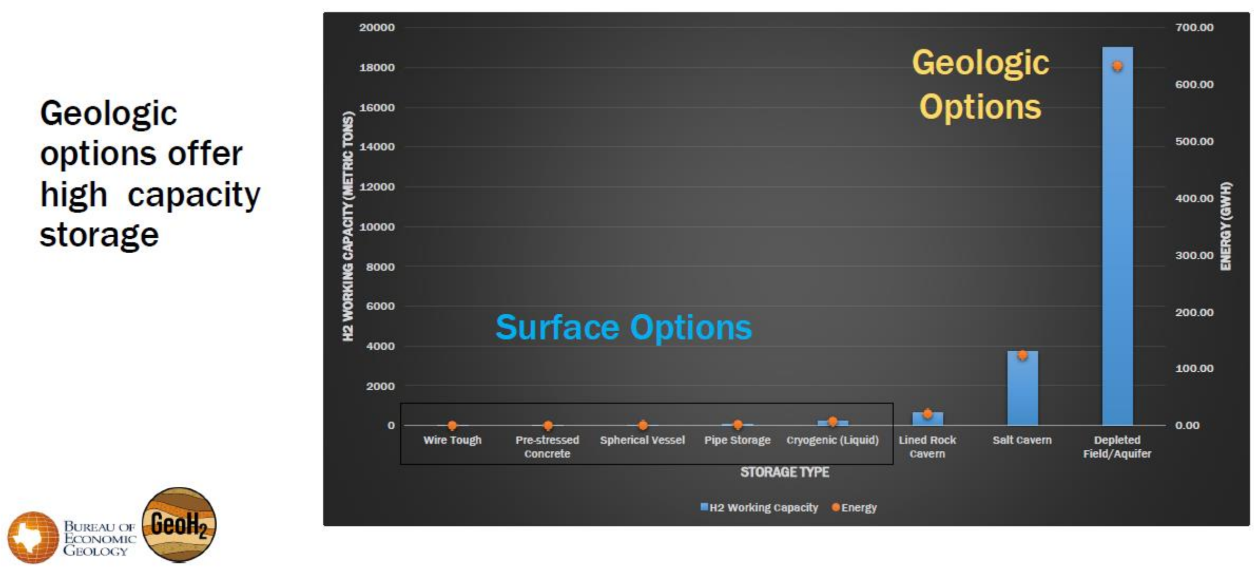
Potential UHS options include the following:

- Solution-mined salt caverns in geologic salt basins
- Porous rock formations including depleted oil and gas reservoirs and saline aquifers
- Mechanically excavated void space
    - i. Constructed specifically for gas storage purposes
    - ii. Mine shafts and chambers created during extraction of other ores

Refer to Appendix C.1 for a map of all potential storage locations in the AOI considered in this evaluation.

The geologic storage options each have their own advantages and challenges. UHS options offer greater storage capacity compared to surficial storage in spheres or pipelines (see Figure 13.12), and levelized costs of storage presented in literature suggest that depleted reservoirs in oil and gas fields offer the most economical options.[54]

Figure 13.12 Indicative H2 Storage Options by Unit Capacity



[54] Lord, A.S., Kobos, P.H. and Borns, D.J., 2014. Geologic storage of hydrogen: Scaling up to meet city transportation demands. International journal of hydrogen energy, 39(28), pp.15570-15582.

Chen, F., Ma, Z., Nasrabadi, H., Chen, B., Mehana, M.Z.S. and Van Wijk, J., 2023. Capacity assessment and cost analysis of geologic storage of hydrogen: A case study in Intermountain-West Region USA. International Journal of Hydrogen Energy, 48(24), pp.9008 9022.

B.2.3.1 Salt Caverns

Hydrogen has been safely and effectively stored in underground geologic salt formations in solution mined caverns for many decades. Caverns are constructed by drilling a well into a geologic body of salt and injecting water into the well to dissolve the salt. The solution brine is circulated out of the well leaving a void space in the salt that can be used for storage of gases or liquids. The salt cavern undergoes mechanical integrity testing to make sure potential leakage from the storage facility meets permit standards. The size, shape, and working pressure of the salt cavern depend on the salt body composition, shape, and burial depth below ground surface.

Solution mining techniques used to construct salt caverns for petroleum storage are technologically mature and there is a high degree of confidence that storage facilities can be constructed and operated safely for many decades in suitable geologic environments. In addition to proven viability through commercial operations for four decades, salt caverns offer certain advantages including: 1) increased certainty of feasibility of construction, permitting, and operation,2) increased ability to accurately estimate cost to construct, 3) increased ability to design the size of salt cavern or caverns to optimize storage efficiency, 4) limited potential for hydrogen loss by degradation or leakage, and 5) limited potential for contamination by other fluids in the subsurface.

While salt caverns, at present, represent the most commercially tested method of UHS, the basins where salt caverns may be constructed via solution mining techniques are geographically limited and are not present in California (refer to map of UHS options in Appendix C.1). Instead, they are geographically isolated within the AOI to Nevada, Utah, and Arizona and pipeline infrastructure would be required to access them.

The size of any single salt cavern is limited by geotechnical considerations and multiple caverns may be required to satisfy storage needs due to the low density of hydrogen. Key geologic aspects of salt basins that impact the feasibility of salt cavern construction in a particular salt basin include depth, form (domal vs. bedded), rock composition and presence of impurities in the salt basin.

B.2.3.2 Proposed Salt Cavern Storage Projects Inside and Outside the AOI

There is a site under construction in Utah, and a proposed storage project in Arizona. Brief descriptions of each project are provided below.

ACES Delta Hydrogen Hub (Delta, UT)

The feasibility of solution mining storage caverns in the AOI has been demonstrated near Delta, UT for fuels storage (Sawtooth Storage, LLC). The ACES Delta hub has drilled wells and is permitted to develop salt cavern storage facilities for hydrogen. Two salt caverns will be capable of storing up to 5,500 tonnes of working capacity. The hub will initially run on a blend of 30% green hydrogen and 70% natural gas starting in 2025 and will incrementally expand to 100% green hydrogen in 2045. Chevron New Energies Inc. acquired a majority stake in the project in 2023. Press releases indicate that test wells were drilled, and solution mining of salt caverns is imminent or underway as of December 2023.

Mohave Green Energy Hub (Mohave County, AZ)

Mohave Green Energy Hub, LLC has stated intent to develop a salt cavern hydrogen storage facility via solution-mining in the Red Lake Salt Basin in Mohave County in Western Arizona (Mohave Green Energy Hub, LLC), though this project is less advanced than the Delta Utah ACES project.

B.2.3.2.1 Depleted reservoirs in oil and gas fields

Oil and gas fields and their associated depleted reservoirs are targets for UHS for many reasons, including widespread distribution, large potential storage capacities, presumed low cost compared to above-ground storage, and safety from natural disaster or sabotage compared to above-ground containers due to distance from ground surface affected by flood, extreme weather, or attack by foreign or domestic terrorists. Furthermore, the geologic structures represented by oil and gas fields have provided containment of buoyant fluids (oil and/or gas and/or natural gas liquids) and prevented or limited upward migration of the fluids to the ground surface over timespans of millions of years. This supports their potential to contain natural gas and other gases, including hydrogen, under a wide variety of pressures. The technical aspects of storage and recovery of hydrogen in depleted reservoirs have been investigated by applying geologic principles, reservoir simulations, and early-stage pilot projects. There is broad consensus within the scientific and engineering community that UHS in porous rocks (and specifically in depleted reservoirs) is technically feasible,[55] but there is ongoing research into the geologic site selection criteria and engineering design guidance.

[55] Foh, S., Novil, M., Rockar, E., and Randolph, P., 1979. Underground hydrogen storage. final report. [salt caverns, excavated caverns, aquifers, and depleted fields] (No. BNL-51275). Brookhaven National Lab., Upton, NY (USA).
Amid, A., Mignard, D. and Wilkinson, M., 2016. Seasonal storage of hydrogen in a depleted natural gas reservoir. International Journal of Hydrogen Energy, 41, 5549–5558, https://doi.org/10.1016/j.ijhydene.2016.02.036.

Another advantage of depleted reservoirs in oil and gas fields is that because they held economically attractive accumulations, extensive effort and cost has been expended to understand the fluid flow characteristics of the depleted reservoirs and individual fields in general throughout the AOI. This includes aspects of field depths, pressures, and dimensions, as well as fluid flow characteristics such as porosity, permeability, and potential production rates due to extensive development and data collection activities during operation and production. Intragranular porosity, or simply "porosity," refers to the void spaces between individual grains of sand, silt, or gravel which host subsurface fluids such as groundwater, oil, or gas. These data reduce uncertainties regarding important material parameters for UHS in the fields such as gas flow rates and volumes. Many fields have existing well and pipeline infrastructure which may be acceptable for hydrogen injection and withdrawal and/or monitoring purposes in reducing CAPEX for storage facility development (subject to engineering evaluation in future Angeles Link phases). However, due to the unique properties of hydrogen gas, there remain uncertainties with respect to the movement and recoverability of hydrogen injected for storage in depleted reservoirs, primarily relating to loss of hydrogen via biological and geochemical activity, and leakage through sealing rocks and improperly sealed wellbores. Additionally, interaction of hydrogen with existing field infrastructure originally implemented for oil and gas storage and extraction may cause adverse effects such as embrittlement of casing and tubing, which has the potential to lead to well integrity issues and potential leak pathways.[56]

There are currently no permitted examples of UHS in depleted reservoirs, and engineering and geological requirements for UHS are currently not defined. The lack of a regulatory framework may result in delays and challenges to implementation.

For a depleted field to perform adequately as a UHS facility, it must be capable of storing the necessary quantity of hydrogen to release during periods when demand outpaces supply. Pressure in a depleted field can be restored to a desired pressure over time through injection of gases. Depending on the volume of the depleted reservoir, and the reservoir pressure desired for operations, pressure can be restored in the reservoir with a "cushion gas" such as nitrogen or natural gas (i.e., the pressure

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Heinemann, N., Alcalde, J., Miocic, J.M., Hangx, S.J., Kallmeyer, J., Ostertag-Henning, C., Hassanpouryouzband, A., Thaysen, E.M., Strobel, G.J., Schmidt-Hattenberger, C. and Edlmann, K., 2021. Enabling large-scale hydrogen storage in porous media–the scientific challenges. Energy & Environmental Science, 14(2), pp.853-864.

[56] (n.d.). Subsurface Hydrogen Assessment, Storage, and Technology Acceleration (SHASTA) program website, DoE, accessed 11/17/2023, https://edx.netl.doe.gov/shasta/well-integrity-issues-for-hydrogen-storage/.

need not be built with pure hydrogen).[57] Cushion gas can constitute a major CAPEX cost, especially for highly depleted, larger fields.[58] Residual natural gas in depleted reservoirs in oil and gas fields will serve as a cushion gas already in place, which could significantly reduce CAPEX.[59]

There is extensive research on UHS underway in academic, industry, and government organizations. Areas of investigation include reservoir simulation studies of hydrogen gas behavior during storage,[60] containment mechanisms and security, economic analysis, and cost estimation.[61] In addition, multiple universities maintain consortia focused on UHS and other aspects of hydrogen as an emerging energy source. Notable consortia and their areas of focus include but are not limited to:

Project SHASTA (Subsurface Hydrogen Assessment, Storage, and Technology Acceleration, DOE National Laboratories

- Laboratory, field, and simulation studies of pure hydrogen and hydrogen blended with natural gas underground storage.

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[57] Kanaani, M., Sedaee, B., & Asadian-Pakfar, M, 2022. Role of Cushion Gas on Underground Hydrogen Storage in Depleted Oil Reservoirs. Journal of Energy Storage (ISSN 2352-152X), 103783.

[58] Chen, F., Ma, Z., Nasrabadi, H., Chen, B., Mehana, M.Z.S. and Van Wijk, J., 2023. Capacity assessment and cost analysis of geologic storage of hydrogen: A case study in Intermountain-West Region USA. International Journal of Hydrogen Energy, 48(24), pp.9008 9022.
Heinemann, N., Alcalde, J., Miocic, J.M., Hangx, S.J., Kallmeyer, J., Ostertag-Henning, C., Hassanpouryouzband, A., Thaysen, E.M., Strobel, G.J., Schmidt-Hattenberger, C. and Edlmann, K., 2021. Enabling large-scale hydrogen storage in porous media–the scientific challenges. Energy & Environmental Science, 14(2), pp.853-864.

[59] Chen, F., Ma, Z., Nasrabadi, H., Chen, B., Mehana, M.Z.S. and Van Wijk, J., 2023. Capacity assessment and cost analysis of geologic storage of hydrogen: A case study in Intermountain-West Region USA. International Journal of Hydrogen Energy, 48(24), pp.9008 9022.

[60] Lysyy, M., Ferno, M., & Ersland, G., 2021. Seasonal hydrogen storage in a depleted oil and gas field. International Journal of Hydrogen Energy, 25160-25174.

[61] Khadka Mishra, S., Ganguli, S., Freeman, G., Moncheur de Rieudotte, M., & Huerta, N, 2023. Local-Scale Framework for Techno-Economic Analysis of Subsurface Hydrogen Storage, SAND2023-1724049/PNNL-35058;. Richland, WA: U.S. Department of Energy, Sandia National Laboratories and Pacific Northwest National Laboratory.

- Topics include material compatibility with hydrogen, rock-gas interactions, flow characterization and dynamics, microbial interactions, and interactions with geologic materials, among others.

$GeoH_2$ program, Bureau of Economic Geology, University of Texas, Austin:

- Geological storage of gaseous hydrogen
- Techno-economic and value-chain analysis
- Novel concepts including in situ generation and natural hydrogen

Stanford Hydrogen Initiative, Stanford University

- Hydrogen storage feasibility in a variety of underground systems
- Hydrogen gas behavior during storage
- Hydrogen loss through biogeochemical reactions
- Risks of loss of containment from storage reservoirs, through caprock, faults, fractures, or leaky wells
- Development of real-time monitoring technologies to assure storage integrity and safety
- Levels of support from key stakeholders and the public
- Expected regulatory environment

In addition, the CEC recently issued a solicitation to fund a project that will evaluate the feasibility of using existing underground gas storage facilities to store clean renewable hydrogen in California.[62]

B.2.3.2.2 Saline Aquifers

Saline aquifers share many characteristics of depleted reservoirs in oil and gas fields in that they potentially have tremendous pore space volume representing potential hydrogen storage space. Hydrogen-rich manufactured gas (also sometimes referred to as "town gas") has been stored in relatively shallow saline aquifers and recovered for many decades in relatively small quantities.[63] However, as is the case with oil and gas

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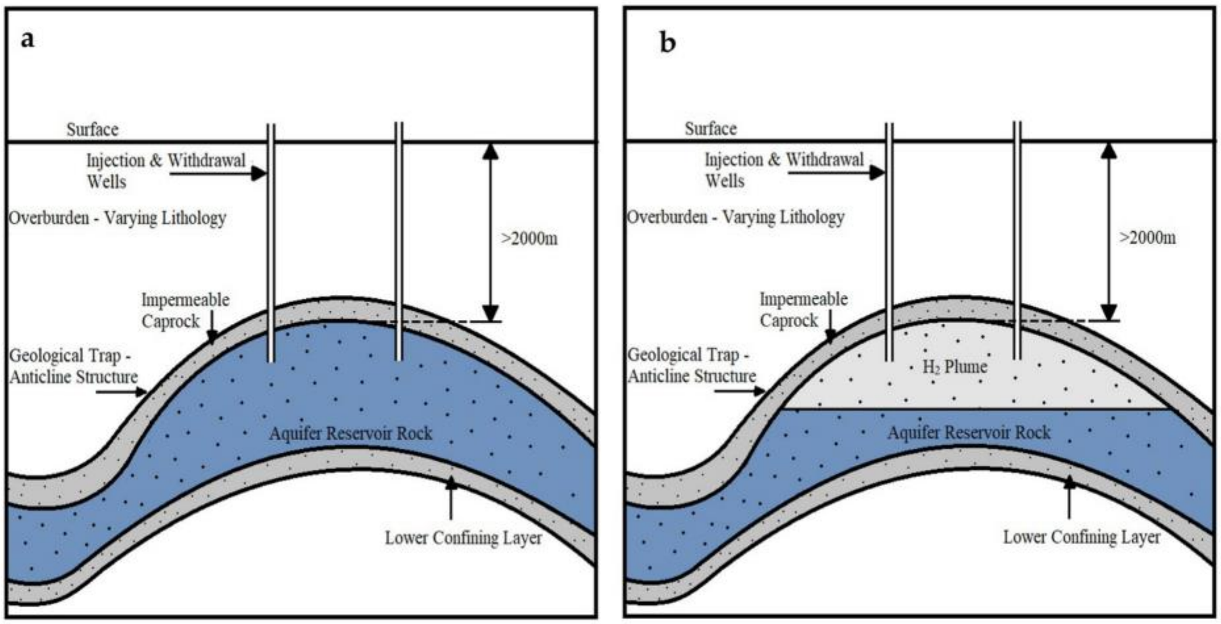
[62] https://www.energy.ca.gov/solicitations/2024-04/gfo-23-503-feasibility-underground-hydrogen-storage-california.

[63] Heinemann, N., Wilkinson, M., Adie, K., Edlmann, K., Thaysen, EM., Hassanpouryouzband, A., Haszeldine, RS., Cushion Gas in Hydrogen Storage—A Costly CAPEX or a Valuable Resource for Energy Crises? Hydrogen, 2022; 3(4):550-563. https://doi.org/10.3390/hydrogen3040035.

fields, a structural trap is required to limit vertical and lateral migration of hydrogen and enable recovery of hydrogen from storage (Figure 13.13).

Figure 13.13 Schematic saline aquifer conversion to hydrogen storage (Wallace et al., 2021)



Subsurface exploration in sedimentary basins worldwide has historically been focused on exploring for and characterizing oil and gas accumulations instead of deep saline aquifers, and as a result, little data exist with which to site UHS facilities in saline aquifers. Thus, identifying structural containers (traps) in which to inject and store hydrogen would entail extensive and time-consuming exploration work including surface and subsurface data collection.[64] Due to insufficient or incomplete data regarding potential trapping configurations in deep saline aquifers in the AOI, no screening of saline aquifers could be performed as part of this phase.

B.2.3.2.3 Loss Mechanisms of Hydrogen in the Subsurface

Hydrogen is reactive and mobile in the subsurface. When injected into depleted reservoirs or saline aquifers, it is stored in the pore space and can migrate along pressure gradients as a gas, mix with residual gases present within the reservoir and dissolve within formation fluids. The main mechanisms for hydrogen loss include

[64] Zoback, Mark & Smit, Dirk., 2023. Meeting the challenges of large-scale carbon storage and hydrogen production. Proceedings of the National Academy of Sciences of the United States of America. 120. e2202397120. 10.1073/pnas.2202397120.

biodegradation, dilution, migration, dissolution, and chemical transformation (reaction). The likelihood and rate of loss will depend on site characteristics and there is active research in both the processes (e.g., microbial metabolic rates under investigation by Project SHASTA and GeoH2) and the physical properties of hydrogen at reservoir conditions (e.g., relative permeability and interfacial tension angles for hydrogen that determine seal capacity and reservoir flow).

Figure 13.14 Diagrammatic illustration of storage in depleted reservoirs or saline aquifers with associated potential loss mechanisms

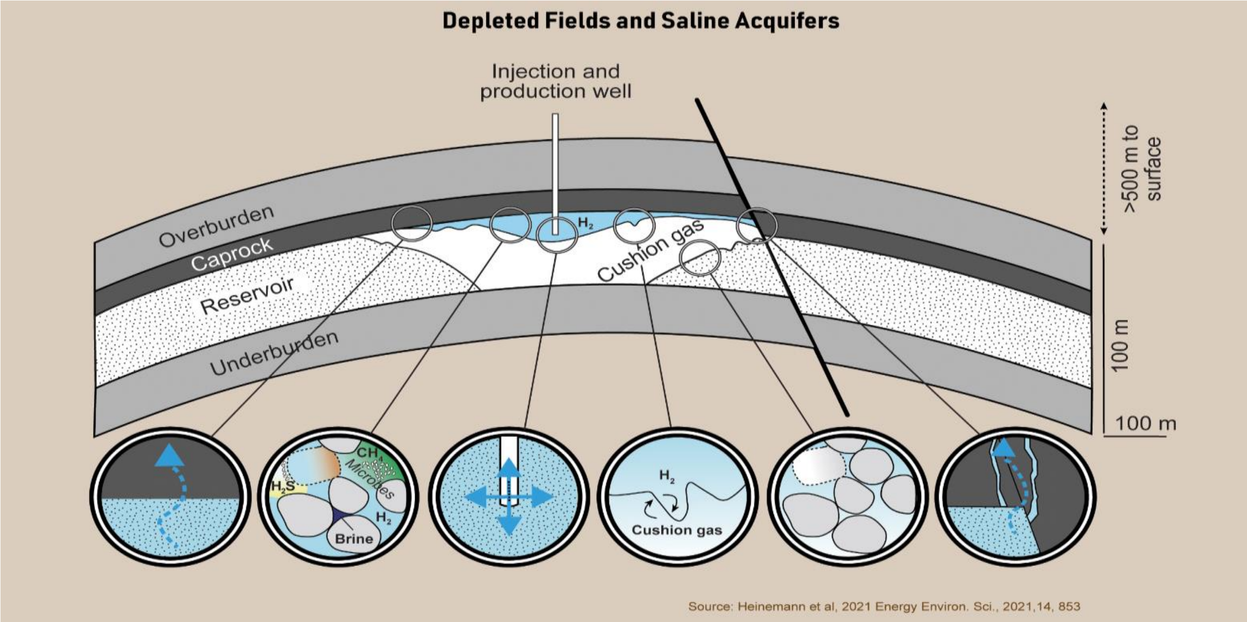


Figure 13.14 shows from left to right, leakage through diffusion into sealing rock (caprock), microbial degradation, injection withdrawal cycles, fingering in cushion gas, geochemical reaction, and leakage through fault planes.[65]

B.2.3.3 Abandoned Mines and Constructed Voids

Due to the abundance of existing abandoned underground mines worldwide, the potential to repurpose the void space for hydrogen storage is being considered.[66]

[65] Heinemann, N., Alcalde, J., Miocic, J.M., Hangx, S.J., Kallmeyer, J., Ostertag-Henning, C., Hassanpouryouzband, A., Thaysen, E.M., Strobel, G.J., Schmidt-Hattenberger, C. and Edlmann, K., 2021. Enabling large-scale hydrogen storage in porous media–the scientific challenges. Energy & Environmental Science, 14(2), pp.853-864.

[66] Lemieux, A., Shkarupin, A. and Sharp, K., 2020. Geologic feasibility of underground hydrogen storage in Canada. International Journal of Hydrogen Energy, 45(56), pp. 32243-32259.

Hydrogen gas could potentially be sealed in the mines with hydrostatic pressures from groundwater or water curtains, or through engineered linings.[67] However, the principal obstacle to development is rock tightness to hydrogen under pressure. It would need to be determined that the host rock (rock surrounding the void space) and shafts or openings to the surface are sufficiently impermeable, capable of holding desired pressures, and withstand cyclic pressure variations without sacrificing the structural integrity of the mine. Alternatively, the mine and shafts could theoretically be sealed with impermeable liners. Abandoned mines have been repurposed for natural gas storage in Sweden and Czechia,[68] but this is not a common practice.

Research into repurposing of abandoned coal mines is active,[69] presumably due to their large size and abundance across the globe. However, it is expected that liners for sealing void space in porous sedimentary rocks would be needed and the technology is not commercially demonstrated.

In addition to retrofitting abandoned underground mines to UHS facilities, there also exists the potential to excavate new shafts and/or caverns in any rock type as storage containers (silos) which could theoretically be operated in a manner similar to operation of a solution-mined salt cavern.[70] The advantage of such built structures is that they can theoretically be constructed in any location, regardless of the geologic conditions. However, excavation could be time-consuming, require large CAPEX, and generate significant greenhouse gas emissions resulting from heavy machinery operation. Deployment of liners may also be expensive and have a significant carbon footprint resulting from extraction of raw materials and manufacturing processes. No existing examples of built hard-rock UHS facilities were identified during this review.

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[67] Lemieux, A., Shkarupin, A. and Sharp, K., 2020. Geologic feasibility of underground hydrogen storage in Canada. International Journal of Hydrogen Energy, 45(56), pp. 32243-32259.

[68] HyUnder. Overview on all known underground storage technologies for hydrogen. https://hyunder.eu/wp-content/uploads/2016/01/D3.1_Overview-of-all-known-underground-storage-technologies.pdf (Accessed 11/8/2023).

[69] Liu, W. and Pei, P., 2021. Evaluation of the Influencing Factors of Using Underground Space of Abandoned Coal Mines to Store Hydrogen Based on the Improved ANP Method. Advances in Materials Science and Engineering, 2021, pp. 1-9.

[70] Lemieux, A., Shkarupin, A. and Sharp, K., 2020. Geologic feasibility of underground hydrogen storage in Canada. International Journal of Hydrogen Energy, 45(56), pp. 32243-32259.

B.2.4 Assessment of Potential Underground Hydrogen Storage Prospects within the Area of Interest

Available subsurface storage options are geologically different, and each has unique geologic characteristics as described in previous sections. The chosen assessment approach is to evaluate geological chance of success and commercial viability separately for each type of storage evaluated. Both geologic and commercial factors are critical for a final design choice and by separating them we can define site storage site options with more clearly documented technical selection criteria. Angeles Link Phase 1 includes a high-level study of these technologies and locations from a geologic feasibility standpoint to inform routing, sizing, and safety considerations. The geologic suitability assessment criteria developed is modeled on a play and prospect evaluation for oil and gas deposits. Each underground storage site was evaluated by these criteria. There are four areas of review: depth, structure, roof or seal stability, and rock composition. Within these four overall categories, there are different geologic elements that can be identified based on the type of storage being assessed. These geologic criteria were evaluated individually to develop a holistic assessment for the site.

Process:

1. Identify the main categories for each underground storage technology.
2. Identify the geologic suitability for each.
3. Identify for each: 1 = High Confidence of Adequacy, 0.5 = High Uncertainty of Adequacy, 0 = High Confidence of Inadequacy.
4. Multiply the confidence level identified for each criterion to generate a composite value.

Each element was assigned a confidence level from 0 to 1: zero (0) would indicate a high confidence of inadequacy, while one (1) would indicate a high level of confidence of adequacy for that element. A value of 0.5 indicates uncertainty; in which either there is little data available to evaluate the element, or the data available do not clearly point to adequate or inadequate confidence. The geologic elements are multiplied together to arrive at a composite relative “chance of success” confidence level. If any single value is 0, the storage candidate would then yield a composite value of “0”, reflecting that it is considered geologically unsuitable and should generally be removed from consideration.

As a basis for developing the evaluation criteria, there was no minimum volume threshold assigned to either salt formations or depleted oil and gas fields. The goal was to identify underground storage site candidates that can potentially, either individually or in aggregate, support regional hydrogen producers and end users.

This method is intended to provide a consistent but flexible evaluation that is self-documenting. The evaluation for each site reflects the information available at the time of evaluation, inclusion of additional data or more detailed analysis may change the evaluation. For the Phase 1 assessment, the goal was to identify sites with inadequacies that preclude development and can be removed from future study. Sites considered may change over the life of the project as results are received from related studies of storage volume requirements, pipeline design, pipeline routing, and environmental permitting. The sections below briefly describe the risk elements considered for each geologic setting and the suitability evaluation criteria are included as Appendix B.

B.2.4.1 Salt Caverns

There are six known salt basins within the AOI that were considered, and solution mining of caverns may be feasible in all six of the salt basins, all of which are located outside of California. The rock salt provinces present in the AOI include the Virgin Valley Salt Basin (NV and AZ), the Red Lake Basin (AZ), the Luke Basin (AZ), the Supai Basin (AZ), the Sevier Valley Basin and Paradox Basin (UT). Of these salt basins, the Sevier Valley Basin and Paradox Basin are known to contain salt that has flowed from the original depositional geometry due to buoyancy forming salt diapirs and domes. The Luke and Red Lake basins salt formations have evidence of salt deformation but there are no reported diapirs or domes.

B.2.4.1.2 Development of Evaluation Criteria

The evaluation criteria developed for underground hydrogen storage in salt caverns is provided in Appendix B.

The evaluation approach in this case differs from depleted oil and gas fields or abandoned underground mines in that there are published best practice guidelines for gas storage salt cavern construction and operation (SMRI Research Report RR2012-03, API Recommended Practice 1114).

Depth - Depth of the salt cavern exerts the primary control on pressure. At greater depths, higher geo-pressures allow hydrogen to be stored at a higher pressure, thus increasing the amount that can be stored.

Form - Storage in salt caverns has to date been mostly in domal salts. Domal salts can have tall, wide caverns that allow for large hydrogen storage volumes. Contrastingly, bedded salts tend to be thinner and interbedded, constraining storage volume and potentially introducing leak pathways, respectively.

Roof Stability – Roof stability depends on the thickness and aerial extent of salt caverns. There must be enough thickness to allow for a tall enough salt cap, and enough width to allow for safe web (wall) thickness between caverns. These dimensions are often determined by regulatory bodies to maintain safe storage operations.

Rock Composition – Rock composition influences geomechanical and geochemical stability. Halite-dominated "clean" salts are favorable over gypsum-anhydrite dominated "dirty" salts.

B.2.4.1.3 Application of Evaluation Criteria and Results

The evaluation criteria developed to assess salt caverns is presented in Appendix B. The criteria were applied to all salt basins within the AOI, and the results are presented in Appendix C.3, Table of Evaluated Salt Provinces. The geologic requirements for salt cavern construction could apply at both the level of an entire salt basin and for areas within a single salt basin. For the initial phase of evaluation, the evaluation was conducted for the entire basin, indicating if for each basin there are locations that meet the identified criteria. Data for evaluation was drawn from published maps and geologic descriptions. A summary of the geology of each salt basin and the references used for evaluation are presented as Appendix C.3.

B.2.4.1.4 Storage Capacity

Hydrogen storage capacity in salt caverns is determined by the number of constructed caverns, cavern size (diameter and height), and operating pressure. In the absence of engineering design for construction and operations, analogous salt caverns – both operating and planned – are useful guides for hydrogen storage capacity to support Angeles Link.

According to recent press releases, ACES Delta in Delta, Utah plans to construct two salt caverns, each capable of storing 5,500 tonnes of working capacity (11,000 tonnes total). Once constructed, ACES Delta would be the highest capacity underground hydrogen storage operation in the United States. The highest-capacity operational hydrogen storage operation is Spindletop (Beaumont, TX), which can store up to 8,230 tonnes. Clemens Dome is the smallest-capacity storage operation with a capacity of 2,400 tonnes.

Storage capacity in salt caverns to support California's hydrogen hub can be approximated at 2,000 – 10,000+ tonnes based on currently operating and proposed projects. Individual cavern storage capacity is a function of cavern design and operating pressures but can be scaled-up or scaled-down depending on demand and production requirements. The most significant lever affecting storage capacity is likely to be the number of constructed caverns.

B.2.4.2 Abandoned Mines

Due to the widespread nature of ore-bearing geologic formations across Nevada, Utah, Arizona, and California, many thousands of abandoned underground mines exist, and these have the theoretical potential to be repurposed as UHS facilities due the fact that they represent void space underground. Refer to Appendix A of the Pipeline Sizing and Design Criteria study. The inventory of underground abandoned mines in the AOI assembled during this study suggests that over 6,600 abandoned structures are present within the AOI. While these structures represent potential storage locations, little to no data beyond location is identified with which to screen the structures for viability, such as depth, size, or host rock. For this reason, no ranking could be performed on the abandoned mines, and no reliable capex or opex estimates could be generated. If hydrogen storage were desired in a particular location, the mine could theoretically be mapped in three dimensions, potentially via unmanned drone survey, and the size and potential for developing a hydrogen storage structure by sealing or lining the void space and surface entry points could be evaluated. A potential evaluation for abandoned underground mines was developed to demonstrate important characteristics of such structures during this work and is presented in Appendix B.

B.2.4.2.1 Development of Evaluation Criteria

The criteria for geologic success of hydrogen storage in abandoned underground mines follows. These criteria are grounded in geologic principles but are based primarily on conceptual research rather than field-tested examples, as the technology is still in its infancy.

Surrounding Rock Fracture/Fault Development - Fractures and faults in surrounding rock represent potential leak pathways for hydrogen. Additionally, they impact rock mass stability and thus the overall competence of the storage facility.

Depth - The depth of abandoned underground mines impacts rock stability, nearness of hydrogen to the surface, and maximum allowable gas storage pressure. Deeper mines are more favorable for stable hydrogen storage conditions.

Mine Shaft Dip Angle - The dip of the mine shafts affects subsurface stress interactions; a larger dip angle means the overburden stress distribution is more complex. A higher dip angle increases the buoyancy pressure hydrogen would exert on the mine walls, and dipping beds introduce a potential migration pathway from the storage site.

Water Table Stability - The water table exerts hydrostatic pressure on underground mines and its fluctuation can lead to instability of the roof and walls. A stable or well-constrained groundwater table helps manage pressure and maintain stability when storing hydrogen.

Loss Potential - Geochemical reactions between hydrogen and rock or gas constituents in abandoned mines can lead to hydrogen losses. These reactions may include pyrite dissolution, microbial consumption, and abiotic sulfate reduction.

Seal and Trap - In the case of hydrogen permeating through surrounding rock, the mine needs to be overlain by an impermeable seal rock and have a structural trap configuration that contains the hydrogen. For cavities in hard rock the seal is provided by a liner.

B.2.4.3 Oil and Gas Reservoirs

Depleted reservoirs in oil and gas fields are abundant in California and offer large potential natural storage capacity for hydrogen in intragranular pore space (e.g., Okoroafor, et. al., 2022). These structures have held accumulations of hydrocarbons under significant pressure for millions of years, suggesting that they may likely be capable of containing other gases such as hydrogen and carbon dioxide over the time scales necessary for UHS. In general, there is broad consensus within the scientific and engineering community that hydrogen storage in porous rocks is technically feasible;[71] however, no large-scale hydrogen storage projects in depleted reservoirs in oil and gas fields have been operated, and thus an uncertainty for operations remains.

While it does not appear that there are any projects where pure hydrogen has been injected, stored, and recovered from depleted hydrocarbon reservoirs, a significant number of studies have been conducted to assess the potential for hydrogen storage in existing underground natural gas storage facilities in the United States.[72] These studies have concluded that blended hydrogen and natural gas storage in depleted reservoirs is

[71] Foh, S., Novil, M., Rockar, E., and Randolph, P., 1979. Underground hydrogen storage. final report. [salt caverns, excavated caverns, aquifers, and depleted fields] (No. BNL-51275). Brookhaven National Lab., Upton, NY (USA). Amid, A., Mignard, D. and Wilkinson, M., 2016. Seasonal storage of hydrogen in a depleted natural gas reservoir. International Journal of Hydrogen Energy, 41, 5549–5558, https://doi.org/10.1016/j.ijhydene.2016.02.036.
Heinemann, N., Alcalde, J., Miocic, J.M., Hangx, S.J., Kallmeyer, J., Ostertag-Henning, C., Hassanpouryouzband, A., Thaysen, E.M., Strobel, G.J., Schmidt-Hattenberger, C. and Edlmann, K., 2021. Enabling large-scale hydrogen storage in porous media–the scientific challenges. Energy & Environmental Science, 14(2), pp.853-864.

[72] Lackey, G., Freeman, G. M., Buscheck, T. A., Haeri, F., White, J. A., Huerta, N., & Goodman, A., 2023. Characterizing hydrogen storage potential in U.S. underground gas storage facilities. Geophysical Research Letters, 50, e2022GL101420. https://doi.org/10.1029/2022GL101420.

feasible and has the potential to foster the transition to a hydrogen-based energy system.

B.2.4.3.1 Development of Evaluation Criteria

The approach taken during the development of the evaluation criteria for depleted reservoirs in oil and gas fields is adapted from petroleum exploration concepts. These concepts consider the critical geologic elements that must all be present for an oil and gas accumulation to be present in the subsurface. The elements include seal, trap, and reservoir. Additionally, the potential for significant loss due to microbial consumption is considered. The evaluation criteria developed for underground hydrogen storage in oil and gas reservoirs is provided in Appendix B.

Seal: Natural accumulations of oil and gas trapped in place by bedrock seals, fine grained rock units with low porosity and permeability and a high capillary entry pressure. Seal quality is determined by the formation rock type, properties, and continuity over the area of interest. Evidence of seal adequacy can either be direct measurements of rock properties or demonstrated accumulations of hydrocarbon in the subsurface.

Trap: An underground storage facility needs a well understood trap of sufficient size to meet storage needs. Compartmentalization of a trap by faults or stratigraphic features increases complexity and may limit storage size and may restrict hydrogen injection and withdrawal rates.

Reservoir: The porosity and permeability of the storage formation (reservoir) will determine the potential maximum injection and withdrawal rates and volume for a storage facility. The reservoir performance of a potential storage site is determined by reservoir porosity and permeability, the size of the reservoir, and formation pore pressure.

Biological and Geochemical Consumption: A potentially significant portion of hydrogen injected into subsurface oil and gas reservoirs could be lost to biological consumption and chemical reactions. Hydrogen is consumed by multiple metabolic pathways active in oil and gas fields. Microbial activity in hydrocarbon reservoirs is a function of temperature with the highest consumption rates occurring at 40-60 °C decreasing with higher temperatures and little or no evidence of biodegradation of oil above 90 °C.[73] Injected hydrogen could react with pore fluids including hydrocarbon and carbon dioxide and minerals, consuming hydrogen.

This method intends to provide a consistent but flexible baseline evaluation solely of the sites' geologic feasibility. Sites considered may change over the development of the

[73] Head, I. M., Jones, D. M. and Larter, S.R., 2003. Biological activity in the deep subsurface and the origin of heavy oil. Nature, 426(6964), pp. 344-352.

California hydrogen hub. The geologic evaluation criteria are provided in Appendix B, and the fields are color coded in stop-light fashion in the attached maps.

B.2.4.3.2 Application of Evaluation Criteria and Results

The evaluation criteria were applied to all California oil and gas fields in or adjacent to the SoCal Gas Service Territory. Project geologists applied the evaluation framework in Appendix B to 297 oil and gas fields in California. The evaluation was based solely on geologic information provided by California Oil and Gas fields (Volume 1 and Volume 2; TR10-12). Importantly, most oil and gas fields have multiple reservoirs. The evaluation framework was applied only to the most prospective oil and gas reservoir within a field.

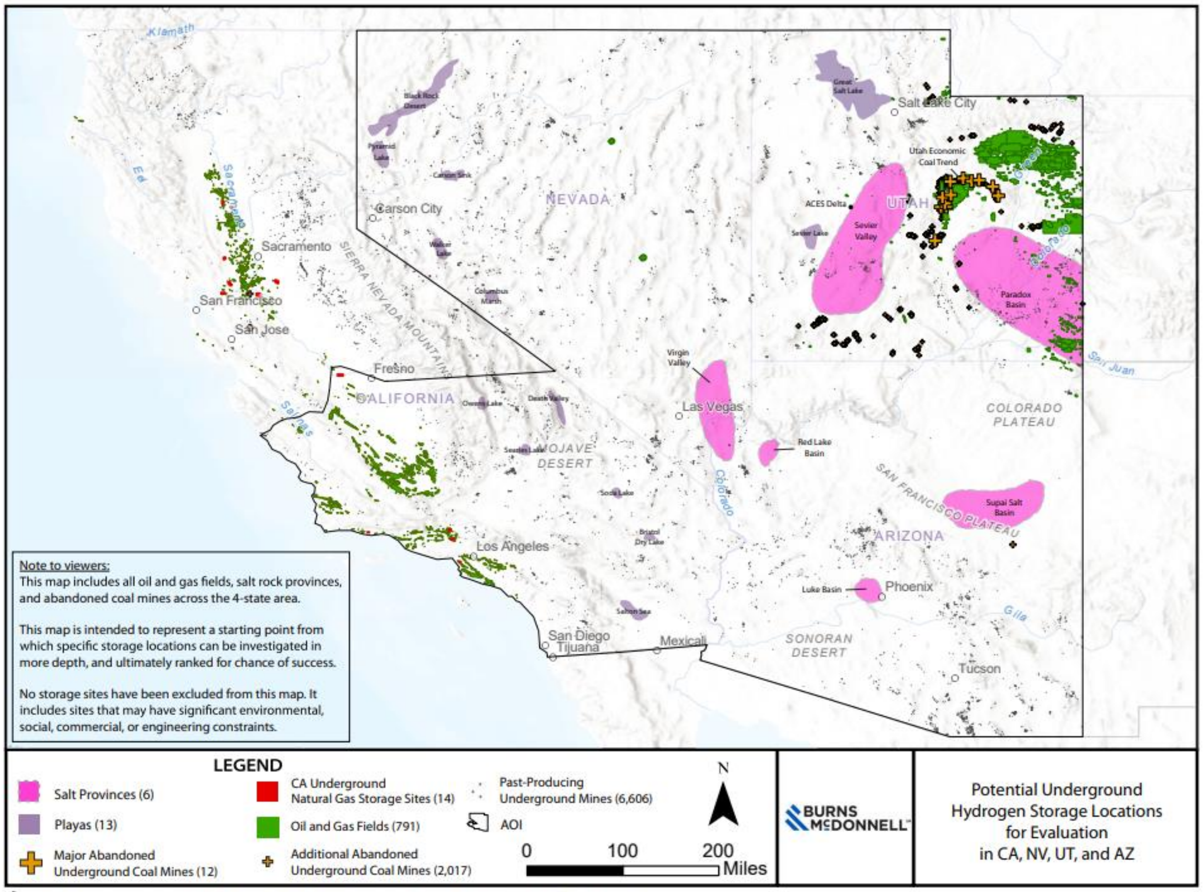
Appendix C.2 presents a series of stop-light maps illustrating the results of the evaluation of oil and gas fields for geologic confidence of adequacy for conversion to hydrogen storage facilities. Two maps are presented for each sub-basin in the SoCalGas service area, one showing only the geologic confidence of adequacy composite value ranges, and a second map showing the geologic confidence of adequacy ranges with population density and quaternary faults. While no regulatory framework exists, population density and proximity to quaternary faults may impact permitting potential UHS sites in Southern California. If this is the case, high composite value fields in the Southern San Joaquin and Salinas Basins (Appendix C.2) may prove to be more straightforward to permit and bring online with fewer regulatory delays.

B.2.4.3.3 Storage Capacity

Petroleum from sedimentary basins in California has been in use by humans for about 13,000 years, with initial collection and use by Indigenous communities. Drilling for subsurface petroleum accumulations began in 1878 and continues to the present day (Takahashi & Gautier, 2007) with over 15 billion barrels of oil equivalent production to date from the San Joaquin basin alone. The SHASTA project has estimated the storage potential of a selection of ten large gas fields in Northern California. The fields capacities were estimated to be from 0.4 million tonnes for the smallest field assessed to 147 million tonnes for the largest field ((Okoroafor, et al., 2022).

13.3 Appendix C

C.1 Map of Potential Underground Hydrogen Storage Locations in the AOI



Source: Salt Provinces: Johnson and Gonzales, 1987, Salt Deposits in the United States and Regional Geologic Characteristics Important for Storage of Radioactive Waste
Abandoned Underground Coal Mines: Krahulec and Rupke, 2016, Utah's Extractive Resource Industries 2015
CA Underground Natural Gas Storage Sites: California Department of Conservation
Oil and Gas Fields: California - California Department of Conservation; Utah - Utah Department of Natural Resources, Oil, Gas, and Mining Division; Nevada - University of Nevada Reno (hand-drawn based on producing wells)
Past-Producing Underground Mines: U.S. Geological Survey Mineral Resources Data System (MRDS)
Playas: Pierce and Rich, 1958, Summary of Rock Salt Deposits in The United States as Possible Disposal Sites for Radioactive Waste

C.2 Evaluation Framework for Depleted Oil and Gas Reservoirs, Salt Caverns, and Abandoned Underground Mines

Evaluation Framework

Depleted Oil and Gas Reservoirs

Geologic Elements Required for Depleted Oil and Gas Reservoirs to be Repurposed for Underground Hydrogen Storage	High Confidence of Adequacy	High Uncertainty of Adequacy	High Confidence of Inadequacy	Value
Seal (Leak Prevention at Top and Sides) Lines of Evidence	**1**	**0.5**	0	
Hydrocarbon Accumulation Height	Tall initial hydrocarbon column at discovery	Trap not "filled to spill" despite adequate charge in the basin indicating weak top or lateral seal	Trap present but minimal or no hydrocarbon column despite known adequate charge	
Seal Lithology	Seal formations that are regionally continuous and proven successful for oil or gas accumulations	environment of deposition or seismic data suggests seal facies present but no rock data	Heavy oil fields known to have tar mat seals	
Fault Seal Characteristics	Known competent fault seal	Faults are known to be present but sealing potential is unknown	Sand-sand juxtaposition across faults	
Rock Data Availability	Multiple well penetrations of rock types with well-documented low permeability and high capillary injection pressures measured in core data	Well penetrations with geophysical log data indicating low porosity lithologies are present	Well penetrations with geophysical log data indicating a lack of low porosity lithologies	
Trap (Container Size and Shape) Lines of Evidence	**1**	**0.5**	**0**	
Trap Structure	Seismic or well data indicating adequate trap size, geometry, and crest elevation	Trap configuration and crest elevation uncertain	Seismic or well data indicating insufficient trap size, geometry, and crest elevation	
Area Under Closure	Well-constrained, high-relief four-way closure or simple fault and/or stratigraphic trap with proven hydrocarbon accumulation	Broad, low-relief trap with potential for significant lateral loss of hydrogen	Highly faulted structural traps	
Field Data Available	Abundant highly reliable pressure or production data indicating single compartment production (may refer to entire field or single zone within field)	Limited or unverified field data	Pressure or production data indicating insufficient volume of single, connected compartment (e.g., known small pressure compartments, or many distinct hydrocarbon-water contacts)	
Reservoir (Acceptable Injection and Recovery Performance) Lines of Evidence	**1**	**0.5**	**0**	
Measured Rock Properties	Known permeable and porous reservoir indicated by field production rate	Multiple well penetrations with high porosity and permeability indicated by geophysical log or core data	Multiple well penetrations of rock type with less than 7 % porosity	
Field History	Production rate or injectivity tests with high rates	Geologic environment of deposition that preserve favorable rock types	Fields which required hydraulic fracturing during primary production	
Pressure Gradient	Sufficient gap between reservoir and fracture pressure to allow injection, verified by field, log, and fluid tests	Conditions favorable to preventing porosity loss from cements (Cenozoic deposition, reservoirs less than 100 C)	Reservoir pressures near fracture gradient with history of wellbore breakouts	
Loss Potential (Biological and Geochemical Processes) Lines of Evidence	**1**	**0.5**	**0**	
Reservoir Temperature	Greater than 90 C (~9000 ft deep)	Reservoirs less than 90 C (~9000 ft deep)		
Geochemical Compatibility	Formation rock and fluid compositions may be compatible with hydrogen	Indications that formation rock and fluid compositions may react with hydrogen, causing losses		
			Composite Value = Seal x Trap x Reservoir x Loss Potential	

Notes:

1. Each element is assigned a value indicating the chance of adequacy, from 0 = high confidence of inadequacy, 0.5 = adequacy is uncertain, but may be positive or negative, to 1 = high confidence in adequacy. The element values are multiplied by each other to generate an overall composite value for the field or field segment under consideration.

2. Inadequacy of any element will remove the field from consideration. For this reason, the "Loss Potential" element does not have a high confidence of Inadequacy entry as the % hydrogen degradation in the subsurface acceptable to the project is an economic decision.

C.2 Evaluation Framework for Depleted Oil and Gas Reservoirs, Salt Caverns, and Abandoned Underground Mines *(Continued)*

Evaluation Framework

Salt Caverns

Chance of Suitability Constructing Salt Mines	High Confidence of Adequacy	High Uncertainty of Adequacy	High Confidence of Inadequacy	Value
Depth (storage pressure limitations)	1	0.5	0	
Hydrogen storage density	Salt body depth is known to be consistent with the pressure desired to meet storage need, existing caverns exist in the province	Salt body thickness / depth is not proven to have high enough pressure to meet storage need	Salt body thickness / depth is too thin / shallow to have high enough pressure to meet storage need	
Form (suitability for cavern formation)	1	0.5	0	
Salt body type	Salt domes, diapirs, or pillows	Bedded salts		
Roof Stability (regulatory / form constraints)	1	0.5	0	
Thickness	Enough thickness to allow a salt cap for roof stability	Thickenss of salt body unknown	Too thin to allow for the required salt cap roof thickness	
Areal Extent	subsurface mapping or proven cavern width to allow for needed storage cavern volumes, with safe web thickness (wall thickness) between caverns	Salt body unmapped, extend uncertain	Too narrow or of too limited extent for safe cavern spacing and web thickness	
Rock Composition (geomechanical and geochemical stability)	1	0.5	0	
Data Availability	Core data with chemical composition and geomechanical properties indicating acceptable properties	Geophysical well log data or offset outcrop sample data	Core data with chemical composition and geomechanical properties indicating unacceptable properties	
Lithology	Halite dominated "clean" salts (domal or minimal interbedded clastics / carbonates)	Gypsum-anhydrite dominated salts or thinly bedded "dirty" (salts with abundant interbedded clastics / carbonates)	Minimal or no halide salts present	
			Composite Value = Depth x Form x Roof Stability x Rock Composition	

Notes:

1. Salt caverns differ from other storage options as the team will be working in two stages: identifying salt bodies that meet geologic requirements, then relying on geologic data to identify areas within salt bodies that can meet design criteria
2. Each element is assigned a value indicating the chance of adequacy, from 0 = high confidence of inadequacy, 0.5 = adequacy is uncertain, but may be positive or negative, to 1 = high confidence in adequacy. The element values are multiplied by each other to generate an overall composite value for the field or field segment under consideration.
3. Design and selection criteria may vary by state, best practice guidance is available in:
Common Practices – Gas Cavern Site Characterization, Design, Construction, Maintenance, and Operation, SMRI Research Report RR2012-03
Recommended Practice for the Design of Solution-Mined Underground Storage Facilities – API Recommended Practice 1114, API, July 2013

Evaluation Framework

Abandoned Underground Mines

Geologic Chance of Success in Abandoned Underground Mines	High Confidence of Success	High Uncertainty of Adequacy	High Confidence of Inadequacy	Value
Surrounding Rock Fracture/Fault Development Lines of Evidence	1	0.5	0	
Geologic containment	Host rock is hard rock with no evidence of faults or fractures	Evidence of faults / fractures, but faults are inactive and confined to subsurface	Extensively faulted and heavily fractured. Faults are known to be active.	
Depth Lines of Evidence	1	0.5	0	
Nearness to surface (poorly constrained due to lack of examples)	>1000 feet	500-1000 feet	<500 feet	
Overburden stress complexity	1	0.5	0	
Mine shaft dip angle	0-30 degrees	30-90 degrees		
Hydrostatic Pressure Stability	1	0.5	0	
Potentiometric surface fluctuation and uncertainty	Proven year-round stability or well-constrained predictability of groundwater table	Fluctuating but predictable groundwater table	Highly fluctuating and poorly constrained groundwater table	
Loss Potential	1	0.5	0	
Geochemical compatibility	Formation rock and fluid compositions are compatible with hydrogen, verified by rock and fluid data and modeling calculations	Formation rock and fluid compositions react with hydrogen, hydrogen loss expected	Formation rock and fluid compositions known to be highly reactive with hydrogen	
Seal and Trap	1	0.5	0	
Host rock permeability	Core analysis and mapping demonstrate high confidence in laterally continuous very low-permeability host rock	Host rock competence unknown	No evidence of caprock and/or structural trap	
Void structure	Clearly defined large chamber with few shafts	complex chambers, poorly constrained extent	chamber insufficient size	
			Composite Value = Surrounding Rock x Depth x Coal Seam Dip Angle x Water Table x Loss Potential x Seal	

Notes:

1. Each element is assigned a value indicating the chance of adequacy, from 0 = high confidence of inadequacy, 0.5 = adequacy is uncertain, but may be positive or negative, to 1 = high confidence in adequacy. The element values are multiplied by each other to generate an overall composite value for the field or field segment under consideration.

C.3 Table of Evaluated Salt Basins

BURNS & McDONNELL — Geologic Salt Basins - Evaluation Framework

Salt Basin	Depth (Storge Pressure) Comments	Depth Value	Form Comments	Form Value	Roof Stability Comments	Roof Stability Value	Rock Composition Comments	Rock Composition Value	Composite Value
Luke Salt	Greater than 1000 m thick at some locations, with top of salt between 150-1200 m below ground surface	100%	Salt body geometry is interpreted as largely a result of original depositional pattern, with deposition from an isolated waterbody that decreased in extent over time, with interbedded shales at the margin. There is some salt movement at the center of the deposit.	75%	Greater than 1000 m thick at some locations. Areal extent of salt is ~100 sq km, but variable depth to top of salt may indicates limited thickness at the margins of the salt body. Additional data on base of salt from either seismic or wellbore penetrations would reduce uncertainty in the available storage volume potential of the salt body.	100%	Geochemical data is available indicating a high proportion of halite, with limited interbeds of shales.	100%	75%
Paradox	Salts in the southern portion of the basin are at > 1500 m below ground surface, and shallower in salt-cored anticlines in the northern portion of the basin.	100%	Salts deposited in the Paradox Member of the Hermosa Formation (Pennsylvanian). The Paradox Basin can be divided into two provinces, with bedded salts in the southern portion and a series of salt cored anticlines in the northern portion of the basin, sub-parallel to the Umcompahgre Uplift.	100%	Areal extent of 30,000 square kilometers. Within salt cored anticlines the thickness of salt reaches up to 4200 m thick.	50%	Paradox member salts include anhydrite and shale interbeds.	50%	25%
Sevier	The Aces project has demonstrated that there are conditions sufficient to store 12,000 tonnes of hydrogen within permitted caverns. There are also existing liquid petroleum caverns within diapirs.	100%	Deposited in the Jurassic as part of the Carmel-Arapien shale. There are salt diapirs within the basin, and recent salt movement. There are some areas with recent salt.	100%	The Sevier Valley salts are less than 30 m thick in some parts of the basin, with thick diapiric structures along a central anticline.	100%	Lithology is dominated by halite within mobile salts, outside of the central anticline region there is likely significant interbedded sulfate and clasic sediments.	75%	75%
Supai	Depth to top of salt is 300-500 m below ground surface.	100%	The Supai Formation is a bedded salt with thickness variations attriuted to original deposition.	50%	The Upper Supai Formation has interbedded evaporites with thickness range of 0-145 meter, limiting the height of potential storage caverns. Areal extent of the Upper Supai Formation are 6000 square kilometers	75%	The Upper Supai Formation has interbedded evaporites with thickness range of 0-145 meter, limiting the height of potential storage caverns. Areal extent of the Upper Supai Formation is 6000 square kilometers	25%	9%
Red Lake	Red Lake is one of the thickest and largest accumulations of non-marine evaporites in the world. There is limited information on the full thickness of the salt, it exceeds 1200 m in thickness, and top of salt is at ~500 m below ground surface.	100%	Depositional environment is accumulation of non-marine evaporites in a rapidly subsiding extensional basin. Salt extent is control by both initial deposition and by later halokinesis, placing the Red Lake salt body between the categories of a salt dome and a bedded salt, with a higher degree of interbeds around the margin of the deposit.	75%	Thickness is > 1200 m in some areas, thickness is generally poorly constrained but easily exceeds the thickness needed for salt cavern construciton.	100%	Evaporite composition is halite dominated, extent of intebeds are poorly delineated with present data.	75%	56%
Virgin Valley	Top of salt varies from ground surface to up to 500 m below ground surface. Salt thickness not known over the entire body, but is mapped at > 1000 m thick in some areas.	100%	Thick halite deposites within the lower Muddy Creek Formation, deposited wtihin a saline lake in the Cenozoic Era. The salt body shows evidence of elastic deformation, with unhealed fractures from recent (Holocene) faulting. The salt forms domes with some indications of flow in the deeper portion of the salt body.	50%	Salt thickness is not known over the entire salt body, but limited borehole data indicates thickness > 500 m, and geologic mapping indicating > 1000 m thickness. Areal extent is !	75%	Coarsely crystalline halite with sparse indicators of bedding. Within the deeper portion of the salt body (below 120 m of top of salt), lithology is > 93% halite.	100%	38%

C.4 Table of Evaluated Depleted Oil and Gas fields

BURNS & McDONNELL — California Oil And Gas Fields - Evaluation Framework

Field	Reservoir	Seal Value	Seal Comments	Trap Value	Trap Comments	Reservoir Value	Reservoir Comment	Loss Value	Loss Comment	Composite Value
Alegria	Rincon	50%	Seal properties unknown in the Rincon, reservoirs are in sands within the Rincon, distribution is not known from available materials.	100%	4-way closure, not fault dependent	50%	50-100 thick, 400-800 mD, porosity 15-30%	50%	<2000 ft deep	13%
Aliso Canyon	Sesnon-Frew	50%	Current gas storage in the Sesnon-Frew interval. Seal potential of faults is unknown for hydrogen.	100%	3-way fault dependent closure, main field is contained within single fault blocks.	100%	17-30% porosity, 234 mD in air	75%	9000 ft deep, reservoir temperature of 80 C	38%
Alondra	Shist Conglomerate	50%	Fault dependent closure, seal properties of faults unknown. Seal properties of the Puente and Repetto are unknown. Similar to the gas storage facility at Playa Del Rey.	100%	Simple structure of modest size, no apparent internal fault compartments.	100%	22% porosity, permeability 1000 mD	100%	135 C, 9295 ft, no risk of biodegradation, need to investigate geochemical loss potential at high temperatures	50%
Anaheim	Oil Sand	25%	Shallow field with fault dependent closure	50%	Very flat, simple 3 way fault closure	50%	Likely high residual oil saturation, no porosity or permeability data.	50%	40 C, 4350 ft	3%
Ant Hill - Jewett	Jewett	100%	500 feet of Freeman-Jewett shale - same seal for submitted Class VI injection permits in CA. Proven 250' oil column.	50%	Broad, low-relief trap that appears to be stratigraphic. Net thickness of 30' and 80 acre area.	50%	Low confidence ('estimated') reservoir properties.	50%	49 C initial reservoir temp. Light oil.	13%
Ant Hill - Olcese	Olcese	100%	~1000 feet of Round Mountain seal; faults appear to seal.	50%	Broad, low-relief fault and structural (combination) trap	100%	Low confidence ('estimated') reservoir properties.	50%	49 C initial reservoir temp. Light oil.	25%
Antelope Hills - Agua	Agua	50%	Unconformity seal that appears to be sand-on-sand with Santos.	50%	Heavily faulted, complex structural trap	50%	Low estimated permeability (400 Md), estimated porosities (uncertain)	50%	60 C reservoir temperature	6%
Antelope Plains - 8th Eocene	8th Eocene	100%	Fully encased in Kreyenhagen shale (Canoas sub member); lateral limits uncertain	50%	Trap configuration and crest evaluation uncertain; structure appears low relief	50%	Highly uncertain porosity, permeability estimated low. Only 35' net thickness	50%	Reservoir Temp 47 C	13%
Arroyo	Dollie	0%	Elberta reservoir is overlain sandy shales, unlikely to be an adequate seal for hydrogen.	25%	Trap mapping is very uncertain, limits of accumulation appear to be driven by limits of permeability to heavy oil production, trap complexity unknown, structural controls on column height	100%	22-35 %, perm 750-1000 mD, heavy oil field that underwent cyclic steam production, may have high residual oil saturation.	50%	32-38 C	0%
Ash Slough - Blewett	Blewett	100%	500+ feet of Moreno shale encasing Blewett sand.	100%	Pinch-out trap geometry with proven hydrocarbon column; dip	100%	High peak gas rates (2.8 MMCF), 30% porosity	75%	62 C	75%
Asphalto - Carneros	Carneros	100%	500' of media / devilwater-gould seal. Proven accumulation.	50%	Unknown trap configuration - appears folded. Not clear if faulted.	50%	6 MMCF Peak Gas production; 13% porosity, 7 mD (estimated).	100%	Temperature 101+ C	25%
Bandini	OConnell, C.W.O.D.	25%	Faulted 4-way anticline, primary reservoir interval is sealed by faults on all sides. Deeper reservoirs may be an option with a high seal potential, but limited information on fault seal available.	50%	Deeper reservoir intervals may have sufficient traps, limited structural information available, cross section indicates traps are structural-stratigraphic. Unknown if there are faults within the closure.	100%	Porosity 25, permeability 27-299	75%	6500-8400 ft	9%
Bardsdale	Llajas (Eocene)	100%	Multiple sealing intervals w/ 1000 ft tall initial column of light oil and gas	50%	3-way fault dependent closure, with small 4-way independent closure w/ normal faults perpendicular to main fault trace. Uncertainty due to little available mapped data	50%	Porosity not listed, no information available in volume	75%	Reservoirs greater than 7500 ft deep Hypersaline aquifer - 32,500 TDS	19%
Barham Ranch	Monterey	0%	Sealing units are arenaceous zone, appears to be saturated diatomite.	50%	Faulted 4-way, broad relief	0%	Fractured shale reservoir, porosity is likely limited to fractures	25%	High sulfur heavy oil, 2800 ft deep	0%
Beer Nose - Bloemer	Bloemer	50%	Thin, interbedded sands/shales form the seal	50%	partially reliant on fault seal	50%	12% porosity, 8 Md perm	100%	137 C	13%
Belgian Anticline - Oceanic	Oceanic	50%	Little-no information	50%	Little-no information	100%	506-6000 mD Perm, 27% phi	75%	81 C reservoir temp	19%
Bellevue - Stevens	Stevens	25%	Reliant on fault seal.	25%	Normal fault seal with minimal structural relief (shallow dip).	100%		50%	57 C	3%
Bellevue W - Stevens	Stevens	50%	Reliant on fault seal, but not complex structure	75%	High relief but thin accumulations	100%	Stevens. 28% porosity, 600 mD perm, 25' thick	75%	72 C	28%
Beverly Hills	Repetto Sands	50%	Multiple columns, difficult to determine fill to spill due to complexity of fault network, sealing unit is Modelo formation	0%	3 way fault dependent closure at least 15 mapped faults	100%	21.1 % porosity interbedded sands within the Modelo shale. Multiple compartments	25%	Hypersaline aquifer, depth is 2500 ft	0%
Big Mountain	Llajas	100%	400 ft initial column in the Sespe, >1000 ft of sealing shales within the Sespe.	100%	Fault bounded closure.	50%	No porosity data in the Eocene formation, the Llajas is a high quality reservoir in other areas.	75%	Deepest reservoir at 6200 ft	38%
Bitterwater - Bickmore Canyon	Bickmore Canyon	25%	San Andreas Fault Seal	25%	Combination trap reliant on fault seal	50%	Unknown porosity / perm values	50%	34 C	2%
Blackwells Corner - Agua	Agua	25%	Seal depiction unclear; likely stratigraphic (self-sealing); Truncation against Tulare unconformity relies on unconformity seal	50%	High relief, but no clear closure configuration. Appears unfaulted	100%	31 percent porosity, 670 Md, 85' thick	50%	52 C	6%
Bouquet Canyon	Mint Canyon	100%	Sealing units are Mint Canyon and Towsley Formation, interbedded siltstones and shales	50%	Main field may be small, but channelized system draped over simple 4 way closure with no faults noted on map, very old field, unlikely to have been mapped on seismic	50%	No information	50%	Light oil, 2340 ft deep	13%
Bowerbank - Stevens	Stevens	100%	1500' of Monterey seal	75%	Unfaulted four-way closure in shallower horizons, uncertain in Stevens. Broad / low relief	100%	18% porosity, 75 mD permeability, 10,000+ thickness. Stevens	100%	125 C	75%
Boyle Heights	Puente	50%	Structure as mapped is not fill to spill	50%	4 way anticline, no faults mapped	50%	400 ft thick, no lithology information included	25%	Hypersaline reservoir, black oil, 2500 ft	3%
Brea	Multiple reservoirs	100%	> 2000 ft columns of heavy oil, seal may in part be due to in place tars	50%	Multiple fault compartments with different trap styles including 3 way against faults, stratigraphic pinch outs. This is a multi-billion barrel field, individual compartments may be sufficient in size	75%	Puente and Repetto sands, these units are high quality reservoir in other fields.	25%	1800 ft	9%
Buena Vista - 555 Stevens	555 Stevens	50%	Not enough information	50%	Not enough information	100%	25-32% porosity, 1000-3000 Md perm, 300 feet thick. Stevens	75%	73 C	19%
Burrel - Zilch	Zilch	75%	Appears self-sealing, but Zilch not documented as a sealing facies	50%	Unfaulted, stratigraphic trap, but very broad and low relief	75%	32% porosity, Unknown perm, known oil producer; 15' thick	50%	59 C	14%
Buttonwillow - San Joaquin	San Joaquin	50%	Interbedded silts and sands of the San Joaquin formation	100%	Unfaulted 4-way closure with moderately high relief	25%	Many non-continuous, not connected sand lenses.	50%	37 C	6%
Cal Canal - Stevens	Stevens	100%	Sealed by unconformity (N marker) which is overlain by 4000 feet of Reef Ridge (Monterey)	100%	4 way closure, high relief. One fault present but trap is not reliant on fault.	100%	10-11% porosity, .1-.5 mD perm; however, ~2 MMCF peak gas production	100%	143 C	100%
Calders Corner - Upper Stevens	Upper Stevens	25%	Reliant on fault seal and fault may create sand-on-sand contact	50%	Faulted anticline, broad and low relief	100%	21% porosity, 235-500 Md perm, 25' net thickness	75%	72 C	9%
Camden - Camden Sand	Camden Sand	50%	Sealed by interbedded silts/shales of the Zilch formation	50%	Stratigraphic trap up-dip, lateral seal by faults. Pinch out of sand delineated reasonably well.	50%	Unknown porosity / permeability, only 17' net thickness. <50K peak rates	50%	55 C	6%
Canada Larga	Q Sands	100%	> 500 ft column of light oil	75%	Tilted stratigraphic top, limit mapping data available	75%	Sandy unit within the Pico formation	75%	5720 ft	42%
Canal - Upper Stevens	Upper Stevens	100%	~1000' of Reef Ridge (Monterey) Seal	100%	Unfaulted 4-way closure	100%	15-20% porosity, 10-1000mD perm, 100' net thickness	100%	98 C	100%
Canfield Ranch - Stevens	Stevens	50%	Accumulations dependent on fault seal	50%	Broad, low relief structures, faulted	50%	Stevens sand, but highly compartmentalized, poor connectivity	100%	Maximum reservoir temperature of sands reach 107 F	13%
Canton Creek	Modelo	50%	Limited information, Modelo Formation is a regionally extensive shale	50%	Unknown trap configuration, no mapped faults	0%	Fractured shale reservoir, <50 bbl/day production	50%	Average depth is 900 ft	0%
Cantua Nueva - Temblor	Temblor	75%	Thick section of Monterey seal, but type log appears to have interbedded sands	75%	Stratigraphic trap, unfaulted, extent of producing zone unclear (trap not fully delineated)	75%	31% porosity, 130-410 Md perm, 20' thick, but appears vertically and laterally discontinuous (connectivity issue)	75%	80 C	32%

BURNS & McDONNELL — California Oil And Gas Fields - Evaluation Framework

Field	Reservoir	Seal Value	Seal Comments	Trap Value	Trap Comments	Reservoir Value	Reservoir Comment	Loss Value	Loss Comment	Composite Value
Capitan	Gaviota	100%	200 ft column	50%	Low relief 3-way fault dependent closure, with small independent 4-way	100%	20% porosity in Goldwater Gas zone	50%	4400 ft deep in deepest zone	25%
Capitola Park - Media	Media	75%	Thick Media (Temblor) Seal, but log appears interbedded	75%	Unfaulted 4 way closure; extent of trap unclear	75%	24% porosity, 150 mD, 50' thick; low rates (2 MMCF rates)	50%	21 C	21%
Careaga Canyon	Monterey	100%	>3000 ft column supported over ~7 miles	100%	Fault dependent 3 way closure, small independent closure at the top. Very large field	50%	Fractured Shale, has production rates of <50 bbl/day up to 1572 bbl/day	100%	7960-8400 ft, reservoir temperature > 90 C	50%
Carneros Creek - Carneros	Carneros	50%	Thick Temblor (Media) sealing facies but heavily faulted	50%	Faulted combination trap; accumulation reliant on fault - potential storage location in isolated fault block	100%	28_34% porosity, .5-1 mD, 115' thick	50%	42 C	13%
Cascade	Saugus	100%	350 ft column that appears fill to spill on map	100%	High side fault dependent 3 way	50%	No porosity data	25%	Reservoir temperature <40 C	13%
Casmalia	Point Sal, Lospe	100%	OWC does not fit to structure, laterally extensive seal units in the Sisquoc Formation	50%	Faulted 3 way closure, the faults may or may not intersect stratigraphic compartments in below the Monterey	100%	22, 15% porosity	50%	71 C, <90C	25%
Castaic Hills	Modelo	100%	Sealed by shales within the Modelo Formation.	100%	Structural stratigraphic trap, along the San Gabriel Fault, high side of a normal fault with a rollover anticline	100%	Multiple reservoir units, data available for the Radovich, Sterling, and Sterling East pools, porosity from 23-35%, permeability to air of 192 to 2200 mD	50%	Reservoir temp of ~40 C	50%
Cat Canyon	Sisquoc	100%	Shale units within the Sisquoc formation, appear laterally extensive, columns height within the Sisquoc are unclear (HC extent seems blended between the Sisquoc and Monterey)	50%	Field has multiple, large compartments, there are faults bounding blocks, they are mapped as single faults. Overall structure is large, with	100%	Primary reservoir within the field is within the Monterey, this rating is for the sand units is the Sisquoc, porosity listed as 27-31%.	25%	Field temperature is 40 C	13%
Central Cuyama	Branch Canyon	0%	Ultimate seal provided by Santa Margarita and Morales Formations that have sufficient thickness, the branch canyon has many sand and shale interbeds that may compromise seal	50%	Minimal data available, trap might be small	100%	19% porosity	50%	87 C	0%
Chaffee Canyon	Matilija Sand, Llajas	100%	Interbedded sands and shales in the Pico Formation and Llajas at the base.	100%	Simple 3 way fault dependent closure, OWC appears controlled by sand/sand juxtaposition across faults (supporting fault seal within oil leg).	50%	10% porosity noted in the Matilija	50%	Reservoir depth is 6330 ft on average, crest is < 5500 ft,	25%
Cheney Ranch - Jergins	Jergins	100%	Thick (1000') section of continuous Tierra Loma Shale seal	75%	Unfaulted stratigraphic trap	50%	Unknown porosity / permeability; 650 MMCF peak gas	75%	76.7 C	28%
Cheviot Hills	Modelo	100%	Sealed by shale units of the Modelo Formation, ~2000 ft of shales in multiple penetrations The Repetto lies unconformably above the Modelo. The lower Repetto in this area has >1000 ft shale in lower member in this location.	50%	Multiple faults within the field and fault dependent seals on the sides. Independent 4 way closures within the structure Very thick reservoir and low dip at crest may inhibit recovery, maybe compartmentalized on a production timescale	100%	33% porosity in Rancho Sands	100%	126 C	50%
Chico-Martinez - Etchegoin	Etchegoin	25%	San Joaquin shale facies seal (not a marine shale) with throughgoing faults	50%	Most of accumulation reliant on faults, some element of pinch outs, potential sand-on-sand geometries	75%	33% porosity, 900 Md perm; Etchegoin typically known as lower quality shallow marine sand	50%	23 C	5%
Chino-Soquel	Puente (Royalty Services Interval)	50%	~200 ft column, with multiple intervals sealed against faults. Seals are the basal members of the Middle Mercury and Soquel Formations, limited thickness and number of consolidated seal unit due to shallow depth.	100%	Structural stratigraphic trap mapped as one compartment.	100%	18-24 % porosity in sands	25%	Deepest interval is at 1,800 ft	13%
Chowchilla - Panoche	Panoche	50%	~500' of Moreno shale continuous seal, but tr	50%	Trap configuration / crest uncertain	100%	26% porosity, 60 mD, 50' thick, 3.2 million mcf / year peak	75%	75 C	19%
Cienaga Canyon - Vaqueros	Vaqueros	50%	Temblor seal, highly interbedded sand/shale deposits; not known sealing facies. Fault cuts through producing zone	75%	Four way closure with fault within reservoir	75%	26% porosity, 500 mD, 1100 bbl. peak oil	50%	50 C	14%
Coalinga - Temblor	Temblor	25%	Sealed by Santa Margarita, a known coarse-clastic. Likely tar mat seal up-dip	25%	Formation crops out up dip	75%	27-33% porosity, 300 - 10,000 Md, not a known excellent reservoir	50%	27 C	2%
Coalinga E Extension - Gatchell	Gatchell	75%	Well delineated sub crop / pinch out, but sealing capability of Turritella Silt and Domengine unclear	75%	Simple pinch-out trap geometry, well delineated	100%	20% porosity, 421 Md perm, up to 625' thick	100%	100 C	56%
Comanche Point - Santa Margarita	Santa Margarita	50%	Sealed by "Transition" and Chanac, which are interbedded sand-dominated facies	50%	Charge reliant on fault trap	50%	Santa Margarita known as poorly sorted, angular sand; cross sections suggests discontinuous compartments; 25% porosity, 300 Md, 100' THICK	50%	26 C	6%
Conejo	Alluvium	0%	Heavy oil in alluvium.	0%	Biodegraded in place, no trap	50%	No data	0%	150 ft average depth	0%
Cristianitos Creek	Visbeek Sand	50%	Not investigated	0%	Very small stratigraphic trap	50%	No data	75%	85 C	0%
Cymric - Carneros	Carneros	25%	Monterey seal, but highly faulted and structurally complex	25%	Highly faulted structural traps; faults that likely extend to surface	100%	26% porosity, 120 Md perm, 250' thick	100%	126 C	6%
Deer Creek - Santa Margarita	Santa Margarita	75%	Unconformity seal with Chanac on top - Chanac known as interbedded sand/shale	75%	Stratigraphic trap with minimal accumulation	50%	Santa Margarita known as poorly sorted, angular sand; cross sections suggests discreet, disconnected sand bodies; 24% porosity, 2000 Md PERM, 20' thick sands on average	100%	148 C	28%
Del Valle	Bering	100%	Bering is sealed by the Modelo and the lower member of the Del Valle	50%	Gentle, faulted 4-way w/ multiple reservoir levels, selected reservoir is Bering, the lowermost unit is the Lincoln. Faults bound the sides, but there is independent closure.	100%	13-21% porosity, but appears to be very thick sands	100%	85 C in the Bering, the Lincoln is at 9700 ft, and will be over 90	50%
Devils Den, Alferitz	San Joaquin	75%	Encased within Kreyenhagen shale (known seal / source rock), but nearby faults could have unknown splays that penetrate seal	75%	Unfaulted four-way closure, but nearby faults could cause structural uncertainty	100%	Point of rocks, 33% porosity and 60% initial SO, 500 Md perm	50%	21 C	28%
Devil's Den, Bates	Point of Rocks	50%	Monterey intraformational seal (pinch out) overlain Etchegoin fine grained facies. Etchegoin typically interbedded and highly variable	75%	Stratigraphic trap, homocline, unclear if pinch out is well delineated with well control	50%	Bates formation, estimated 22% porosity, 50 Md perm, 50K peak oil	50%	50 C	9%
Dominguez	Calendar, multiple units	100%	Shales in the Pico and Puente Formation	0%	At least 15 mapped faults, some hold separate columns, some appear to share an OWC	50%	No data, but in the Repetto formation which regionally has good reservoir properties	50%	Deepest reservoir intervals are at ~7600 ft, most are more shallow	0%
Dudley Ridge, Tulare	Tulare	100%	Sealed by interbedded shales within the Tulare Formation	100%	Pinch out trap, but well data suggests exact pitchout location is poorly delineated	50%	Mutiple reservoir level, may cause poor communication between reservoir units	50%	40 C	25%
Dyer Creek, Vedder	Vedder	75%	~500' of Freeman-Jewett seal, but faulted. Seal thickness appears larger than fault throw.	25%	Accumulation is against hanging wall of normal fault, lateral closure is not clear	100%	Vedder is a known reservoir with good porosity and permeability, flows on primary production. 31% porosity, ~1800 Md perm	50%	39 C	9%
Eagle Rest, Eocene Sand	Eocene Sand	50%	Tejon, appears interbedded, highly tilted and folded (potential for fracturing)	25%	Complex fault seal with deformation around fault zone	50%	Eocene sand not widely known as prolific producer. 21-25% porosity, 30-180 md perm.	75%	85 C	5%
East Buena Park	Repetto	50%	Interbedded shales and siltstones, column height unclear	50%	Lack of information	75%	Repetto Sands generally acceptable reservoir in the area, sediments are deep, but Pliocene in age.	100%	9240 ft deep	19%

C.4 Table of Evaluated Depleted Oil and Gas fields *(Continued)*

BURNS & McDONNELL — California Oil And Gas Fields - Evaluation Framework

Field	Reservoir	Seal Value	Seal Comments	Trap Value	Trap Comments	Reservoir Value	Reservoir Comment	Loss Value	Loss Comment	Composite Value
East Coyote	Repetto (multiple intervals)	100%	Sealed by multiple shale units in the Repetto and Pico formations.	0%	Mapped as channels draped over a high, may be differential compaction, may have difficulty accessing the entire field due to separate 4 way closures. Complex fault compartmentalization	100%	Repetto Formation, Puente Formation	75%	Deepest intervals are at 5500 ft average depth, 74 C	0%
Edison, Edison Groves, Olcese	Olcese	25%	~500' Round Mountain seal. Fault and interbedded	25%	Combination structural / stratigraphic trap with thoroughgoing faults. Broad and low relief	75%	Serrated log signal (indicating fine scale interbeds), but 25-30% porosity and 1-2 darcy's permeability	50%	41 C	2%
Edison, Jeppi, Vedder		25	Highly faulted caprcok with faults that penetrate completely through reservoir and seal	25	Multiple fault blocks, structurally complex	100	Vedder is a known reservoir with good poro/perm, flows on primary production. 24% porosity, ~500 Md perm	50	56 C	0.03125
Edison, Main Area, Frmn Jewt	Jewett	25	Highly faulted caprcok with faults that penetrate completely through reservoir and seal	25	Multiple fault blocks, structurally complex	100	Vedder is a known reservoir with good poro/perm, flows on primary production. 24% porosity, ~500 Md perm	50	56 C	0.03125
Edison, Portals-Fairfax, Nozu	Nozu	25	Round Mountain seal appears interbedded with sand. Minor faulting interpreted	50	Poorly delineated pinchout trap with throughgoing faults that may affect flow	50	Little-no well control through Nozu reservoir, estimated porosity at 24%, perm at 1200 MD	50	49 C	0.0625
Edison, Race Trck Hll, Pyr. Hil	Pyramid Hills	25	Heavily faulted Freeman_Jewitt, likely uncertainty on which units faults cut	25	Highly complex fault traps	50	High porosity / permeability, but extremely compartmentalized and discontinous	50	54 C	0.015625
Edison, West Area, Vedder Undf	Vedder	75	Internal Freeman-Jewett seal + Round Mountain secondary seal. Nozu divides the two seals and is a sand	75	Stratigraphic (pinch out) trap. Thin, low relief geometry	75	Pyramid Hill - Vedder undifferentiated,	50	51 C	0.2109375
Edison, Northeast, Chanac	Chanac	0.25	Interbedded Kern River sands / silts, which is not a known seal for tall hydrocarbon columns	25	Stratigraphic traps, very complex and challenging to delineate	25	High porosity / permeability, but discontinuous braided fluvial with abundant interbedded silts	50	26 C	0.0078125
El Rio	Sespe	50%	Mapped as sandy units within the upper Sespe, sealed by silts and shales within the Sespe, overlying unit is the Conejo volcanics. High chance that the seals are not laterally continuous, though difficult to evaluate given the limited data available.	50%	Mapped as fault bounded 3 way w/ some independent closure, limited data available	50%	No data	100%	>11,000 ft deep	13%
El Segundo	Repetto Sands	100%	Sealed by shale units within the Repetto and the Pico, column height exceeds 200 ft, gas sands previously used for LP storage	100%	4 way closure, with shallow dip, but thick reservoir units to give enough mass	50%	Pliocene Repetto Sands, no porosity data listed	50%	Deepest Pliocene gas bearing unit is ~4150 ft	25%
Elizabeth Canyon	Castaic	50%	Seal is the lower member of the Castaic Formation, though widespread, interbedded sands a shales, may not be laterally continuous, data not available to assess	0%	Low side fault trap, as mapped is small, with ratty looking sands on logs that may cause vertical compartmentalization.	50%	No data presented for porosity or permeability. Log data suggests over all low net to gross, but does not indicate porosity	25%	Deepest reservoir is 2000 ft deep	0%
Elk Hills, Carneros	242 Sand	75%	Thick~500-1000' Reef Ridge (Monterey) shale seal, potential unmapped faults. Seal is also N marker which is a regional unconformity	75%	Four way closure, high amplitude structure, potential unmapped faults	100%	Thick, high porosity permeability 242 Sand reservoir	50%	Unknown temperature but likely below 90 C	28%
Elwood Canyon	Vaqueros and Sespe	100%	Sealed by the lower Rincon and interbedded shales in the Sespe formation, the lower Rincon is > 2000 ft of shale	50%	High side fault trap, on a roll over fold, as mapped, limited faults	100%	14% porosity, with an estimated 900 mD permeability	75%	Reservoir temp is 67 C	38%
English Colony, 28-22 Stevens	28-22 Stevens	100%	N Marker unconformity overlain by ~500' of Reef Ridge, no mapped faults	75%	Stratigraphic pinch out, map control is limited	100%	Stevens is 27% porosity, 2.2 - 4.0 Darcys perm. Known prolific producer	75%	73 C	56%
Esperanza	Kraemer	100%	~800 foot column, sealed by the lower Yorba member of the Puente formation.	100%	Fault dependent closure on two sides, as mapped, the reservoir is within a single fault block.	100%	21% porosity	25%	1600 ft depth	25%
Eureka Canyon	Pico	0%	Accumulations are mapped as stratigraphic traps within the Modelo or undifferentiated marine strata. Up dip strata are not penetrated within the fault block in presented data. Deepest interval is <1000 ft below ground surface.	50%	Mapped as tilted stratigraphic traps on either side of a fault, well control is not sufficient to explain the map pattern.	100%	24% porosity, 120-340 mD	25%	Depth ranges from 200-1800ft	0%
Fillmore	Spalding	100%	Column is >200 ft tall. Stratigraphic seals provided by ~1300 ft of shale in the Pico Formation.	50%	Stratigraphic trap, the up dip limit of the field is not clear from data presented	100%	20% porosity, permeability estimated to by 70-80 mD	100%	Reservoir temp 110 C	50%
Five Points, Eocene	Eocene	25%	1000+ feet of Kreyenhagen shale seal, but throughgoing strike slip faults that connect reservoir to units above seal	75%	Stratigraphic trap well known in Eocene sands, notably Domengine	50%	Transgressive sand deposit, known to have shallow marine bioturbation, somewhat laterally discontinuous. 8% porosity, 6-45 mD perm	50%	81 C	5%
Four Deer	Monterey	100%	Internal seals within the Monterey and shales in the Sisquoc Formation.	50%	Extent of mapped accumulation does not show fit to structure, appears to sit along the axis of an anticline plunging away from a fault, unclear if fault dependent or not from data presented.	0%	Fractured shale w/ unknown extent of fractures	100%	90 C	0%
Fruitvale, Vedder	Vedder	50%	~1000 feet of Freeman-Jewett seal, but Gold Book provides no cross section to it, causing uncertainty	50%	Unknown trap configuration	50%	Reservoir properties not provided	50%	Reservoir temperature not provided	6%
Gaffey	Repetto	50%	Fault dependent seal, hydrocarbon distribution not indicated on map, cross section implies ~200 ft column, seal are shale interbeds in the Repetto and a shale rich zone at the top of the Repetto. Uncertainty in the column heigh and low thickness in immediately overlying seal are the reason for 0.5	0%	Trap is on high side of thrust fault formed by a rollover fold, mapped as structural-stratigraphic trap with Repetto sands pinching out near the crest of the anticline, cumulative production is 10,000 bbl, indicating trap is likely too small.	50%	No porosity data available, Repetto sands are successful in other areas.	50%	Average depth 1500 ft, heavy oil field	0%
Garrison City Gas, Mitchel Sand	Mitchel Sand	75%	~1,000' of San Joaquin-Etchegoin. No mapped faults, but known to be an interbedded mix sand-shale deposit	100%	Unfaulted four-way closure	75%	Laterally continuous, but Etchegoin known to be bioturbated and poorly sorted. Porosity 24% and permeability 300 Md (both estimated)	50%	62 C	28%
Gill Ranch Gas, 1st Panoche	1st Panoche	50%	Moreno Shale seal, highly faulted	50%	Faulted anticline	75%	Coarsening upwards laterally continuous sand package. However, porosity/permeability unknown	50%	53 C	9%
Glen Annie	Vaqueros	50%	Sealed by >1500 ft of shale in the Rincon Formation, <200 ft column.	0%	Mapped as stratigraphic trap within the Vaqueros, total production is ~ 5 million CF of gas	50%	25-30%, porosity is estimated	50%	42 C, 3350 ft	0%
Goleta	Sand intervals within Sespe	50%	Ultimate seal is shales in the Sespe, mapping is not in specific enough detail for evaluating seal for each reservoir interval.	0%	140,000 total production, trap is a combination structural-stratigraphic trap, with channels draped a fold in the headwall of a fault (no information on fault motion).	100%	18-25 % porosity, 200-1000 Md	50%	400-1400 ft depth	0%
Gonyer Anticline, Gonyer	Gonyer	25%	Fault transects the Media seal. Media is highly interbedded, sand-dominated	25%	Faulted anticline. Accumulation completely reliant on fault seal	50%	Gonyer Sand is 21% porosity, 150 Md perm, but serrated log signal and interbedded	50%	27 deg C	2%
Goosloo, Upper Stevens	Upper Stevens	25%	~1000' of Fruitvale and Reef Ridge shale	25%	Fault Seal; Trap requires two faults 1to seal	100%	Upper Stevens is known prolific producer, deepwater sands. 19% porosity and 100 Md perm (estimated)	75%	88 C	5%
Greeley, Vedder	Rio Bravo- Vedder	50%	thick section of Freeman-Jewett seal, throughgoing fault	50%	Faulted anticline, but only one fault (Greeley) that appears well constrained and sealing	100%	Vedder is a known prolific reservoir, 18-22% porosity, 26 MD perm	100%	124 C	25%

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Field	Reservoir	Seal Value	Seal Comments	Trap Value	Trap Comments	Reservoir Value	Reservoir Comment	Loss Value	Loss Comment	Composite Value
Guadalupe	Sisquoc	0%	Tar sands, biodegraded in place form the seal	0%	"Trap" is formed by tar sands overlying silt and sand units with higher quality oils (8-14 degree). No discernable structural or stratigraphic trap from mapping	50%	Enhanced recovery required through field life, porosity and permeability of sand is high, but may be reduced by residual oil presence	50%	68 C	0%
Guijarral Hills, Gatchell	Gatchell	100%	1,000' of unfaulted Kreyenhagen Shale seal	75%	Unfaulted stratigraphic trap (pinch out)	75%	Gatchell sand is low porosity (9-13%) and low permeability (0-285)	100%	93 C	56%
Halsey Canyon	Val Verde	100%	Modelo formation and lowermost Saugus-Pico Formation. Laterally continuous shales regionally, and >1500 ft thick in this location.	100%	200 ft thick single reservoir unit with 3 fault blocks as mapped. Compartmentalization limits size.	50%	No data presented	50%	5063 ft average depth	25%
Hanford, Zilch	Zilch	25%	Santa Margarita overlies the Zilch; Santa Margarita is a sandstone with interbedded shales and is a known producer not a seal	50%	Stratigraphic, appears poorly delineated. Broad and low-relief	50%	Very interbedded sandstone with no porosity / permeability data available	50%	42 C	3%
Harris Canyon	Pt Sal	50%	No data presented	50%	No data presented	50%	35-60 md to air, 20-30% porosity	50%	average depth 5600ft	6%
Harvester Gas, Atwell	Atwell Sand	50%	San Joaquin & 'Cutter Zone' seal - not known regional shales, logs appear interbedded	100%	Unfaulted four-way closure	50%	No porosity / permeability values provided; cross section suggests compartmentalized, challenging to delineate sands	50%	50 C	13%
Helm, Eocene & Cretaceous	Eocene Cretaceous	50%	~400' of Kreyenhagen shale seal, but faulted	50%	Faulted anticline; potential Unfaulted areas in north area of field	75%	Multiple Eocene & Cretaceous reservoirs with 23-32% porosity and 237-661 Md permeability	75%	79 C	14%
Hollister, Basement	Basement	25%	Unconformity seal, appears to be sand-on-sand with reservoir	25%	Fault seal	25%	Fractured basement	50%	43 C	1%
Holser	Holser	50%	Shale intervals within the Modelo. < 500 ft, trap also has fault seal, where multiple faults converge	50%	Sub thrust footwall fold with primarily fault dependent closure, likely compartmentalized	50%	No information	50%	4450 ft, limited data available	6%
Honor Rancho, main area	Gabriel Sand, Wayside A-C sands	100%	Shales within the Modelo and Pico Formations	100%	500+ foot tall sands with an up dip stratigraphic pinch out near the crest of a trap. There are multiple compartments, the Wayside A is the largest and is not mapped with any faults present (in DGGR Volume 2).	100%	Porosity 23, permeability to air 320 mD	50%	5300 ft	50%
Honor Rancho, southest area		100%	Modelo Shale ~ 500 ft shale directly overlying the reservoir, fault dependent seal supporting an initial column of >2000 ft height	100%	3 way fault dependent closure, structure maped as single compartment, ~ 50 ft net sand	100%	23 %, 320 mD	75%	5300 ft, * Higher temperature gradient based on gas storage field data	75%
Hopper Canyon	Sand Zones within the Modelo	100%	Shallowest interval is within 500 ft of the surface. All zones are within the Modelo, seal rating is only for Zone III, as I-II are very shallow.	100%	Mapped as a 4 way closure, single compartment with sands draped over an anticline	50%	No data presented	50%	2700	25%
Hopper Canyon, North	Sands within the Modelo Formation	0.5	Contained within the Modelo formation, no data presented on column height.	0	100 kbbl total production, field too small	0.5	Well drilled prior to 1911, no data available	0.5	Average Depth 1000 ft	0
Horse Meadows	Horse Medow Zone within the Tuna Canyon Formation	1	Sealed by several hundred feet in the Paleocene	0	3 way fault dependent closure, cumulative production is 136,566 bbl, size is limited by reservoir extent and closure size	0.5	3 zones within the Tuna Canyon, no porosity data available	0.5	4150 ft	0
Howard Townsite	Odea and 8th	1	600 ft column, with multiple reservoir levels separated by shales within the Repetto and Puente Formations. Fault dependent closure on the SE side of the O'Dea unit.	1	Mapping suggests single compartment reservoirs in the lower units within the field, there is faulting on the upper unit on the south east side.	0	20% in the O'Dea, no information for the 8t.	0	0	1
Huasnsa	Monterey	0.5	Monterey and Santa Margarita, location of pool not shown on type log, seal high quality regionally	0.5	Subsurface structural information unavailable	0	Fractured shale	0.5	2085-3015ft	0
Huntington Beach	Upper Jones	1	Seals are shale intervals in the Repetto and Pico Formations, there are many reservoir levels, the Upper and Lower Jones Zones are sealed by the upper Puente, >2000 ft column. Multiple sealing faults within the field	0	> 25 mapped faults throughout the field	1	25% porosity, sands have blocky character on logs, 425 net thickness Upper and Lower Jones combined	0	65.6 C (150F), 4300-3600 ft deep	0
Hyperion	Fractured Schist, Nodular Shale	1	Shales in the lower Puente, >1500 ft	0	4 way closure on a basement high, structure is small, and the porous reservoir zone is also small.	0	Fractured schist	0.5	No depth or temperatures given, ~7000 ft based on logs, but oil is heavy (10-15 API).	0
Inglewood	Sentous	50%	Mapped pool shows good fit to structure, with 150-200 ft columns within separate compartments, seal would need to be evaluated for a specific fault compartment	0%	Multiple reservoir levels, largest reservoirs are highly faults (>20 mapped faults), the Sentous is one of the lower reservoir intervals that is perhaps not as faulted, but still has intersecting faults.	50%	18% porosity, 34 mD in the Sentous	100%	101.7 C (215 F)	0%
Jacalitos, Temblor	Temblor	100%	Monterey / Reef Ridge seal, unfaulted, clear and consistent low resistivity log signal	75%	Unfaulted four-way closure, but asymmetrical and broad, with a fault present	75%	23-26% porosity, 200 md permeability. Temblor is a shallow marine sand with relatively strong connectivity	50%	63 C	28%
Jasmin West, Famoso	Famoso	50%	Thin, faulted, intraformational seal	50%	Fault trap	50%	Famoso is a known poorly sorted, heterolithic sandstone; Estimated porosity 25%, permeability 200-500 Md	50%	50 C	6%
Jasmin, Pyramid Hill	Pyramid Hill	50%	Continuous, correlative section of Freeman-Jewett, but faulted	50%	Fault trap	75%	Estimated porosity of 37% and permeability of 1300 mD, very little well control	50%	36 C	9%
Jerry Slough, Fractured Shale	Fractured Shale	50%	Mixed intraformational Monterey seal + Etchegoin caprock; Etchegoin typically shallow marine sand. N marker unconformity provides additional seal capacity	100%	Four-way closure	50%	Fractured shale - difficult porosity / permeability pathways to predict. Requires further study	100%	120 C	25%
Jesus Maria	Monterey, all intervals	100%	Monterey and Sisquoc are seals. Within the Monterey, bentonitic brown facies is primary top seal.	50%	Stratigraphic trap within the Monterey, extent limited possibly by extent of fractured reservoir, but controls on distribution not clear	0%	fractured shale	50%	43.3 C (110 F)	0%
Kern Bluff, Vedder	Vedder	50%	~1000' of Freeman-Jewett Seal, but may be faulted at depth	50%	No information on trap configuration in Gold book. Requires further study.	50%	No information on reservoir in Gold book. Requires further study.	50%	No information on loss potential lines of evidenced in Gold book. Requires further study.	6%
Kern Front, Vedder	Vedder	50%	~1000' of Freeman-Jewett Seal, but may be faulted at depth	50%	No information on trap configuration in Gold book. Requires further study.	50%	No information on reservoir in Gold book. Requires further study.	50%	No information on loss potential lines of evidenced in Gold book. Requires further study.	6%
Kern River, Vedder	Vedder	50%	~1000' of Freeman-Jewett Seal, faulted at depth	50%	Fault trap	100%	Laterally continuous sandstone with 25-30% porosity and 500 Md permeability	50%	60 C	13%
Kern Sumner, Vedder	Vedder	50%	~1000' of Freeman-Jewett Seal, but may be faulted at depth	50%	No information on trap configuration in Gold book. Requires further study.	50%	No information on reservoir in Gold book. Requires further study.	50%	No information on loss potential lines of evidenced in Gold book. Requires further study.	6%
Kettleman City, Vaqueros	Vaqueros	100%	Unfaulted 1,000' section of Monterey (McLure) seal. Regionally continuous	50%	Trap configuration appears stratigraphic but sands do not appear correlative between wells	75%	Thinly bedded sands, 17% porosity, 213 md perm; connectivity appears poor	100%	123 C	38%
Kettleman Middle Dome, Temblor	Temblor	100%	1000+ feet of Monterey (McLure) seal, unfractured, regionally extensive	100%	four-way closure	50%	No rock properties provided in Gold Book. Further study required	50%	No temperature available in Gold Book. Requires further study	25%
Kettleman North Dome	McAdams	75%	Thick Kreyenhagen seal but known to be fractured and oil bearing	100%	Well constrained four-way closure	75%	Porosity 14-16%, but low side perm (65-75 Md). Log signatures shows some interbedded silts potentially	100%	107 C	56%

C.4 Table of Evaluated Depleted Oil and Gas fields *(Continued)*

BURNS & McDONNELL — California Oil And Gas Fields - Evaluation Framework

Field	Reservoir	Seal Value	Seal Comments	Trap Value	Trap Comments	Reservoir Value	Reservoir Comment	Loss Value	Loss Comment	Composite Value
King City	Thorup zone	100%	Monterey, >1000 ft thick, column heigh is 200 feet, fault dependent seals	100%	Faulted anticline, with central fault separating out N and S compartments.	100%	32% porosity, blocky sands	50%	43.3 C (110 F), 13 API oil in place	50%
Kraemer	Kraemer Zone	100%	Multiple reservoir levels are separated by shale intervals within the Puente, with the entire structure sealed by shales in the Puente formation (Yorba member), column height is > 400 ft	100%	Faulted 4 way, two compartments	100%	300 ft net thickness, 20% Porosity	50%	47.8 C (118 F), 2400 ft average depth	50%
Kraemer, NE	Travis Zone	50%	Shale at the base of Soquel member of the Puente, column height is not indicated on map but appears small	0%	389 bbl total production, 3 way fault dependent closure with small independent 4 way that is the only portion filled with hydrocarbon	50%	No information	50%	3035 ft	0%
Kraemer, West	Kraemer Zone	50%	Sealed by the shale interval at the base of the Yorba member of the Puente, <40 foot column, unclear if structure is filled to spill	0%	Cumulative production 9583 bbl, 3 way fault dependent closure	50%	No information on porosity or permeability, 100 ft net set thickness	50%	3100 ft deep	0%
Kreyenhagen, Temblor	Temblor	0%	No seal, reservoir extends to ground surface	25%	Intraformational trap, likely tar mat based on how close to surface	25%	Low porosity, low permeability, no well control provided in Gold Book	50%	32 C	0%
La Goleta	Vaqueros	100%	Rincon is the sealing interval, >1000 foot shales	100%	Faulted 4 way, mapped as a single fault, with column controlled by juxtaposition of the Vaqueros across the fault in part of the field, may be one connected compartment	100%	22-27% porosity, 100-500 mD permeability	50%	62.8-68.3 C (145-155 F)	50%
La Mirada	Puente Topanga	100%	Sealed by the Repetto and Pico, thousands of feet thick.	0%	Trap formed by angular unconformity between the Puente and Repetto formations, multiple reservoir units. Limited data available, extent of hydrocarbon not mapped, no wells available along strike. Along well transect, trap has ~1000 ft relief over 1 mile	50%	No information	100%	Average depth 11,900 ft	0%
Lakeside South, Stevens	Stevens	100%	N Marker / Monterey (Reef Ridge) Seal, unfaulted	50%	Trap appears stratigraphic but no delineation of sub crop	75%	Thick, high net package of Stevens Sand, but low porosity (18%) and permeability (90 Md)	75%	85 C	28%
Lakeside, Stevens	Stevens	50%	Monterey / N Marker unconformity seal, but faulted	50%	Fault Trap	100%	Thick, high net package of Stevens Sand, 23% porosity, 55 Md perm (estimated)	75%	80 C	19%
Landslide, Stevens	Stevens	75%	Unfaulted N Chert (Monterey Shale) and Reef Ridge seal, but log signature suggests some interbedding	50%	Stratigraphic trap, channelized, well control not shown, uncertainty around subcrop locations	50%	No porosity or permeability values provided in Gold Book	100%	104 C	19%
Lapworth	Conglomerate in lower Repetto	100%	Sealed by the lower Repetto	0%	Cumulative production is 55,000 bbl, stratigraphic trap, with extent of field not mapped consistent with the structure	50%	No information, producing reservoir is a conglomerate with average net thickness of 20 ft	50%	Average depth 3,100 ft	25%
Las Cienegas	Multiple units within the Puente Formation	100%	Intraformational seals in the Puente, entire structure is sealed by shales in the lower Repetto. Column size ranges up to 1000 ft	100%	Faulted 4-way structure, with multiple fault blocks, some with independent oil columns, some that may be in communication. There are a number of blocks within the larger field that could be candidates	100%	There is not reservoir information for every reservoir, but for the reservoirs with data, porosities range form 18-34%	0%	Reported temperatures range 43.3-68.3 C (110-155 F)	100%
Las Llajas	Las Llajas	100%	Overlying seal is the Modelo	0%	3 way against fault, looks like a simple structure, but very small, less than .1 sq miles in area and 1 reservoir interval	50%	No information	50%	Average depth 977 ft	0%
Las Posas	Sands in the Sespe	100%	Shales within the Sespe Formation, column heigh is at least 300 ft based on cross section	50%	Channelized sands on the footwall of a normal fault. No information on extent	50%	No information	50%	4600 ft depth	13%
Las Varas Canyon	Multiple units within the Sespe	50%	Intraformational seals within the Sespe, <50 ft columns	0%	Faulted anticline, structure is small, with 4,990 bbl total production	50%	Estimated porosities of 18-24%	50%	1800-2450 depth range, including all reservoir levels	0%
Lawndale	Schist Conglomerate	100%	Nodular and other shales at the base of the Puente Formation, structure is mapped fill to spill, 250 ft column	100%	Trap is schist conglomerates onlapping onto the Catalina Schist, may be size constrained	100%	28% porosity	50%	7900 ft	50%
Leffingwell	Woodward Zone	50%	Intraformational seals in the and an unknown thickness of shale at the uppermost Puente Formation.	50%	Low dip, broad structure, fault dependent closure with limited number of mapped faults	50%	17.6-21% porosity, 30-100 mD permeability	50%	6875-8400 ft	6%
Lompoc	Monterey	100%	400 ft column, with several hundred feet of shale at the base of the Sisquoc.	100%	Lompoc Anticline, independent 4 way closure	50%	Fractured Shale, 450-500 ft net thickness, fracture porosity is unpredictable, but the high net in this location may lead to adequacy	50%	2250-2750 ft	25%
Long Beach	Lower Repetto	100%	Shales at the base of the "Pico", > 1000 ft column	50%	3 way fault dependent closure, faulting is complex, but there are fault blocks that may have sufficient storage	100%	31% porosity, net thickness 430 ft	50%	54 C	25%
Long Beach Airport	Multiple zones within the Upper Puente	100%	500 ft column in main fault block, sealed by the uppermost Puente, with overlying regional seal in the lower "Repetto"	100%	At least 6 mapped faults, with reservoir juxtaposition across faults. The main fault block may be of sufficient size to be a candidate on its own.	100%	24-27% porosity, 1200 ft thick	50%	8200 ft deep, no temperature given	50%
Long Canyon	Pico Formation (thin sand stringers)	50%	Column height unknown, sealed by shales within the Repetto and Pico Formations	0%	Sub thrust plunging anticline, limited mapping available, total field production is less than 10,000 bbl oil, with no gas	0%	Net thickness is "Thin and stringers", no porosity-permeability data given	100%	Average depth between 12,200-15,150 ft	0%
Lopez Canyon	Ida B	50%	Sealed by shale within the Point Sal Formation, no column height information, single well field	0%	Mapped as sand channel over an anticline, limited information, produced < 2000 bbl oil, 6,076 Mcf of gas	50%	Fractured Shale	50%	41.7 C (107 F)	0%
Los Alamos	Monterey	50%	Sealed by shales at the base of the Sisquoc, no column height information	100%	Sub-thrust anticline	50%	Fractured shale reservoir, porosity not well constrained, 550 ft "net" thickness	100%	96.7 C (206 F)	25%
Los Angeles City	First Zone, Second Zone	0%	Continuous tar column to surface, deeper unit outside of main area has fault dependent seal	0%	Combination of trapping mechanisms, with asphalt and heavy oil trapped in place near the surface, and a deeper, fault dependent closure in part of the field	100%	34% porosity with ~185 ft net thickness	0%	900-1500 ft average depth	0%
Los Angeles, East	Multiple sand units within the Repetto and Puente Formation	100%	Intraformational seals in the Puente, and shales at the base of the "Repetto", ~70 ft column, unclear if structure is fill to spill	50%	Broad 4-way closure with low dip	100%	18-22 % porosity	50%	Reservoir temperature 73.9 C (165 F), 8100-8560 ft	25%
Los Angeles Downtown	Multiple sand units within the Repetto and Puente Formation	100%	200 ft column, sealed by the Repetto	100%	Faulted anticline, limited faults	50%	30% porosity, reported net thicknesses are very high, but are represented as discontinuous	50%	59.4- 75.6 C (139-168 F)	25%
Los Lobos, Reef Ridge Sand	Reef Ridge Sand	50%	Faulted N marker seal with Etchegoin shale on top, Etchegoin not a regional shale	50%	Combination fault and stratigraphic trap, appears complex	50%	23% estimated porosity, but only 20 Md estimated permeability.	50%	60 C	6%
Lost Hills Northwest, Antelope	Antelope	100%	Reef Ridge regional shale seal, unfaulted	100%	Simple four way closure	0%	Fractured shale reservoir, unknown how hydrogen will behave	50%	32 C	0%
Lost Hills, Point of Rocks	Point of Rocks	75%	Tumey / Kreyenhagen seal, unknown if faulted (overlying strata are faulted)	75%	Four way closure but potentially faulted at depth	50%	Reservoir properties not provided, known deepwater turbidite deposit.	100%	Likely >90 C based on geothermal gradient	28%
Lynch Canyon	Lanigan	50%	Sealed by the Monterey, this is a heavy oil field, with limited column height information	50%	Trap formed by sandy interval, the Lanigan sand, onlapping onto a basement step or high. Trap is low dip	100%	26-42% porosity, 55 ft net thickness	50%	40 C (104 F)	13%
Lyon Canyon	6th and 7th Zone within the Modelo	100%	Sealed by intraformational seals in the Modelo Formation	0%	Combination structural-stratigraphic trap, 374,719 bbl.	100%	No information	100%	9130-9775 ft	0%
Mahala	Wills Zone, in the West Mahala Zone	100%	Sealed by the lower Soquel formation.	50%	Complex field with multiple trap styles. The West Mahala and Mahala areas may be sufficient independently, there is some faulting	100%	25-100 ft net, 20-23 % porosity	50%	62.8 C (145 F)	25%

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Field	Reservoir	Seal Value	Seal Comments	Trap Value	Trap Comments	Reservoir Value	Reservoir Comment	Loss Value	Loss Comment	Composite Value
McClung, Stevens	Stevens	25%	Faulted N Marker / Reef Ridge seal, faults connect reservoir to Etchegoin sand above	50%	Fault trap, minimal accumulation column height, which may be indicative or limited fault trap capacity	100%	Stevens Reservoir a known prolific sand, 22% porosity and 200 mD perm	75%	73 C	9%
McCool Ranch	McCool Ranch	100%	Sealed by the lower Monterey Formation	50%	Lombardi sand units within the onlapping onto Santa Lucia Granodiorite basement. The closure is gently dipping and broad.	100%	22-38% porosity, net thickness 30-40 ft	50%	2250-2150 ft average depth, no temperatures	25%
McDonald Anticline, Agua	Agua	25%	Heavily faulted upper Santos formation seal	25%	Heavily faulted traps, multiple compartments	100%	Many reservoirs, with porosity typically between 25-45%, permeability up to 3000 mD	50%	54 C	3%
McKittrick, Phacoides	Phacoides	75%	Thick Santos seal, may be faulted as provided data suggests faulting in overlying Carneros	75%	Unfaulted four-way closure, high amplitude, potential faulting at depth	100%	Continuous, correlative sand package with 17% porosity and 140 Md perm	100%	110 C	56%
Merrill Ave Gas, Blewett	Blewett	100%	Continuous, unfaulted Moreno Shale seal	75%	Stratigraphic trap, well control not provided causing uncertainty in sub crop location	75%	27-34% porosity, 20-1700 Md perm; wide range	50%	65 C	28%
Mesa	Vaqueros	100%	Sealed by the Rincon Formation, > 1000 ft of shales, >100 ft column, mapped as fill to spill	50%	Independent 4 way closure on the headwall of a normal fault, fairly gentle dip	0%	60 ft net sand, with 22-27% porosity (estimated)	50%	2150 ft average depth	25%
Midway-Sunset, Republic	Republic	50%	Antelope (Monterey) seal, but known to be highly fractured in Midway Sunset	50%	Anticlinal structure with significant uncertainty in fault presence	75%	31% porosity, 150mD perm, known deepwater fan deposit	50%	46-76 C	9%
Mint Road Gas, Blewett	Blewett	50%	Moreno Shale seal, but throughgoing fault that connects to reservoir above seal	50%	Fault trap	75%	35% porosity, 54 Md perm; reservoir is thin	50%	76 C	9%
Mission	Fernando Zone	100%	Sealed by shale in the lower Pico, fault seal is by juxtaposition with the Modelo shale. Where sand/sand juxtaposition occurs there are wet sands.	100%	3 way fault dependent closure,	50%	No information	50%	6000 ft average depth	25%
Moffat Ranch Gas, Domengine	Domengine	50%	Faulted Kreyenhagen Shale seal	50%	Complex trap, combination fault, unconformity, and fault	50%	Thin, transgressive lag deposit	50%	44 C	6%
Monroe Swell	Beedy and Doud zones within the Monterey	50%	Sealed by the Monterey Formation, unclear if fill to spill due to available mapping	50%	Combination structural stratigraphic trap in folded sediments onlapping basement. Extent of trap unclear due to available mapping	100%	15-35% porosity, 500-1500 mD	50%	40- 43.3 C (104-110F)	13%
Montalvo	Colonia Zone and Gas Sands	100%	Colonia Zone sands sealed within the Sespe, and gas sands in the Pico, sealed within the Pico	0%	Field is in the hanging wall of the Oakridge Fault, highly faulted with at least 16 mapped faults	100%	Colonia Zone, 21% porosity, 243 mD	100%	110 C (230 F) in the Colonia	0%
Montebello	Main Area, 1st-3rd Zones, East and West Zones, 4-8th Zone	100%	Intraformational seals in the Puente and "Repetto" Formations	100%	At least 8 reservoir units, the 3 primary structures, trap for main zone is a 4 way closure of unclear origin, the west area is an anticline, and low-side 3 way closure. The field has multiple, disconnected compartments, but individual units may be extensive enough to be a storage candidate.	100%	Porosity data not available for all units, but for those that are 27-29% porosity, 50-700 mD	50%	Only temperatures are from shallowest zone, 43.3- 54.4 C (110-130 F), deepest interval (7650 ft)	50%
Monument Junction, Antelope	Antelope Shale	25%	Fractured reef ridge shale, appears interbedded with sand	25%	Heavily faulted anticline with apparent sand-on-sand contacts across fault	0%	Fractured shale, unknown how hydrogen will behave	75%	87 C	0%
Moorpark	Unnamed Sands within the Sespe	100%	Limited mapping, but shown as an 800 ft column, sealed by shale units within the Sespe	50%	Diagramed as stratigraphic trap within the Sespe or channels on a larger structure, map seems limited to two well penetrations, insufficient data	50%	No information on porosity or permeability, 80 ft net reservoir	50%	4250 ft	13%
Moorpark, west	Sand within the Sespe Formation	50%	Seals are shales within the Sespe Formation, unknown column height or field extent to evaluate fit to structure.	50%	3 way fault dependent closures, on both high and low side of the Canada de la Brea fault, channels draped on anticline in the NE portion of the field, limited mapping increases uncertainty	100%	Porosity 23.3% in unnamed interval, net reservoir for all reservoirs >400 ft	50%	62.8 C (145 F)	13%
Morales Canyon	Vaqueros	0%	Fault dependent seal that juxtaposes the reservoir in the Morales Formation with shales in the Soda Lake formation, there is an unknown column, but cross section indicates sand-sand juxtaposition may limit size, and no way to evaluate fit to structure	50%	Sub thrust 3 way against a fault	50%	No data presented	50%	59.4 C (139 F)	0%
Mount Poso, Vedder	Vedder	50%	Heavily faulted Freeman-Jewett seal	25%	Highly complex fault traps	75%	Vedder is subdivide into multiple zones and compartments. 35% porosity, 1,500 Md	50%	75 C	5%
Mountain View, Nozu	Nozu	50%	Laterally continuous Round Mountain seal, but faulted	50%	Poorly delineated fault and stratigraphic trap	75%	Sand appears continuous based on logs, but pool data suggests variable saturation, potentially due to reservoir quality variation. 22% porosity, 180 deg Perm	75%	81 C	14%
Newgate	Clark, Hathaway, and Santa Fe members of the Puente Formation	50%	Sealed by shale intervals within the Puente formation, and fault dependent seal, it is not mapped as fit to structure, but mapping available is limited.	50%	Footwall of a normal fault, 4 reservoir units, very little mapping information available.	50%	No data presented for porosity or permeability, ~300 ft net reservoir for all reservoir levels.	50%	7700-8900 ft	6%
Newhall	Multiple within the Neogene Section	0%	Multiple different seals at various areas, not enough information to evaluate, area is known for oil seeps at the surface.	50%	Field is spread over multiple areas, individual areas appear too small for storage. Variety of trap styles and sizes	100%	Various reservoir units, some with >20% porosity	50%	Max depth is 1581 ft	0%
Newhall-Potrero	7th Zone	100%	7th sand zone within the Modelo Formation, sealed by shale units within the Modelo.	50%	Structure is complexly faulted, with over a dozen faults mapped at the top of the Third Zone. The 7th zone is below the shallow level faults, based on a single cross section. Unknown if there are additional faults in the deep section. Anticline structure, but with high uncertainty.	50%	12.5% porosity, 24 mD	100%	11,806 average depth, 161.7 C (323 F)	25%
Newport	Mesa Sand	100%	Sealed by shales at the base of the "Pico" Formation	100%	Structural and stratigraphic traps, with two areas, one dependent on fault seal, the other limited by reservoir extent.	100%	No information	50%	1225 average depth	50%
Newport West	Multiple reservoir intervals within the "Repetto" and Puente Formations	100%	Very large field with individual fault compartments with greater than 1000 ft column heights, sealed by shales within the Puente and Repetto. Multiple accumulations have fault seal demonstrated by column height.	50%	Very complex faulted structure, at the convergence of two strike-slip faults, with many separated compartments. Some blocks are large enough to be candidates alone, but would need to be evaluated individually	100%	450-1500 mD, 36-25.5 % porosity	50%	43.3- 73.9 C (110-165 F)	25%
North Beldridge - Temblor	Temblor	75%	4,000 feet of Monterey shale sealing Temblor. Shale above is fractured	100%	Unfaulted 4-way closure	100%	25% porosity, 1100 mD, very high peak production rates	100%	96 C	75%
North Coles Levee - Stevens	Stevens	100%	Thick Monterey Seal directly atop Stevens sand	100%	Four way closure, not faulted in reservoir	75%	20% porosity, 114 Md perm, 35-230' thick; sand appears fingered, not connected in parts	100%	110 C	75%
North Deer Creek Santa Margarita	Santa Margarita	50%	Interbedded silt/clay/sand of the Santa Margarita is the seal (interformational seal)	75%	Unfaulted stratigraphic trap, lateral extents uncertain	50%	Santa Margarita known as poorly sorted, angular sand; cross sections suggests discreent, disconnected sand bodies; 32% porosity, 1800 Md perm, 25' thick sands on average	50%	21 C	9%
Oak Canyon	8 Zones within the Modelo	100%	Sealed by shale units within the Modelo, multiple reservoir levels separated by shale breaks	100%	3 mapped thrust faults setting up high and low side fault dependent traps, multiple compartments	100%		50%	55.6-100.5 C (132-213 F), highest temperatures are in the lowermost reservoir level, left at 0.5 for the majority of the field	50%

SoCalGas

C.4 Table of Evaluated Depleted Oil and Gas fields *(Continued)*

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Field	Reservoir	Seal Value	Seal Comments	Trap Value	Trap Comments	Reservoir Value	Reservoir Comment	Loss Value	Loss Comment	Composite Value
Oak Park	Sespe	0%	Shale units within the Sespe, crest of the structure is a < 500 feet below ground surface with mostly sandy intervals between crest and ground surface	100%	Hanging wall fault dependent closure, 3 mapped fault, 1 main compartment with two reservoir intervals.	100%		50%	40.6C (105 F)	0%
Oakridge	Topanga-Vaqueros	100%	Sealed by the basal units of the Monterey, ~ 500 ft above reservoir level is the Santa Susana fault plane	100%	Trap setup is in the footwall of the Santa Susana fault in a anticline. There are high and low side accumulations on either side of a secondary thrust fault.	100%	30% porosity, 430 mD	50%	43.3C (110 F)	50%
Oakview	Vaqueros	100%	Sealed by the Rincon	0%	Produced < 1000 bbl.	50%	No information	50%	1545 ft	0%
Oat Mountain	Multiple Eocene Sands	100%	Individual reservoirs are separated by shales in the Eocene, with overlying seal in the Repetto and Pico Formations, column is up to 600 ft	100%	Sub thrust closure in the main area, single mapped fault	50%	No information on porosity permeability, net reservoir is > 500 ft	50%	57.2 C (135 F) in shallowest interval (only temperature reported), deepest interval is at 9430-9690 ft	25%
Ojai	Multiple Miocene to Pliocene Sands	100%	Top seal by the Monterey Formation	100%	Ojai is comprised of several areas with multiple styles of traps. The highest producing intervals are within the Monterey Shale, including a sand unit within the Monterey in the Silverthread Area, with a 3 way subthrust trap. This unit alone may be of sufficient size for storage.	100%	Multiple reservoirs within the Miocene to Pliocene sections, some fractured shale, some sands with up to 30% porosity.	50%	30 C	50%
Olive	Dinkler Sand	100%	Sealed by shale at base of the Pico Formation.	50%	Fault complex with normal and reverse faults, setting up high and low side fault dependent closure, extent of field limited by lateral facies change. Individual fault compartments may be too small to develop as storage fields.	100%	22%, 82 mD, 200 ft net reservoir	50%	60 C (122 F)	25%
Orcutt	Monterey	100%	Sealed by the uppermost units of the Monterey Formation and the Sisquoc.	100%	Overall structure is an anticline in the hanging wall of the Orcutt Fault. Field has at least 4 fault bend folds. There are minor secondary areas, this is for the main area.	0%	Fractured shale makes up the main reservoirs in the Monterey, that are most of the main area.	50%	1700 ft	0%
Oxnard	Sespe	100%	Reservoir in the Sespe sealed by shales at the base of the Conejo-Topanga. Upper reservoir in the Monterey, not considered due to lack of top seal.	0%	Structural trap with a highly complicated fault network.	100%	15-28% porosity, net reservoir thickness is > 500 ft	50%	Reservoirs up to 73.9C (165 F) in deeper intervals.	0%
Pacoima	1-3 Gas sand	100%	Gas sands are isolated sands within the Lower Middle Mohnian (Modelo), and are sealed by shale interbeds. Well logs do not show above the reservoir section.	100%	4 way closure within a single fault block, the NE side is fault dependent	100%	23 % porosity, 480 mD	50%	73.9C (165 F)	50%
Paloma, Paloma	Paloma	75%	Unfaulted intraformational seal; uncertainty in vertical / lateral extent of seal vs reservoir facies	75%	Unfaulted combination structural stratigraphic trap	100%	Paloma is a Stevens sand with 30,000 peak oil production, 19% porosity and 30-100 md perm	100%	126 C	56%
Paris Valley	Basal Ansberry Sand	100%	Sealed by the Monterey Formation	0%	Independent four way closure, anticline in the headwall of a thrust fault, area of field is mapped very small.	100%	34% porosity, 3113 mD, 70 net reservoir thickness	50%	1090 ft depth	0%
Pioneer, Pioneer	Pioneer	25%	Hazelton Shale (Monterey) that is heavily faulted, appears interbedded	50%	Faulted anticline with both reverse and normal faults	75%	29% porosity and 1,500 md perm; multiple stacked reservoir compartments make compartmentalization likely	50%	49 C	5%
Piru	Modelo Sands	50%	No information	50%	No subsurface information, local geologic structure is a syncline	50%	No information	50%	900 ft	6%
Piru Creek	Modelo	100%	Sealed by the Modelo Formation	50%	No information, geologic structure in the area is a syncline	50%	No information	50%	2000 ft	13%
Placerita	Upper and Lower Kraft Zone	100%	Sealed by shale units within the Saugus, field has > 1000 ft column, fault dependent closure	100%	3 way fault dependent trap, no mapped faults within the main compartment	100%	35% porosity, >500 net reservoir	50%	600-1700 ft	50%
Playa Del Rey	Lower and Schist Conglomerate	100%	Seal by shales within the Puente Formation	100%	Trap setup by sands and schist conglomerates onlapping Catalina Schist,	100%	26%, 500 mD	50%	6200 ft	50%
Pleasant Valley	Temblor and Gatchell	100%	Sealed by interbedded shales within the Temblor and Gatchell Formations	50%	Insufficient map to evaluate, appears to be channels draped on inclined beds	100%	Temblor and Gatchell Sands, with 20 and 15.5 % porosity, respectively. Permeability in the Gatchell is 70 mD	100%	92.8-113.3 C (199-236 F)	50%
Pleito	Chanac	100%	Sealed by shales within the Chanac Formation	100%	Two primary areas: Creek Area faulted anticline, 3 compartments, Ranch Area, overturned beds in a fault propagation fold.	25%	Oil sand reservoir in the Santa Margarita, evidence of extensive biodegradation, and produced by fireflood. Deeper intervals within the Chanac Formation in the Ranch area have 13-24% porosity, 20-800 mD porosity	100%	70-94 C	25%
Point Concepcion	Gaviota and Sacate Sands	100%	Sealed by shale intervals within the Gaviota, fault dependent seal	100%	High side fault dependent closure, with 3 faults defining the block	100%	16-29 %,51-210 mD	50%	Deepest reservoir is 43.3C (110 F)	50%
Portrero	Sands in the Puente or Repetto Formation	50%	Shales in the Repetto and Puente formation, column heights are ~100-150 ft, but may be fill to spill. Multiple faults and fault dependent seals.	0%	Field is separated into at least 7 fault compartments, with 5 zones within multiple fault blocks, and the field is separated into two areas, limiting possible storage volume.	50%	Deeper reservoir units are the only available data, 15.8-19.2 % porosity.	50%	4930 ft	0%
Poso Creek	Kreyenhagen	100%	Sealed by the Macoma Claystone, column heights are > 250 ft	50%	Premier Area is the largest part of the field, structural traps with multiple fault blocks. Compartments may be in communication across faults.	100%	25-41% porosity, estimated. Permeability 150-7700 mD	50%	39.4 C (103 F)	25%
Prado-Corona	Upper Hunter	50%	Sealed by shales in the Yorba Member of the Puente Formation, fault dependent closure, unable to tell from mapping if fill to spill	0%	highly faulted structural traps	50%	No porosity/permeability data available, > 100 ft net reservoir	50%	2425 ft depth of the deepest interval	0%
Pyramid Hills	Kreyenhagen	100%	Reservoirs are sandy units within the Kreyenhagen, Martinez, and Moreno Formations. Shales within the Kreyenhagen and Moreno Formations act as seals.	100%	Large field with 7 areas, multiple trap closure styles, some fault dependent, some structural stratigraphic, and subcrops. There may be multiple compartments large enough for storage	100%	Reservoir properties vary within the field, but generally fall within the range of 30-38% porosity, with permeability up to 2315 mD	50%	Reservoir temperature up to 43.3 C (110 F)	50%
Quinado Canyon	Gamboa Kelly Sand	100%	Sealed by the Monterey Formation	0%	Field produced 9705 bbl	100%	20-26% porosity	50%	43.3C (110 F)	0%
Railroad Gap	McDonald Sand and Wygal Zone	100%	Sealed by unfractured section of Monterey formation	100%	4 way closure with multiple reservoir levels, no faults mapped within system	100%	Multiple reservoir levels with varying porosity and permeability, this rank refers to the deeper sand units, Macdonald Sand to Wygal Zone	100%	Up to 121.1 C (250 F)	100%
Raisin City	Miocene and Eocene Sections	100%	Sealed by the Kreyenhagen Formation	100%	Faulted anticline. Fault throw is less than the thickness of the overlying seal in cross section (only 1 cross section available).	100%	There are tars in the overlying section, not considered here. The Miocene and Eocene sections have 30.2 and 29.4% porosity, 579 and 168 mD permeability.	50%	50.6-60 C (123-140 F)	50%
Ramona	Black, Kern, and Del Valle	100%	Reservoirs are within the Modelo and are sealed by shales withing the Modelo, column is multiple hundreds of feet (not possible to determine exactly from mapping)	100%	3 way fault dependent closure, traps are in the hanging wall	100%	11-27% porosity, 42-100 mD, > 600 ft net reservoir	50%	2498-4500 ft depth for selected reservoirs	50%

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Field	Reservoir	Seal Value	Seal Comments	Trap Value	Trap Comments	Reservoir Value	Reservoir Comment	Loss Value	Loss Comment	Composite Value
Ramona, North	Del Valley (Deaton)	100%	Top and base seal are shales within the Modelo Formation, column height uncertain due to stratigraphic pinch out between wells, but estimated to be at least several hundred feet	50%	Structural-stratigraphic trap, limited mapping available	50%	No porosity or permeability data for the Deaton Zone, net reservoir thickness is 150 ft	50%	Average depth, 3500 ft	13%
Refugio Cove Gas	Vaqueros and Sespe	50%	Isolated sands within the Covarrubias and Vaqueros, sealed by shales within the Sespe and Rincon, respectively. No column height information or ability to assess fit to structure	50%	Unclear from mapping, may be channels draped over an anticline	100%	26-28 % porosity, 40-130 mD	50%	48.9 C (120 F)	13%
Richfield	Chapman and Kraemer Zones	100%	Sealed by shales within the Puente Formation, >1000 ft columns	100%	Fault compiles with multiple compartments. Size of individual compartments may make them sufficient as storage sites individually. Deeper intervals may lie below faults.	100%	Porosity 22-30%, permeability 537-1095 mD	50%	46.1- 85.6 C (115-186 F)	50%
Rincon	Padre-3rd Grubb	100%	Sealed by shales within the Pico Formation, field is complex, with multiple compartments, difficult to evaluate column height, but appears high.	100%	Subthrust trap in the Oak Grove Area, hydrocarbons are trapped in fold in the foot wall. Full field is very structurally complex, individual fault blocks would need to be evaluated as candidates	50%	Padre is only zone with porosity data (21% porosity), very high net reservoir.	100%	Padre is shallowest zone at 6600 ft, deepest in the 1st Grubb at 10,900 ft (no temperature data).	50%
Rincon Creek	Sands within the Sespe	50%	Sealed by the Sespe Formation, unable to evaluate fit to structure or column height	50%	Sub-thrust anticline, with fault seal and possible independent 4 way closure. Mapping not sufficient to evaluate trap shape.	100%	26% porosity, 40-90 mD	50%	61.7 C (143 F)	13%
Rio Bravo	Vedder	100%	Sealed by the Kreyenhagen Formation	100%	4 way closure with a single mapped fault on the NE corner, and two small offset faults through the structure (fault offset < thickness of seal)	100%	Reservoir is the Vedder Sand, 22% porosity,	100%	122.2 C (252 F), temperature may be high enough to drive reaction between hydrogen and hydrocarbons	100%
Rio Viejo	Stevens	50%	Sealed by the upper units of the Monterey. Locally, seal is sufficient, lateral continuity is unknown.	100%	Stratigraphic trap, sand channel on an inclined surface,	100%	The Stevens Sand, with 28-31% porosity, 28 mD permeability	100%	138.9 C (282 F)	50%
Riverdale	Fruitvale	50%	Interbedded sands and shales within the Zilch Formation	100%	Anticline, with two mapped, small offset faults.	100%	34-37% porosity, 762 mD permeability	100%	71.1 C (160 F)	50%
Rosecrans	Padelford-9th Zone within the Repetto and Puente Formation	100%	Sealed by shale intervals within the Puente and "Repetto", field extent is complicated, but shows an overall fit to structure	0%	Very structurally complex, with multiple fault blocks and reservoir levels	50%	17-28% porosity, 25-40 mD	100%	85- 93.3C (185-200 F) at 7200 ft depth, with deeper zones that do not have temperature data available	0%
Rosecrans, East	Zins to 8th Zone within the "Repetto"	0%	< 100 foot column indicated by extent of field, column size may be limited by sand-sand juxtaposition across the fault	50%	3-way fault dependent closure, very limited mapping displaying the structure	100%	20-28% porosity, no permeability data, > 1000 ft net reservoir	50%	5800-7500 ft	0%
Rosecrans, South	Zins to 8th Zone	100%	Sealed by shale units within the "Repetto" and Puente Formation. Main area on southwest side of the Newport Inglewood fault has > 400 ft column.	100%	Multiple reservoir levels and complex faulting on the NE side of the field. The size of the main fault block, and communication across the Newport-Inglewood fault may be of sufficient size for a storage candidate alone.	100%	20-23% porosity, 25-40 mD, these values are estimates	50%	6200-8600 ft	50%
Rosedale	Chanac	100%	Sealed by shales in the Reef Ridge Formation	100%	Multiple areas of the field with fault dependent traps	100%	Multiple reservoirs with appropriate properties, 24-33% porosity, 300-800 mD permeability	50%	53.3 C (128 F)	50%
Rosedale Ranch	Chanac	50%	Sealed by interbedded shales within the Chanac Formation. May not have sufficient lateral continuity.	0%	Main area is composed of a series of linked normal faults. There are multiple fault compartments, some of which may be in communication	100%	Chanac Formation, 29% porosity, up to 780 D permeability	50%	60C (140 F)	0%
Round Mountain	Vedder	100%	Interbedded shales in the Freeman-Jewett	100%	Fault Complex with multiple field areas, the size of the field is large enough that individual blocks may have sufficient storage	100%	Multiple oil and gas reservoirs in the Freeman Jewett Formation and Vedder Formation. Porosity > 25%, with permeability ranging from 6-11,600 mD	50%	70.6 C (159 F)	50%
Rowland	La Vida	100%	Mapped fill to spill with > 200 ft column height, sealed by shale intervals at the base of the Soquel formation for the upper reservoir, log data are missing for the lower reservoir	0%	3 way fault depend closure on the upthrown side, cumulative production of 1885 bbl oil.	50%	No information	50%	2383-3250 ft depth	0%
Russel Ranch	Dibblee	50%	Fault dependent seals and by undescribed parts of the Painted Rock and Vaquero. Column heights within fault blocks are possible several hundred feet, but need to evaluated individually	0%	Structural trap with > 20 mapped faults. The field is large, but the density of faults creates many separate compartments.	100%	25-32% porosity, 102-1330 mD	50%	3500 ft deep for the deepest interval	0%
Salt Lake	C, D, E Zones	100%	Shale units within the Repetto and Puente Formations.	50%	Thrust fault structure with multiple fault blocks, at least 10 mapped faults within the field. Trapping geometries include high and low side faults, overturned beds, and possible 4 way closures within the field, creating high uncertainty of adequacy.	100%	Porosity values are 34 and 62%, 62% does not seem possible. 34% porosity unit has 311 mD permeability	50%	48.9- 51.7 C (120-125 F)	25%
Salt Late, South	Multiple Repetto Sands	100%	Shale units within the Repetto	50%	Highly inclined stratigraphic traps as mapped, information is unclear on the subsurface structure.	100%	23-29% porosity, 555 ft total net reservoir	50%	52.8- 57.2 C (127-135 F)	25%
San Ardo	Aurignac Oil Sand	100%	Monterey Formation is the seal, with > 400 ft tall column	50%	Broad closure with low dip.	100%	34-39% porosity, with 2000-8000 mD permeability, net thickness 120 ft	50%	38.9- 57.2 C (102-135 F)	0%
San Clemente	Shultz	100%	Top seal are shales within the Pleasants member of the Williams formation. Total column height is not clear from mapping, but the cross section indicates at least ~100 ft	100%	Two separate traps on the up thrown and down thrown side of a fault. Both are fault dependent closure, the downthrown block has a small independent four way.	100%	17% porosity	50%	58.9 C (138 F)	50%
San Joaquin	Eocene	100%	Sealed by the Kreyenhagen Formation, with > 300 m of shale	50%	There are 4 fault blocks within the field, with	100%	32.5% porosity, 539 mD permeability	50%	No temperature reported, but reservoir depth is 7000 ft	25%
San Joaquin, Northwest,	Nortonville	100%	Shales within the Kreyenhagen, ~400 ft thick with multiple penetrations on the structure.	100%	Structure is mapped as a four way closure formed by an anticline without any mapped faults.	100%	30% porosity, 200-500 mD permeability	40%	58.3 C (137 F)	40%
San Miguelito	Grubb, multiple zones	100%	Sealed by shales above the Grubbs, within the Pico Formation. The field is large, and difficult to distinguish independent column heights based on mapping presented. Given the high dip and extent of hydrocarbon, seal appears adequate. Trap may be at leak off.	50%	Fault propagation fold bisected by fault trace. Hydrocarbon accumulations on both high and low side of the fault. Mapping unclear if compartments are connected	100%	> 2000 ft of net reservoir across all zone. 10-25% porosity, with 32-33 mD permeability	100%	Deepest reservoir intervals are 12,300 ft depth, the 3rd Grubbs at 8600 ft depth is 96.1 C (205 F)	50%
San Vincente	Clayton, Dayton, and Hay	100%	All reservoirs have fault dependent seal, top seal for the Dayton are ~400 ft of shale within the Clifton formation. The Hay is a subunit of the Puente formation and is sealed by overlying shales.	50%	The overall field is a subthrust structure with fault dependent closure. There are additional faults not present on the cross section transect so cannot be evaluated.	100%	22-23 % porosity, 100-2000 mD	50%	45 C (113 F)	25%

C.4 Table of Evaluated Depleted Oil and Gas fields *(Continued)*

California Oil And Gas Fields - Evaluation Framework

Field	Reservoir	Seal Value	Seal Comments	Trap Value	Trap Comments	Reservoir Value	Reservoir Comment	Loss Value	Loss Comment	Composite Value
Sansinena	Sansinena	100%	Shales within the Yorba and Sycamore Canyon	0%	Highly faulted structural trap, with at least 15 fault blocks. It is a large field, so individual fault blocks may be large enough to be candidates	50%	The A, C, and D intervals have porosity 21-32 %, permeability of 100-390 mD, other intervals do not have data	50%	Deepest average depth noted is 5200 ft	0%
Santa Clara Avenue	Sands within the Sespe	50%	Sealed by interbedded shales within the reservoir section, with lateral facies change providing up dip seal. Seal is not laterally continuous.	0%	Structural stratigraphic trap formed by inclined beds with sands that shale out up dip to the east. Reservoir connectivity within sand units appears challenged.	50%	Sands within the Sespe Formation. There is limited data, 24% porosity.	-	8630-9000 ft depth	0%
Santa Fe Springs	Repetto and Puente	100%	Sealed by shales within the Repetto, mapping is unclear of column size, but may be up to 500 ft column	100%	4 way closure with faults in the lower intervals	100%	17-32% porosity, 16-820 mD, separation within the zones are not clear, given the variable permeability the flow paths may be complicated	100%	47.2- 104.4 C (177-220 F)	100%
Santa Maria Valley	Monterey	100%	Top seal by shales within the lower Sisquoc	100%	Structural-stratigraphic trap with fault dependent closure in the SE side of the main area and a stratigraphic pinch out in the NW. There are upper tar mat zones that are not considered as part of this evaluation.	0%	Fractured Shale	50%	Deepest reservoir interval is 7000 ft	0%
Santa Paula	Pico and Santa Margarita	0%	Field was produced by tunneling in asphalt mats	0%	Field was produced by tunneling in asphalt mats	50%	No information	50%	Deepest interval is 3130 ft	0%
Santa Susana	1st and 2nd Sespe	100%	Fault dependent seal, and top seal by shales within the Modelo and Sespe formations for the 1st and 2nd Sespe zone, respectively. Column heights are greater than 400 ft	100%	Footwall block between two reverse faults	50%	No porosity and permeability data, 650 total net reservoir	50%	2600 ft	25%
Saticoy	G-K zone within the Pico Formation	100%	Sealed by shale units within the Pico formation, >1000 ft columns, fields may be at leakoff column height	100%	Footwall of thrust fault, with sand units mapped as pinching out before reaching the fault	100%	13.8-25% porosity, with 53.5-200 mD	50%	85 C (185 F), 4000 ft depth	50%
Saugus	15 and 21 Zone	100%	Sand units are within the Modelo and are sealed by shales within the Modelo.	100%	Hydrocarbon accumulations in hanging walls of two blind thrust faults.	50%	15% porosity, 1.6 mD permeability, porosity and permeability are estimated, if these were measured values, rank would be 0.	100%	9500-10000 ft	50%
Sawtelle	Rancho	100%	Sealed by shales in the Modelo Formation	50%	Structure in main area not clear from mapping. Trap is set up by overturned beds in the footwall of the Santa Monica Fault	100%	24% porosity, 30 mD, 350 ft net reservoir	100%	134.4 C (274 F)	50%
Seal Beach	Repetto	100%	Top seal by shale within the Puente and Repetto Formations	100%	Fault complex on either side of a strike slip fault. Multiple fault blocks, some connected, some independent columns. The size of the field may make individual fault blocks viable storage options.	100%	Repetto Sands, 25-30% porosity, 125-200 mD	50%	52 C	50%
Semitropic	San Joaquin	100%	Reservoirs are sands within the San Joaquin Formation, and are sealed by interbedded shales	50%	Trap are sandy channels draped over an anticline with shallow dip.	100%	28% porosity, 1100 mD	50%	San Joaquin Sands reservoir temperatures are up to ~52.8 C (127 F), the deeper, smaller compartments are up to 148.9 C (300 F)	25%
Semitropic, Northwest	San Joaquin	100%	Shales within the Kreyenhagen, ~400 ft thick with multiple penetrations on the structure.	100%	Structure is mapped as a four way closure formed by an anticline without any mapped faults.	100%	30% porosity, 200-500 mD permeability	40%	58.3 C (137 F)	40%
Sespe	Rincon-Vaqueros	50%	Top seal by "Pico" formation undifferentiated sands and shales, little information presented to evaluate.	50%	As mapped, a stratigraphic trap with the Sherwood Zone pinching out up dip. Limited information available.	50%	No information available	50%	Deepest reservoir at 2980 ft	6%
Seventh Standard	27-3 Sand within the Stevens Formation	100%	The accumulation is sealed by shales in the overlying parts of the Stevens Formation.	100%	3 way fault dependent closure with no mapped faults	100%	27% porosity, 110-380 mD permeability	50%	187 F	50%
Shafter	Vedder	0%	The accumulation within the fault dependent structure is limited to an area of 4 way closure indicating that the fault is not sealing	0%	Small 4 way closure within a 3 way fault dependent closure. 54,651 bbl and 45,600 Mcf of gas	100%	15% porosity, 20 D permeability	100%	180 F	0%
Shafter North	Etchegoin	0%	Sealed by the Reef Ridge Shale	50%	Structural stratigraphic trap, the McLure is depicted as a channel on a run of dip, but distribution isn't shown.	50%	No porosity or permeability data available	50%	170 F	13%
Shafter, Southeast, Gas	Kreyenhagen	0%	Reservoir is a sandy unit within the Etchegoin Formation, sealed by shale interbeds	100%	3 way fault dependent closure, field extent does not follow fit to structure in a 1 reservoir field, may indicate unmapped faults or some stratigraphic component to the trap.	100%	28 % porosity, 500 mD permeability	50%	112 F	50%
Sherman	Sherwood	100%	Top seal are shales in the "Pico" and "Repetto" units, base seal in the Modelo Formation. This is a stratigraphic trap.	50%	Limited mapping available but appears to be a tilted stratigraphic trap formed by Miocene strata onlapping the Santa Monica Slate	50%	No porosity or permeability data available, 250 feet net reservoir	50%	1650 ft and 2980 ft for lower interval	13%
Shiells Canyon	El Rancho	100%	Top seal are shales within the Sespe	50%	Main field area is a faulted anticline with at least 6 faults. Faults displacement is less than reservoir thickness, but may be barriers to flow.	100%	18% porosity, 121 mD permeability, 87 ft net reservoir	100%	2250 ft average depth in the intermediate (Rancho) reservoir, the overlying shallow reservoir reports a temperature of 236 F at 1000 ft.	50%
Simi	Sespe	50%	Multiple fields with different seal units, many of the accumulations have either a continuous column to the surface or are sealed by bitumen in place. Rank at .5 for the possibility of using some of the deeper reservoirs.	50%	Coal Canyon area is the most viable trap, a four way closure with no mapped faults. Multiple reservoir levels that can boost volume. Mapped as less than one section in size.	50%	Llajas and Sespe Reservoirs, no data presented.	50%	Deepest reservoirs are at <2000 ft	6%
Sisquoc Ranch	Monterey	50%	Top seal is within the Monterey, no additional information.	50%	Trap is in a fold on the upthrown block of a reverse fault. Mapping is not sufficient to say more.	0%	Fractured shale	50%	43.3 C (110 F)	0%
Somis	Sespe B-1	100%	Seal are shales within the Sespe Formation, field extent is not shown, but column height is >250 ft	50%	Trap is a fault dependent closure against the Simi Fault,	50%	500 ft net reservoir, no porosity or permeability data available	50%	3950 ft	13%
South Beldridge - Lower Tulare	Lower Tulare	50%	Tulare is not a known seal to hold back pressurized O&G columns.	75%	low relief unfaulted anticline	75%	High porosity / perm, braided fluvial (connectivity challenge)	25%	30 C	7%
South Coles Levee - Stevens	Stevens	100%	Thick Monterey Seal directly atop Stevens sand	100%	Four way closure, not faulted in reservoir	75%	20% porosity, 114 Md perm, 35-230' thick; sand appears fingered, not connected in parts	100%	106 C	75%
South Cuyama	Dibblee Sand	100%	> 500 ft oil column, sealed by the Monterey	0%	> 50 mapped faults	25%	177-215 mD porosity, 26-29%	50%	63 C	0%
South Mountain	Bridge	100%	Top seal is shale in the upper Sespe Formation	50%	Complex fault network through the main field area, a thrust fault complex sets up multiple trapping geometries with at least 14 fault blocks. The field is large enough that individual fault blocks may be storage candidates	100%	15% porosity and 24 mD permeability, net reservoir 1000 ft	50%	37.8 C (100 F)	25%
Southeast Burrel - Zilch	Zilch	75%	Appears self-sealing, but Zilch not documented as a sealing facies	50%	Unfaulted, stratigraphic trap, but very broad and low relief	50%	Unknown porosity / perm, 10 feet thick	50%	55 C	9%
Stockdale	Nozu	0%	No fit to structure in mapped extent, seal are shales in the Lower Stevens, and interbedded shales in the Chanac in the old area.	50%	Controls on field extent are unclear, trap may be a structural-stratigraphic trap, limiting information available.	100%	13-15% porosity, 20-400 mD	50%	131 F	25%
Strand	Multiple interval within the Fruitvale Formation	100%	Shales within the Fruitvale	50%	Structurally complex field with multiple reservoir levels. There are 3 primary fault bounded closures	100%	19% porosity, 110 mD	50%	178 F	25%
Summerland	Multiple options, Vaqueros and Sespe Chosen	100%	Vaqueros sealed by Rincon, Sespe producing intervals sealed by the upper Sespe	100%	Imbricate thrust faults that are propagated to the surface have formed stacked, steeply dipping units. Multiple traps make up the field, with fault dependent closures in the hanging walls.	50%	No data	50%	3200 ft	25%

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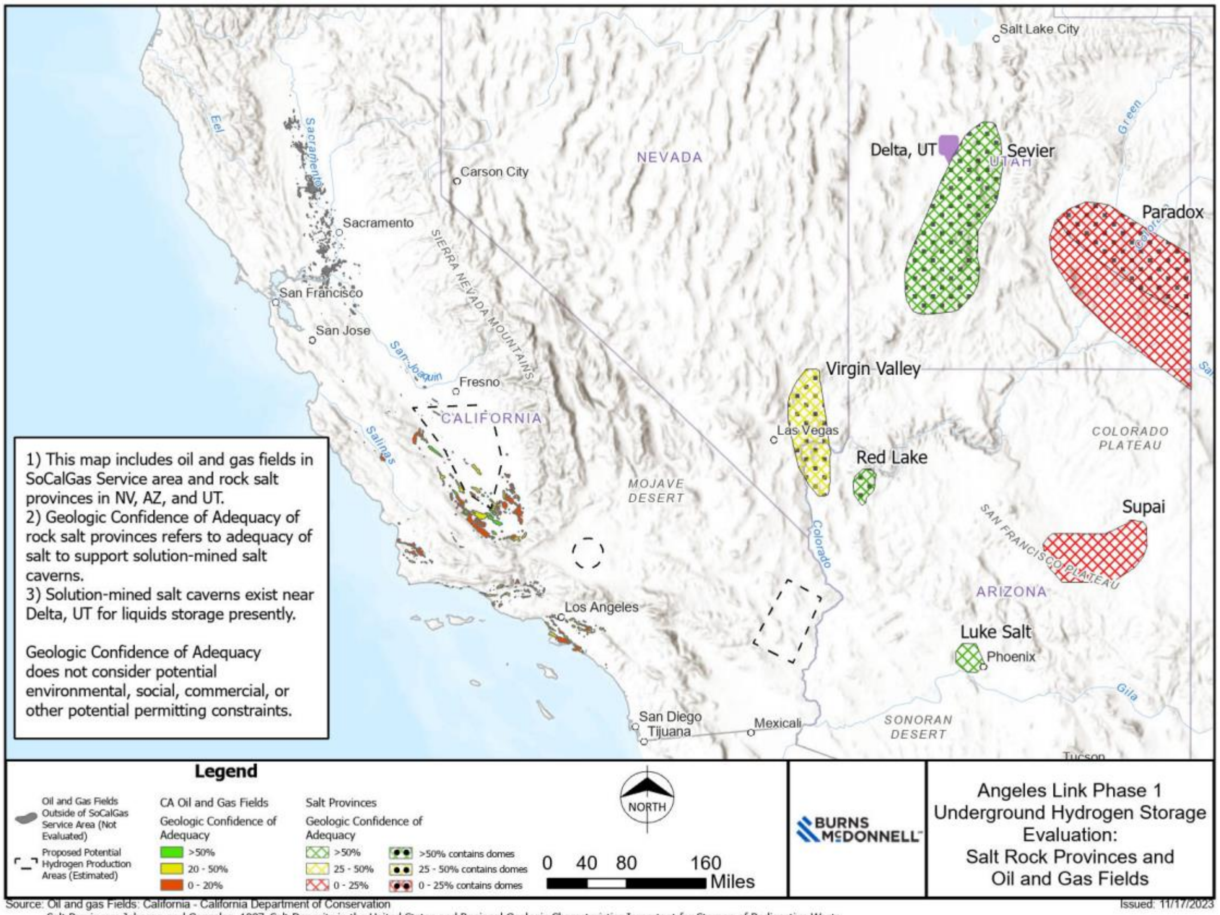
Field	Reservoir	Seal Value	Seal Comments	Trap Value	Trap Comments	Reservoir Value	Reservoir Comment	Loss Value	Loss Comment	Composite Value
Sunset Beach	Lomita Lands	100%	300 ft column sealed by shales in the lower Puente Formation	100%	Tilted beds in the footwall below, structure is an anticline	50%	No information	50%	2750 ft	25%
Talbert	Sands within the Repetto	100%	Shales within the Repetto and Puente Formations, column heights are between ~ 100-400 ft	50%	Field include at least three areas, with both high side and low closures. The areas are separate enough to be considered separation candidates, though that may make them too small	50%	Limited data, 100 net in at least two pools	0%	5400-5700	25%
Tapio	Yule Sand	100%	Sealed by shales within the Pico-Saugus Formation >300 ft column	50%	Trap is formed by an angular unconformity between the Pico-Saugus and the underlying Castaic Formation. The trap is cut by 3 mapped faults. Dip is gentle.	50%	100 ft net thickness, no porosity/permeability data	50%	1050 ft	13%
Tapo Canyon, South	Multiple reservoirs within the Sespe and Modelo Formation	100%	Intraformational seals within the Sespe and Modelo Formations	50%	Highly faulted, with at least 8 mapped faults. Between the complexity of multiple reservoir levels and faults with > throw than reservoir thicknesses reservoir connectivity will be difficult to assess	100%	Porosity 25-33, with	50%	47.2C (117 F) at deepest interval	25%
Tapo Ridge	1325 Sand	100%	Sealed by several hundred feet of the Modelo Formation, 400 ft column.	100%	Unfaulted anticline	50%	No information on porosity and permeability, 160 ft net reservoir.	50%	1750 ft	25%
Tapo, North	5 zones within the Modelo Formation	100%	Shale intervals within the Modelo	50%	10 fault compartments. The overall structure is combined structural-stratigraphic trap 3 way trap. The complexity of faulting, and the of multiple reservoir levels, will make assessing connectivity challenging.	100%	Total net is > 500 ft, porosity data is only available for the V Zone at 30%	50%	Deepest interval is at 2000 ft	25%
Taylor Canyon	Quail Canyon	100%	Sealed by the Soda Lake Member of the Vaquerous, with > 1000 ft of shale.	100%	3-way fault dependent closure, in the headwall of a normal fault.	100%	20-30% porosity, 200 ft net reservoir	50%	51.7-54.4C (125-130 F), 5620 ft average depth	50%
Tejon	Multiple reservoirs in the Miocene, Pliocene, and Pleistocene age strata	100%	Seal may be limiting factor on some pools, but overall there are laterally extensive shales within the Fruitvale, Santa Margarita, and Kern River-Chanac Formations.	100%	There are 4 main areas of the field, with multiple reservoir levels present at each of them. Due to the large size of the field, individual compartments are likely large enough to serve as storage. There are variety of trapping mechanisms, with 3 way and 4 way closures, some structural, some structural-stratigraphic traps present.	100%	Reservoir properties vary by level and area of the field but are overall excellent, with porosity in the 20-35% range, and permeability up 3350 mD.	50%	Multiple reservoirs at different depths, max depth is ~57.2 C (135 F)	50%
Tejon Flats	San Emigdio	50%	Sealed by interbedded sand and shales in the San Emigdio and Vedder. Section above the discovery is high net sand, suggesting seal continuity may be a problem, but not enough data presented to assess.	0%	Cumulative production of 22118 bbl oil and 7632 Mcf gas, trap size is too small.	0%	22% porosity, 150 mD, net thickness 7 ft, insufficient net thickness	50%	~54.5 C (130 F)	0%
Tejon Hills	Santa Margarita, Valv, Vedder, and San Emigdio	100%	Santa Margarita and Valv are sealed by shales in the Chanac, Fruitvale, respectively. Type log for Valv-Pulv appears inconsistent with tabulated data. Vedder is sealed by basalt, and San Emigdio is sealed by shale in the lower Vedder.	50%	Minimum of 11 mapped compartments, with multiple reservoir levels. Most compartments are bounded by faults on three sides, based on map pattern, there may be communication between fault blocks.	100%	Santa Margarita, Valv, Vedder have ~30-45% porosity, with up to 8000 mD permeability.	50%	Max reservoir temperature is ~45.5 (114 F)	25%
Tejon, North	Multiple reservoirs within the Vedder Formation	100%	Shales in the Vedder Formation,	0%	Fault complex with > 20 fault compartments, mapping doesn't indicate basement involved faulting	50%	Multiple reservoirs with variable properties	100%	Deepest reservoir intervals is 115 C (239 F)	0%
Temblor Hills	Temblor	100%	Sealed by shales in the Temblor and Keyenhagen Formations	0%	Traps are formed within an imbricate thrust fault complex, with both 3 and 4 way closures, field produces from thin sands, unlikely to be large enough for adequate storage	50%	11-18%, 15 mD	50%	50 C (122 F)	0%
Temblor Ranch	Wygal Phacoides	50%	Sealed by shales within the Temblor formation, field distribution does not conform to structure, and the oil column is only within the top section of sand. Spill point may be leak across the fault.	50%	Size appears marginal, field is separated into two areas both fault dependent structures on two sides of closure.	100%	Porosity and permeability are inferred, 21% and 20 mD, respectively.	50%	21.1 C (70 F)	13%
Temblor, East	Temblor	100%	Seal by the lower units of the Monterey Formation	0%	Very small 3 way fault dependent closure	100%	22% porosity, 100 mD permeability, properties are estimated	50%	46.1 C (115 F)	0%
Temescal	F Zone	100%	Sealed by intraformational seals in the Modelo Formation, 800 ft column	100%	4-way closure with no mapped faults	100%	300 ft net reservoir, 20% porosity	50%	2600 ft depth	50%
Ten Section	Stevens	100%	Field is mapped as fill to spill from a 4 way closure with 350 ft column height. Immediately overlying seal is a shale break within the Stevens Formation, but there are additional sealing units above.	100%	Anticline with no mapped faults through the structure.	100%	20% porosity, 10-3000 mD permeability	100%	93.3 C (200 F) reservoir temperature	100%
Terra Bella	Santa Margarita	50%	Mapping is insufficient to evaluate seal continuity	0%	Mapping is insufficient to evaluate trap configuration and size, cummulative production is 17,653 bbl oil	100%	31% porosity and 2000 mD permeability, value are inferred	50%	32.2 C (90 F)	0%
Timber Canyon	A and B Sand in the Santa Margarita	0%	Very tall columns as mapped, > 3000 ft, sealed beneath the Santa Margarita. Top of the oil column is mapped as within 500 ft of ground surface, for the purposes of hydrogen storage, < 500 overburden would not demonstrate containment	50%	Fault complex with at least 7 mapped faults. A variety of traps are present	100%	Porosity 20-31%, permeability 200 mD	50%	3000 ft average depth	0%
Torrance	Upper Del Amo Zone	100%	Intraformational seals within the Puente.	100%	Normal fault complex, with at least 5 faults. Within each fault block, the structure appears simple. Fault blocks may be large enough to operate as independent units.	0%	0	50%	29% porosity, 114 mD	50%
Torrey Canyon	Sespe Formation, multiple sand intervals	100%	Sealed by shales within the Sespe Formation and fault dependent seals. Supported column heights are > 300 ft	0%	Fault dependent closures in the headwall of a thrust fault. There are at least 8 mapped faults within the field, including fault splays.	50%	12 % Porosity, 41 mD permeability	50%	78.9C (174 F)	0%
Trico Gas	Atwell Island, First Mya	100%	Sealed by shales within the Tulare and San Joaquin formation. Field is mapped as fit to structure, but with no identified spill point	50%	Fields is a large anticline with 4 sub-crests, simple structure, but broad with shallow dip (~50 ft elevation change over 1.5 miles)	100%	26-34% porosity, 1200-1500 mD	50%	62.2 C (144 F) temperature	25%
Trico, Northwest, Gas	Mya and Atwell Island	100%	Sealed by shales within the Tulare and San Joaquin formations.	100%	Trap is a complex 4 way closure, trap overall has gentle dip. Pinnacles on the structure may be of sufficient size.	50%	28-34% porosity, 135 mD, average net thickness 8-10 ft, may not have enough reservoir of sufficient quality for storage	50%	42.2-47.8 C (108-118 F)	25%
Tulare Lake	Tulare Sands	100%	Reservoirs are interbeds of sand within shale at the base of the Temblor Formation, the sands produced independently, but there may be communication between zones, compromising seal for any one zone.	50%	Gentle 4 way closure, structure may be too broad.	100%	12.5-17% porosity, 60-186 mD	100%	Reservoir temperatures are 125.6-128.3 C (258-263 F)	50%
Turk Anticline	McDonald Sands	50%	Sealed by shales of the Upper Temblor formation, mapping is not sufficient to evaluate seal.	50%	As mapped, trap is unclear, may be a channel draped over the western side of an anticline, but very limited data presented.	50%	20 ft net thickness, the porosity and permeability are good, 500 mD, 29.5% porosity	50%	85.6 C (186 F)	6%
Turnbull	St Clewenger	50%	Sealed by the "Upper Siltstone, column is at least 300 ft tall. Siltstone seals may be heterogeneous and there are large bodies of sand overlying the siltstone.	100%	3 way fault dependent closure, headwall of a listric normal fault	100%	27% porosity, 105 mD permeability	50%	Average depth of deepest interval is 3950 ft	25%

C.4 Table of Evaluated Depleted Oil and Gas fields *(Continued)*

BURNS & McDONNELL — California Oil And Gas Fields - Evaluation Framework

Field	Reservoir	Seal Value	Seal Comments	Trap Value	Trap Comments	Reservoir Value	Reservoir Comment	Loss Value	Loss Comment	Composite Value
Union Avenue	Santa Margarita	100%	Sealed by interbed sands and shales of the Chenac formation.	100%	3 way fault dependent closure, dip may be too gentle.	100%	20-30% porosity, 1400 mD permeability	50%	Reservoir temperature 54.4 (130 F)	50%
Union Station	Massive Zone	50%	Intraformational seals within the Puente, max column height of 100 ft, otherwise limited information	0%	22 % porosity, 10-17 mD	100%	Reservoir is 23-18% porosity in the Puente Formation, `0-20 mD permeability	50%	186 C	0%
Vallecitos	Multiple, Domengine-Yakut, San Carlos Sand	100%	Kreyenhagen and Lodo Shale formations are seals for various pools. In general thick, laterally extensive marine shales. There are some pools near ground surface that do not have sufficient seal.	100%	Structurally complex synclinal area, the field is spread among multiple pools with different trapping configurations. Difficult to summarize due to variety of structures, but enough options that individual pools may be of sufficient size.	100%	18-33 % porosity in the Yakut-Domengine, up to 780 mD permeability.	50%	Highest reported reservoir temperature is 52.2 C (126 F), many pools at lower temperatures	50%
Valpredo	Santa Margarita	50%	Sealed by undifferentiated Pliocene and Pleistocene aged sediments overlying an angular unconformity at the top of the Santa Margarita. The uncertainty is due to the lack of information about the extent of field and crest of structure.	50%	Field is in the high side of a reverse fault, the crest of the structure is not shown on the map figure, and the trapping mechanism is unknown. There is a normal fault within the field that offsets the Santa Margarita, with throw < formation thickness.	100%	24 % porosity, 200 mD permeability (estimated).	50%	58.9 C (138 F), 6715 ft depth	13%
Van Ness	Miocene	0%	Reservoir is within the Zilch Formation, with interbedded sands and shales. Local seal is in shale. The section is overall sandy, and seal may not be continuous throughout area.	50%	Mapping is not sufficient to understand structure (mapped horizon is in different geologic unit, above an angular inconformity).	100%	28% porosity, 250 mD permeability.	50%	63.9 C (147 F)	0%
Venice Beach	Schist Sand	50%	Sealed by shales within the Puente Formation, column height is a minimum of 100 ft. Log information difficult to see in diagrams, increasing uncertainty	50%	Trap is formed by sands onlapping Catalina Schist basement. There is a basement cutting fault running through the anticline trap.	50%	No property information.	50%	6000 ft average depth of schist sands	6%
Ventura	7 Zones within the Pico Formation	50%	Intraformational seals within the Pico Formation. Separation between reservoir levels appear thin, but the well log lacks depth information so not possible to tell.	100%	Faulted 4-way, with at least two thrust faults with the field area.	100%	Extremely high net reservoir - over 2000 ft, with porosity 17-20%, permeability is 17-48 mD	100%	Deepest intervals are at 101.7-148.9C (215-300 F)	50%
Walnut	Yule Zone	100%	600 ft tall column. Sealed by shales at the top of the Pico Formation	100%	Trap formed by angular unconformity between the Pico and the underlying Castaic Formations, the Yule Zone sands pinch out.	100%	17% porosity, 100 ft net thickness	50%	35C (95 F)	50%
Wasco	A-2 Sand at the base of the Freeman-Jewett	100%	Shales in the Freeman-Jewett and Olcese Formations.	50%	Mapped structure shows limited information available, not enough to evaluate structural shape other than very shallow dip.	100%	12-15 % porosity, 278 mD permeability.	100%	136.1 C (277 F)	50%
Wayside Canyon	Sespe Formation, multiple sand intervals	50%	Column height is unclear due to complicated reservoir architecture. Intraformational seals within the Sespe are the primary seals. Again, the complicated depositional pattern may cause a lack of continuity	100%	4 way closure with faults on Southern margin	50%	No information	0%	4500 ft	25%
Welcome Valley	Tumey	0%	Sealed by clay rich sediments in alluvium and viscosity of heavy oil	100%	Trap is a subcrop underneath alluvium.	0%	Fractured shale	50%	23.9 C (75 F)	0%
West Buena Park	Repetto	100%	>2000 ft column	50%	Unknown structure, may be anticline	75%	No porosity data available, Repetto sands	100%	11,000 ft deep	38%
West Coyote	Emery Zone (Repetto)	100%	Sealed by shale intervals within the Repetto and Pico Formations	100%	Faulted 4 way, mapped as one fault that	100%	Porosity 20% in > 500 ft of sandstones	50%	5500 ft depth	50%
West Mountain	Sespe	40%	Sealed by interbedded shales within the Sespe, may have limited lateral continuity	100%	Faulted anticline formed at the confluence of a strike slip and normal fault. The reservoir has multiple levels, within	50%	Sespe Formation sands in channels. No porosity or permeability data given.	50%	4500 ft depth	10%
Westhaven	Temblor	100%	Sealed by the lowermost Monterey Formation (locally the McLure Member), > 900 ft thick on the type log.	0%	Limited map data available, structure appears to be 4 way closure with low dip. Trap is too broad and small for storage purposes.	50%	18-21% porosity, 20-25 mD permeability, low ranking is due to low measured permeability. Average net thickness is 6 ft.	100%	Reservoir temperature is 137.8 C (280 F).	0%
Wheeler Ridge, SE Area	72-34 Sand	100%	Shales within the Olcese Formation, multiple units above, including the Fruitvale Shale.	100%	Trap is subthrust fold with one fault running through.	100%	24% porosity, with 570 mD permeability. There is 130 ft net thickness.	50%	71.1 C (160 F) reservoir temperature	50%
Wheeler Ridge, Windgap	72-34 Sand	100%	Seal is the Fruitvale Shale, with > 1000 ft thickness in type log. Field limit is sand extent on two sides, on remaining side not drawn as fit to structure.	100%	Trap is a subtrust folded structure, bounded to the NE by a down to the SW normal fault. The normal fault may or may not be at the limit of the field.	100%	29% porosity, with 855 mD permeability. There is 150 ft net thickness.	50%	60 C (140 F) reservoir temperature	50%
White Wolf	Yowlumne Sand	50%	Heavy oil field very close to ground surface (815 ft average depth, crest is within 600 ft of surface). Seal	50%	Fault complex with at least 6 faults.	100%	Porosity is 30%, permeability is 339 mD.	50%	Average depth is 850 ft, reservoir temp is 22.8 C (73 F)	13%
Whittier	Puente Formation	100%	> 1000 ft column in at least 1 compartment within the field. This is a complex field, seals are shales within the Puente Formation	100%	Complex field with multiple reservoirs and > 6 fault blocks within the field. Due to large size, may be a candidate within single fault block	100%	Net thickness 200 ft, 13-20 % porosity	50%	1600 ft average depth	50%
Whittier Heights, North	Upper Zone and Lower Zone in the La Vida	100%	Intraformational seals within the Puente Formation, ~300 ft column	100%	3 way fault dependent closure, in the footwall of a normal fault.	50%	140 net thickness, no porosity/permeability data	50%	1600 ft	25%
Wilmington	Multiple within the Puente Formation	50%	Sealed by the "Pico Formation", Field is very close to the surface, deeper intervals may have adequate seals	0%	> 20 faults within the field	100%	12-29% porosity, 26-1638 mD	100%	114.4C (238 F)	0%
Yorba Linda	Main Zone, Shell Zone	50%	Sealed by shales within the "Repetto", column height not clear from mapping	100%	Stratigraphic trap underneath an angular unconformity between the "Repetto" and La Habra zones	100%	25-44 porosity, up to 2000 mD	50%	21.1- 46.1C (70-115 F)	25%
Yowlumne	Monterey Sand	100%	2200 ft column in the Yowlumne Sand,	100%	Trap is a structural stratigraphic trap, with a sand channel draped over stratigraphic contours	100%	18-20 % porosity, 50-100 mD, reservoir is a sand unit within the Monterey Formation.	100%	11,200-13,300 ft depth	100%
Zaca	Monterey	100%	Sealed by the arenaceous and cherty units of the Monterey	50%	Fault dependent closure, on head wall side of a normal fault, multiple fault compartments, unclear if they are in communication	50%	Fractured shale, higher uncertainty on reservoir quality	50%	151.7- 71.1 C (25-160 F)	13%

C.5 Maps of Evaluated Underground Storage Site



Source: Oil and gas Fields: California - California Department of Conservation
Salt Provinces: Johnson and Gonzalez, 1987, Salt Deposits in the United States and Regional Geologic Characteristics Important for Storage of Radioactive Waste

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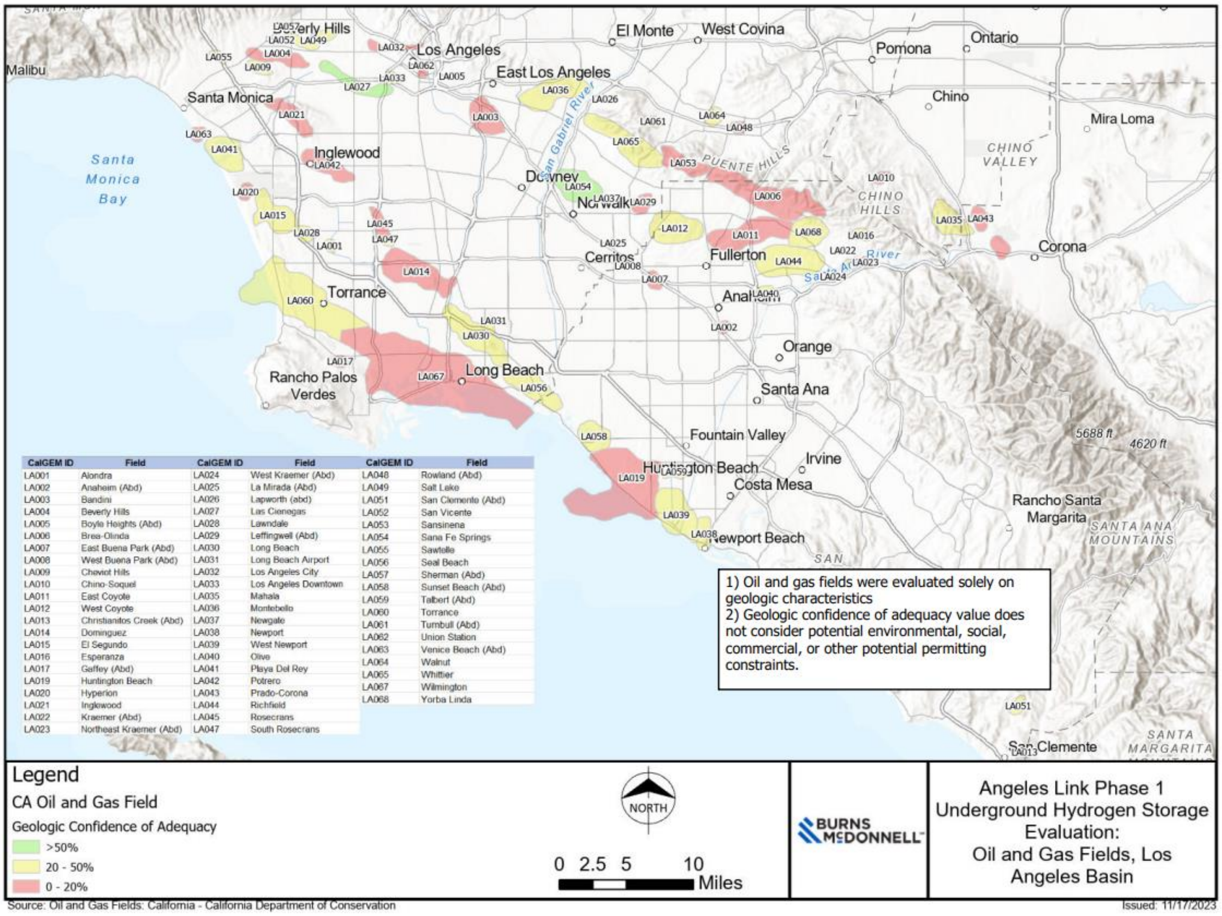
C.5 Maps of Evaluated Underground Storage Site *(Continued)*



CalGEM ID	Field	CalGEM ID	Field	CalGEM ID	Field
LA001	Alondra	LA024	West Kraemer (Abd)	LA048	Rowland (Abd)
LA002	Anaheim (Abd)	LA025	La Mirada (Abd)	LA049	Salt Lake
LA003	Bandini	LA026	Lapworth (abd)	LA051	San Clemente (Abd)
LA004	Beverly Hills	LA027	Las Cienegas	LA052	San Vicente
LA005	Boyle Heights (Abd)	LA028	Lawndale	LA053	Sansinena
LA006	Brea-Olinda	LA029	Leffingwell (Abd)	LA054	Sana Fe Springs
LA007	East Buena Park (Abd)	LA030	Long Beach	LA055	Sawtelle
LA008	West Buena Park (Abd)	LA031	Long Beach Airport	LA056	Seal Beach
LA009	Cheviot Hills	LA032	Los Angeles City	LA057	Sherman (Abd)
LA010	Chino-Soquel	LA033	Los Angeles Downtown	LA058	Sunset Beach (Abd)
LA011	East Coyote	LA035	Mahala	LA059	Talbert (Abd)
LA012	West Coyote	LA036	Montebello	LA060	Torrance
LA013	Christianitos Creek (Abd)	LA037	Newgate	LA061	Turnbull (Abd)
LA014	Dominguez	LA038	Newport	LA062	Union Station
LA015	El Segundo	LA039	West Newport	LA063	Venice Beach (Abd)
LA016	Esperanza	LA040	Olive	LA064	Walnut
LA017	Gaffey (Abd)	LA041	Playa Del Rey	LA065	Whittier
LA019	Huntington Beach	LA042	Potrero	LA067	Wilmington
LA020	Hyperion	LA043	Prado-Corona	LA068	Yorba Linda
LA021	Inglewood	LA044	Richfield		
LA022	Kraemer (Abd)	LA045	Rosecrans		
LA023	Northeast Kraemer (Abd)	LA047	South Rosecrans		

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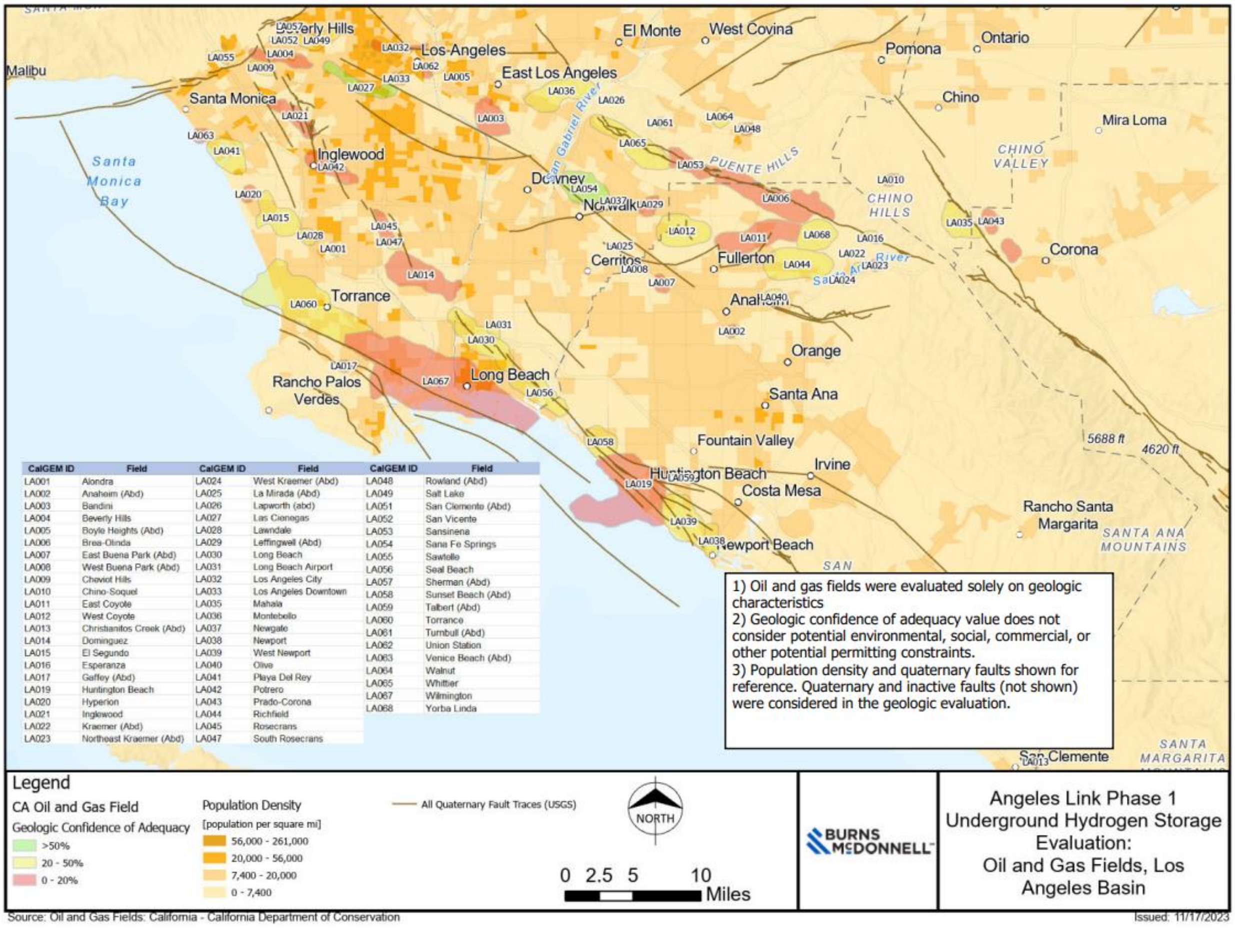

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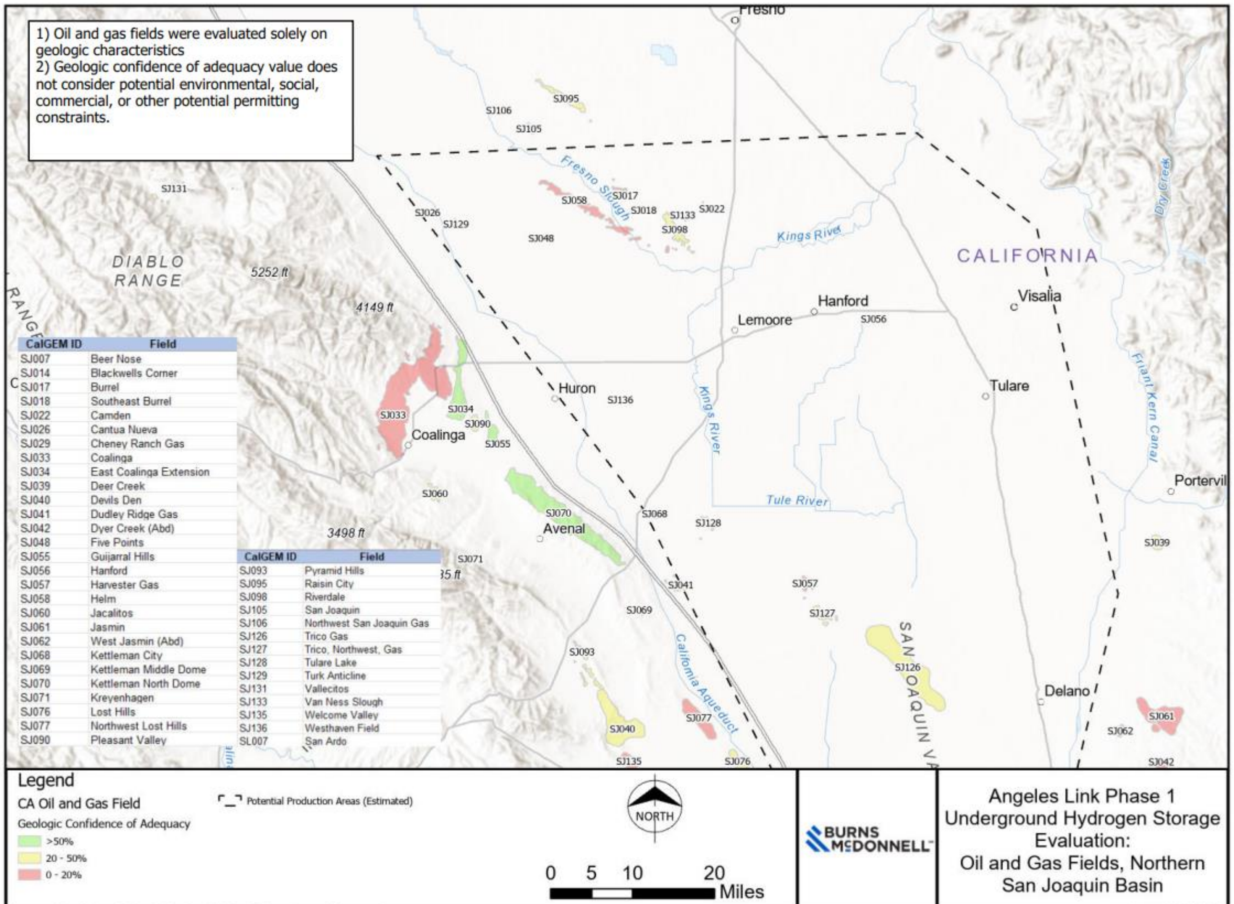

Source: Oil and Gas Fields: California - California Department of Conservation

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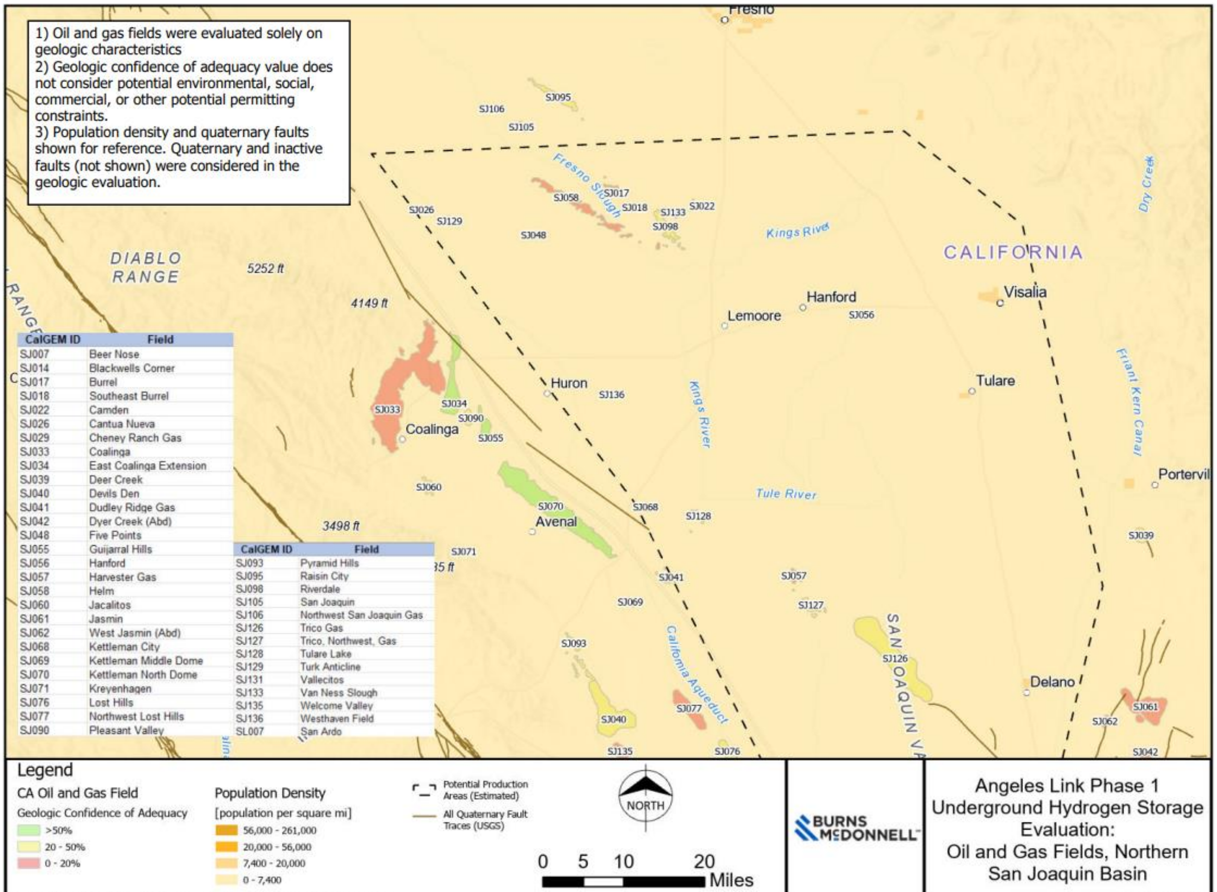

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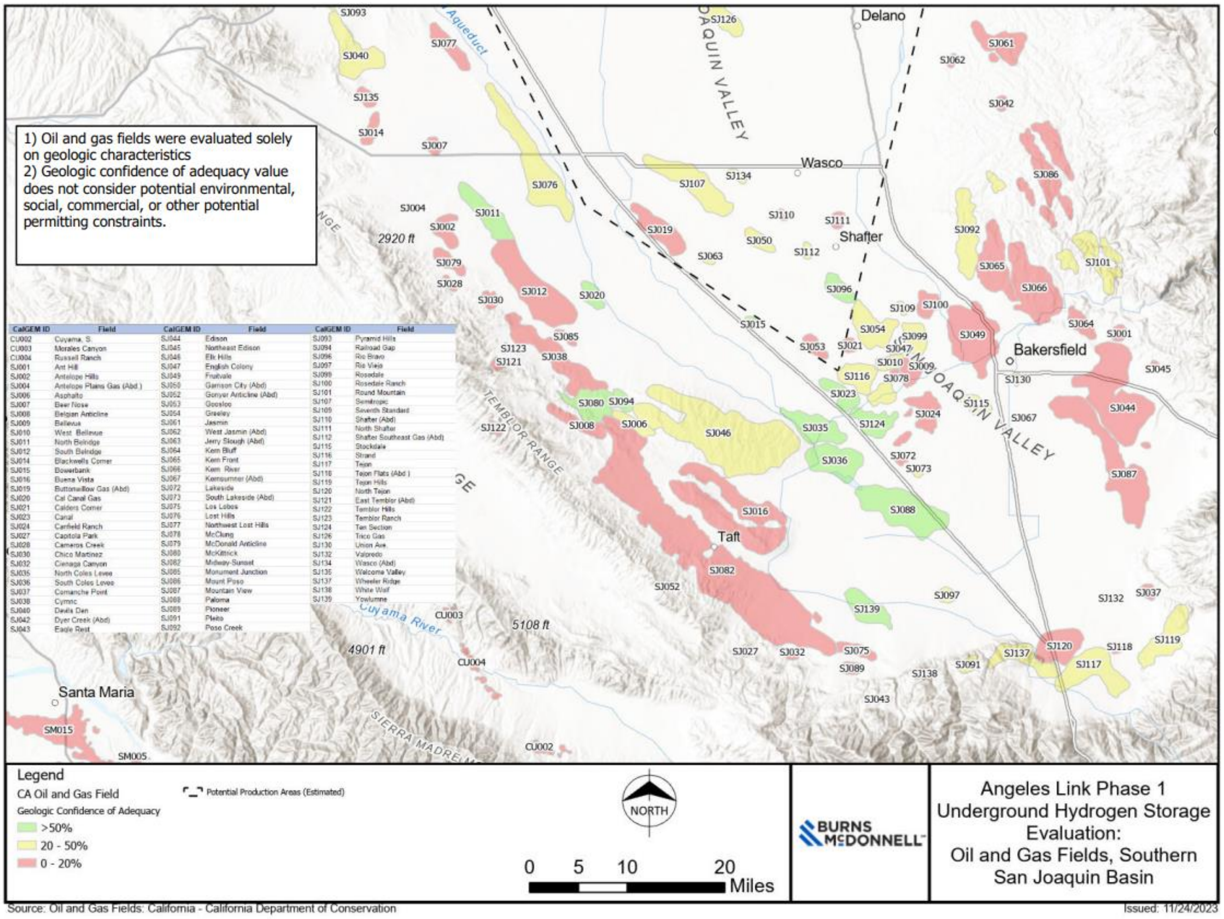

Source: Oil and Gas Fields: California - California Department of Conservation

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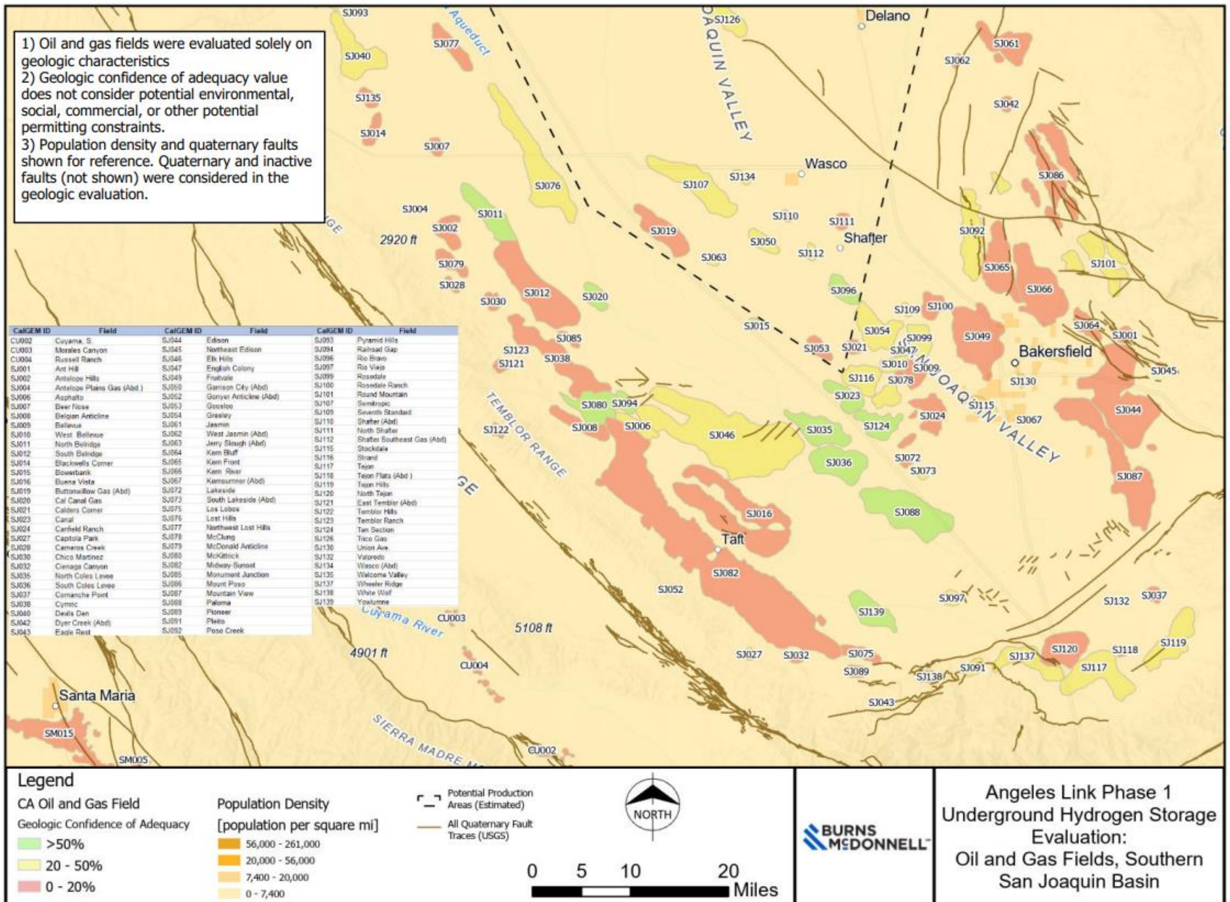
C.5 Maps of Evaluated Underground Storage Site *(Continued)*



Source: Oil and Gas Fields: California - California Department of Conservation
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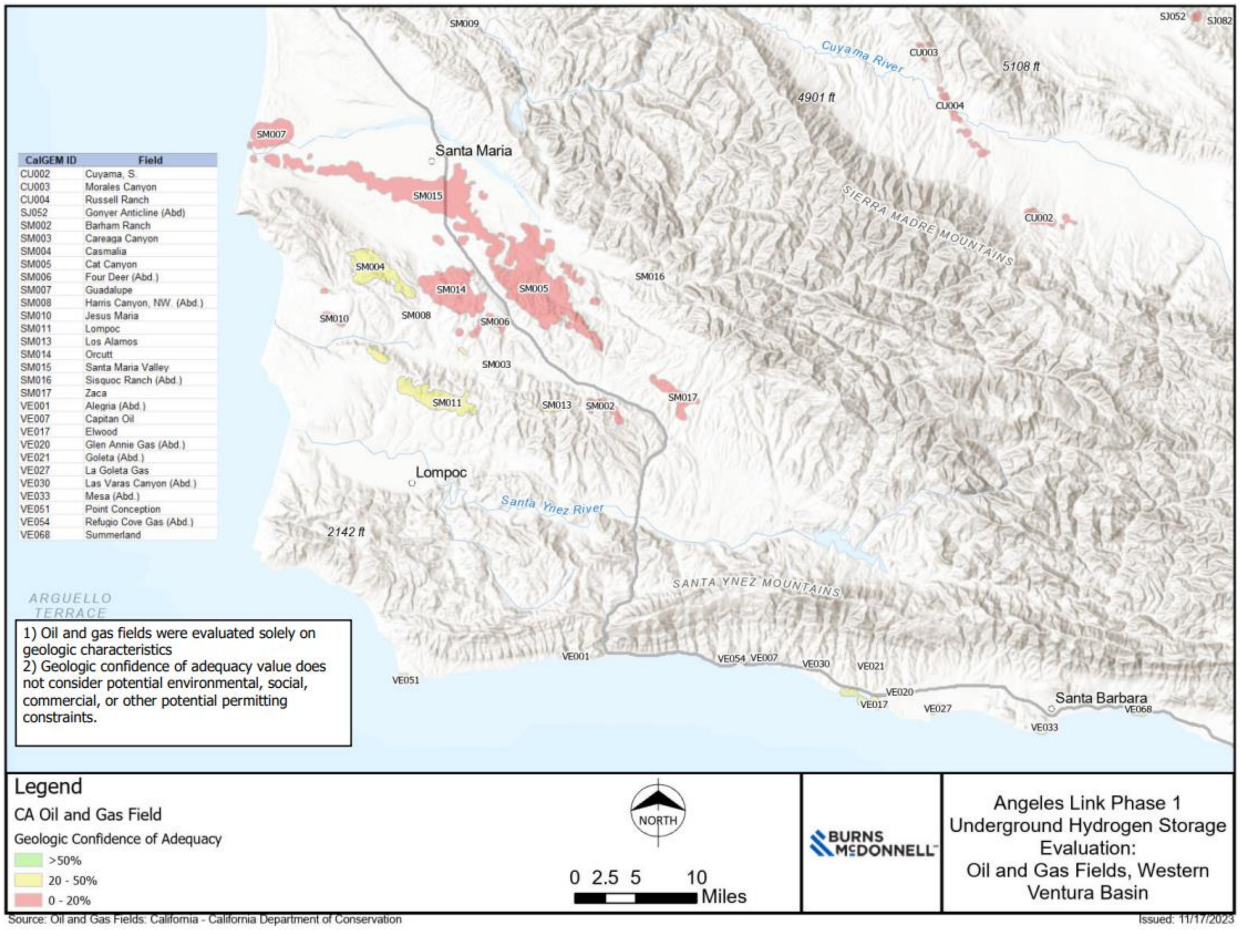

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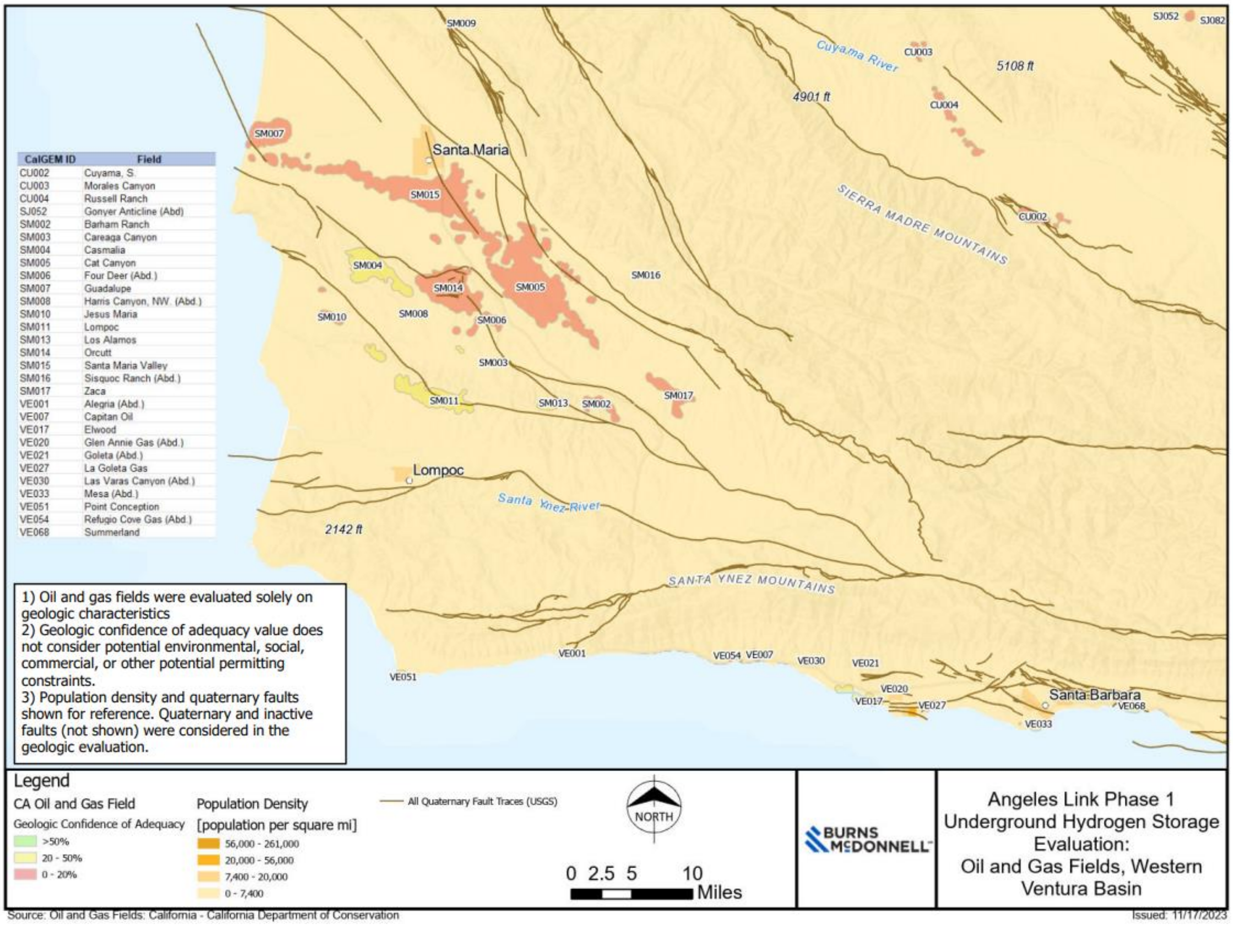

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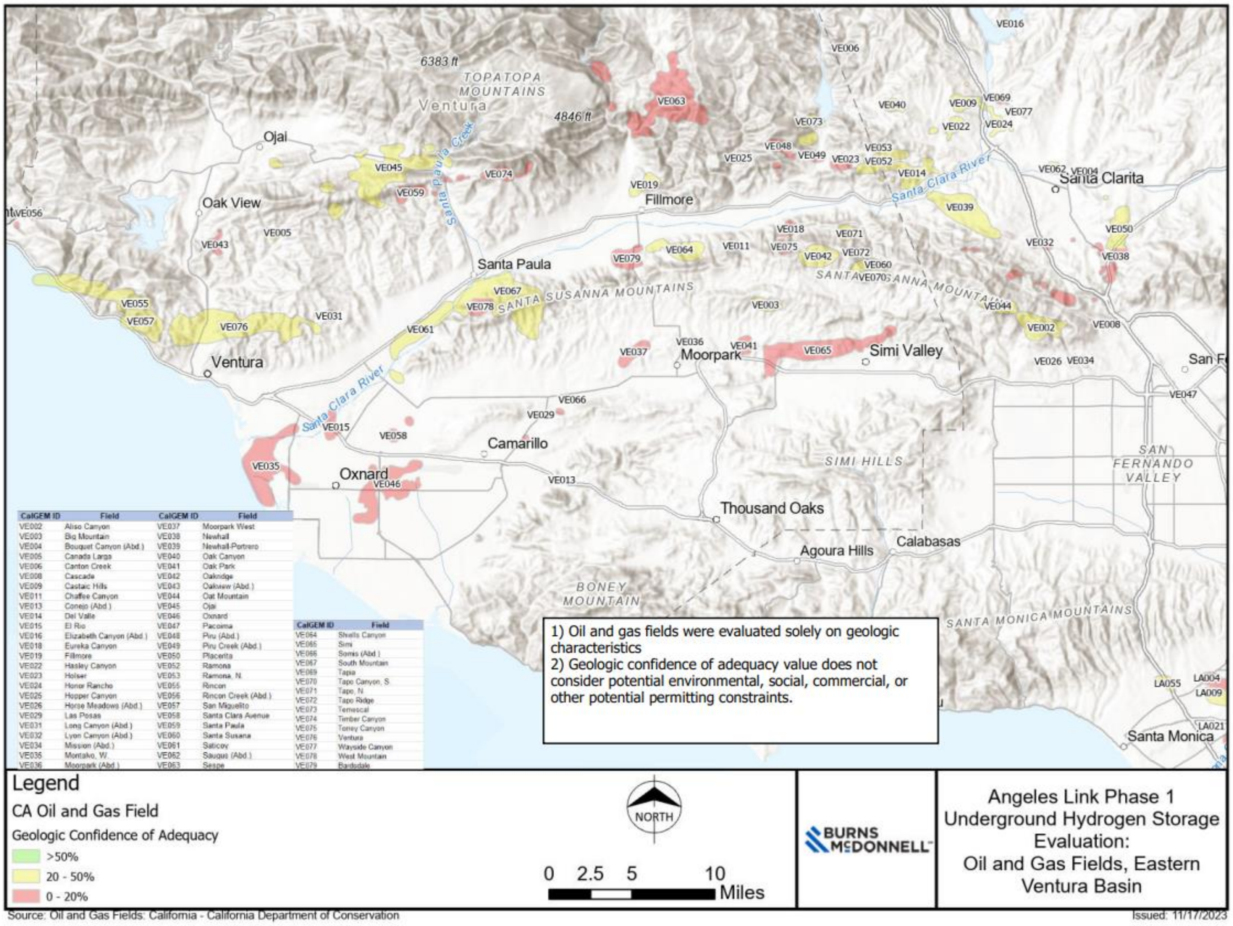

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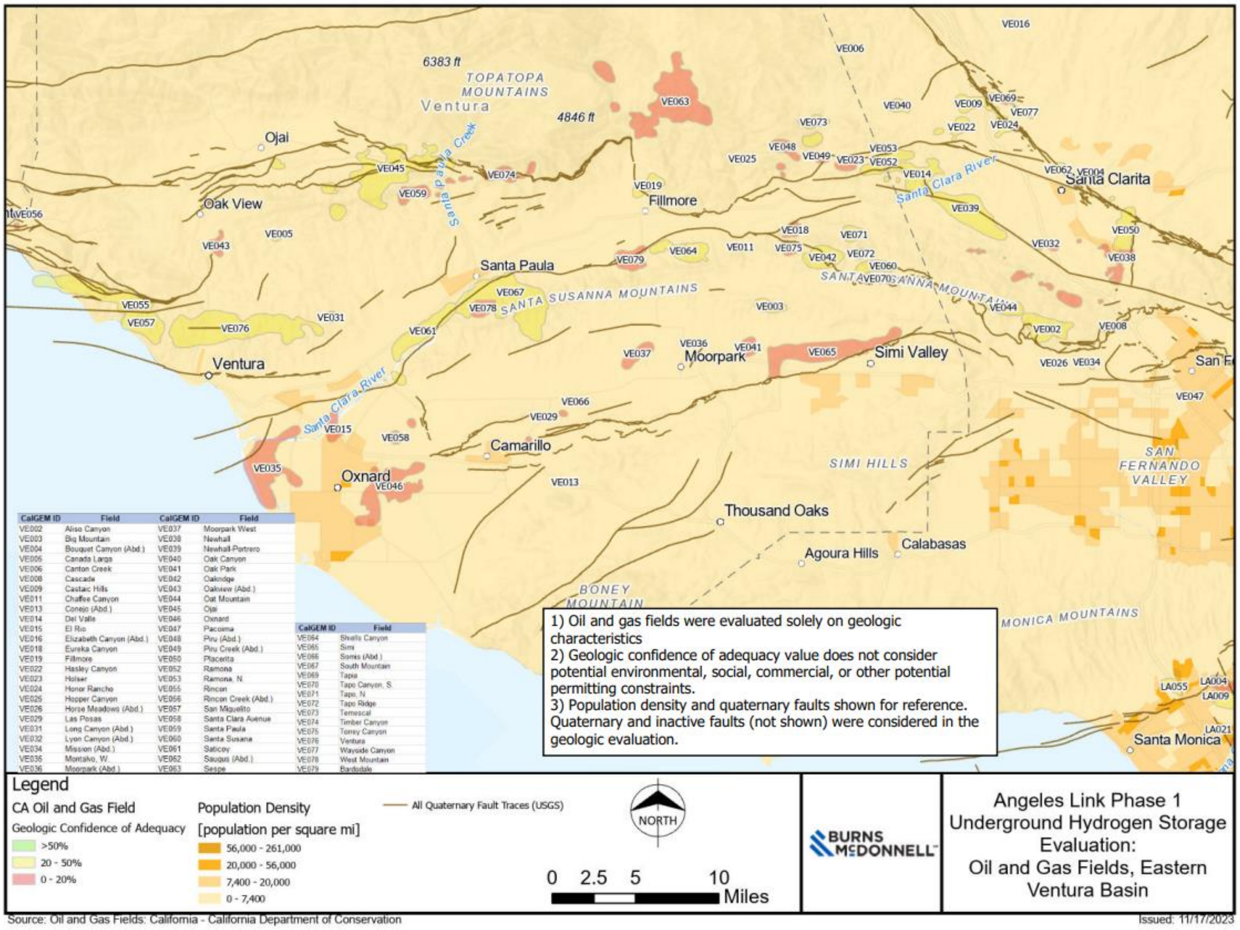

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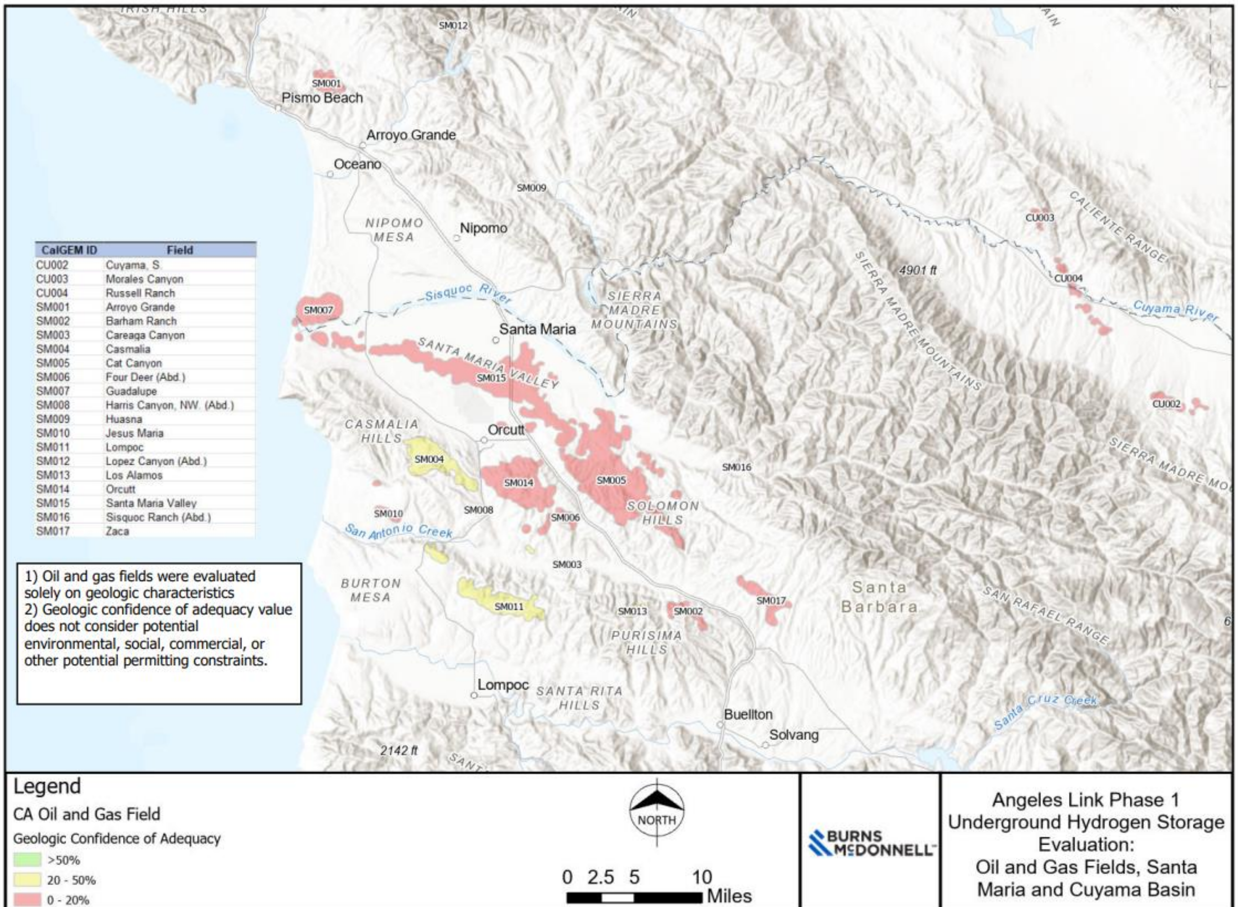

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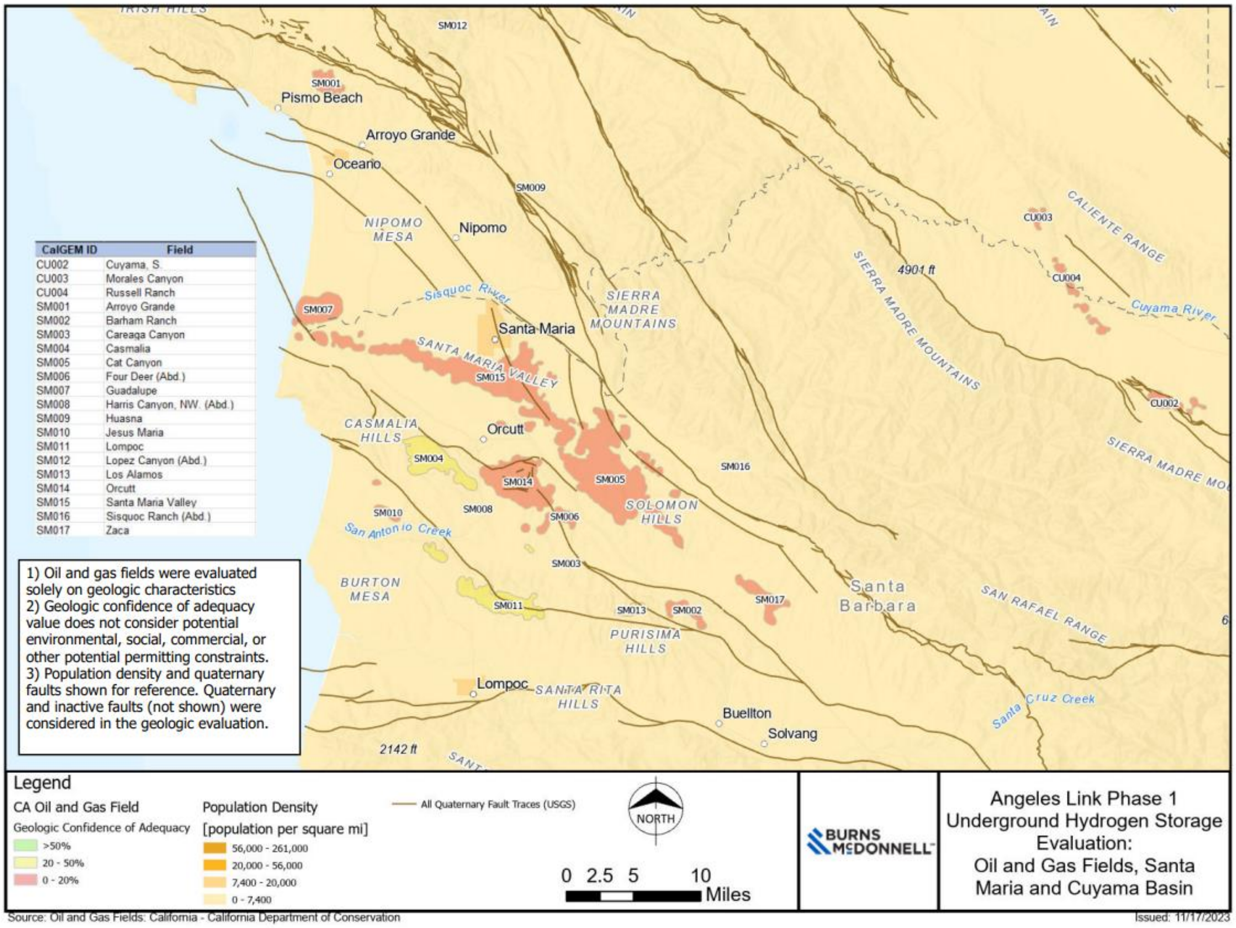

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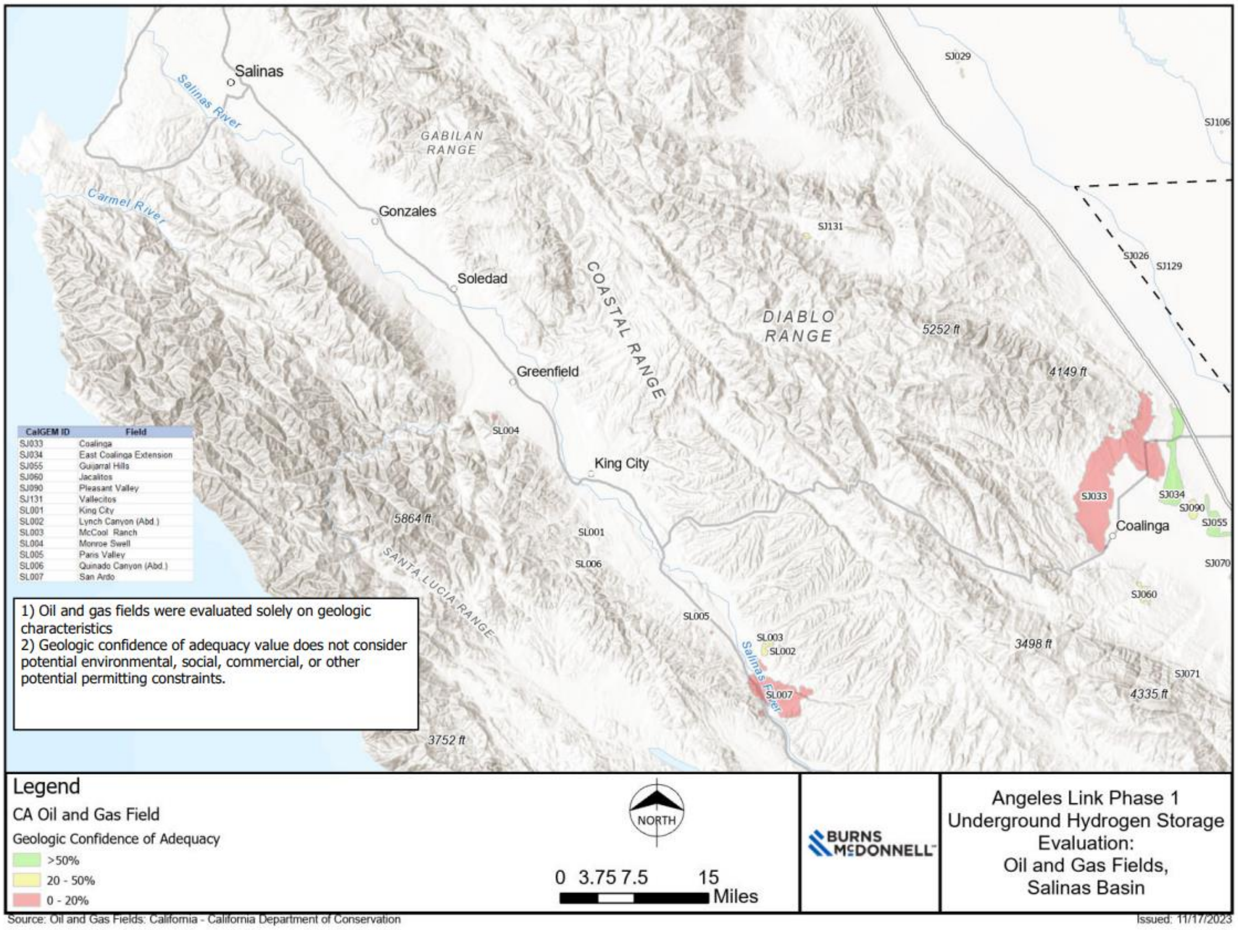

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