Angeles Link – Phase 1
Quarterly Report (Q3 2024)

For the period of July 1, 2024 through September 30, 2024

Appendix 1D - Draft Reports:
Production Study
Design Study
Routing Analysis

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ANGELES LINK PHASE 1

Production Planning & Assessment

DRAFT – JULY 2024

SoCalGas commissioned this analysis 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 Input

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 draft 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 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 with local utility distribution power for minimum power needs to enable startup and shut down (Section 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

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

[2] Decision (D).22-12-055 specifies use of clean renewable hydrogen, which is hydrogen produced with emissions less than 4 kg CO_2 for each kg H_2 and not derived from fossil fuels.

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.

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 (CPUC) requirements of SoCalGas as determined in its final decision (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 Angeles Link Final Decision states, "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 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

[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] California Public Utilities Commission (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.
[6] Refer to Section 2.3 for the applicable clean renewable hydrogen definition.

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 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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[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").

[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/2023-12/greet-manual_2023-12-20.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). While the CPUC definition of clean renewable hydrogen does not currently require adherence to the three "pillars," 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.[15]

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.[16] 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.

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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/2023-12/greet-manual_2023-12-20.pdf

[14] "Assessing Lifecycle Greenhouse Gas Emissions Associated with Electricity Use for the Section 45V Clean Hydrogen Production Tax Credit." DOE. December 2023. Link to Guidance.

[15] *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 behind the meter clean, renewable resources will be used to meet the requirement of 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 - how close hydrogen production needs to be located to renewable electricity generation. The 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 behind the meter to a co-located hydrogen production facility.

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

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. 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.[17] 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,[18] 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 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 to help confirm that hydrogen produced meets the clean renewable hydrogen standards.

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

[17] Examples include: 1) Open Hydrogen Initiative (OHI) (gti.energy); 2) Home | Green Hydrogen Organization (gh2.org)
[18] Section 45V(c)(2)(B)(ii).

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.[19]
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.

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

[20] "Hydrogen Shot Technology Assessment," December 5, 2023. https://netl.doe.gov/projects/files/HydrogenShotTechnologyAssessmentThermalConversionApproaches_120523.pdf

4.0 Electrolysis[21]

4.1 Technology Overview

Various electrolyzers are explored in this assessment, including Alkaline, Proton Exchange Membrane, Solid Oxide Electrolyzer Cell, and Anion Exchange Membrane 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 (PEM), and solid oxide electrolyzer cell (SOEC). Anion Exchange Membrane (AEM) 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."[22]

4.1.1 Alkaline

Alkaline electrolysis is the oldest and most well-established technology for producing hydrogen from water. 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: $2OH^-_{(aq)} \rightarrow ½O_{2(g)} + H_2O_{(l)} + 2e^-$

Overall: $H_2O_{(l)} \rightarrow H_{2(g)} + ½O_{2(g)}$

[21] Information in this section was provided by vendors where possible, and publicly available data for information not directly obtained through vendor solicited requests.

[22] Innovation Trends in Electrolyzers for Hydrogen Production (irena.org)

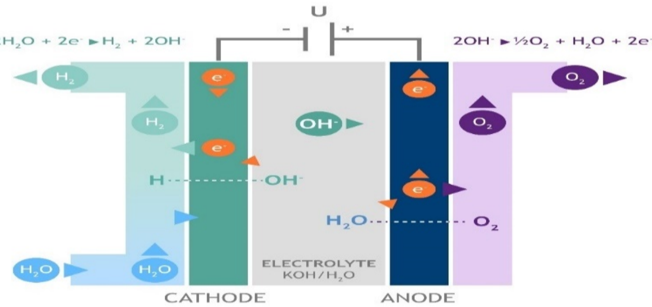

Figure 4.1 Alkaline Process Diagram

The main advantage of alkaline electrolysis is the maturity of the technology, being used for more than a century.[23] 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 partial load (turndown) restrictions associated with Alkaline electrolyzers. 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: $H_2O_{(l)} \rightarrow \frac{1}{2}O_{2(g)} + 2H^+_{(aq)} + 2e^-$
Cathode: $2H^+_{(aq)} + 2e^- \rightarrow H_{2(g)}$
Overall: $H_2O_{(l)} \rightarrow H_{2(g)} + \frac{1}{2}O_{2(g)}$

[23] Alkaline electrolyzers: Powering industries and overcoming fundamental challenges - ScienceDirect

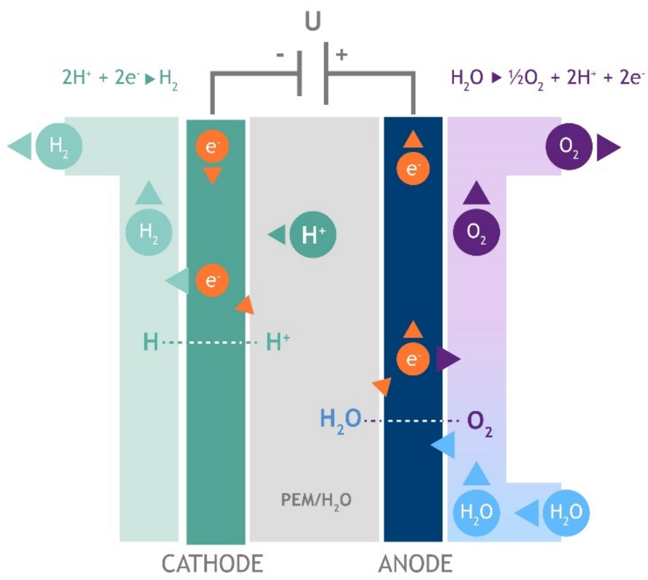

Figure 4.2 PEM Process Diagram

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. 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: $H_2O_{(l)} \rightarrow H_{2(g)} + ½O_{2(g)}$

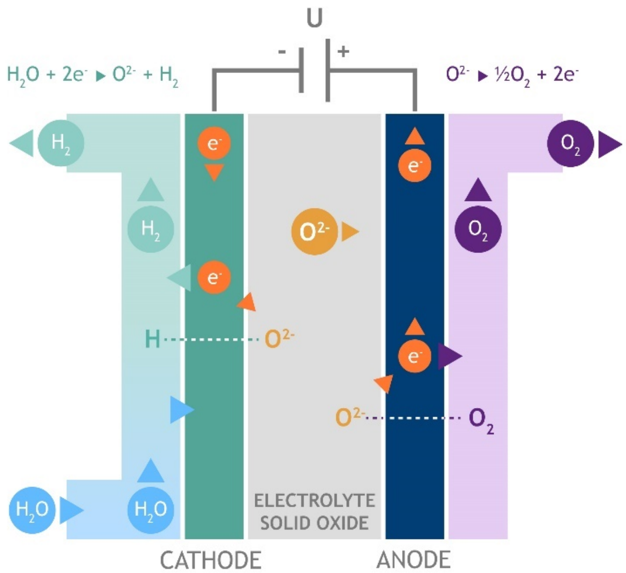

Figure 4.3 SOEC Process Diagram

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. 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: $H_2O_{(l)} \rightarrow H_{2(g)} + ½O_{2(g)}$

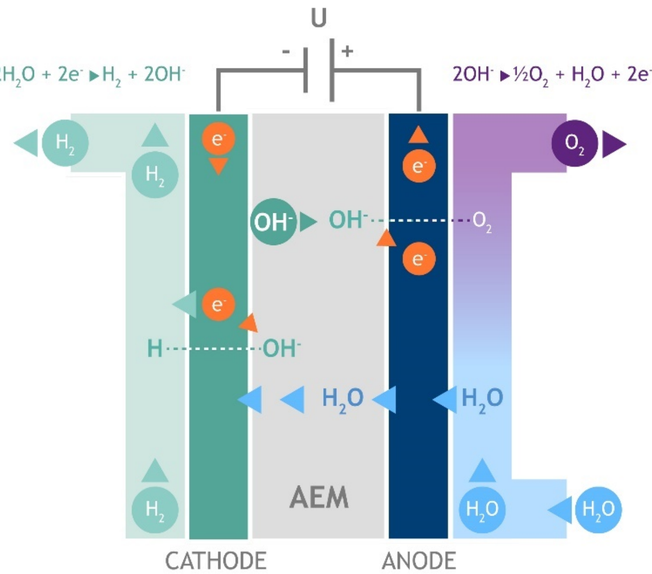

Figure 4.4 AEM Process Diagram

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 Table

	Alkaline (AEL)	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 – 52	~54	37.5* - 43
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 11 GW per year in 2022. The rapid scale-up in electrolyzer capacity is expected to continue in the coming years as announced projects suggest an installed electrolyzer capacity reaching 135 GW globally by the year 2030. However, only 10% of these announced projects have reached a Final Investment Decision (FID) and 25% have been announced with no specified location.[24]

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.[25] Table 4.3 below shows the top 11 planned electrolyzer projects in the United States ranked by size as of Q1 2024:

Table 4.3 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):

[24] See full report @ Executive summary – Global Hydrogen Review 2022 – Analysis - IEA

Table 4.4 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[26]

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 65 GW/year by 2030 with Europe and China accounting for approximately 65% of the growth.[27] 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 of PEM capacity by 2025.[28] Nel also has recently announced plans to build a 4 GW capacity manufacturing facility in Michigan.[29] 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. The global manufacturing output capacity of electrolyzers is projected to be approximately 270 GW by 2030.[30]

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

[26] 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/).
[27] See full report @ Executive summary – Global Hydrogen Review 2022 – Analysis - IEA
[28] Expanding production capacity in Wallingford | Nel Hydrogen
[29] Nel plans gigafactory in Michigan | Nel Hydrogen
[30] See full report @ Executive summary – Global Hydrogen Review 2022 – Analysis - IEA

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 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 draft GHG Study Report Appendix for information regarding a summary of carbon intensity values compiled based on a review of existing literature.

[31] "2022 Global Hydrogen Review." International Energy Agency (IEA).

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 below summarizes the results of this study, showing various sources of RNG and the respective potential to displace traditional natural gas.

Figure 5.1 Comparison of Renewable Natural Gas Sources[34]

	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.)

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

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[32] Biomass Energy in 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.
woody biomass, probably a better source. Biomethane also includes woody biomass as described in PUC code section 650 @ https://casetext.com/statute/california-codes/california-public-utilities-code/division-1-regulation-of-public-utilities/part-1-public-utilities-act/chapter-3-rights-and-obligations-of-public-utilities/article-10-biomethane-procurement/section-650-biomet

[34] Renewable Natural Gas in California: Characteristics, Potential, and Incentives: 2023 Update. Verdant. August 2023 RNG in California Update August 2023 LCFS Thru End of 2022

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).[35] 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 1 million tons (.91 million tonnes) of hydrogen annually. Further studies would be needed to address biomass availability specifically within SoCalGas's service territory.

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

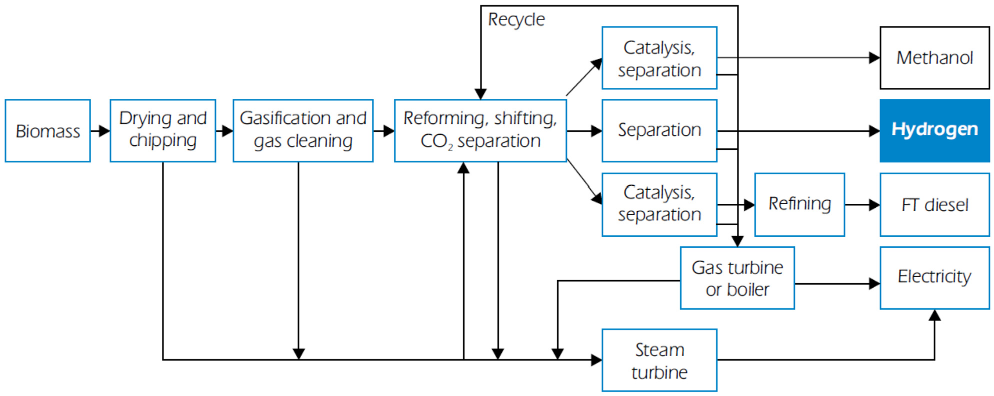
Steam methane reforming (SMR) is the most common hydrogen production method in the U.S. The raw biogas is typically produced from anaerobic digesters, which requires cleaning and upgrading, with the separation of impurities such as sulfur and siloxanes. This upgraded biogas (i.e., biomethane) is then 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.

[35] California Biomass Consortium, 2013 projections.
[36] Hydrogen from Biomass: State of the Art and Research Challenges. Milne, Elam, and Evans. NREL.
[37] Hydrogen Production and Storage: Research Priorities and Gaps." IEA 2006

Figure 5.2 Biomass Gasification to Hydrogen Process Diagram



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

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.

[38] Biomass Energy in California. California Energy Commission.

5.2 Biomass Emissions

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

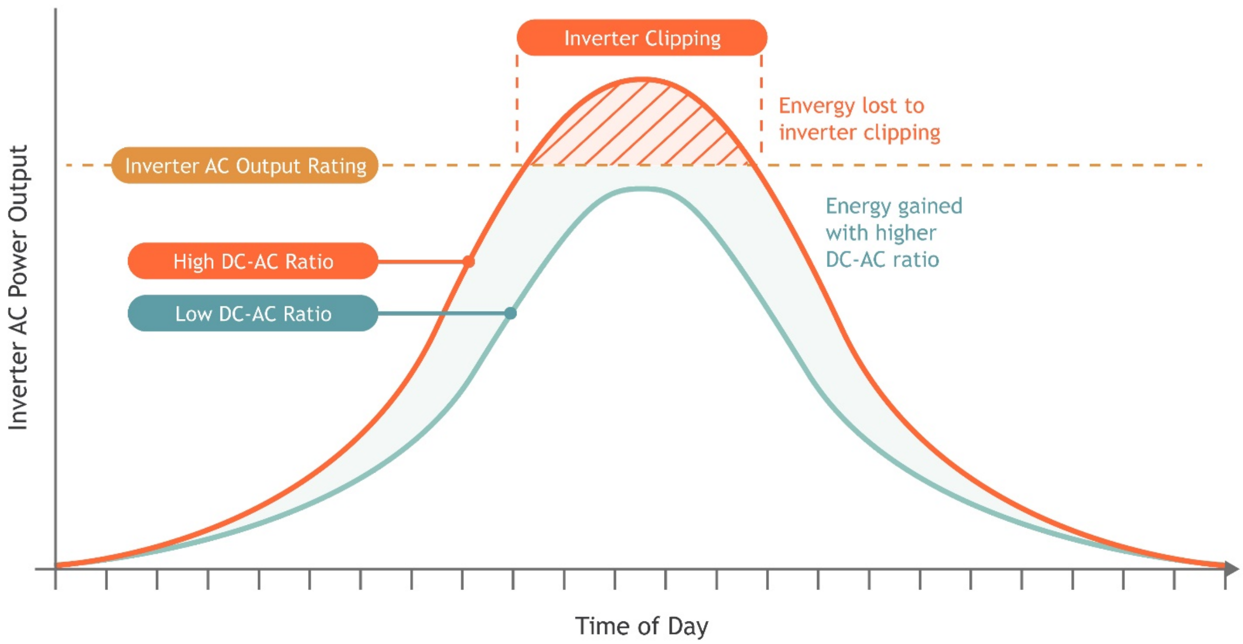
In a DC coupled system, the solar and BESS are coupled on the DC side and share a bi-directional inverter. This system eliminates the need for a set of inverters, switchgear, and other BOP costs. Electrical losses through the inverter are also eliminated.,. In this arrangement, single BESS containers 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).

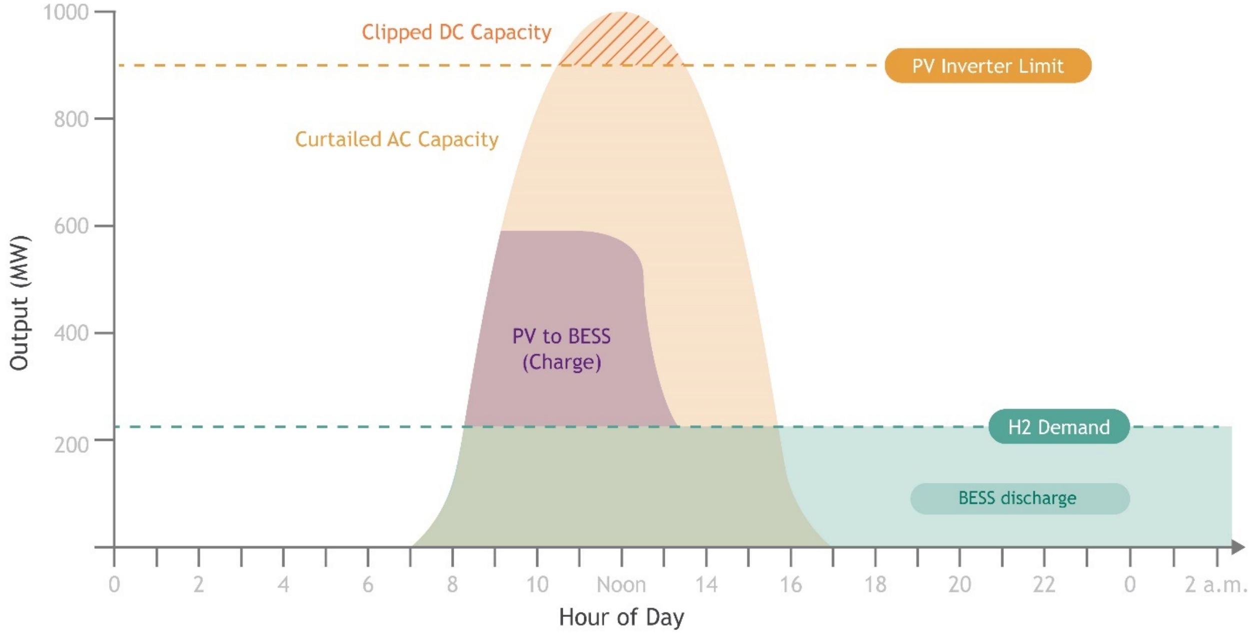
Figure 6.1 Impact of Solar Sizing – AC to DC Ratios



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 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	
CAPEX Electrolyzer Facility	$/kW	$3,000/kWac	In-house estimating
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

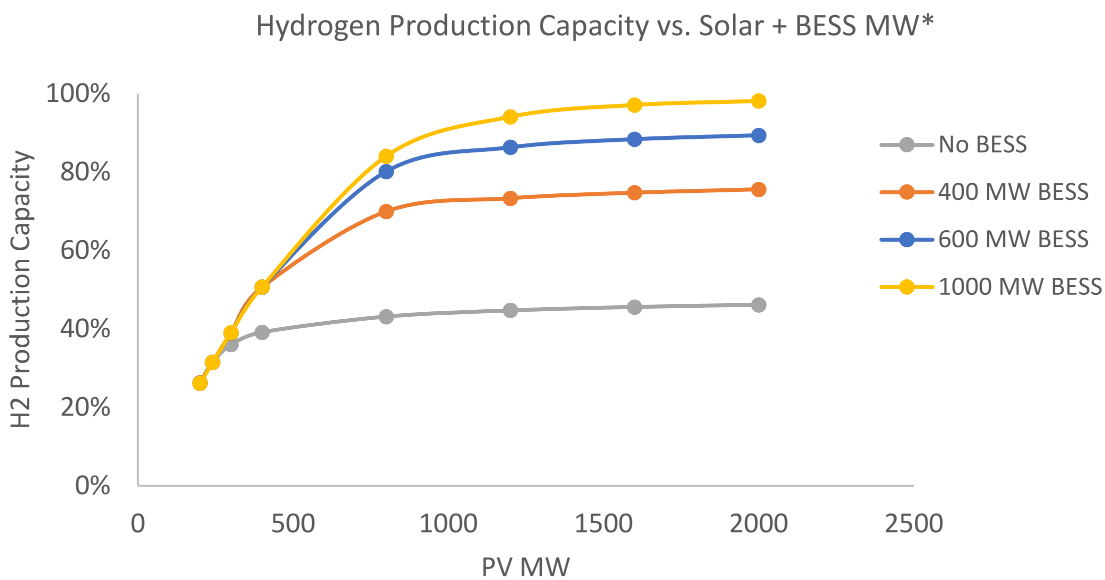
Parameter	Value
Project Life (PV, BESS, and Hydrogen Facility)	35
Solar Installed Power (MWdc)	Optimization Parameter
Solar Rated Power (MWac)	Optimization Parameter
Solar DC:AC Ratio @ PV/BESS POI	1.25
Solar MWac Maximum @ PV/BESS POI	226 MWac
Solar Panels	550 Wp monofacial w/ tracking
Annual Solar 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

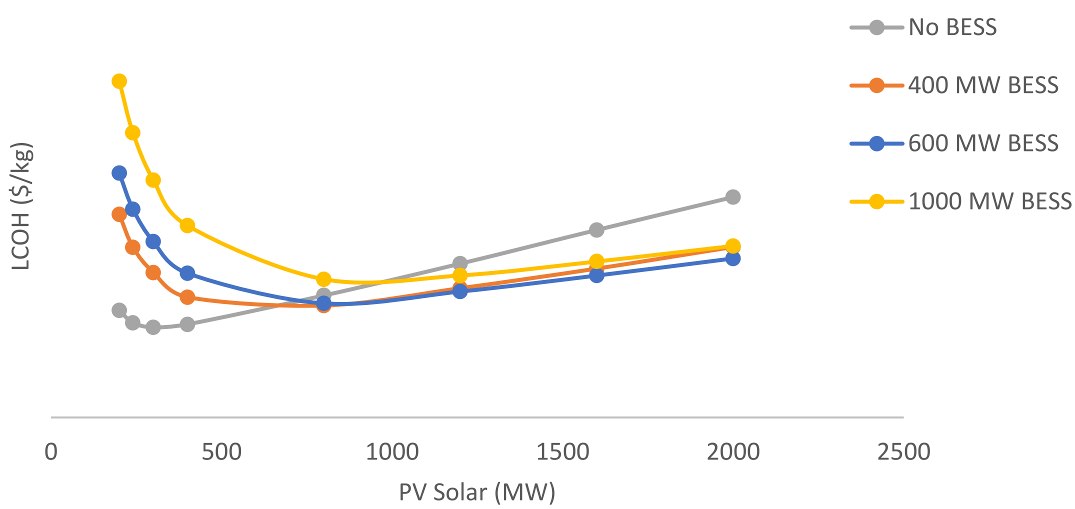
The result of the modeling is an hourly hybrid energy output at the hydrogen POI. Multiple cases of varying solar and BESS sizes were analyzed for a 200 MW hydrogen production capacity. Assuming a constant hourly electric demand is required at the hydrogen facility to produce hydrogen at full output, 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 million (M) tonnes per year (TPY) of hydrogen demand by 2045 in its conservative scenario, 3.2M TPY in the moderate scenario, and 5.9M TPY 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 project throughput of approximately 0.5 M TPY under a low case scenario (1.9M TPY total demand in the conservative scenario) and up to 1.5 M TPY under a high case scenario (5.9M TPY 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 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 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.

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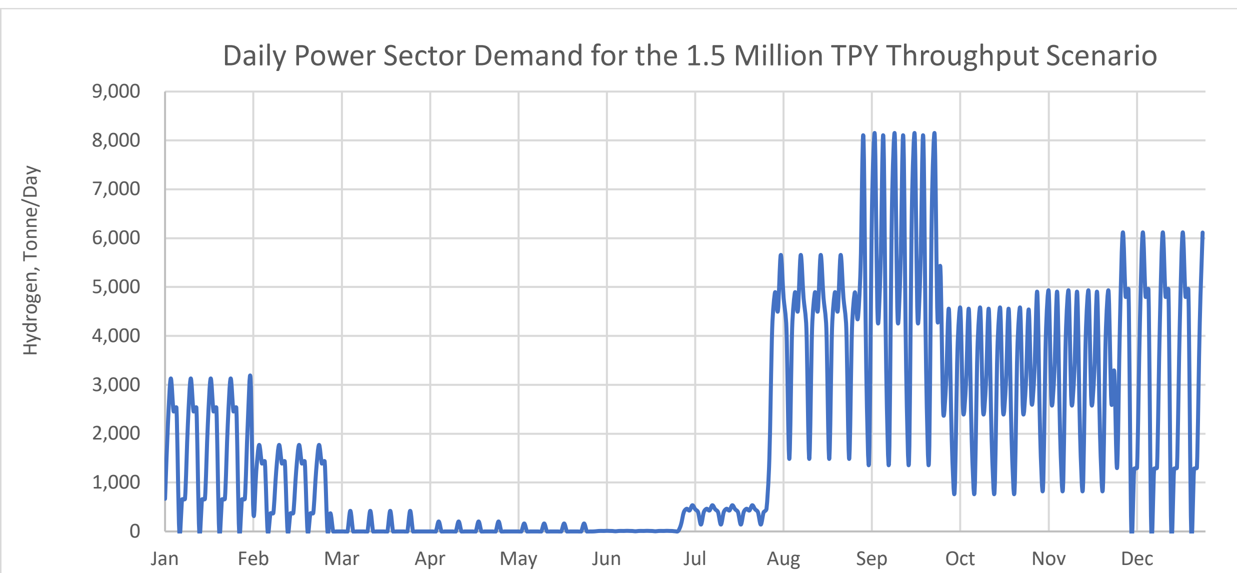
[39] Based on work performed for the Demand Study.
[40] Based on discussions with the consultant who performed the Demand Study.
[41] Based on discussions with the consultant who performed the Demand Study.

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 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.

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[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.

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:

- 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, potential reliability requirements for outages

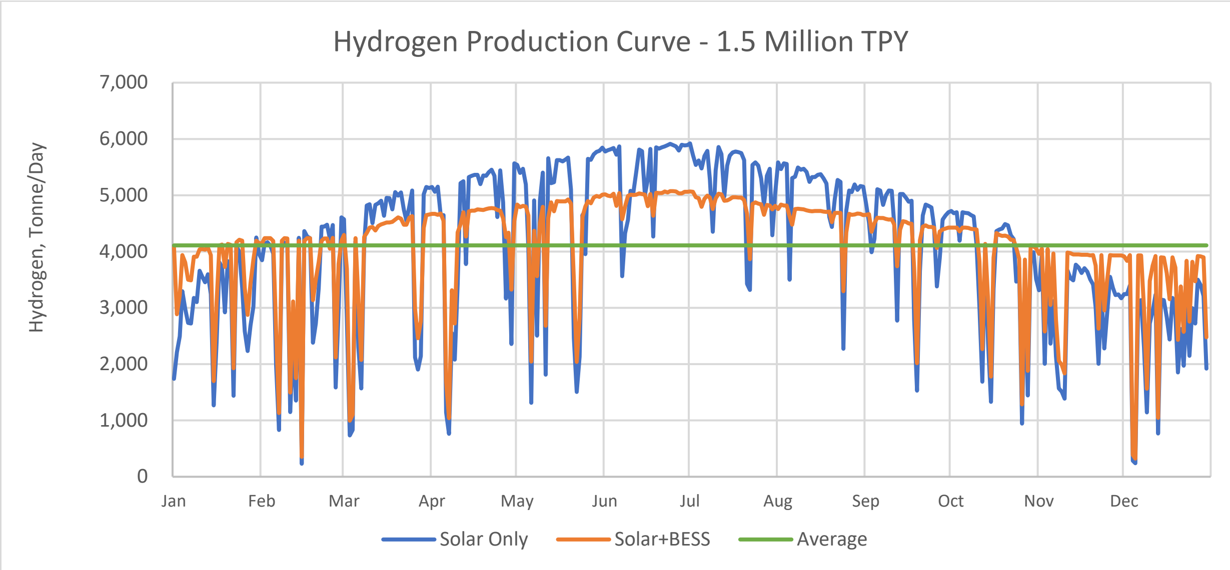
Clean hydrogen production and above ground and underground storage is not currently part of Angeles Link. As Angeles Link is further designed and, in alignment with the development of system requirements, the role of storage to support regional hydrogen producers and end users should be considered. Distributed 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 hydrogen hub 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 MTPY 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 MTPY and 0.5 MTPY cases.

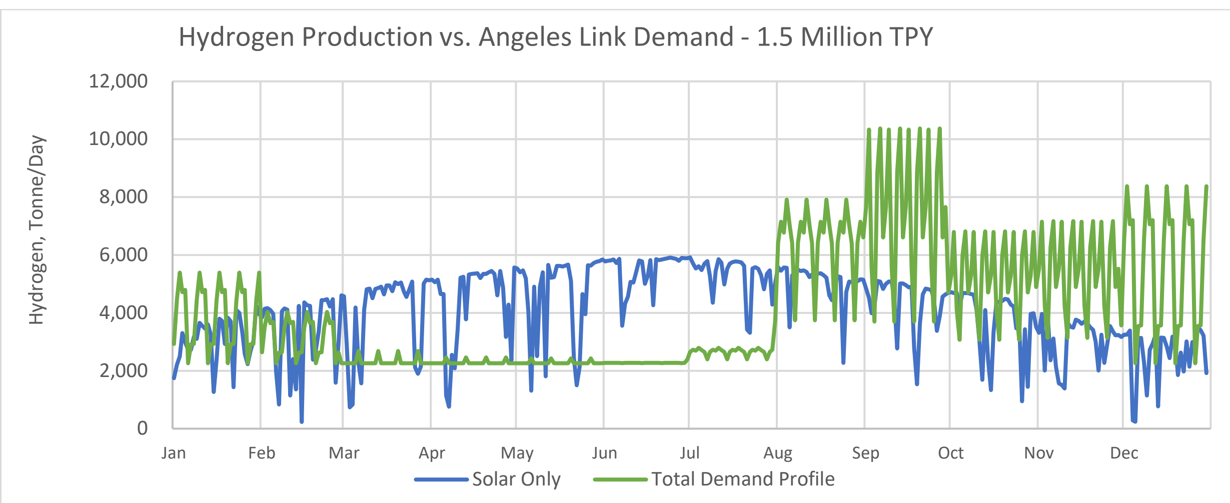
[43] Referring to hydrogen supplied via solar/electrolyzers (and solar + BESS / electrolyzers).

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 (reference Table 7.1). 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, the charts 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

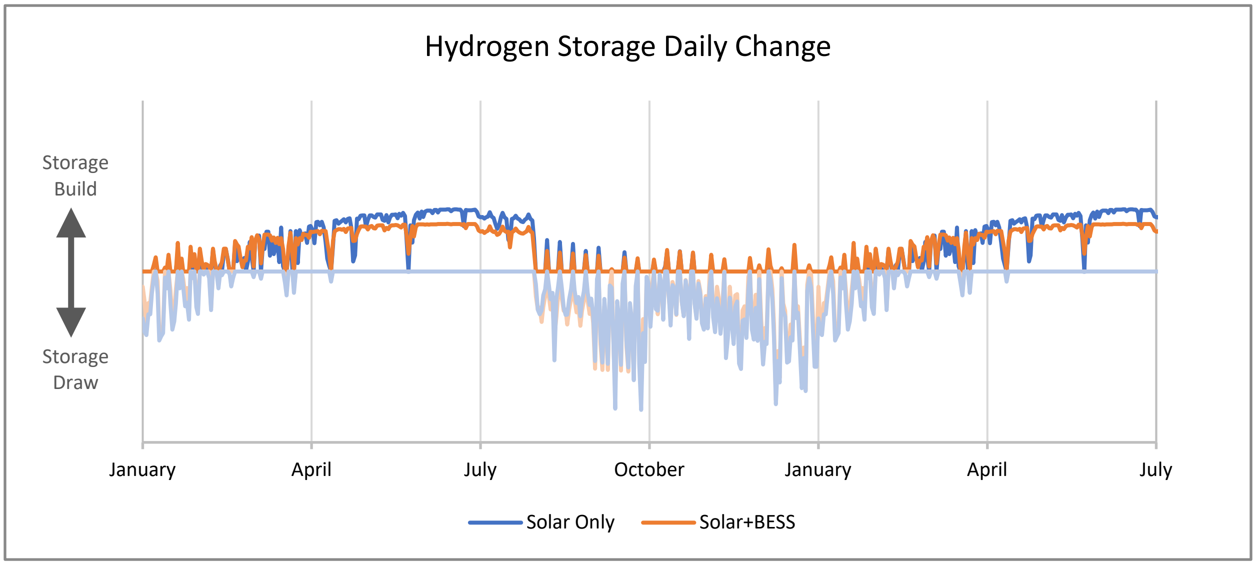
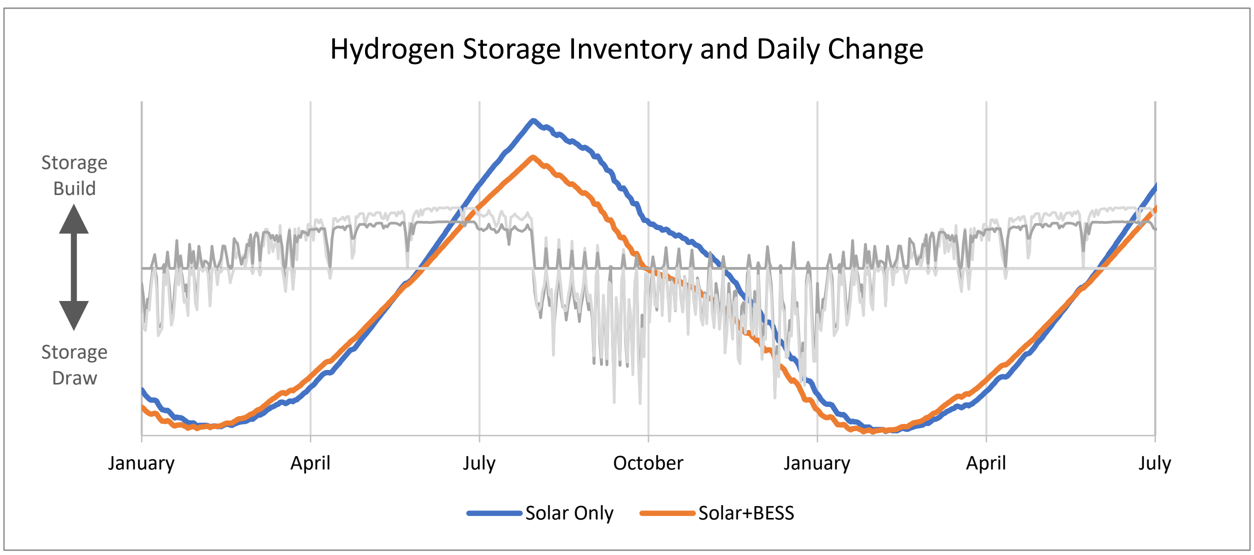


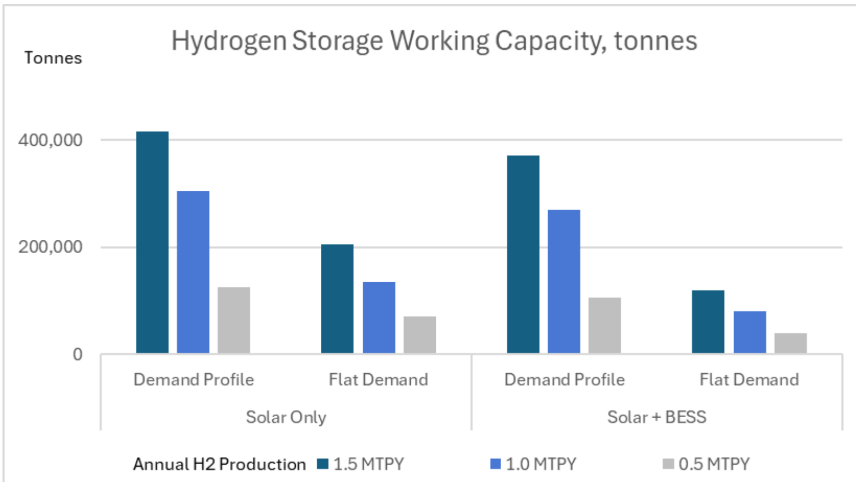
Figure 8.4 Illustrative 2045 Hydrogen Storage Cycles – Solar and Solar + BESS Production



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

- **Storage Technologies**

- Commercially available above ground 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]

Above ground storage. While above ground hydrogen storage technologies are technically viable, storing hydrogen above ground 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, above ground 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 above ground 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 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.

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

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

Figure 9.1 Hydrogen Facility Flow Diagram

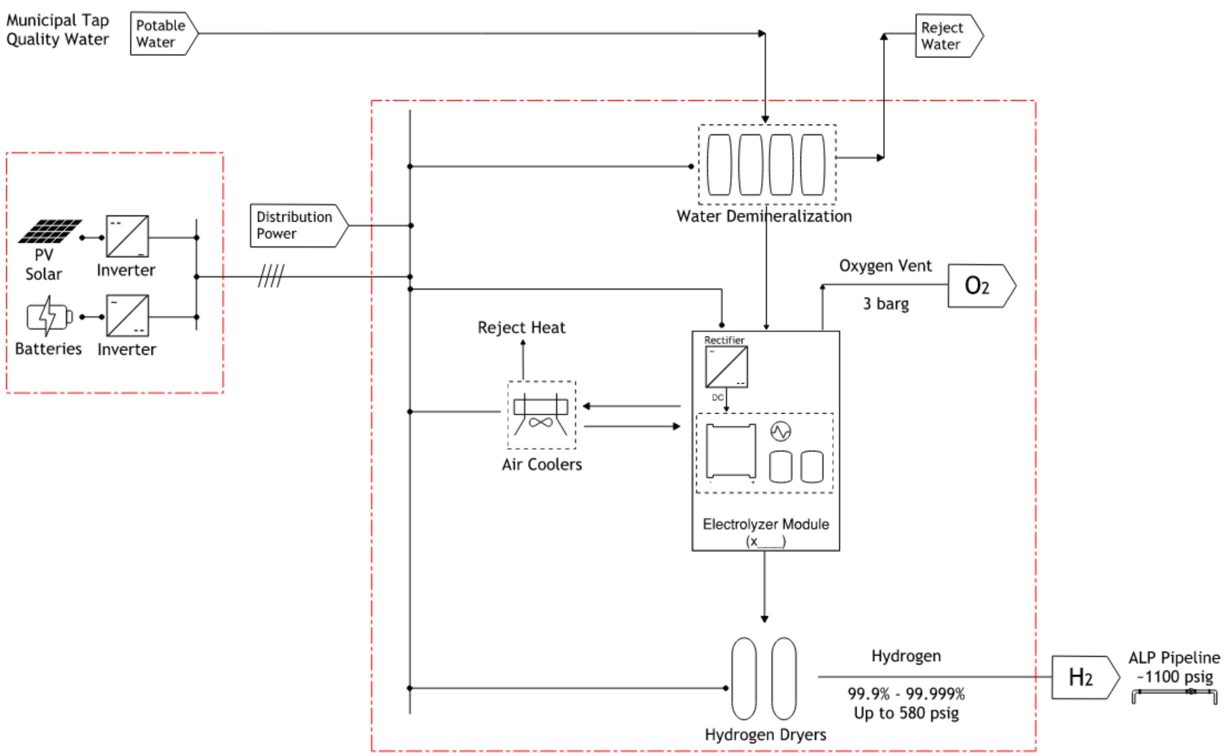


Table 9.1 Hydrogen Facility Scope Assumptions

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.

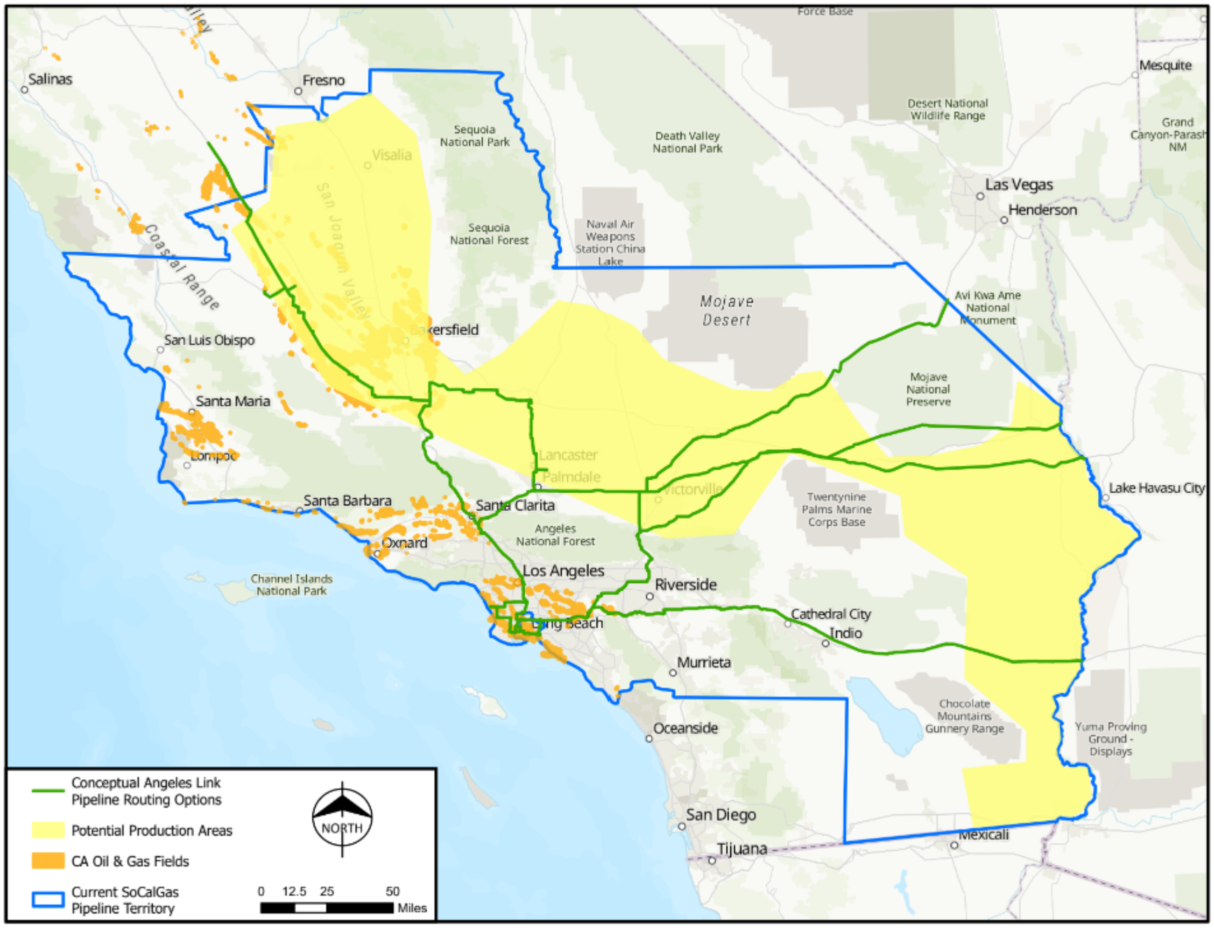
10.2 Land Assessment Methodology

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

[46] Meet-Arches_October-2023.pdf (archesh2.org)

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% 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

[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 SB100 clean firm power report plus SI.pdf (edf.org)

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, 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 MTPY, 1 MTPY, and 1.5 MTPY Angeles Link throughput scenarios.

Table 11.1 Hydrogen Production Facility Cost Estimates

Average Annual Hydrogen Production	Single Facility	0.5 MTPY	1 MTPY	1.5 MPTY
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 Comments

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 the Production Study. Below is a summary of some of feedback received related to 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.[48]

- **Environmental Defense Fund (EDF)**
  - Cautions against optimistic projections of hydrogen sourced via biomass and biomethane and comments that the most realistic source of hydrogen production will be electrolysis using renewable electricity. Adherence to the "three pillars" of hydrogen production using renewable electricity (i.e., hourly matching, additionality, and deliverability) should be a basic project assumption.
  - It is important to understand how the potential Angeles Link project may be configured for some level of hydrogen storage for future use.
- **Food & Water Watch**
  - Would like clarity on production costs, including costs associated with building electrolyzers, electrolyzer facilities, and producing hydrogen. The costs must also be accurately compared with the costs of non-hydrogen alternatives, namely electrification.
  - Seeks greater transparency on risks associated with underground and aboveground storage.[49]
- **Physicians for Social Responsibility - Los Angeles (PSR-LA)**
  - Study should only analyze H2 production powered by new and surplus renewable energy and not consider use of carbon credits or other forms of hydrogen that come from nuclear power, carbon capture schemes, biomass/biogas.
  - Disregarding or providing incomplete information about the emissions (climate and air pollutant) impacts of production methods and proposed end uses of the delivered hydrogen paints an incomplete picture of the overall climate impacts of the Angeles Link project.
- **Air Products:**
  - Specify assumptions used concerning production capacity for various technologies and projects, and how those assumptions were determined, and set forth the criteria used to determine the locations of potential H2 and renewable energy production, in addition to when those projects would come online.

[48] https://www.socalgas.com/sustainability/hydrogen/angeles-link

[49] Preliminary findings related to third-party storage were originally provided in the preliminary findings for the Pipeline Sizing & Design Criteria study. The evaluation of third-party storage now resides in the Production Study. Accordingly, storage related comments were consolidated from Pipeline Sizing & Design Criteria study and are referenced here.

- Concerned that green H2 production could draw down renewable energy supporting the state's electricity grid. Commented that hydrogen should be produced from new renewable electricity buildout. Detail measures to support reliable supply if production is not grid connected.
- Evaluate the emissions from electric generation associated with various hydrogen production methods.
- Clarify whether the space requirements account for energy storage needs, what utilization rates have been assumed for the electrolyzers, and whether this utilization been factored into the number of electrolyzers and solar needed
- Consider competition of existing solar projects, how is battery storage considered, whether land requirements include above ground storage and other facilities, and whether underground storage locations have been evaluated for suitability.
- Detail purity specifications for different end uses, which could impact production.

- **Utility Consumers Action Network (UCAN)**
  - Only new sources of carbon-free electricity should be evaluated. Other sources, like biomass for example, should not be considered.
- **Communities for a Better Environment (CBE)**
  - Study should only analyze hydrogen production powered by new or surplus renewable energy and not consider resource shuffling like use of carbon credits.
  - Production analysis must include costs associated with building out additional renewable energy sources and electrolyzer facilities.
  - Recommends recognizing and considering the Equity Principles for Hydrogen (published October 10, 2023).
  - Raised environmental justice concerns about hydrogen production in heavily-impacted communities like the San Joaquin Valley, Lancaster, and Blythe.
  - Raised concerns about the water use associated with H2 production.
- **Protect Playa Now Comments**
  - Provide greater transparency regarding risks associated with underground and aboveground storage.[50]
- **Vote Solar Comments**
  - Interest in how hydrogen will be stored.[51]
- **Cal Advocates**

[50] Storage related comment consolidated from Pipeline Sizing & Design Criteria study.
[51] Storage related comment consolidated from Pipeline Sizing & Design Criteria study.

- Requests that the draft production study clearly describe and analyze the roles of storage and curtailed renewable generation.

- Requests that the production study identify whether there are any legal or land use policy limitations that would impact production.

- **Other stakeholder feedback:**

  - Raised concerns about potential competition for the land needed to produce enough hydrogen for the assumed throughput volume of 1.5 MMTPY. Asked for 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.

  - Inquired about the H2 purity/quality standards that would be required.

12.1 Summary of How Comments were Addressed

- **Hydrogen Production Methods and Assumptions:** 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. For 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).

- **Hydrogen Storage:** Considered the role of hydrogen storage options that could help balance clean renewable hydrogen production and demand profiles in section 8. Potential 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. For information regarding Hydrogen Leakage related to storage, please refer to the Hydrogen Leakage Assessment Draft Report. Safety information concerning pipeline transmission, storage, and transportation is found in the Draft Plan for Applicable Safety Requirements.

- **Production Study Assumptions and Criteria:** 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, 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 Costs**: Capital and operating costs were estimated and are described in section 11.

- **Land Requirements:** Land requirements for solar power coupled with electrolyzers were evaluated to determine feasibility of hydrogen production for 1.5 MMTPY. For design purposes, this study calculates the amount of land required for solar coupled with electrolyzers, as described in section 10.

- **Hydrogen Purity/Quality:** 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).

- **Environmental Justice:** Environmental justice concerns related specifically to hydrogen production were not included in this study; however, SoCalGas does address environmental justice considerations related to Angeles Link more generally in a separate study. Please refer to the Environmental & Environmental Social Justice Analysis**.**

- **Water:** Water related concerns that could impact hydrogen production (i.e., water availability, quality, cost, etc.) are addressed in a separate study. Please refer to the Water Resources Evaluation.

- **Permitting/Land Use**: 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:

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 CO_2. 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.

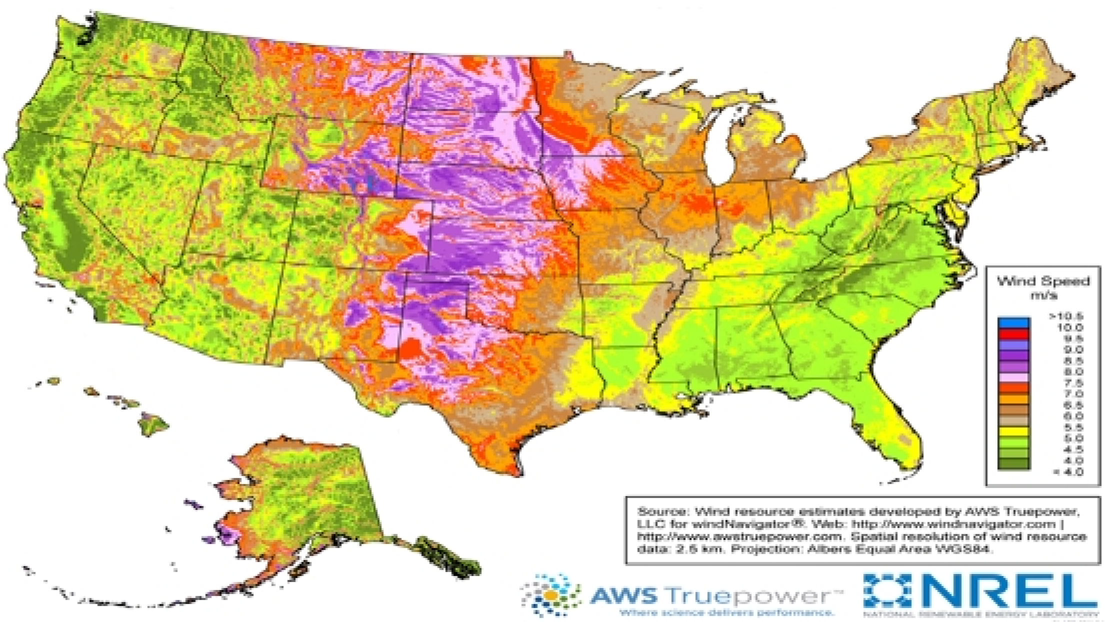
Hydroelectric: Southern California currently benefits from significant hydroelectric generation throughout California. While hydro represent projects with the largest average size, there of few hydro projects in SoCalGas's service territory and the feasibility to scale is unlikely since for new hydroelectric 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:

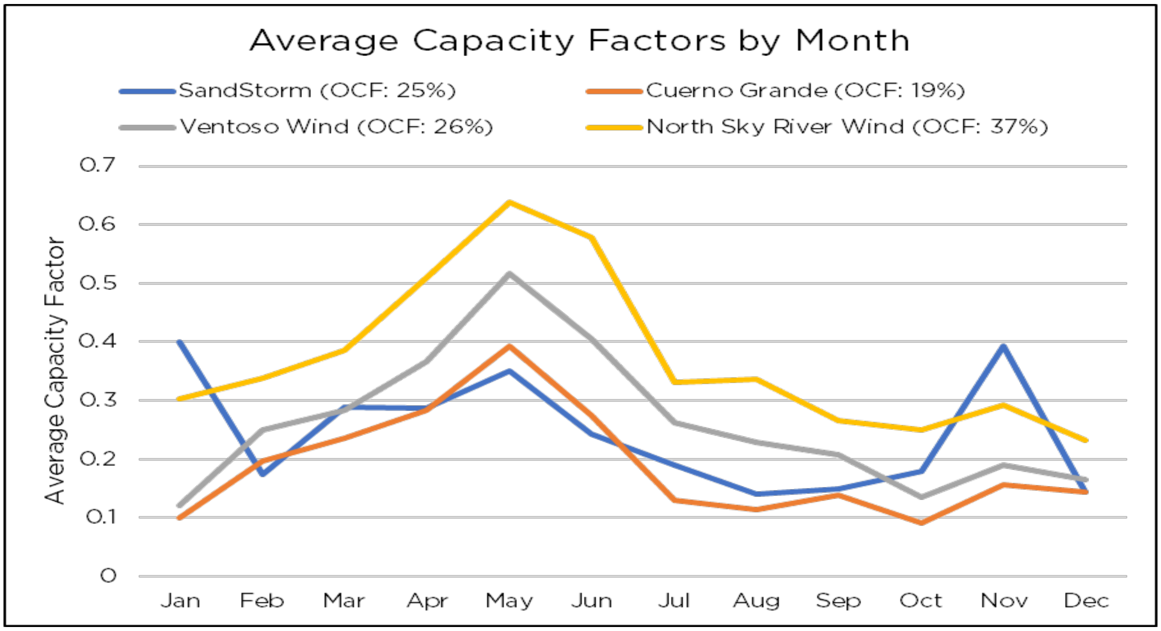
Wind: Wind renewable technology is proven worldwide and is a mature technology. Wind projects can be developed at a large scale given enough land and there is significant land available for wind projects in SoCalGas's service territory. Wind can also be developed without an interconnection to a grid 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 the figure 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.

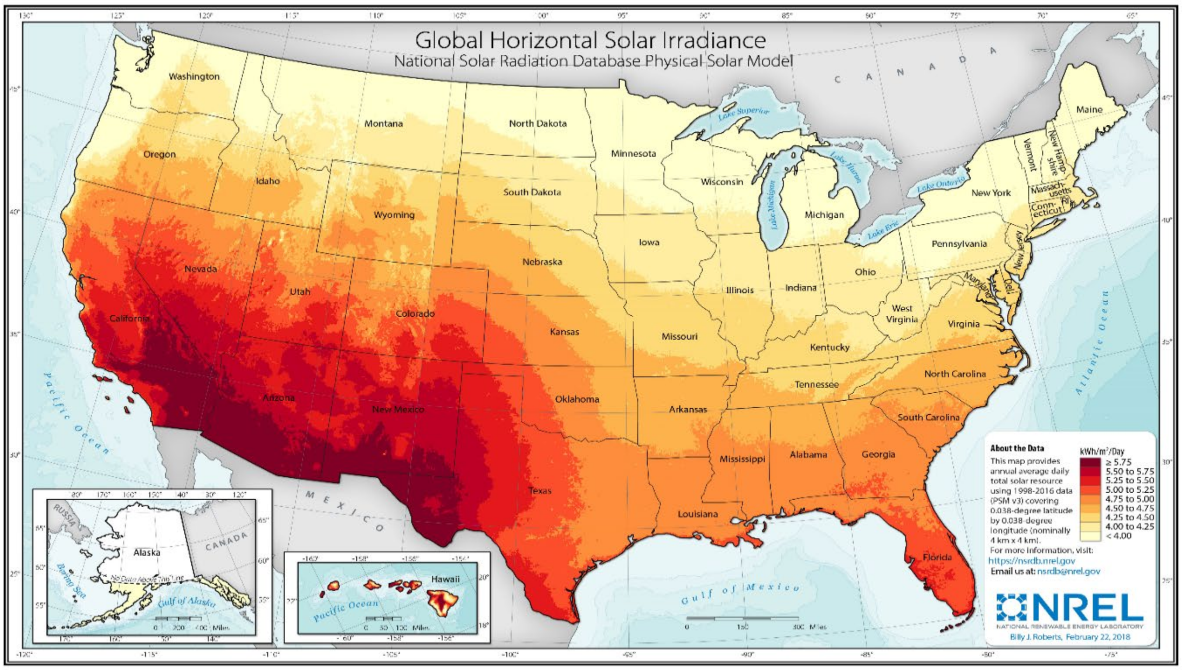
Figure 13.2 Range of Wind Capacity Factors in SGC Territory



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.

<u>Solar</u>: 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

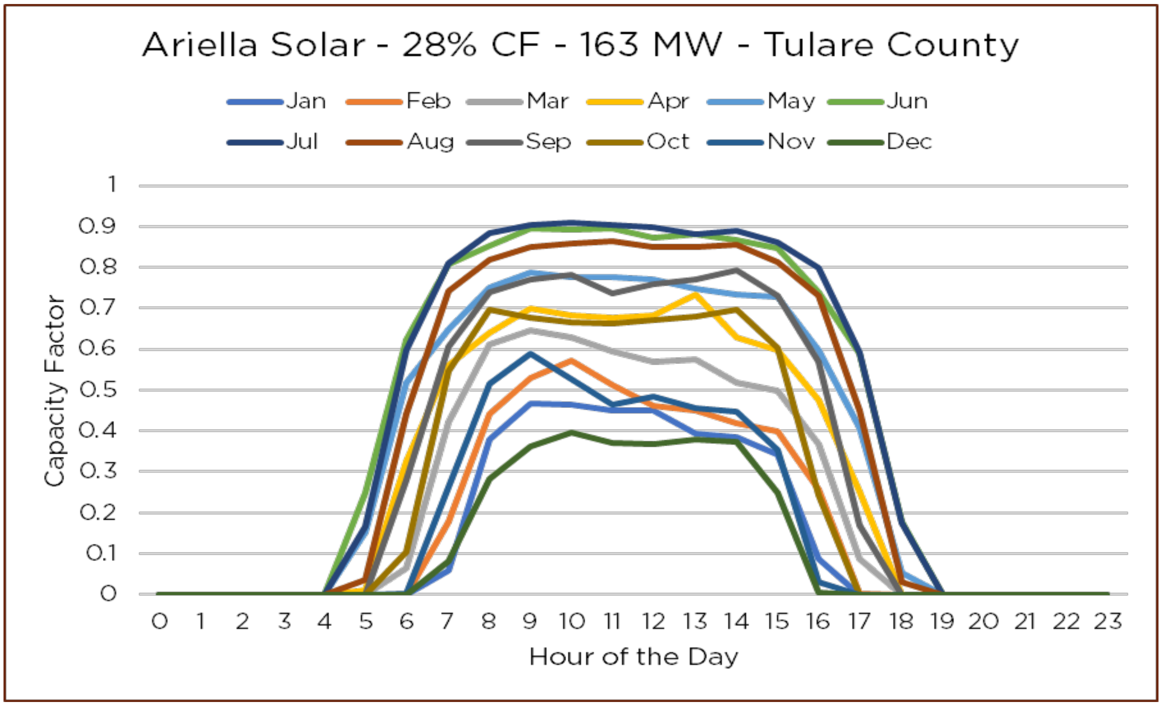


Figure 13.5 Average Monthly Solar Capacity Factors

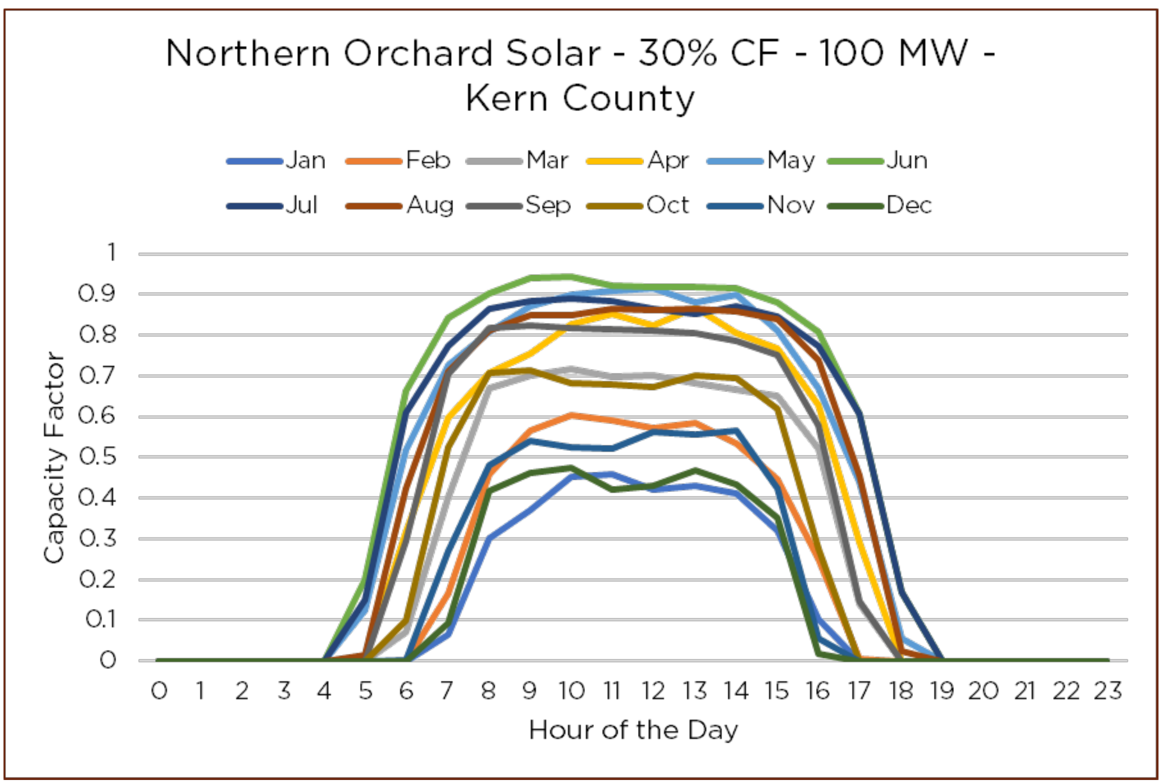
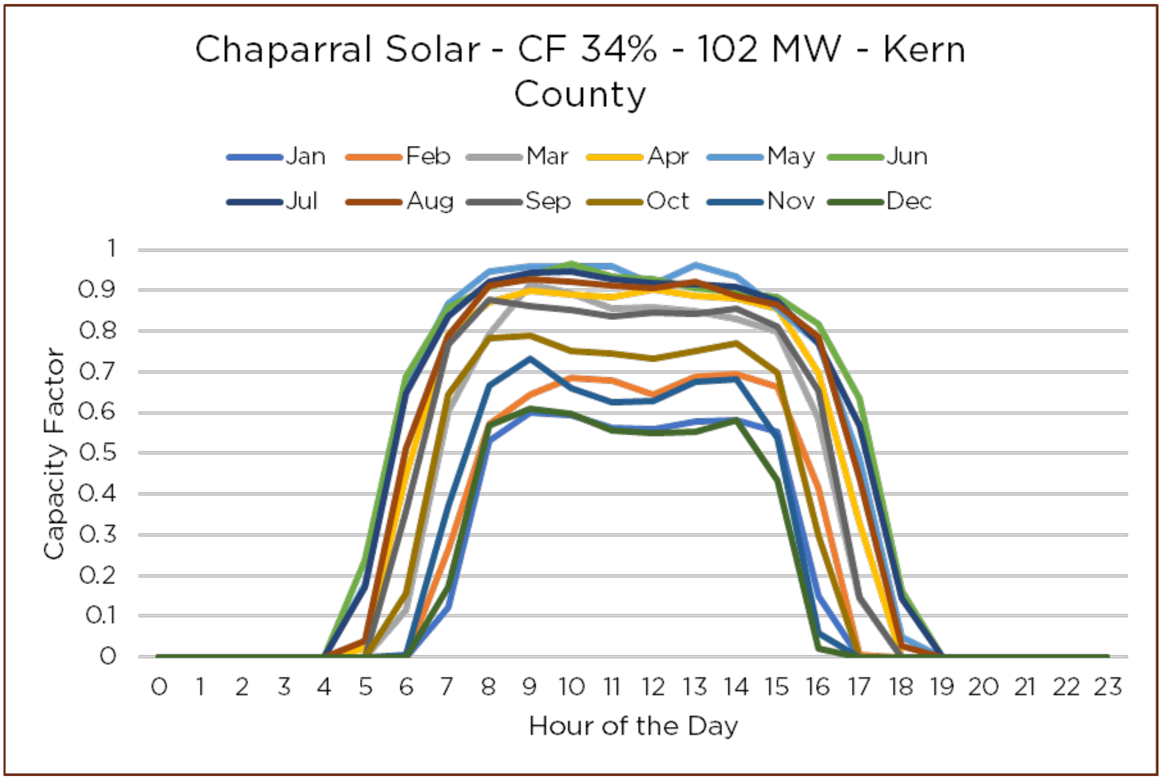


Figure 13.6 High Monthly Solar Capacity Factors



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.

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 Southern California. Analysis from the CPUC in its 2022-2023 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 7Existing 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 13.8 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 13.9 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

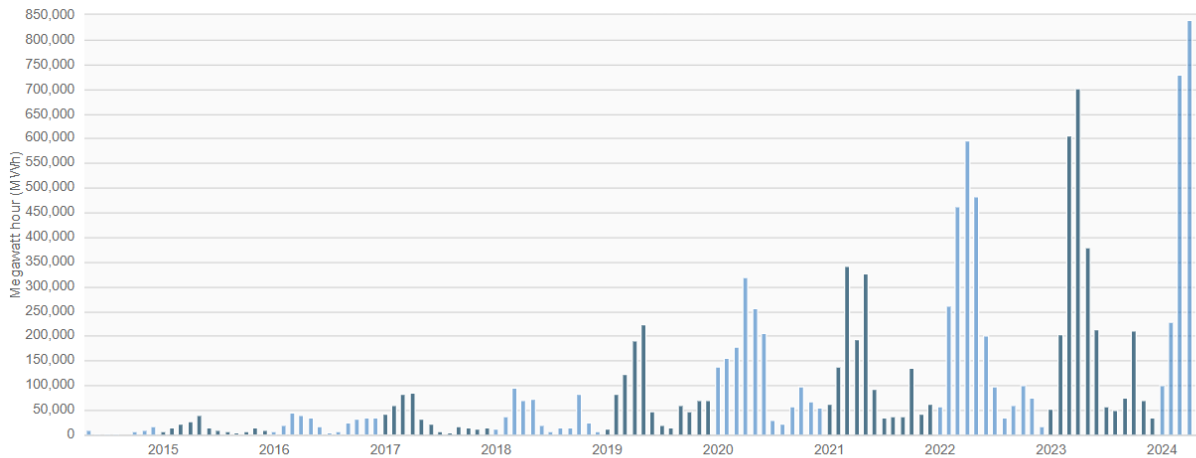
Electric curtailment occurs when a generating resource is turned down or limited because the electric system cannot take the energy as the transmission system is constrained or there is not enough demand for energy. In California, CAISO manages two types of curtailments that occur on the electric grid: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

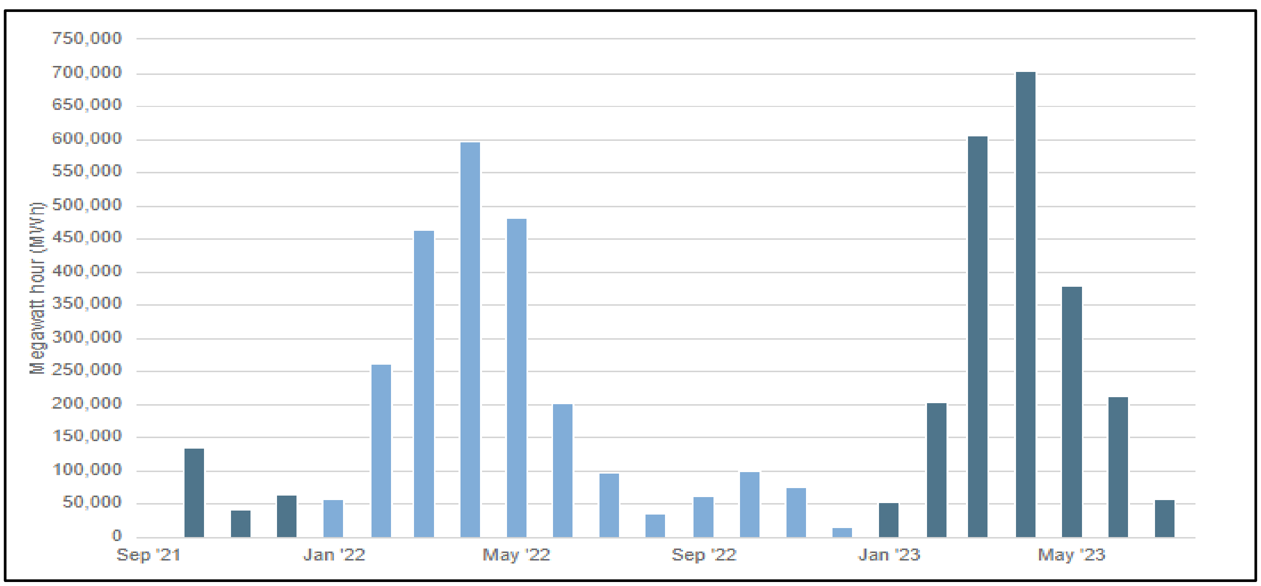
Figure 13.7 and 13.8: CAISO Solar/Wind Curtailments show curtailed energy for both the past 10 years ending May 2024 as well as the two years ending July 2023 and includes system and local curtailments.

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



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

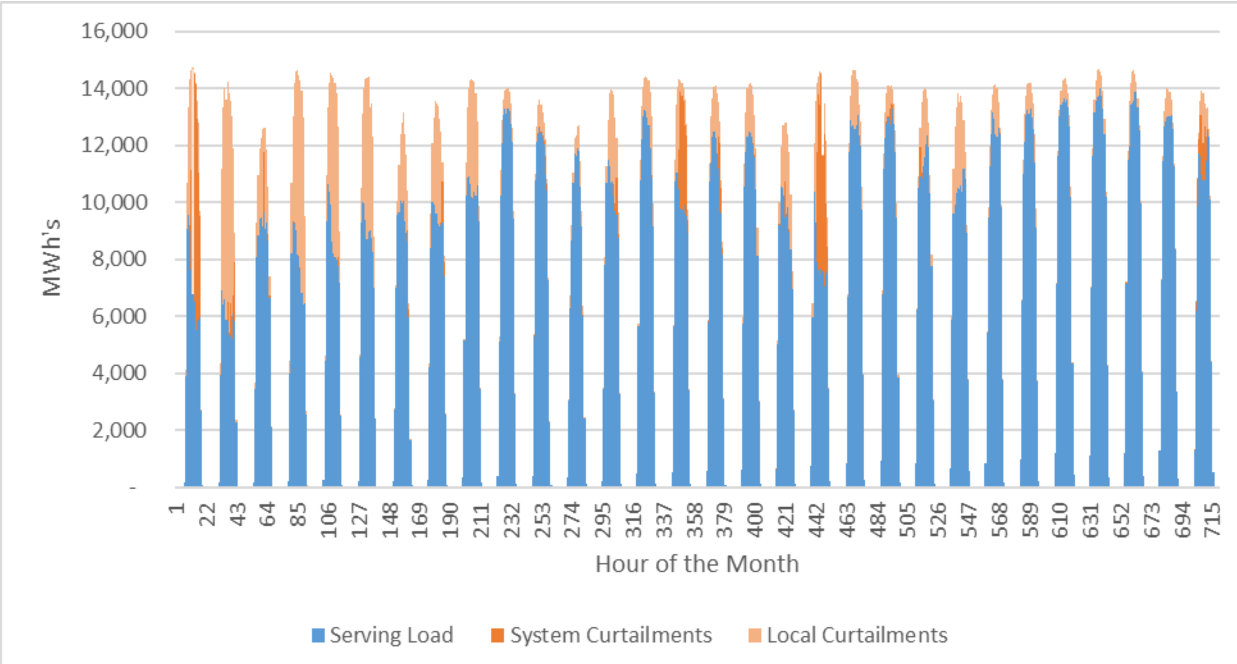
Figure 13.8 CAISO Solar/Wind Curtailments – 2 Years Ending July 2023



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.

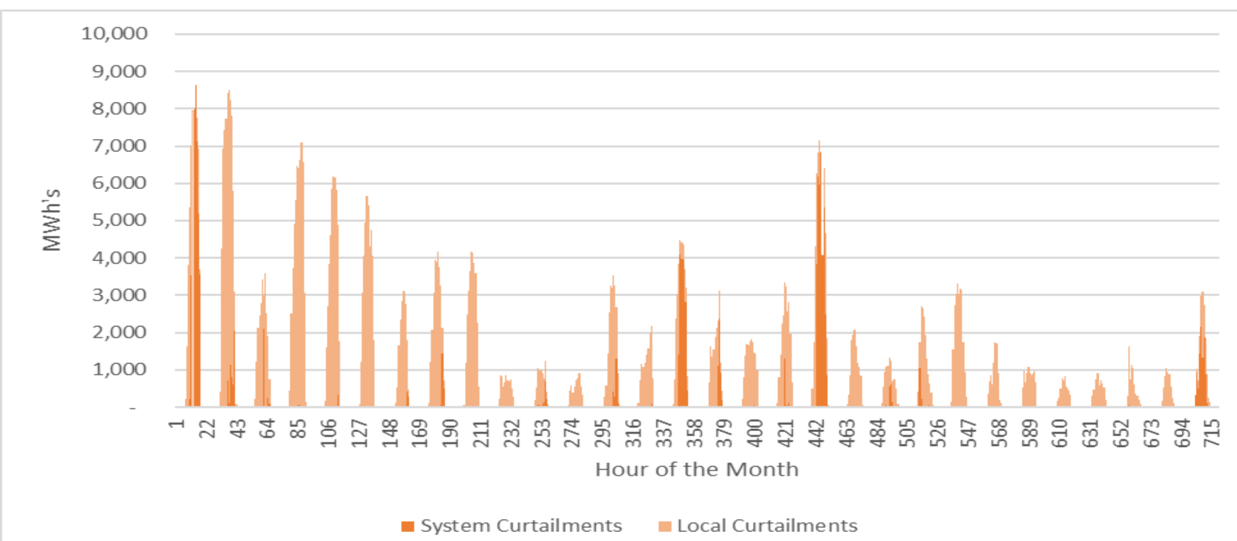
Figure 13.9 CAISO Solar Generation – April 2023



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.

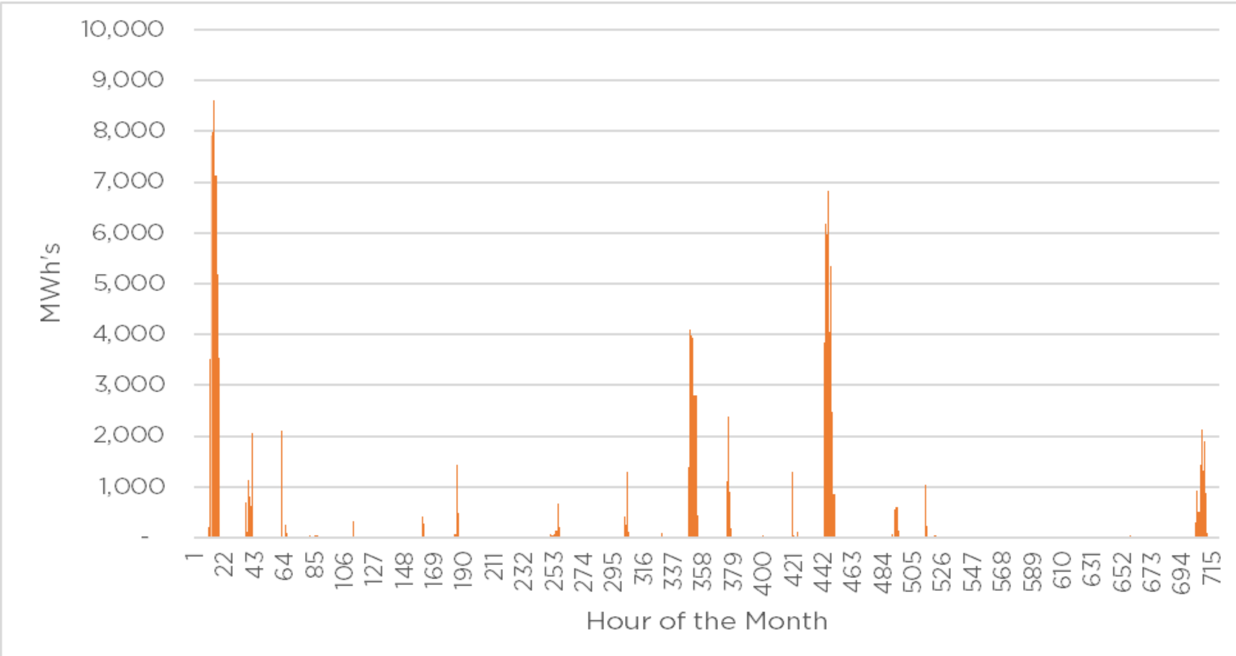
Figure 13.10 CAISO Solar Curtailments – April 2023



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 Above ground Storage

Commercially available above ground 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.[52]

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.[53] 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.-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.[54] 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

[52] Eberle, Mueller, & von Helmolt, 2012
[53] Gülzow, E., & Bohn, L. (2010). Cryogenic Storage of Hydrogen. Wiley-VCH Verlag GmbH & Co. KGaA.
[54] Züttel et al, 2010

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.

B.1.5 Above ground Storage Options Comparison

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,[55] 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 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

[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.
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.

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 project phases.

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

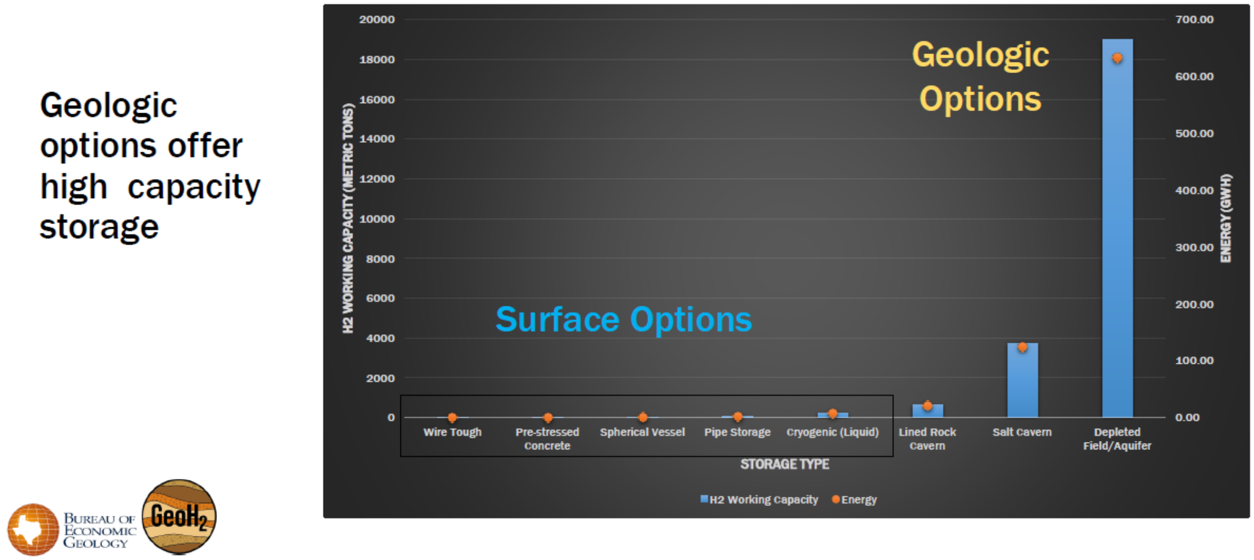
Potential UHS options include the following:

- 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, and levelized costs of storage presented in literature suggest that depleted reservoirs in oil and gas fields offer the most economical options.[56]

[56] 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.

Figure 13.12 Indicative H2 Storage Options by Unit Capacity



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,[57] but there is ongoing research into the geologic site selection criteria and engineering design guidance.

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

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[57] 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.

for hydrogen injection and withdrawal and/or monitoring purposes in reducing CAPEX for storage facility development (subject to engineering evaluation in future project 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.[58]

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 need not be built with pure hydrogen).[59] Cushion gas can constitute a major CAPEX cost, especially for highly depleted, larger fields.[60] 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.[61]

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,[62] containment mechanisms and security, economic analysis, and cost estimation.[63] 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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[58] (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/.
[59] 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.
[60] 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.
[61] 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.
[62] Lysyy, M., Ferno, M., & Ersland, G., 2021. Seasonal hydrogen storage in a depleted oil and gas field. International Journal of Hydrogen Energy, 25160-25174.
[63] 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.[64]

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.[65] However, as is the case with oil and gas fields, a structural trap is required to limit vertical and lateral migration of hydrogen and enable recovery of hydrogen from storage (Figure 13.13).

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

[65] 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.

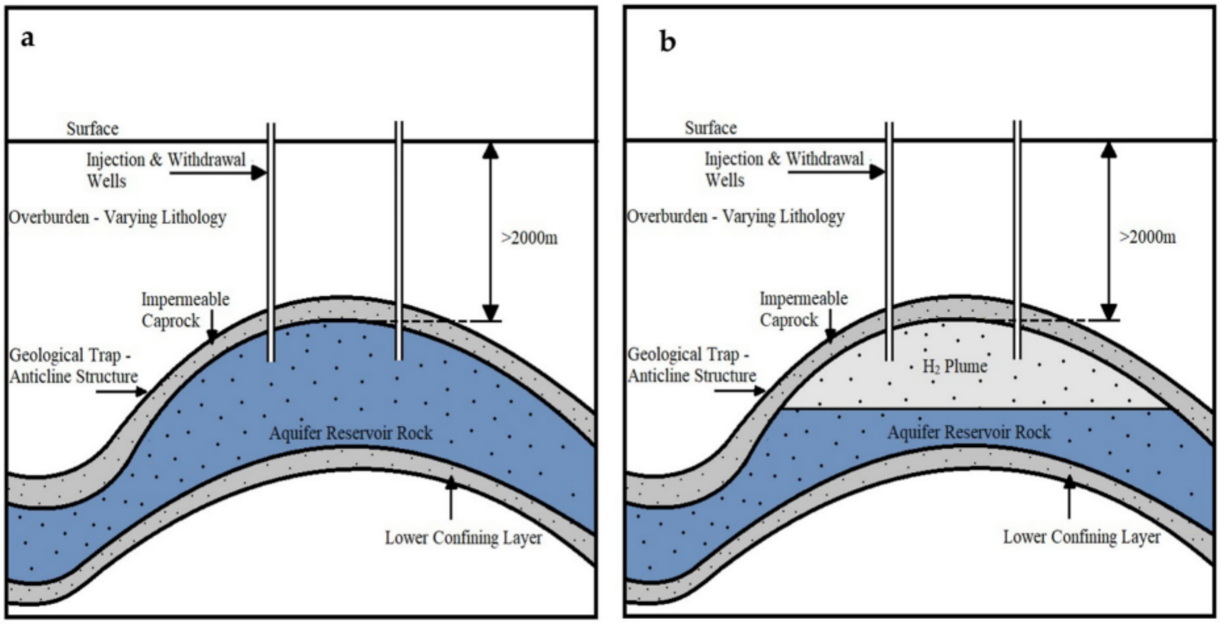

Figure 13.13 Schematic saline aquifer conversion to hydrogen storage (Wallace et al., 2021)

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.[66] 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 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 GeoH_2) 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).

[66] 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.

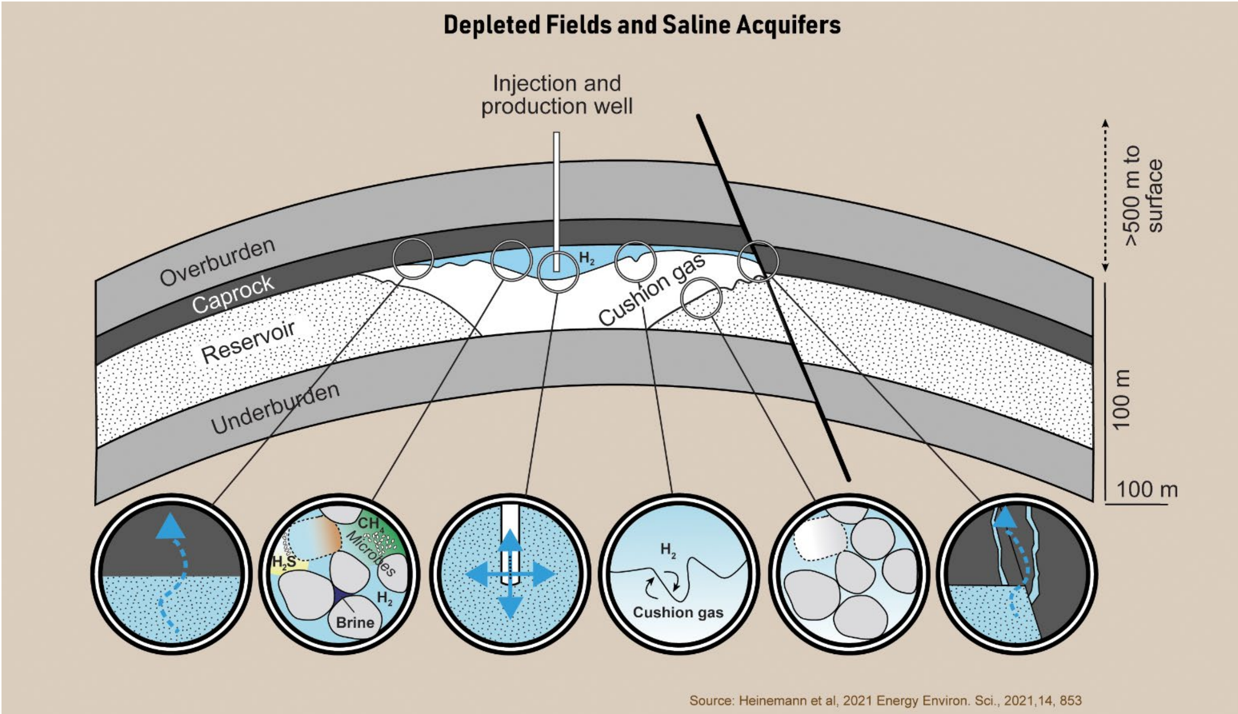

Figure 13.14 Diagrammatic illustration of storage in depleted reservoirs or saline aquifers with associated potential loss mechanisms.

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.[67]

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.[68] Hydrogen gas could potentially be sealed in the mines with hydrostatic pressures from groundwater or water curtains, or through engineered linings.[69] 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,[70] but this is not a common practice.

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[67] 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.
[68] 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.
[69] 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.
[70] 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)

Research into repurposing of abandoned coal mines is active,[71] 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.[72] 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.

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.

[71] 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.
[72] 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.

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;[73] 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.[74] These studies have concluded that blended hydrogen and natural gas storage in depleted reservoirs is 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

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[73] 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.
[74] 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.

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.[75] 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 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.

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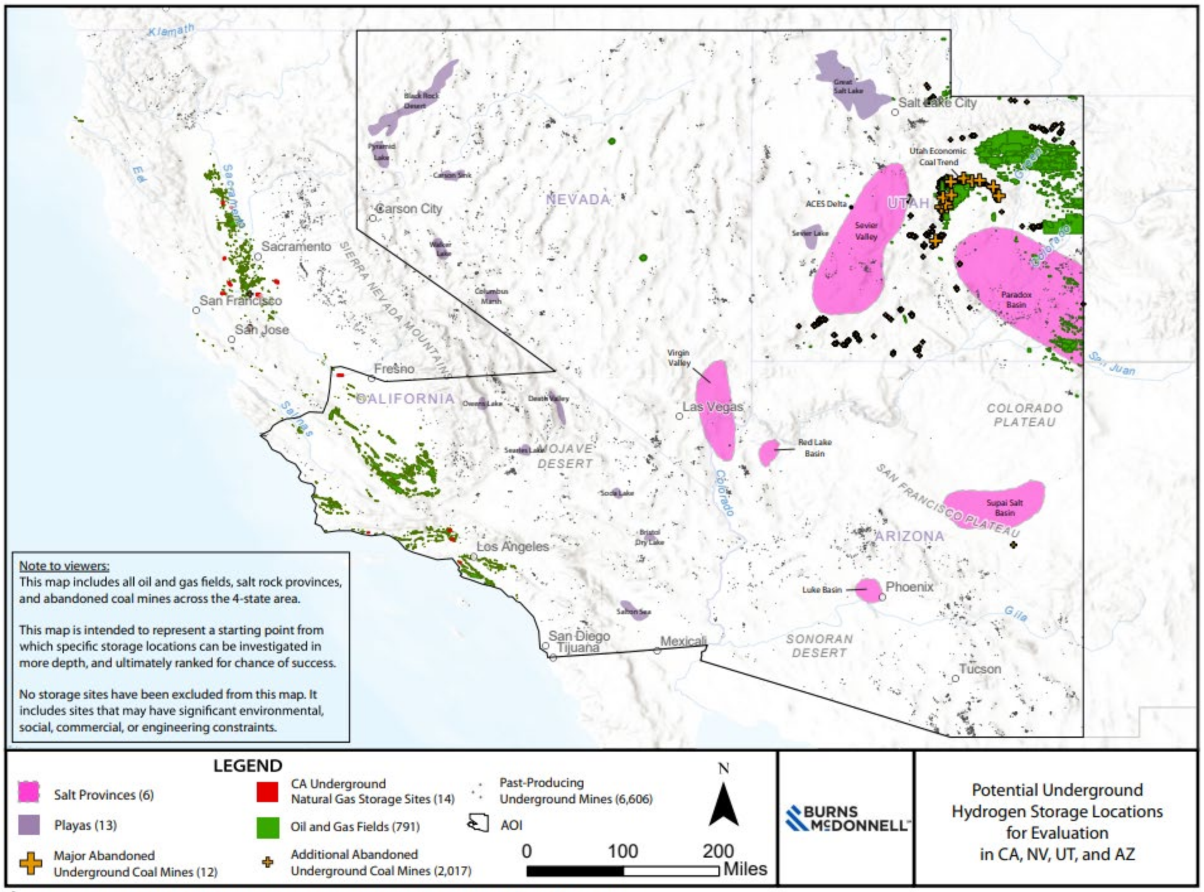
[75] Head, I. M., Jones, D. M. and Larter, S.R., 2003. Biological activity in the deep subsurface and the origin of heavy oil. Nature, 426(6964), pp. 344-352.

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	Thickens 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%	5770 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	Gaviotta	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 Hl, Pyr. Hl	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%		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, southeast 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%

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
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%

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
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%
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 complies with multiple compartments. Size of individual compartments may make them sufficient as storage sites individually. Deeper intervals may be 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 Lake, 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)*

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
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 8-1	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 Belridge - 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%

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

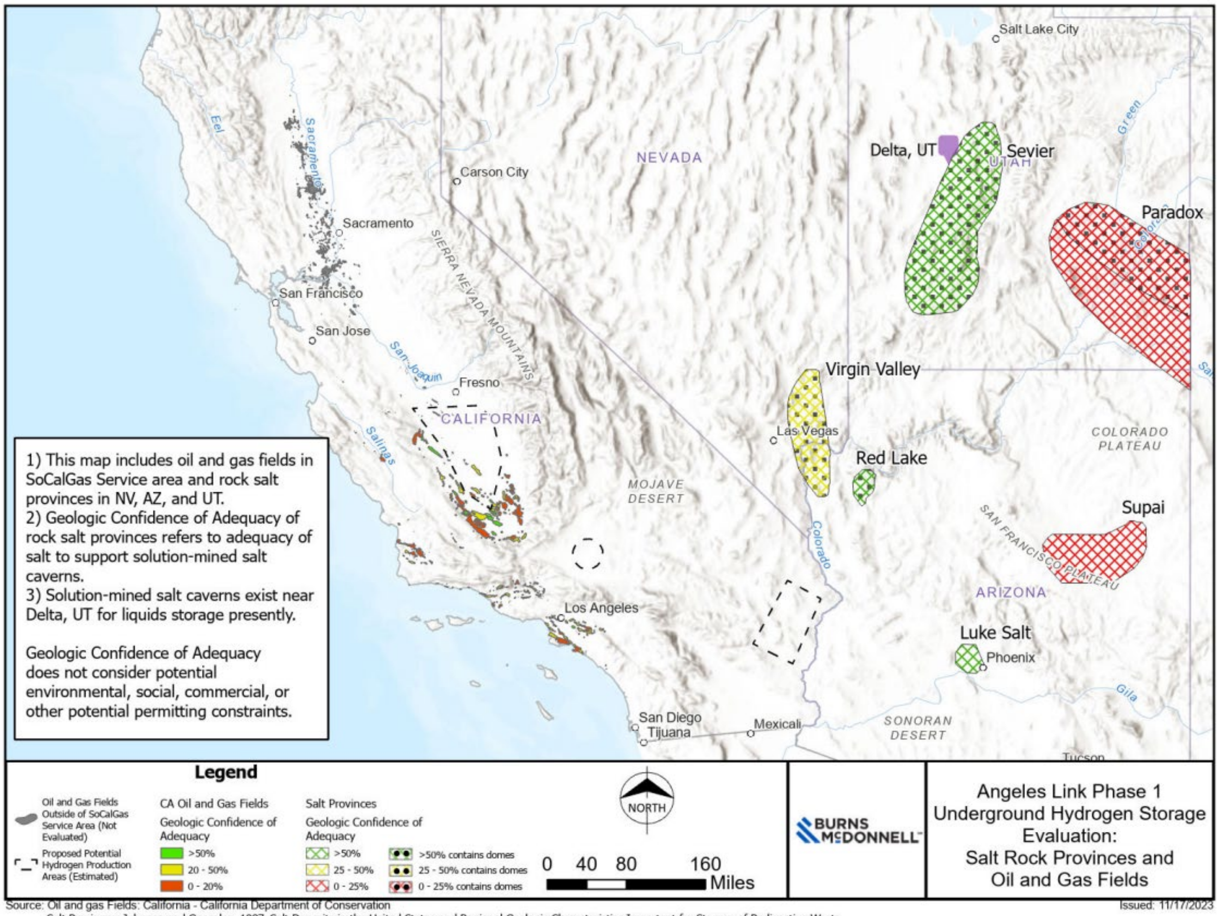
Field	Reservoir	Seal Value	Seal Comments	Trap Value	Trap Comments	Reservoir Value	Reservoir Comment	Loss Value	Loss Comment	Composite Value
Sunset Beach	Lomita Lands	100%	300 ft column sealed by shales in the lower Puente Formation	100%	Tilted beds in the footwall below, structure is an anticline	50%	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 17,651 bbl oil	100%	31% porosity and 2000 mD permeability, valus 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 Clevenger	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%

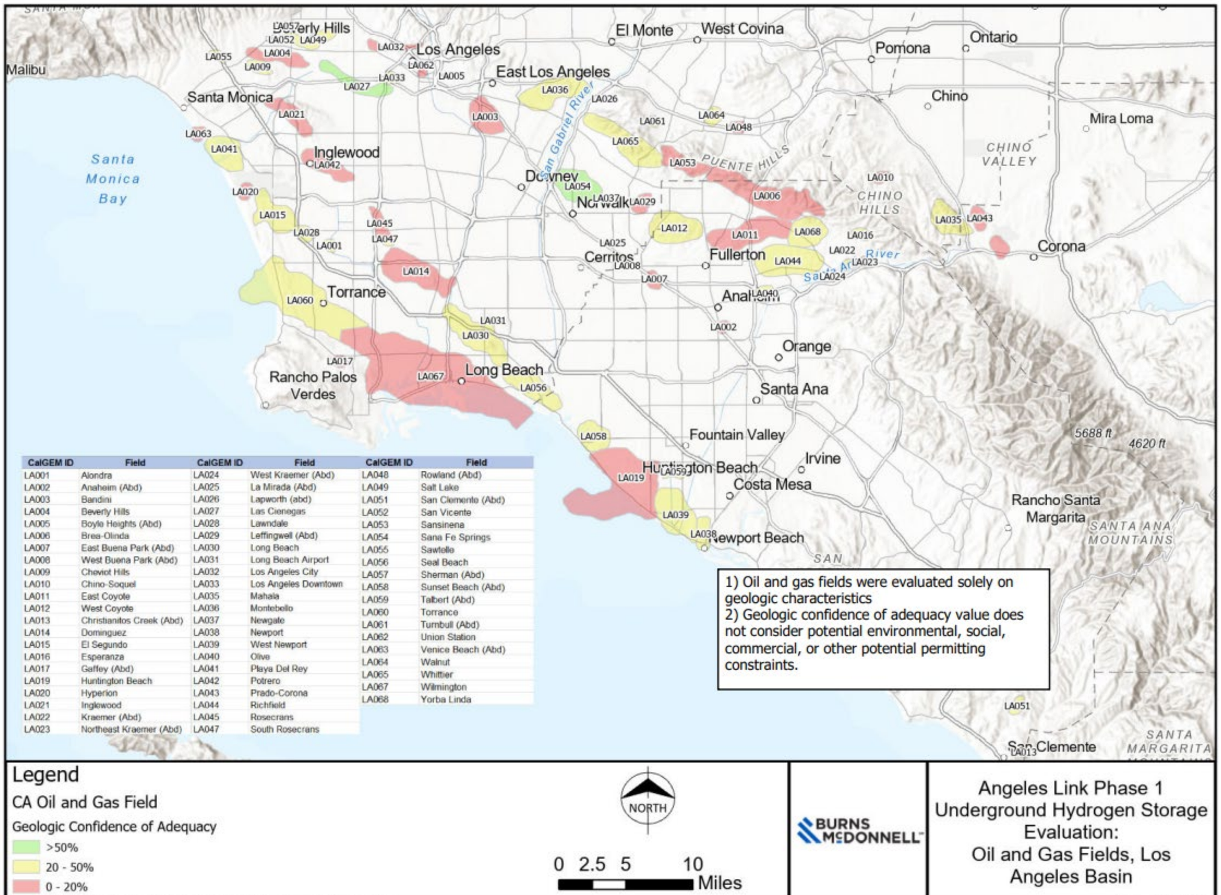
C.5 Maps of Evaluated Underground Storage Site



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

Issued: 11/17/2023

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



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

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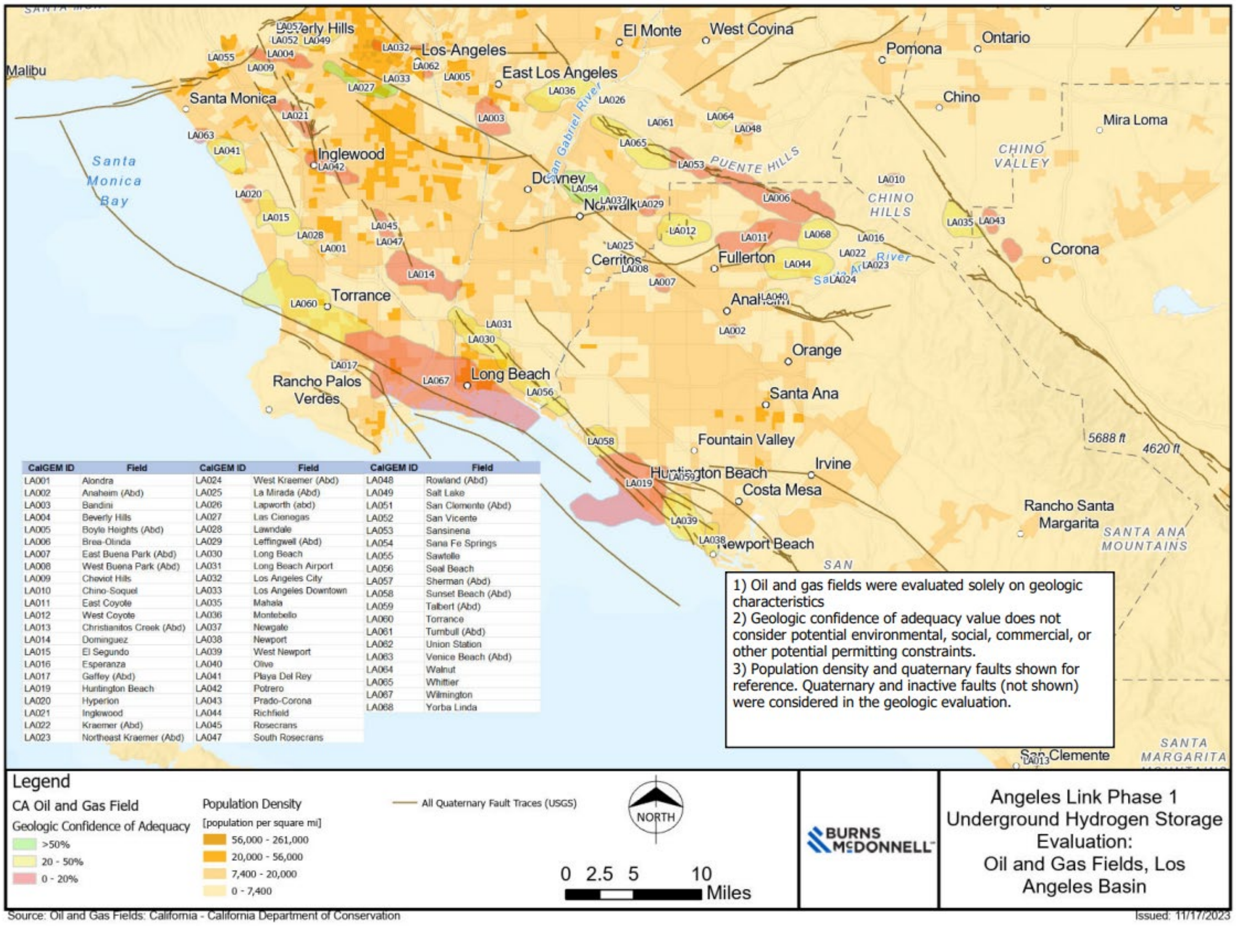
C.5 Maps of Evaluated Underground Storage Site *(Continued)*



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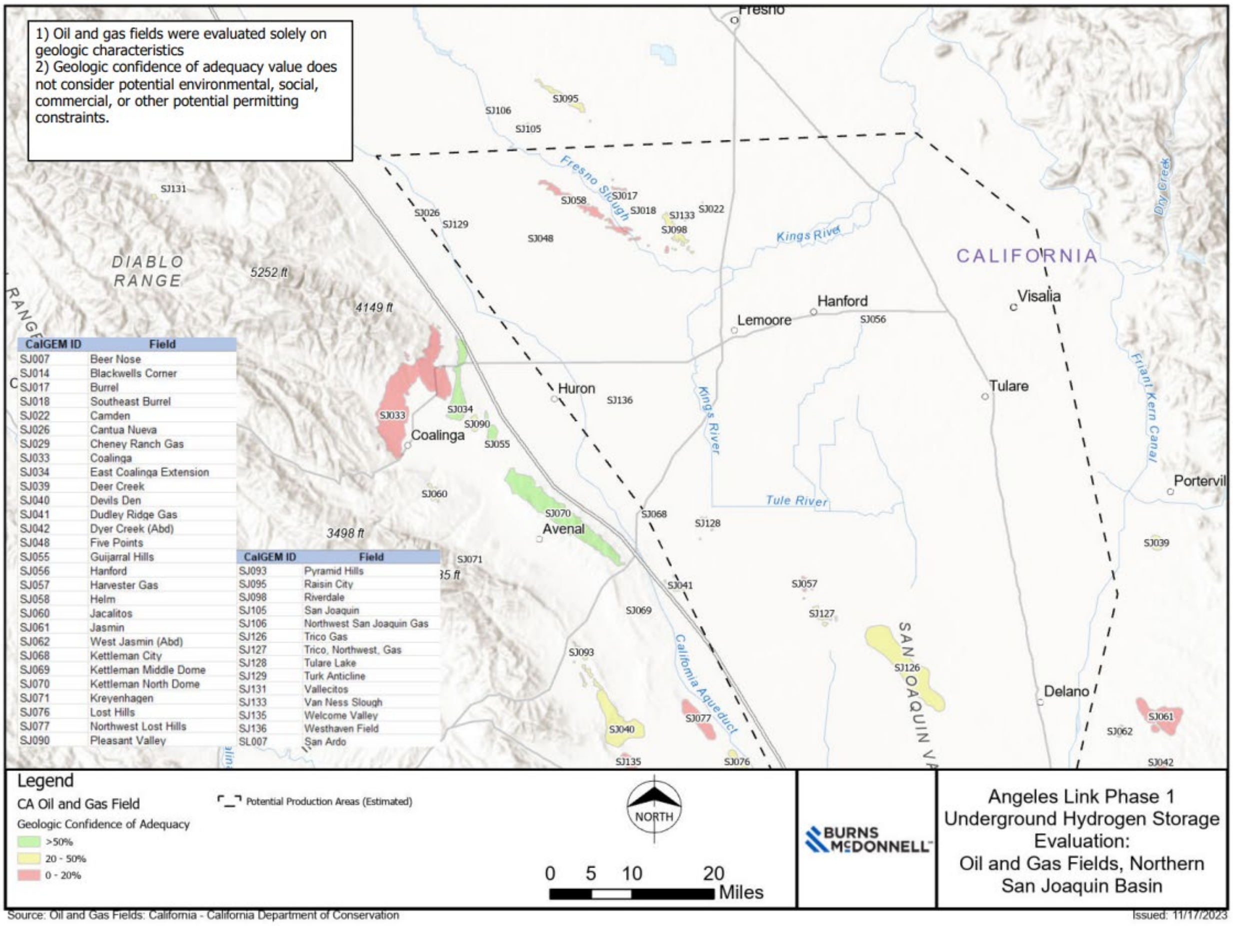

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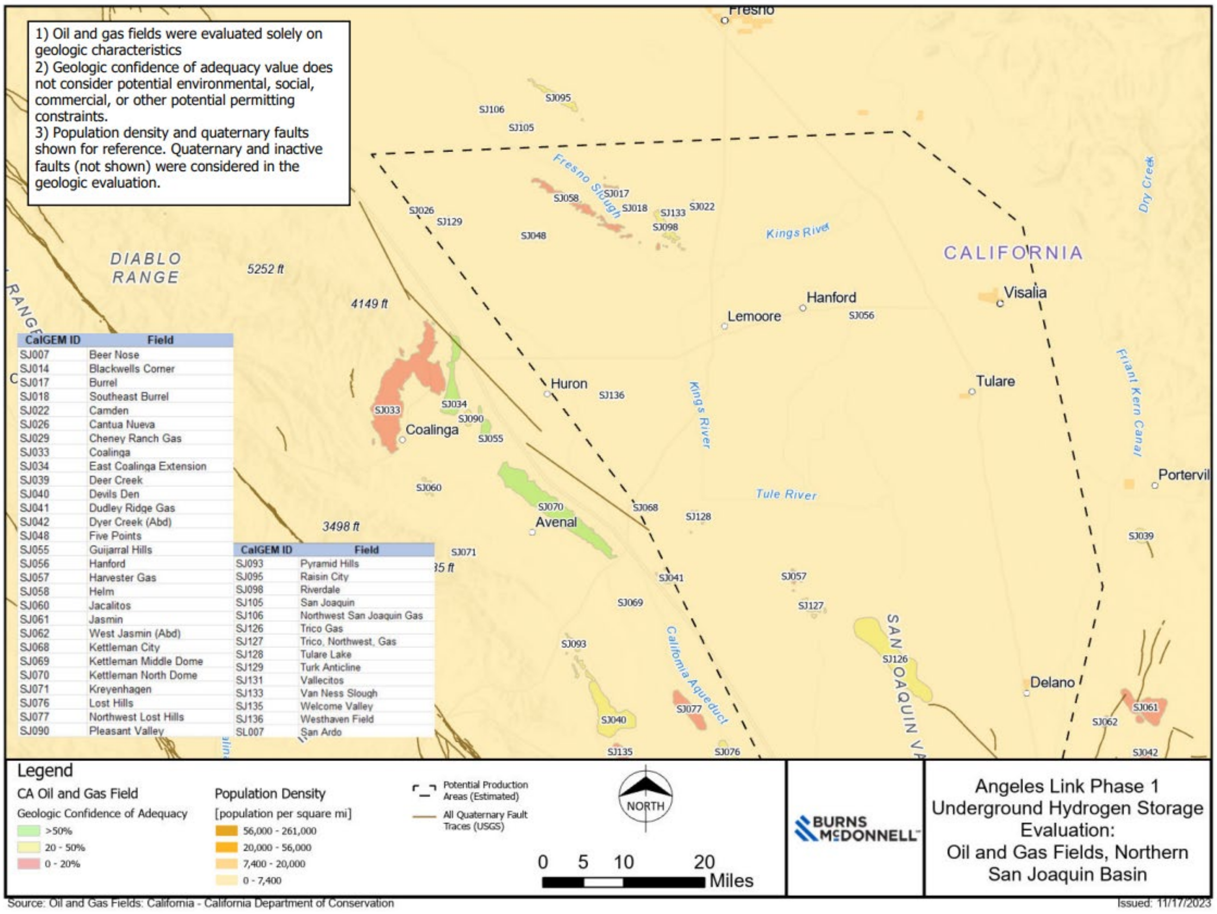

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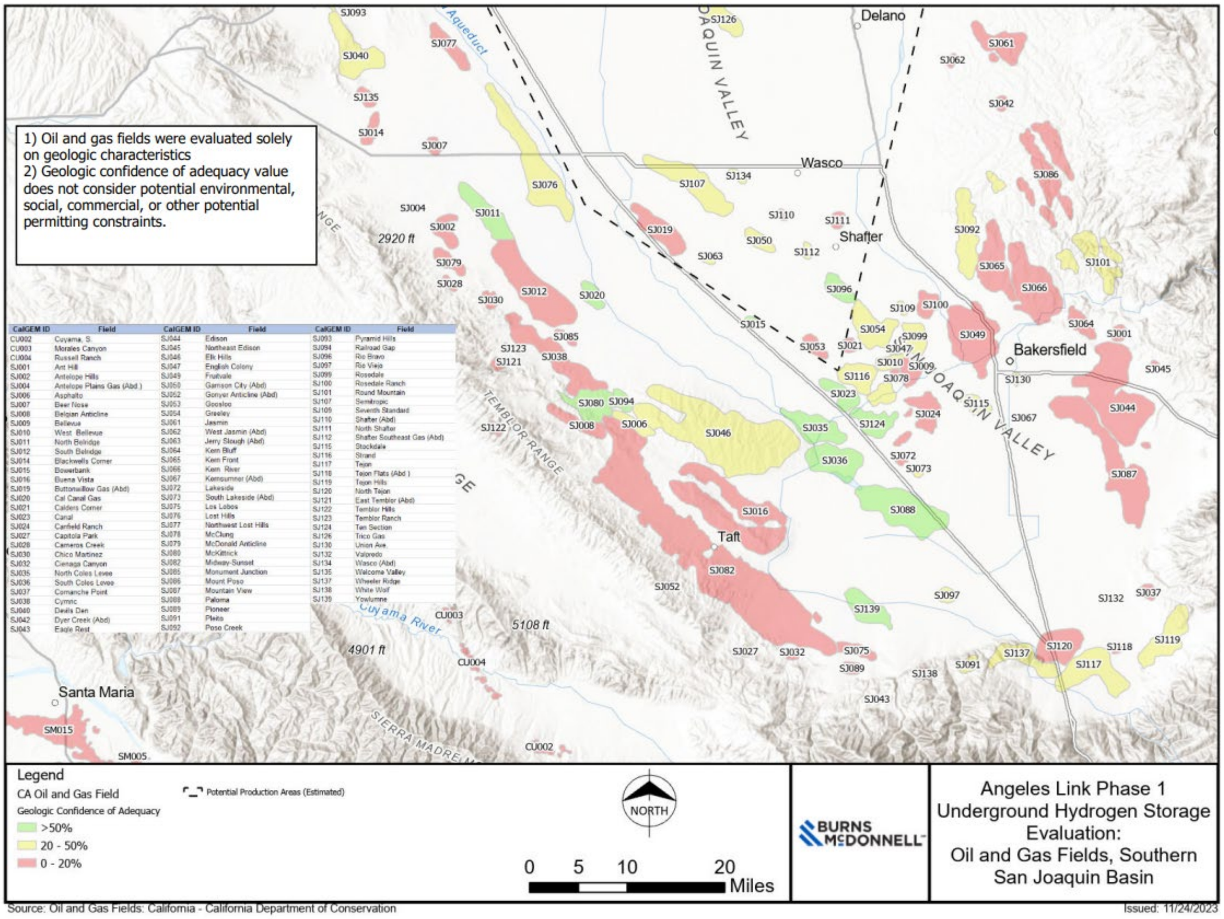

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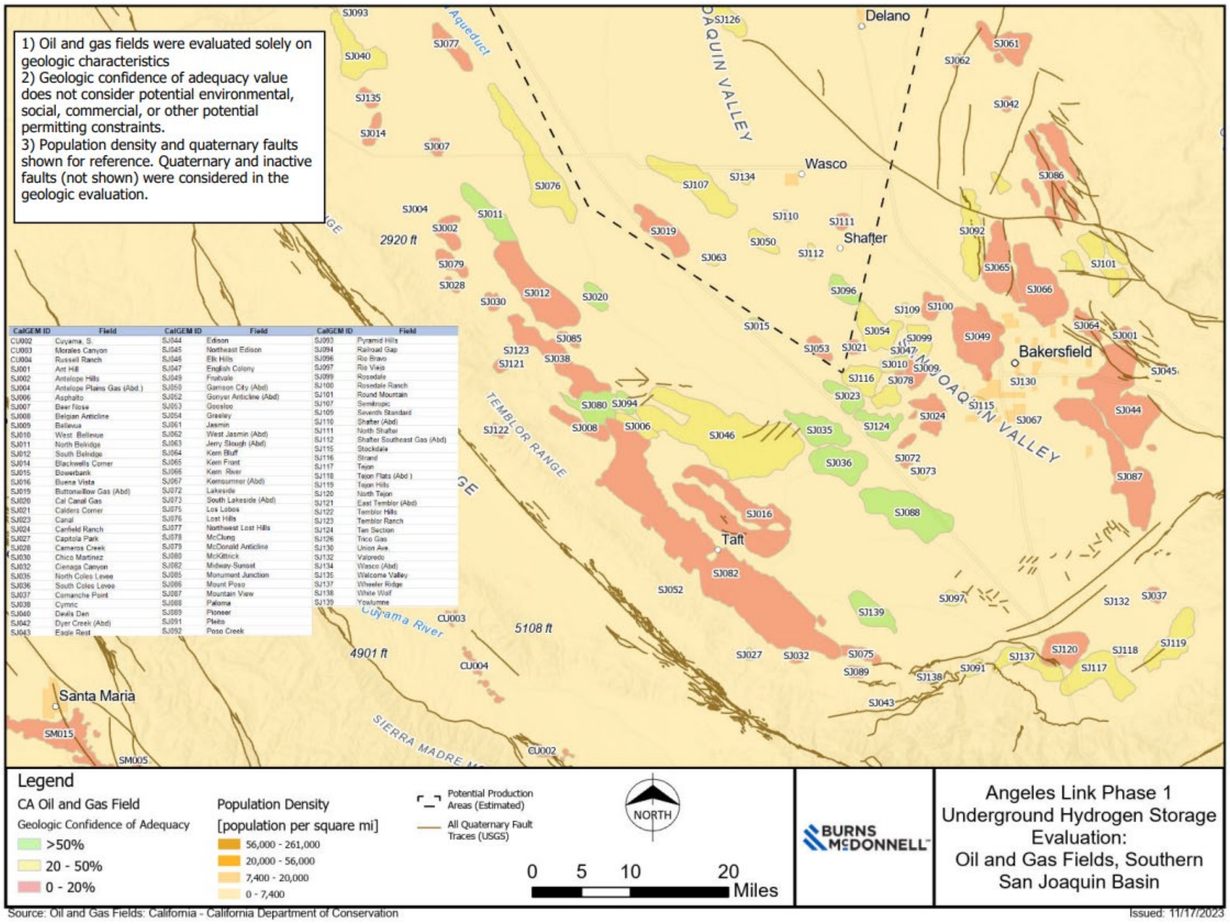

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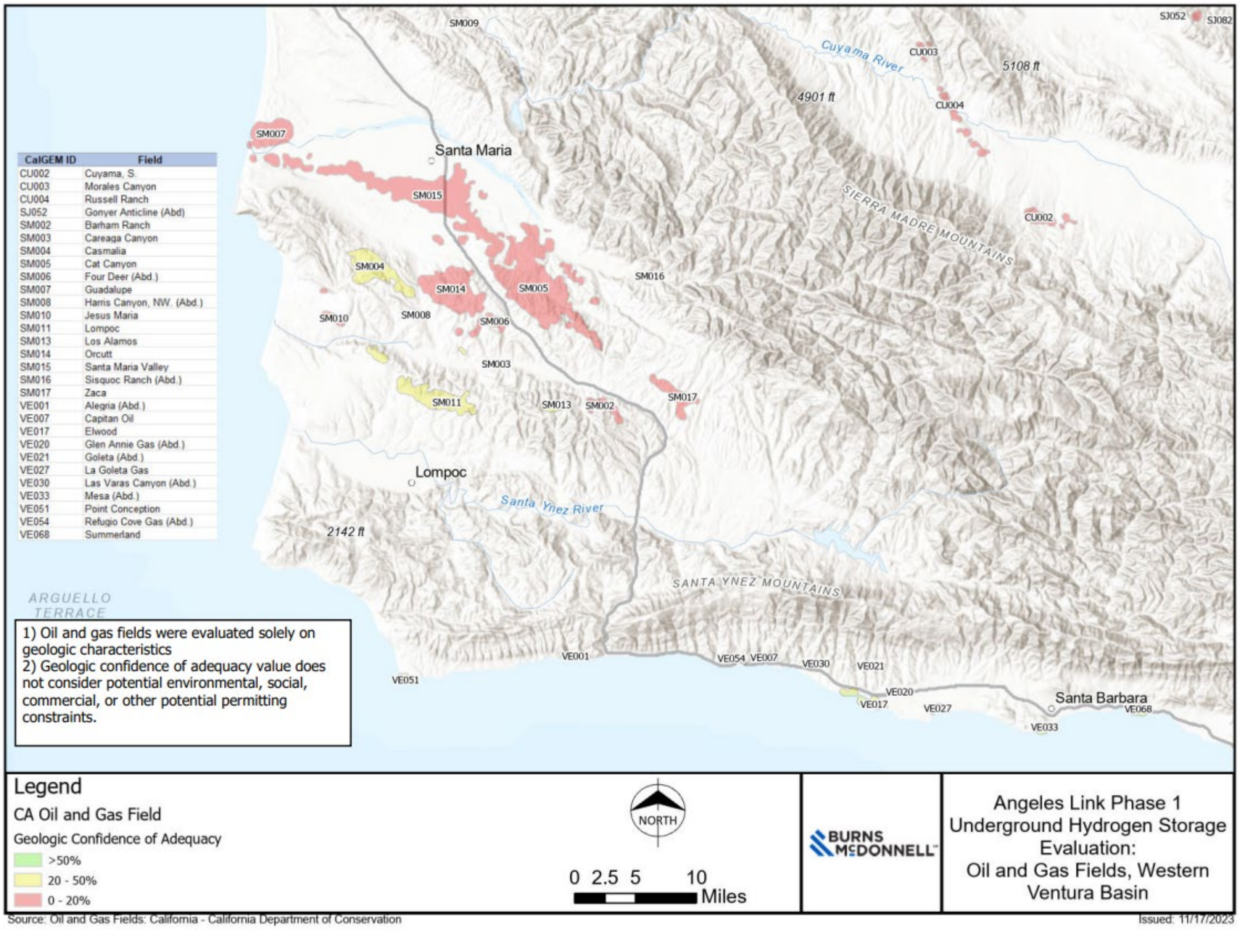

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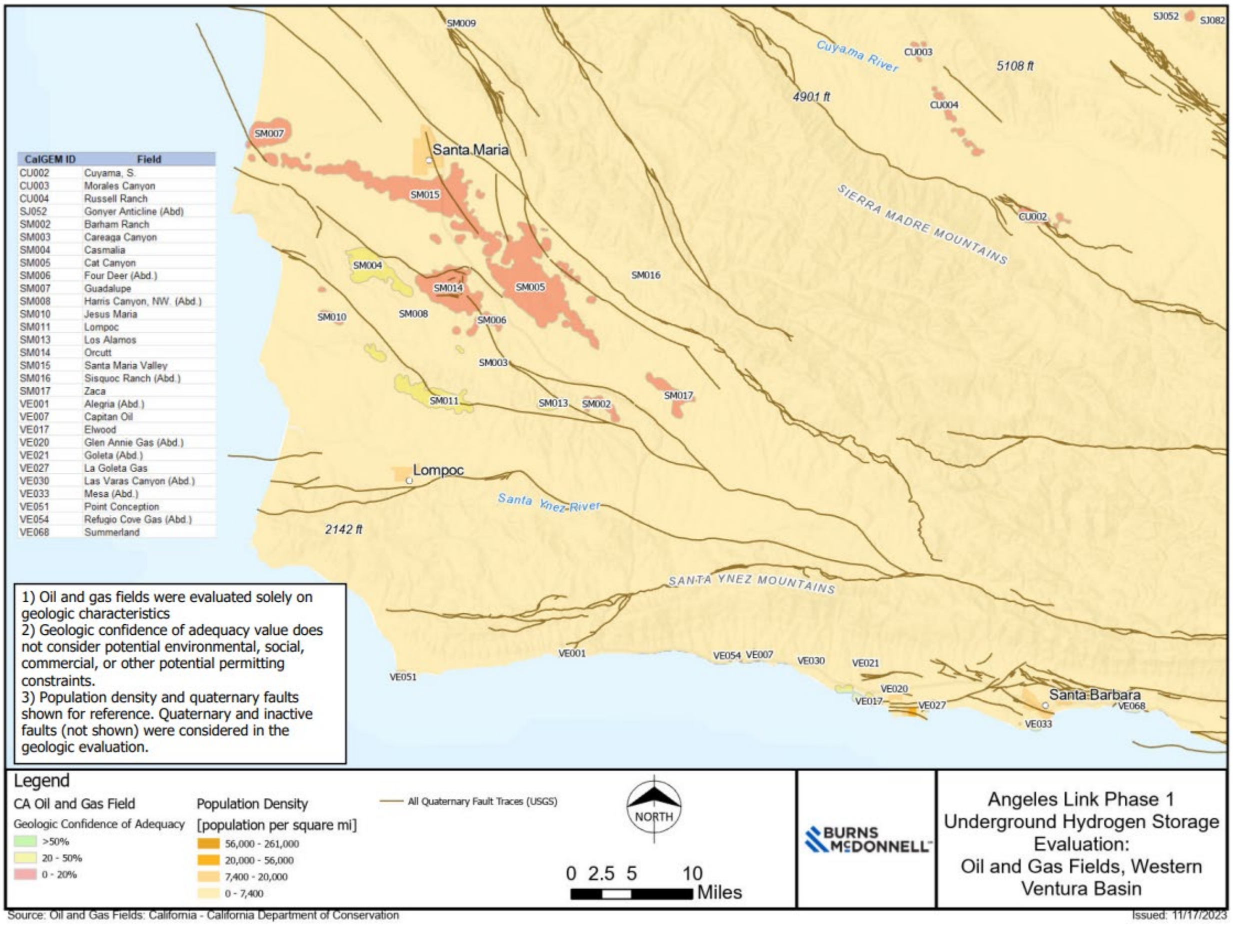

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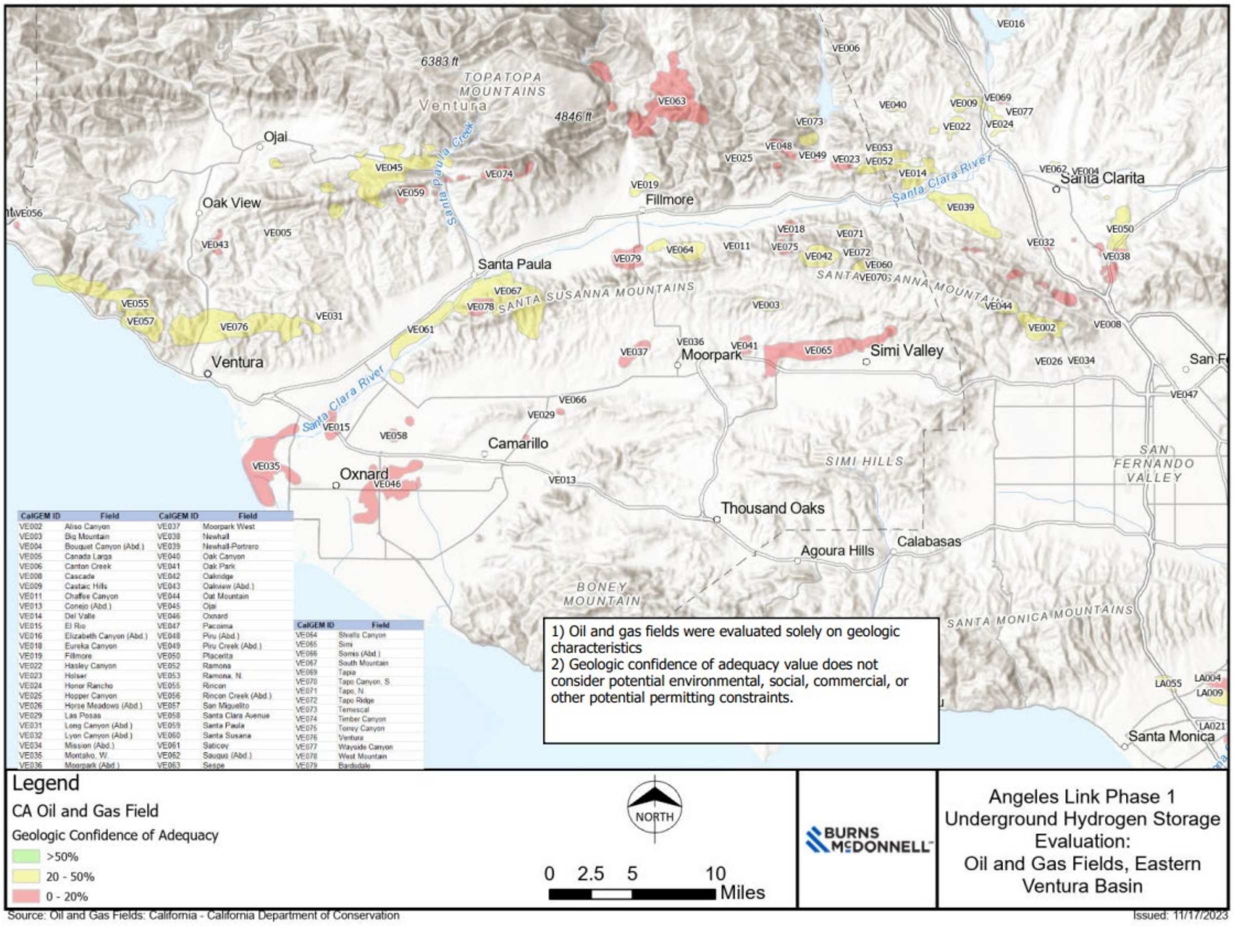

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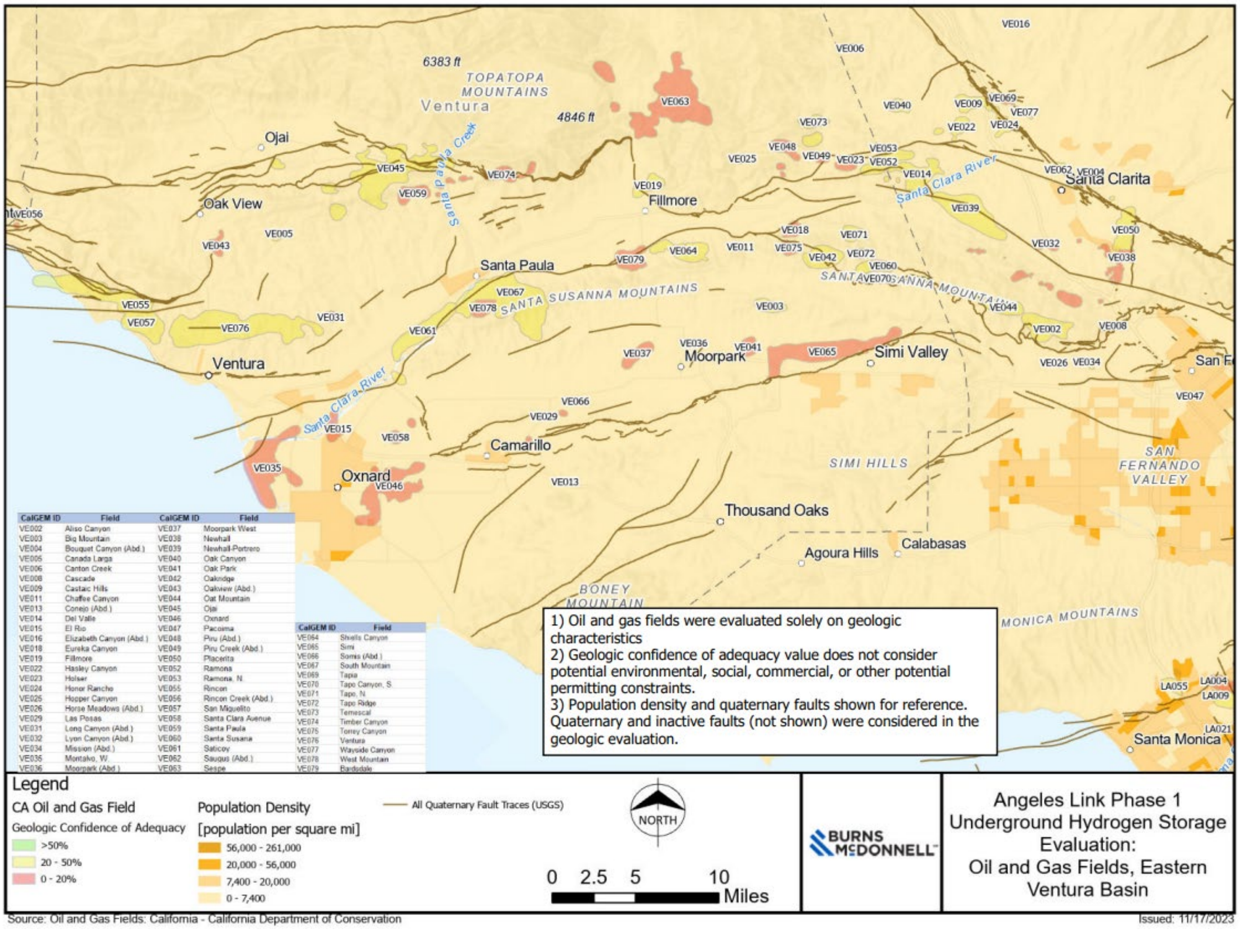

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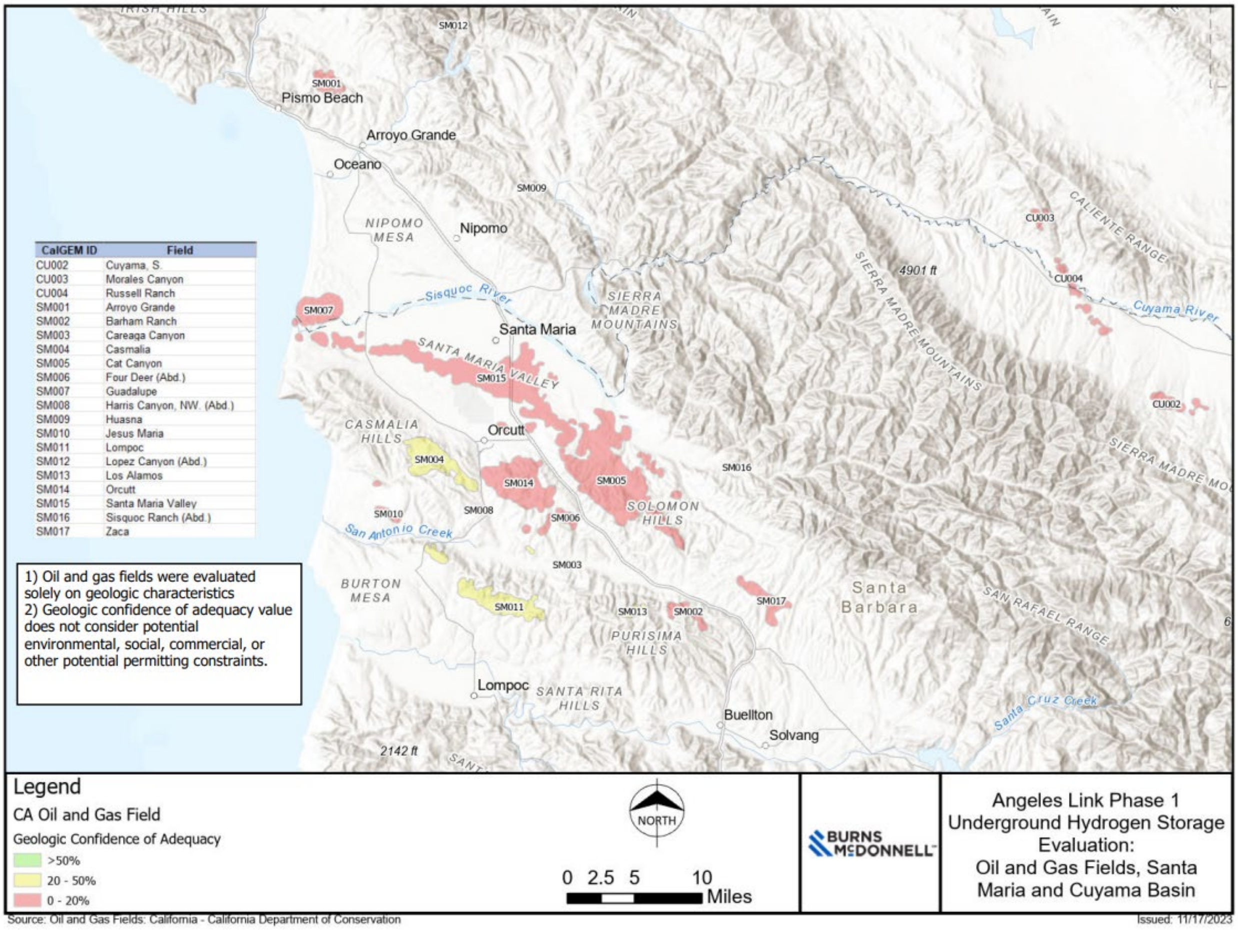

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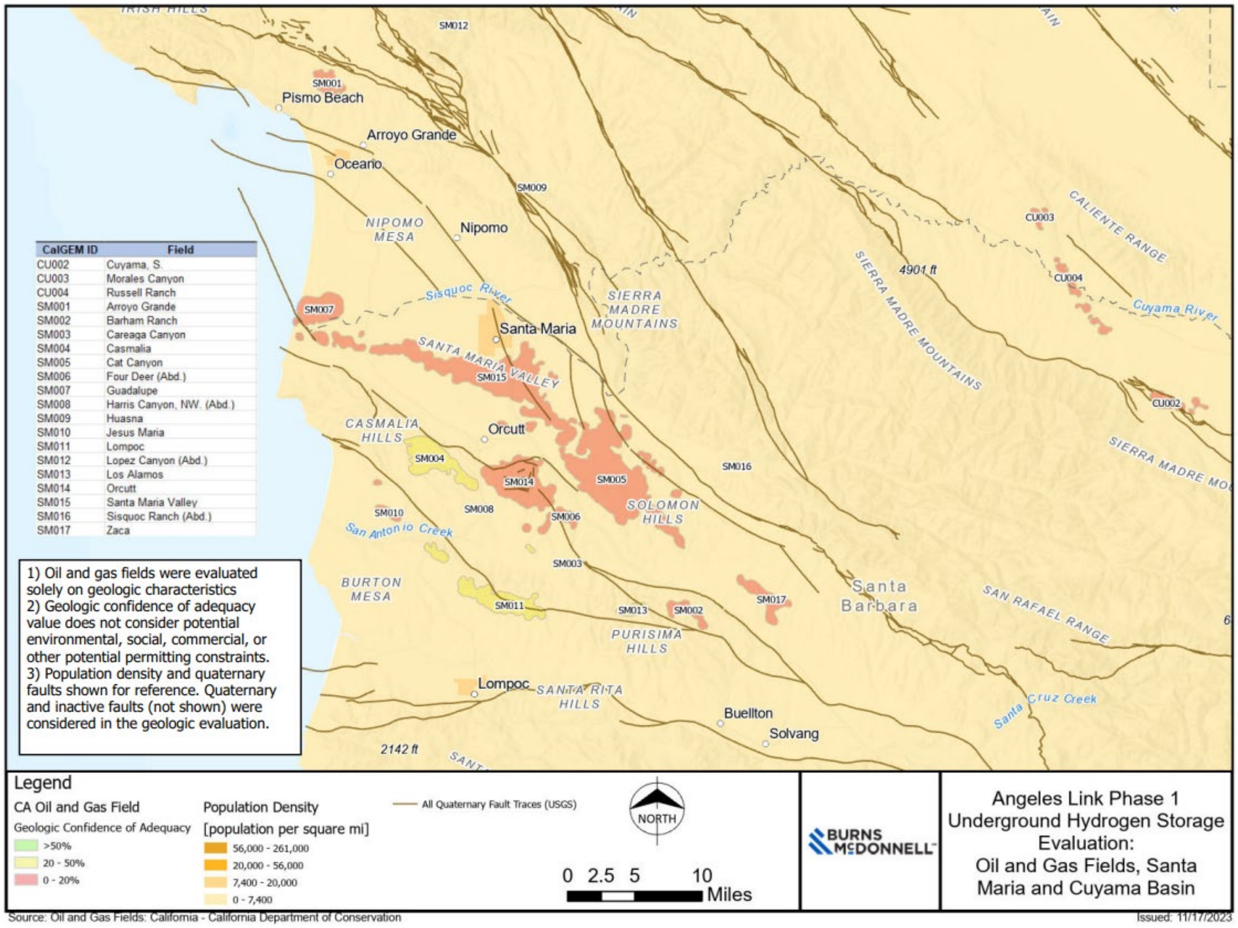

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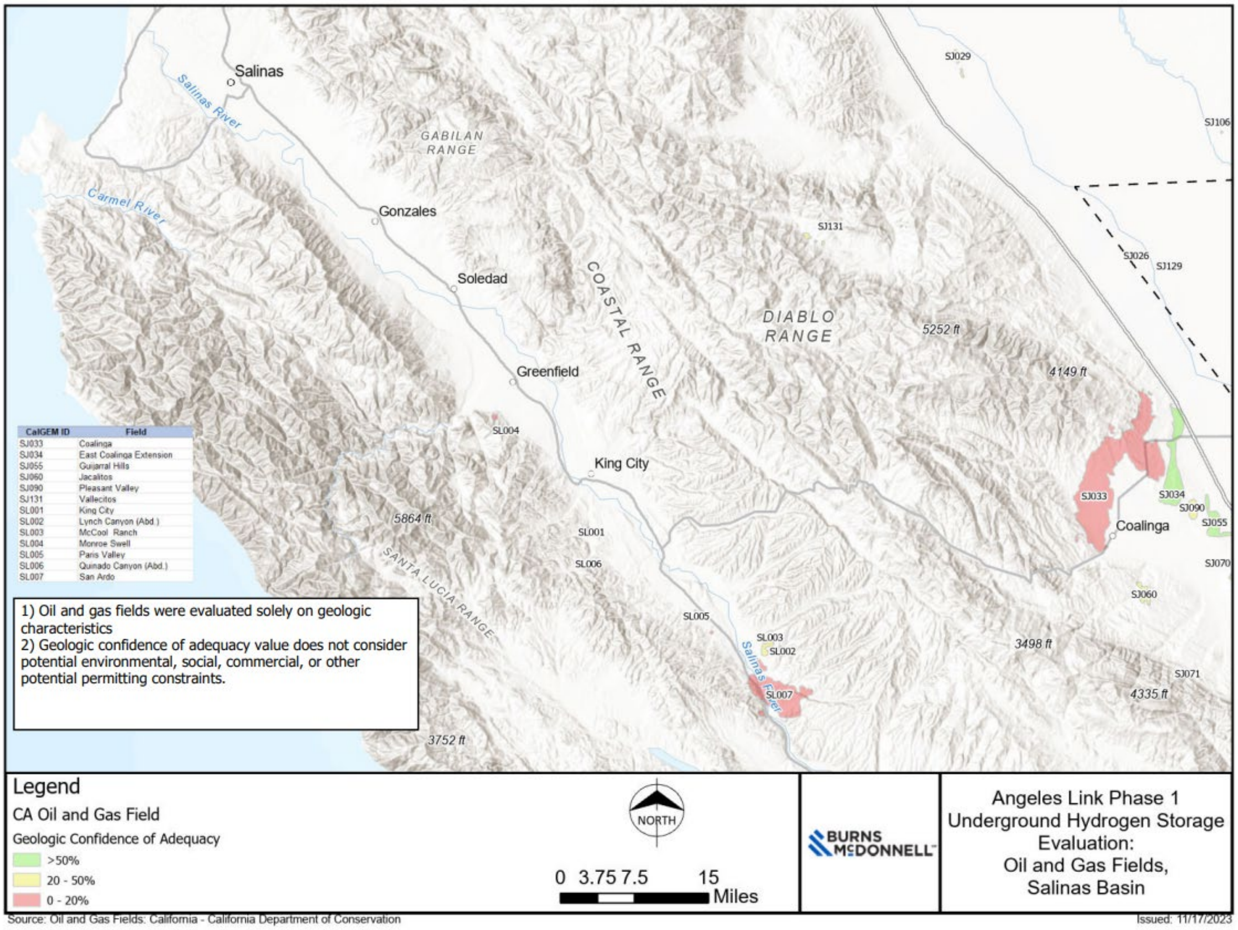
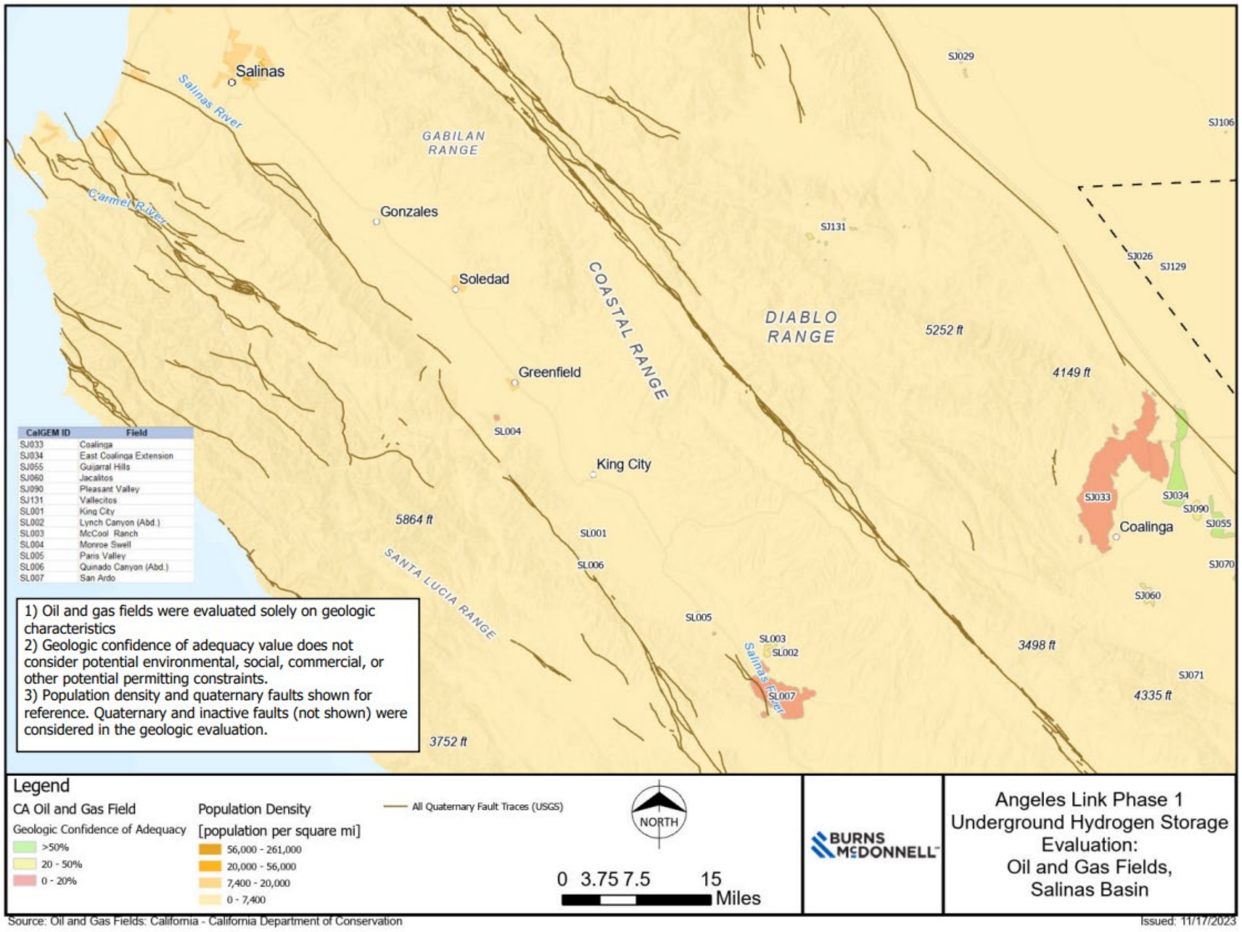


C.5 Maps of Evaluated Underground Storage Site *(Continued)*



ANGELES LINK PHASE 1

PIPELINE SIZING & DESIGN CRITERIA

DRAFT

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

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

Abbreviation	Term/Phrase/Name
AACE	Association for the Advancement of Cost Engineering
ANSI	American National Standards Institute
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
Bscfd	Billion standard cubic feet per day
CBOSG	Community Based Organizations Stakeholder Group
CPUC	California Public Utilities Commission
DOT	Department of Transportation
GIS	Geographic Information Systems
ksi	1,000 pounds per square inch (psig)
ID	Inside Diameter
ILI	Inline Inspection
LEL	Lower Explosive Limit
M&R	Metering & Regulation
MAOP	Maximum Allowable Operating Pressure
MAWP	Maximum Allowable Working Pressure
MDMT	Minimum Design Metal Temperature
MMscfd	Million standard cubic feet per day
MMTPY	Million metric tons (tonnes) per year
NACE	National Association of Corrosion Engineers
NDE	Non-Destructive Examination
NFPA	National Fire Protection Association
NPS	Nominal Pipe Size
OD	Outside Diameter
P&ID	Piping & Instrumentation Diagram
PAG	Planning Advisory Group
PHMSA	Pipeline and Hazardous Materials Safety Administration
psig	Pounds per square inch (gauge)
scf	Standard Cubic Foot
SJV	San Joaquin Valley
SMYS	Specified Minimum Yield Strength
Tonne	Metric ton (1,000 kg)
TPD	Tonnes per day
TPY	Tonnes per year
WT	Wall Thickness

EXECUTIVE SUMMARY

Southern California Gas Company (SoCalGas) is proposing to develop a clean renewable hydrogen[1] pipeline system to facilitate transportation of clean renewable hydrogen from multiple regional third-party production sources and storage sites to various delivery points and end users in Central and Southern California, including in the Los Angeles Basin. The CPUC's Phase 1 Decision, approving the Memorandum Account for SoCalGas's proposed Angeles Link requires SoCalGas to identify and compare routes and configurations for Angeles Link. The Pipeline Sizing and Design Criteria Study (Design Study) establishes a preliminary engineering and design basis that supports the consideration of cost estimates, reliability, and resiliency. The Design Study is focused on the transport of clean renewable hydrogen via pipeline and includes evaluation of compression and ancillary equipment.

The objective of this Design Study is to evaluate and determine a preliminary range of pipeline diameters and pressure profiles. Additionally, technical specifications such as operating parameters, suitable equipment, logistics, and materials of construction were considered to support an efficient and reliable pipeline system. This evaluation was completed through literature review, hydraulic modeling, and data from other Phase 1 Studies, including the Production Planning & Assessment (Production Study), the Demand Study, the Preliminary Routing/Configuration Analysis (Routing Analysis), and the Plan for Applicable Safety Requirements (Safety Study). Data from this study was utilized in the High-Level Economic Analysis & Cost Effectiveness Study (Cost Effectiveness Study), the Project Options & Alternatives (Alternatives Study), and the Workforce Planning & Training Evaluation (Workforce Evaluation).

Information from the Production Study, the Demand Study, and the Routing Analysis were integrated to identify eight operational scenarios for initial hydraulic evaluation. The costs from these various scenarios are part of the basis of analysis in the Cost Effectiveness Study and Workforce Evaluation. Additional hydraulic evaluation was completed for the four potential preferred routes identified in the Routing Analysis. Multiple sizing options were considered, with a focus on maintaining reasonable pressure loss and providing operational resiliency.

The key findings are presented below for potential preferred routes and are discussed further within this document. These findings are based on analysis and information available during Angeles Link Phase 1 development and may be subject to change. Future considerations to advance engineering design, project requirements, and execution are also discussed in this document.

- **Preliminary Design Criteria**
  - The appropriate pipe sizes could range from 16-inch up to 36-inch in nominal diameter.
  - Two to three compressor stations will likely be necessary.

[1] In the California Public Utilities Commission (CPUC)'s Angeles Link Phase 1 Decision (D).22-12-055 (Phase 1 Decision), clean renewable hydrogen refers to hydrogen that does not exceed 4 kilograms of carbon dioxide equivalent (CO2e) produced on a lifecycle basis per kilogram of hydrogen produced and does not use fossil fuels in the hydrogen production process, where fossil fuels are defined as a mixture of hydrocarbons including coal, petroleum, or natural gas, occurring in and extracted from underground deposits.

- The lowest delivery pressure to the Ports of Los Angeles and Long Beach was assumed to be approximately 200 pounds per square inch gauge (psig) while the upper bounds of the modeled system did not go above 1200 psig.[2]
- Select pipelines were modeled and assessed as single run and dual run (e.g., two parallel lines) for functional flexibility, and system resiliency and capacity considerations.
- American Petroleum Institute (API) 5L X52 pipe is recommended based on preliminary calculations and operating parameters.

Stakeholder Feedback

The input and feedback from stakeholders including the Planning Advisory Group (PAG) and Community Based Organization Stakeholder Group (CBOSG) has been helpful to the development of this draft Design Study. Several key themes regarding material specifications, and design considerations, including electric reliability, were addressed in Chapters 5 and Appendix B respectively. Refer to Chapter 8 for Stakeholder comment details and summary of responses. All feedback received is included, in its original form, in the quarterly reports submitted to the CPUC and published on SoCalGas' website.[3]

1. INTRODUCTION – PIPELINE SIZING & DESIGN

Pipeline systems are designed to operate using a variety of different facilities to transport gas from sources of supply to sources of demand. This includes the point where gas enters the system, its transfer to areas of high demand, and eventual utilization by end users. Today, SoCalGas owns and operates a natural gas system of over 3,000 miles of transmission pipelines, over 100,000 miles of distribution and service pipelines, nine compressor stations, and four underground natural gas storage facilities.[4] Compressor stations increase pressure in pipelines that operate over long distances to keep gas flowing. Underground storage facilities are used to help meet demand by balancing load between supply and demand and maintaining a stable gas flow throughout the pipeline system.

A hydrogen gas pipeline system would have a similar architecture to a natural gas pipeline system, whereby similar facilities and pipeline system operation parameters would be employed. Operational differences may also drive design choices with regard to supply and offtake. For example, load balancing on a clean renewable hydrogen system may require consideration of the fluctuations in production of clean renewable hydrogen generated via electrolysis paired with solar driven by daily and seasonal photovoltaic impacts. Load balancing on the natural gas system today requires considerations of a similar manner. Gas supply and demand can vary based on weather conditions such as disruptions to supply during severe weather events, increase in demand during winter to heat residential and commercial buildings, and summer months to meet increased electric power demand for natural gas.[5]

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[2] Refer to Design Pressure Section 3.2. The system modeled may be effective for MAOP of 1200 psig however, this is subject to change depending on actual operating parameters, and material selections.
[3] Angeles Link: SoCalGas, (n.d.-a). https://www.socalgas.com/sustainability/hydrogen/angeles-link
[4] Form 10-K for Sempra filed 02/27/2024. (n.d.). https://investor.sempra.com/static-files/fd1dd362-92ec-42a9-a1e1-009866e4a413
[5] U.S. Energy Information Administration - EIA - independent statistics and analysis. Factors affecting natural gas prices - U.S. Energy Information Administration (EIA). (n.d.). https://www.eia.gov/energyexplained/natural-gas/factors-affecting-natural-gas-prices.php

1.1 Components of a Pipeline System

A pipeline system design includes a variety of components. Additional features may be necessary on a case-by-case basis. The following is a list of the components that may be part of a clean renewable hydrogen pipeline system:

1. **Pipelines:** Tubular sections made from materials compatible with hydrogen to transport the gas from one point to another. They must be designed to resist hydrogen embrittlement[6] and withstand the specific pressures and temperatures of hydrogen gas.
2. **Compressors:** Mechanical equipment, typically found in transmission stations, used to increase the pressure of the hydrogen gas to adequate levels for transmission through the pipeline. They are essential for maintaining flow and overcoming frictional losses along the pipeline length.
3. **Air Cooled Heat Exchangers:** Heat transfer equipment, typically found in transmission stations, used to cool the hot discharge gas from compressors to acceptable temperatures conducive to pipeline transportation.
4. **Valves:** Including isolation valves, control valves, and safety valves; these components regulate, direct, or control the flow of hydrogen by opening, closing, or partially obstructing various passageways.
5. **Pressure Relief Valves (PRVs):** Safety devices designed to open at a predetermined pressure to prevent an excess pressure build-up that could jeopardize the pipeline's structural integrity.
6. **Emergency Shutdown Systems (ESDs):** Systems designed to rapidly shut down compressor station equipment and/or facilities under certain conditions in the event of a detected leak or other hazardous situations that will isolate sections of the pipeline to minimize risks.
7. **Pressure Limiting Station (PLS):** Devices that regulate or limit the flow of gas at a specific set point to achieve or maintain a certain pressure to keep pipeline operations within the determined pressure limits.
8. **Pig Launchers & Receivers:** Facilities used for the insertion and retrieval of in-line inspection tools used to clean and inspect the pipeline.
9. **Metering Stations:** These stations measure the flow rate of hydrogen through the pipeline and are utilized for operational control and billing purposes.
10. **Corrosion Protection Systems:** Includes cathodic protection and protective coatings that are designed to prevent internal and external corrosion.
11. **Leak Detection Systems:** Technologies deployed along the pipeline to detect and locate leaks based on pressure, acoustic signals, or chemical sensors. These are components essential for the early detection of failures or breaches in pipeline integrity.
12. **Control & Monitoring Systems:** Centralized systems that use field technology, sensors and communication methods to monitor and control the physical parameters of the pipeline.

The final design of a system and the selection of the above components will take into account federal, state, and industry codes and standards. The system will be designed to meet operational requirements, account for facility locations, and to support construction, operations, and integrity management objectives. As such, during the feasibility analysis, pipeline design activities occur at a high-level and identify a basis for further evaluation. Pipeline materials, pipeline diameter, anticipated compression

[6] Refer to Hydrogen Embrittlement Section 5.2.

requirements, and ability for pipeline cleaning and inspections (piggability) are evaluated at a feasibility level within this report. Ancillary components in addition to the pipeline system may include third-party production and storage facilities, offtake equipment specific to individual applications, and potentially equipment specific to gas purification or scrubbing.

1.2 Pipeline Sizing Process

In gas distribution and transmission systems, the sizing of pipelines is a critical engineering task that influences efficiency, safety, and operational viability. This section of the report introduces the key concepts and considerations involved in pipeline sizing that are applied in this report to Angeles Link.

Pipeline sizing is the process of determining the optimal diameter and wall thickness of a pipeline so that it can safely and efficiently transport the required volume of gas under given operating conditions.

Effective pipeline sizing requires a thorough understanding of the physical and chemical properties of hydrogen as well as the dynamics of gas flow through pipelines. These include considerations of the gas's compressibility which affects how its volume changes with pressure; the type of flow – whether laminar or turbulent – which influences the pressure losses in the pipe; and the Reynolds number, a dimensionless quantity that helps determine the flow regime based on pipe dimensions, flow velocity, and gas viscosity.

Hydrogen is the lightest of all gases, which can significantly influence its behavior within a pipeline system. It has a low molecular weight, which can lead to higher flow rates while its low viscosity leads to a higher Reynolds number at comparable conditions, which could result in turbulent flow. Due to hydrogen's small molecule size and high diffusivity, pipelines must be constructed with materials that minimize permeation.

Temperature and pressure conditions, both environmental and operational, must also be carefully evaluated. Additionally, the required flow rate – dictated by consumer demand and production capacities – plays a fundamental role in determining the appropriate pipe diameter. By understanding and applying these considerations, the pipeline can be sized to meet current demand while also maintaining scalability for future needs without significant reengineering.

Sizing and design features identified within this report are subject to change as additional information and analysis of the system is completed. The Future Considerations Chapter of this report includes discussion on the next steps that progress the degree of certainty for pipeline sizing and design.

1.3 Study Approach

The Design Study allows for the integration of data from several related Angeles Link Phase 1 studies, including the Production, Demand, and Safety Studies. This information is used to build the basis of the system evaluation from where the design parameters can be established to support hydraulic modeling. Hydraulic modeling is then used to evaluate Scenarios 1-8, which consider different potential routing pathways (Routing Analysis), production capacities and total system volumes (Production Study) from a hydraulic standpoint. Additional modeling is then completed for the four potential preferred routes (Routing Analysis) to evaluate pipeline configuration to determine preliminary sizing and material recommendations. These sizing and material recommendations are utilized for the purposes of cost estimation for Scenarios 1-8, which are then used to inform the Cost Effectiveness and Alternatives Study.

The following steps illustrate the activities completed within this Study and are explored in greater detail in the subsequent chapters.

1) Study Integration – System Description
2) Assumptions – Design Parameters
3) Scenario Evaluation – Hydraulic Analysis and System Resiliency
4) Material Review & Cost

2. SYSTEM DESCRIPTION

2.1. System Overview

The objective of Angeles Link is to transport clean renewable hydrogen, likely from multiple local and longer term regional clean hydrogen production sources to various delivery points in Central and Southern California, including the Los Angeles Basin (including the concentrated commercial and industrial area in and around the Ports of Los Angeles and Long Beach). Therefore, the Production Study and the Demand Study included in the Angeles Link Phase 1 feasibility studies provide information that is critical to the pipeline system sizing and design. These studies identify characteristics of the potential hydrogen supply to the pipeline along with the potential offtake from the pipeline.

The system is evaluated at varying levels of total system capacity, illustrative of possible temporal growth. This allows for evaluation considering the potential for short-term versus long-term sizing, with a total system capacity used for evaluation of the Angeles Link Phase 1 potential preferred routes.

2.2. Hydrogen Production

The Production Study identified three primary areas within SoCalGas's service territory for potential hydrogen production sites. The three potential Production Areas are referred to as San Joaquin Valley (SJV), Lancaster, and Blythe. Although these areas were identified as locations with a higher likelihood for large-scale production, hydrogen production facilities may also be located outside of these identified areas. Under Scenarios 1-8, production was modeled within pipeline routing as a supply that ranged from 500,000 – 750,000 tonnes per year (TPY) from various combinations of production areas.

As the location of the conceptual production facilities was not identified beyond the general areas illustrated below in Figure 1, the lateral, or secondary pipeline(s) that would connect to the main pipeline to transport hydrogen from individual production facilities to the larger system were excluded from the hydraulic model. See the Production Study for further detail.

2.3. Hydrogen Demand

The Demand Study projected potential demand for clean renewable hydrogen across the mobility, power generation, and industrial sectors in SoCalGas' service territory through 2045. See the Demand Study for further detail.

The Angeles Link system proposes to transport a portion of the projected demand under three cases as well using the 2045 throughput sector ratios interpolated to approximately 0.5, 1.0, and 1.5 million tonnes per year (MMTPY). See Production Study for further detail. These Angeles Link specific throughput assumptions were used in this Design Study. Table 1 illustrates these various assumed annual throughputs.

Table 1 - Angeles Link Demand Cases

Angeles Link Phase 1 Study	Case 1	Case 2	Case 3
Sizing & Design Study	0.5 MMTPY	1.0 MMTPY	1.5 MMTPY

The Demand Study identified potential users and off-takers across Central and Southern California. Demand locations significantly influence the operational conditions of the system, including pressures and flow rates. For the purposes of hydraulic modeling and sizing for maximum throughput, it was assumed that all demand was concentrated at a single point within the Los Angeles Basin (LA Basin). This is a conservative assumption as potential off-takes were identified in the Demand Study located upstream of the LA Basin, where hydrogen may be withdrawn by off-takers located in Central and Southern California.

2.4. Hydrogen Storage

As noted in the Production Study, the storage of hydrogen can be used to balance fluctuations in supply and demand. Storage would hold excess hydrogen during production periods when supply exceeds demand, and provide hydrogen when demand exceeds supply. The volume of storage needed is in direct correlation to the operating and usage characteristics of the production and offtake facilities. Hydrogen may be stored and accessed within the pipeline system as well as in aboveground or underground hydrogen storage facilities discussed in the Production Study. 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 system line-pack, can provide storage capacity while scale storage technologies are developed over time to support regional hydrogen hub requirements.

2.5. Pipeline Routes

The Routing Analysis identified a variety of different conceptual pipeline routes. The pipeline distances and elevation along the selected routes were modeled in ProMax[7], the hydraulic simulation software utilized in this study. Combinations of the conceptual Production Areas and pipeline routes shown in Figure 1 were evaluated, along with the preferred routes identified by the Routing Analysis. See the Routing Analysis for further detail on conceptual route evaluation process, routing analysis, and resulting preferred routes.

[7] Refer to Section 4.1 for Pipe Modeling Software details.

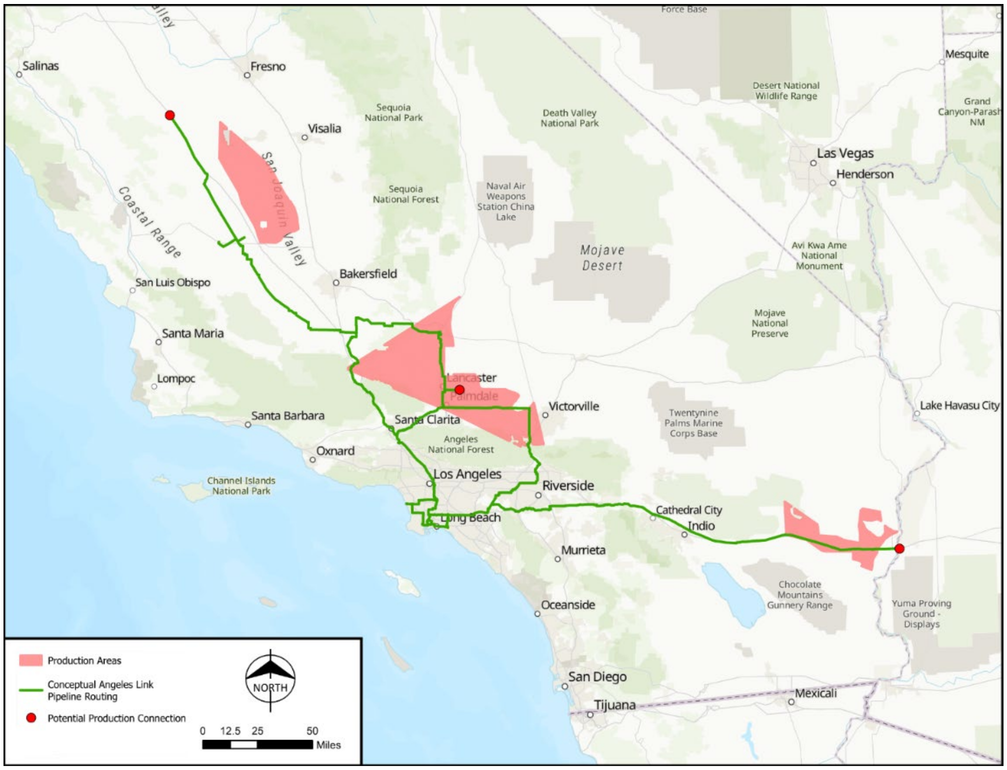

Figure 1 - Conceptual Production Areas and Pipeline Routing

3. DESIGN PARAMETERS

Specific criteria were used to conduct the preliminary engineering and design evaluation described in this document. These criteria form the design parameters for pipeline sizing, to guide engineering calculations and simulations. This chapter discusses the various criteria that were taken into consideration, and their impact on the study's results.

3.1. Industry Codes, Standards, and Best Practices

Transmission of clean renewable hydrogen across the value chain must prioritize safety and leverage applicable industry experience and best practice, regulations, codes, and standards. For example, the Pipeline and Hazardous Materials Safety Administration (PHMSA) sets pipeline safety regulations (Title 49 Code of Federal Regulations (CFR) Parts 190-199), which include specific requirements for the design, construction, operation, and maintenance of hydrogen pipelines. Industry specific requirements may be set by other agencies such as the American Petroleum Institute (API) and the American Society of Mechanical Engineers (ASME). States may have additional regulations, particularly concerning environmental impacts and safety measures. Refer to the Safety Study for details on applicable state codes and regulations.

ASME has developed a consensus design standard for hydrogen pipelines and plant piping in a document called ASME B31.12[8], "*Hydrogen Piping and Pipelines*" which covers the transportation of hydrogen, detailing requirements for materials, design, fabrication, and testing to ensure safety and efficiency. ASME B31.8, "*Gas Transmission and Distribution Piping Systems*" is another key design standard. Incorporating these standards by reference into federal regulations allow PHMSA to enforce industry standards and guidelines set by organizations like API or ASME. However, even when industry codes are not specifically incorporated by reference, they may offer relevant guidance and best practices for consideration. As compliance with codes and regulations are incorporated into the pipeline design, design governance will prioritize the more stringent requirements to increase safety.

As stated in the Safety Study, industry best practices for hydrogen pipelines emphasize the importance of integrating safety management systems, risk assessments, and the adoption of new technologies for leak detection and emergency response. The industry also focuses on ongoing research and development to address the challenges of hydrogen embrittlement and the unique properties of hydrogen.

These guidelines and regulations are designed to confirm that hydrogen pipelines are built and operated safely, efficiently, and sustainably, aligning with the broader goals of federal energy policies and environmental protection standards.

The following is a list of several key codes and standards applicable to hydrogen pipelines and related facilities:

- API 617, 618, 619, ISO 13631 for Compressors
- API 661 for Air Coolers
- API 1104, *Welding Pipelines and Related Facilities*
- ASME B31.3, *Process Piping*
- ASME B31.8, *Gas Transmission and Distribution Piping Systems*
- ASME B31.12, *Hydrogen Piping and Pipelines*
- ASME BPVC (Boiled and Pressure Vessel Code) Section VIII, *Rules for Construction of Pressure Vessels*
- ASME BPVC Section IX, *Welding, Brazing, and Fusing Qualifications*
- ASME BPVC Section XIII, *Rules for Overpressure Protection*
- 49 CFR Part 191 (Code of Federal Regulations), *Transportation of Natural and Other Gas By Pipeline; Annual, Incident, and Other Reporting*
- 49 CFR Part 192 (Code of Federal Regulations), *Transportation of Natural and Other Gas By Pipeline: Minimum Federal Safety Standards*
- CGA G-5.5 (Compressed Gas Association), *Standard for Hydrogen Vent Systems*
- NFPA 54 National Fuel Gas Code

[8] The latest edition of ASME B31.12 was published in 2019. As hydrogen pipelines have been recognized as a critical part of the energy transition, ASME members recently voted to update ASME B31.8 to address hydrogen pipelines and retire B31.12. This would include Hydrogen Industrial Piping in this project, currently be covered by ASME B31.12, which will be incorporated into ASME B31.8.

3.2. Design Pressure

An initial discharge pressure from each pipeline compressor station was assumed to be the maximum allowable operating pressure (MAOP) of 1,200 psig. Based on system requirements to achieve the annual throughput of 1.5 MMTPY discussed in Section 2.3, the MAOP of 1,200 psig was selected to stay within a pressure rating of Class 600, as defined by American National Standards Institute (ANSI). The efficacy of 1,200 psig as the maximum pressure was later confirmed through the various hydraulic calculations performed in this study. At lower MAOP, the available pressure drop becomes a limiting factor to reach the desired pressure at the destination. Because hydrogen is a compressible gas, the pressure drop within a pipeline increases for a given flow rate at lower pipeline system pressures.[9] Maintaining a higher system pressure allows greater pipeline flow rates with less pressure drop from the pipeline inlet to the pipeline outlet. Minimum delivery pressure within the LA Basin was assumed to be 200 psig.

For purposes of modeling, the initial inlet pressure (suction pressure) to the compressor stations was determined to be 500 psig. It is assumed that third-party hydrogen production facilities will provide adequate pressure via their equipment to successfully connect to the Angeles Link system. Electrolyzer technologies produce hydrogen at an outlet pressure typically between 430 and 580 psig.[10] In addition, the intake pressure will ultimately be contingent upon the location of the third-party producer with respect to the broader system; intake pressure for third-party connections may vary between station inlet pressure and pipeline MAOP. The actual compressor station inlet pressure may vary depending on system requirements, operating parameters, and equipment selection, which will be further evaluated in a future phase of the project.

3.3. Design Flow Rates

The Production Study included calculations that estimate the average annual flow rates for the clean renewable hydrogen transported through the Angeles Link system. Calculations from this study were used to apply the average annual flow rate for a total system capacity of 1.5 MMTPY to the steady-state hydraulics within this Study for the sizing of Angeles Link. This flow rate results in approximately 4,110 TPD. Average annual flow rates based on total system capacity of 0.5 MMTPY and 1.0 MMTPY were also applied within the scenarios evaluated and discussed further in Section 4.5.

The hydrogen supply follows a solar (without battery storage) energy hourly profile, which varies by the hour and season. The Production Study concluded that the maximum hourly flow injection rates from production may be 2.8 times the average annual injection flow rates. Furthermore, the peak demand may be highly driven by the power generation sector with potential hourly demand data indicating peak flow rates may exceed 3.8 times the average production rate from storage to the demand locations.

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[9] Yousefi, S., Eslami, H., & Owladeghaffari, H. (2017). Investigation of the critical flow and heat transfer phenomena of hydrogen gas in a micro-channel. International Journal of Hydrogen Energy, 42(10), 7173-7186. https://doi.org/10.1016/j.ijhydene.2016.09.242

[10] Ikhmal Salehmin , M. N., Husaini, T., Goh, J., & Sulong, A. B. (2022, July 14). High-pressure PEM water electrolyser: A review on challenges and mitigation strategies towards green and low-cost hydrogen production. Energy Conversion and Management. https://www.sciencedirect.com/science/article/abs/pii/S0196890422007786; 30-40bar to PSI by 1 bar = 14.5038 PSI

Application of higher flow rates representative of a single event in a steady-state model, such as a maximum hourly flow rate, increase the probability of overestimating the system requirements to accommodate a single factor, without considering other system conditions. The variations in flow rate that are expected due to the mismatch between supply production and demand requirements must be further evaluated using transient modeling, as discussed in the Future Considerations Chapter. This may affect future system pipeline sizing recommendations.

3.4. Gas Composition for Modeling

Electrolyzers produce hydrogen at purity levels ranging from 99.9% to 99.999%.[11] The purity of hydrogen impacts its application. For fuel cells, particularly those used in transportation and portable applications, high-purity hydrogen (above 99.99%) is crucial to prevent catalyst poisoning and operate efficiently.[12] In contrast, hydrogen combustion engines are less sensitive to lower purity levels, as they can tolerate certain impurities without significant performance degradation.[13] For the purposes of modeling, a gas composition of pure hydrogen (100%) was assumed.

3.5. Pipe Sizing Philosophy

Pipelines are safe, efficient and because most are buried underground, largely unseen.[14] PHMSA acknowledges that the efficiency of volumes transported by pipeline are beyond the capacity of other forms of transportation[15], and furthermore DOE concludes that dedicated hydrogen pipelines moving large volumes over long distances are critical to achieving economies of scale.[16] To transport the total annual throughput of 1.5 MMTPY, it would take approximately 12,700 gaseous trucks at 1 ton per load capacity and 3,400 loading bays dispatching four trucks per day to deliver hydrogen from production to potential off-takers in Central and Southern California, including the LA Basin[17]. The current SoCalGas system has pipelines sized from 2-inch to 36-inch in diameter, and pipelines throughout the country range in size from 2-inch to 42-inch. While existing hydrogen pipelines in the United States range in size from 10-inch to 24-inch, there are global initiatives such as the European Hydrogen Backbone[18] that propose a

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[11] International Energy Agency (IEA). (2020). The Future of Hydrogen. https://www.iea.org/reports/the-future-of-hydrogen

[12] Fuel Cells and Hydrogen 2 Joint Undertaking (FCH2JU). (2016). Hydrogen roadmap Europe – A sustainable pathway for the European energy transition. Publications Office. https://data.europa.eu/doi/10.2843/341510

[13] National Renewable Energy Laboratory (NREL). (2021). Hydrogen Purity for Fuel Cell Vehicles. https://www.nrel.gov/hydrogen/hydrogen-purity.html

[14] Where are the pipelines?. Energy API. (n.d.-c). https://www.api.org/oil-and-natural-gas/wells-to-consumer/transporting-oil-natural-gas/pipeline/where-are-the-pipelines

[15] General Pipeline Faqs. PHMSA. (n.d.-a). https://www.phmsa.dot.gov/faqs/general-pipeline-faqs

[16] Office of Technology Transitions, Office of Clean Energy Demonstrations, Hydrogen & Fuel Cell Technologies Office, Elgowainy, A., Penev, M., Crane, D., Cummins, K., Klembara, M., Chan, V., Tian, L., Shah, J., & Wagner, J. (2023). Pathways to commercial liftoff: Clean hydrogen. https://liftoff.energy.gov/wp-content/uploads/2023/05/20230523-Pathways-to-Commercial-Liftoff-Clean-Hydrogen.pdf

[17] See Angeles Link Phase 1 Cost Effectiveness Study, Table 22

[18] Jens, J., Wang, A., Van Der Leun, K., Peters, D., Buseman, M., & Guidehouse. (2021). Extending the European hydrogen backbone. In A European Hydrogen Infrastructure Vision Covering 21 Countries. https://ehb.eu/files/downloads/European-Hydrogen-Backbone-April-2021-V3.pdf

dedicated hydrogen pipeline transport network spanning tens of thousands of kilometers with diameters up to 48-inch.

Utilizing commonly manufactured pipe sizes and minimizing variation can provide benefits. These benefits include more predictable and consistent flow characteristics as well as interchangeability of piping components such as fittings, flanges, and valves, and cost-efficiency when procuring, manufacturing, operating, and inspecting materials in bulk. In general, the hydraulic analysis sought to utilize a set of common pipe sizes that range from 12-inch to 36-inch.

Proposed pipeline routes that aim to connect areas of clean renewable hydrogen production with areas of demand, tend to originate closer to or within areas of rural land and travel to serve demand in more concentrated urban centers. The population density, proximity to, and occupancy of buildings tend to increase as pipelines travel from rural to urban areas. These factors are considered for pipeline design and generally result in smaller pipe sizes due to requirements for operating conditions and constructability.

As gas flows through a pipeline, it experiences friction against the pipe walls leading to pressure loss, or "drop". The pressure drop available in the system impacts the selection of pipe size, as it will determine the power and flow requirements to maintain the operating pressure. Smaller pipe sizes result in larger pressure drop, while larger pipe sizes result in lower pressure drop. Balancing pipe size and power requirements is essential to overcome pressure losses while maintaining system efficiency and economic feasibility.

Pipelines are sized in terms of their internal and outer diameter. These two measurements will be different as they account for the wall thickness of the pipe material. Material specifications and requirements for different sizes are governed by standards.

While pipelines themselves transport energy efficiently, pipeline size affects the efficiency of supply chain and logistics components during siting, construction, and operation. Pipeline diameters and wall thickness area affected by a variety of logistic components:

Commercial Availability – While pipes can be milled in any size needed, using commercially available standard pipe sizes can maximize cost effectiveness. Specifications of custom pipe may result in a limitation on the manufacturers available, decrease availability and increase cost, and there may also be a mismatch between the pipeline and appurtenances or fixtures needed to operate and connect. Custom pipe can therefore result in additional customization to the fittings, other pipeline fixtures, and the equipment needed to construct and operate. Standard sizes result in an increase in the availability of materials and therefore, lower cost.

Materials Storage – Pipeline diameter also affects the maximum allowable stacking heights for the material from a storage standpoint, adding additional logistic elements for consideration.[19] This is typically due to the weight and the ease of handling.

Handling – The weight and size of loads during loading and unloading in transportation is important to the evaluation of the potential challenges it may present both in terms of equipment used in the process and the risks to job personnel. In general, smaller and lighter loads result in simpler handling.

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[19] American Ductile Iron Pipe Stacking. (n.d.-a). https://liberty.american-usa.com/SubmittalsPDF/ADIP/PDF/OtherTopics/Loading_and_Stacking.pdf

3.6. Compressor Assumptions

3.6.1. Compression at Production Sites

It is assumed that compression at third-party hydrogen production facilities and storage locations will be third-party owned and operated. Production facilities should provide the pressure to transport hydrogen to an Angeles Link system. It is expected that storage locations will provide the pressure to store hydrogen at the appropriate conditions for the selected storage technology. Refer to the Production Study Appendix B for more information on storage technology requirements.

3.6.2. Compression into Angeles Link Pipeline

Compression from the point of injection from third-party producers to the demand centers or point of injection from third-party storage to the demand centers, is expected to be operated by SoCalGas. The various assumed compressor location(s) for purposes of this analysis include:

- San Joaquin Valley (SJV)
- Lancaster
- Blythe
- Wheeler Ridge (Preferred Route Configuration D, with intermediate compression)

Intermediate compression was considered to reduce operating near MAOP and to potentially increase pack and draft capabilities to provide daily operational buffer capacity and longer-term hydrogen storage.

3.6.3. Compressor Types

Three compressor types that may be used to transport clean renewable hydrogen are centrifugal, diaphragm, and reciprocating. The different compressors' varying functions and benefits are described below.

Centrifugal compressors increase the pressure by using the rotation of impeller blades to increase kinetic energy. The kinetic energy will then increase the potential energy in the form of pressure through the compressor diffuser. Although centrifugal compressors work well in high-flow environments, high pressures may cause the machinery to stall and cause impacts to hydrogen supply downstream. Additionally, hydrogen gas has a low molecular weight which results in low operating density and pressure. This low pressure may increase operating speeds that would require custom impeller material and design to withstand the resulting forces.

Diaphragm compressors are driven by a reciprocating piston-crankshaft mechanism that separates hydraulic fluid/oil from process gas. Since these two fluids remain separated, diaphragm compressors are typically used for hydrogen service end-use where hydrogen purity can be crucial to the safe and reliable operation of equipment. This type of compressor is typical in hydrogen fueling stations. Diaphragm compressors may not be ideal for Angeles Link due to their relatively low flow capacity on an individual unit basis (necessitating many compressors operating in parallel) and their mechanical complexity relative to the other compressor types discussed in this section.

Reciprocating compressors utilize a piston and crankshaft to drive gases at varying flow rates in high-pressure environments. To reduce potential issues arising from hydrogen embrittlement, reciprocating compressors are customizable, allowing specific choices of materials that will be in contact with hydrogen. Therefore, the adaptability and durability of reciprocating compressors compared to their counterparts proves advantageous in situations for varying pressures and flow rates.[20]

After consulting vendors and reviewing compressor options, the reciprocating compressor is recommended on a preliminary basis due to its material adaptability, resiliency, and favorable turn-down ratios[21] that provide versatility in dynamic flow and pressure conditions, which are anticipated for the proposed Angeles Link system. This study assumed reciprocating compressors for cost estimate development purposes and will select a compatible compressor type in a future phase of the project.

Compressor Drives

The compressor drive should consider renewable sources of energy to align with the objective of Angeles Link to develop a clean renewable hydrogen transport system. Compressor drives refer to the mechanism or system responsible for powering the operation of a compressor, like an engine in an automobile. The two main types of compressor drives use electricity or gas as the fuel source. In natural gas applications, typically a share of the gas stream is used as fuel in an engine to drive an attached compressor. For hydrogen applications, a gas driven compressor would utilize a portion of the hydrogen fuel stream to power the compression, and the engine itself functions similarly to a standard automobile engine. The geometry of the pistons and combustion timing must be altered to fit the profile of hydrogen gas as it has a different composition.

Industry leaders and manufacturers are researching dual-drive setup where both electricity and gas are utilized in the compressor drive. There are emerging technologies that would develop 100% hydrogen-driven reciprocating compressors capable of outputting 1,000 kW (1,340 hp), 3,000 kW (4,020 hp), and even 10,000 kW (13,400 hp) power at 50 Hz in the future. The existing hydrogen-driven engines are currently smaller than those needed to efficiently run the compressors required for the Angeles Link system and are primarily designed for generators, which have different operational demands compared to compressors.

Based on available information as of the date of this publication, one known company has a patent for a dual hydrogen driven compression technology[22], and the use of the technology is approved for two compressor packagers for use on natural gas engines available from two manufacturers. Neither of these manufacturers has an existing engine designed to drive a compressor that can run on pure hydrogen. Both manufacturers are developing such an engine for a dual-drive setup.

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[20] Sdanghi, G., Maranzana, G., Celzard, A., & Fierro, V. (2019). Review the current technologies and performances of hydrogen compression for stationary and automotive applications. Renewable and Sustainable Energy Reviews, 102, 150–170. https://doi.org/10.1016/j.rser.2018.11.028

[21] Turn-down is the ratio of maximum capacity to minimum capacity.

[22] There are commercially available compressors that can operate and accommodate up to a 25% hydrogen-natural gas blend, with continuous ratings ranging from 1,515 kW to 2,519 kW (2,030 hp to 3,380 hp). Using blended natural gas and hydrogen fuels in an engine can lower emissions compared to using pure natural gas and can improve overall fuel flexibility and resilience by utilizing hydrogen directly from the pipeline. However, the requirement for two fuel sources means that if the externally sourced natural gas supply is disrupted, the engine cannot run. Managing the blend ratio also adds operational complexity, potentially increasing maintenance and monitoring requirements.

Energy system resiliency in the context of hydrogen or electric-driven compression is another consideration for maintaining reliable pipeline operations while managing emissions. While compressors powered by hydrogen or renewable electricity offer benefits, the interconnected nature of using hydrogen to power electric compression requires a robust backup system to help mitigate risks. This could involve integrating renewable energy sources (e.g., solar with battery storage) or using a hybrid approach (e.g., combining hydrogen and grid electricity) which supports resiliency by helping prevent energy vulnerabilities in one area from impacting another.

Fully hydrogen gas driven engines are commercially available but not at the specifications required for this study's preliminary results. This study assumed electric-driven compressors for cost estimate development purposes and will analyze available technologies in development for hydrogen-fueled engines in a future phase of the project.

Compressor Assumptions for Pipe Sizing

The compressor efficiency was assumed to be 80% after consultation with hydrogen compressor vendors and manufacturers. The temperature and pressure of the fluid in the pipeline are used by the equation of state to calculate physical properties of the fluid, including the density and viscosity which affect the pressure drop throughout the pipeline. The ground type, which affects the pipeline heat transfer rate to the surrounding soils, was based on engineering judgment from existing pipeline hydraulic analyses performed in Southern California.

In future project phases, specific soil parameters should be based on soils reports developed from soil samples along the potential pipeline routes. For the purposes of this study, the heat exchanger pressure drop was assumed to be 0.25 psi based on API 661 Air-Cooled Heat Exchangers. An air-cooled heat exchanger has a pressure drop due to frictional losses and flow resistance as the gas moves through many small tubes, which are used to transfer heat from the gas to the atmosphere. This pressure drop reduces the downstream pressure and can decrease the flow rate. The heat exchanger outlet temperature of 120 °F is based on requirements for Department of Transportation (DOT) pipelines and can be found in CFR 192.112.[23] The parameters in Table 2 were assumed for the Phase 1 hydraulic analysis and will be updated in a future phase of the project when a preferred route is selected.

[23] 49 CFR 192.112 -- Additional design requirements for steel pipe using alternative maximum allowable operating pressure. (n.d.). https://www.ecfr.gov/current/title-49/subtitle-B/chapter-I/subchapter-D/part-192/subpart-C/section-192.112

Table 2 - Compressor Assumptions

Parameter	Value
Compressor Polytropic Efficiencies	80%
Heat Exchanger Pressure Drop	0.25 psi
Compressor Discharge Temperature out of Cooler	120 °F
Centerline of Buried Pipe	48 Inches
Ground Type	Clay, Moist
Pipeline Ambient Temperature	65 °F

Heat Exchangers

When hydrogen gas is compressed, the gas temperature rises from the operating equipment, and a heat exchanger is required downstream from the compressor to lower the stream temperature. This also prevents the compressor from seeing high inlet temperatures in subsequent stages, which can lead to high-temperature upsets and derating piping. Operating with a pressure drop of 0.25 psig, the heat exchangers used in the hydraulic model prevent the hydrogen stream from exceeding 120 °F within the pipeline. The pressure drop of 0.25 psig, as specified in the basis of design, was chosen as a conservative number for gas compression based on engineering experience and this value or a lower one can be specified as the maximum allowable pressure drop during procurement.

3.7. Design Basis

The design parameters discussed in this Chapter were used as the basis for hydraulic analysis and are summarized in Table 3.

Table 3 - Pipeline Design Information Summary

Parameter	Value
Case 1 Flow Rate	0.5 MMTPY
Case 2 Flow Rate	1 MMTPY
Case 3 Flow Rate	1.5 MMTPY
Compressor Station Inlet Pressure	500 psig
LA Basin Demand Pressure	200 psig
Maximum Allowable Operating Pressure	1,200 psig

4. HYDRAULIC ANALYSIS

For the purposes of this study, steady-state average flows were used to develop pipeline size criteria, and the location and operation of third-party storage were excluded from the hydraulic model. In a pipeline system, a steady-state condition occurs when the flow rates entering and leaving the system are equal, maintaining a constant pressure at any given point in time. Conversely, a transient model represents conditions where the flow rates entering and leaving the system can change and be unequal, resulting in fluctuating pressure at any given point in time.

The following additional assumptions and methodologies were applied in the hydraulic study:

a. Hydraulics calculations were performed in ProMax Version 6.0.
b. The hydraulic analysis is based on steady-state calculations.
c. Transient calculations were not performed in this phase of the project.
d. The property package for calculations was GERG-2008 equation of state.
e. Beggs and Brill correlation was used to model the pipeline flow.

4.1. Pipe Modeling Software

ProMax software, a process simulator used for gas processing, refining, and chemical facilities, was used to simulate hydrogen flow through pipeline sections. At the time of this evaluation, ProMax was the only software capable of using GERG-2008[24] and therefore the preferred software to model hydrogen hydraulics with high accuracy. ProMax is a steady-state modeling software and does not have transient modeling capabilities. Flow was modeled by balancing through the system such that the delivery pressures at the LA Basin demand centers were sufficient for intended use (minimum pressure was assumed to be 200 psig at the LA Basin).

4.2. Steady State Analysis

A steady-state model using average annual flow rates was used to determine the preliminary design and evaluate overall system feasibility.

The variability in the production and demand profiles as discussed in Section 3.3 will require further transient hydraulic modeling to understand the time-dependent system response. Transient modeling will require input and information that is currently unknown in Angeles Link Phase 1 such as definitive initial and final operating conditions (flow rates, pressures, and temperatures), detailed pipeline routing and geometry, and distinct location of customers, third-party producers, and third-party storage operators. Transient modeling should be considered in the future, upon further determination of storage site(s), demand sector locations, and pipeline routing selection. The additional modeling should reflect both high-

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[24] ProMax hydraulic analysis include GERG-2008. GERG-2008, a multi-parameter equation of state developed by The Groupe Européen de Recherches Gazières (GERG), is recognized as an equation of state capable of representing the behavior of hydrogen gas in a complex system. The second equation used in the simulation environment is known as the Beggs and Briggs correlation and allows the model to identify multiphase flow behavior subject to various inclination angles, elevations, and directions.

demand/low-production and low-demand/high-production scenarios to fully assess system sizing requirements.

4.3. Pipeline Resiliency

The pipeline system was modeled with select portions as two parallel lines (or dual run) with identical specifications, operating conditions, and routing from one point to another. The dual run configuration acts as a backup if one of the parallel lines is temporarily removed from service, such as during maintenance, inspections, or emergency situations. This pipeline configuration can improve system resiliency during potential disruptions, minimize downtime, and allow for continuous operation.

Another approach to increase operational resiliency is to design a pipeline loop, where multiple pipelines combine and split at various points to form a "loop". A pipeline loop can provide additional backup capability if a portion of that system becomes unavailable; the other pipelines forming the loop could supply flow to maintain operation, sometimes in a bidirectional manner.

Both dual run and pipeline loop configurations can also provide increased storage capacity within the system to meet demands during peak usage periods.

4.4. Model Schematic Overview

The GIS data for the pipeline routes identified in the Routing Analysis was imported into ProMax and used as the basis for the hydraulic simulations. A schematic overview of the main system components and location evaluated are shown in Figure 2. The hydraulic models represent different combinations of these system components based on varying factors such as production and demand locations, target throughput, and pipeline routing configurations.

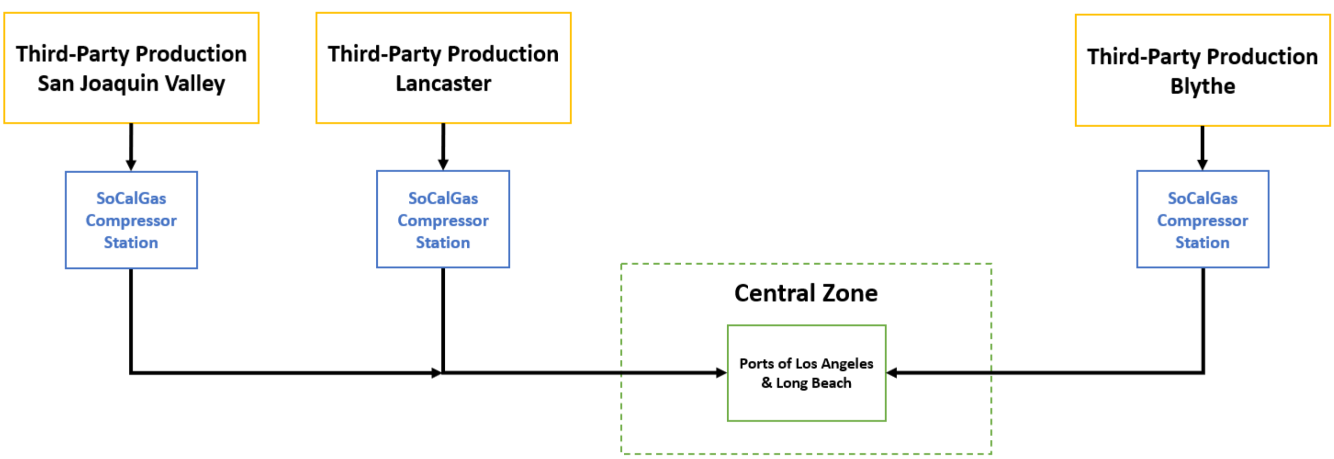


Figure 2 - Schematic Overview of System Components Evaluated

4.5. Scenarios

Results from the Production Study were used as the basis of hydraulic analysis where the following were modeled:

- Scenarios 1 – 3: Case 1 throughput of 0.5 MMTPY
- Scenarios 4 – 6: Case 2 throughput of 1.0 MMTPY
- Scenarios 7 – 8: Case 3 throughput of 1.5 MMTPY

4.5.1. Modeling Hydrogen Storage

While storage is not currently part of Angeles Link and was excluded from the hydraulic analysis, connections to potential storage locations were modeled to evaluate potential pipeline requirements and to develop estimates for the Cost Effectiveness study. For the Lancaster and SJV production locations, it is assumed the pipeline passes by potential underground storage between production and the demand centers in the LA Basin. For the Blythe production location, it is assumed the pipeline can connect to potential salt cavern storage in both Arizona and Utah. To the extent that regional underground storage is developed, such underground storage, including compression into storage and associated hydrogen purification processes after withdrawal from storage, is assumed to be operated by a third party. The compression required for storage is separate from the system hydraulics and is not included in the model. It is assumed that the underground storage cavern is pre-charged with hydrogen such that any additional hydrogen stored by the operation can be fully retrieved by the system.

Storage was not considered in the model to balance the flow between production, storage, and the demand centers. As gas storage systems serve as a buffer to smooth out fluctuations between production and demand, modeling a system that can handle the required throughput without considering storage is a conservative assumption. This approach simplifies the analysis by focusing on the pipeline's capability to meet demand directly, without relying on storage to balance the flows. Storage can also be achieved within a pipeline system through a network of distributed above-ground equipment and utilization of line packing, which refers to storing and then withdrawing gas supplies from the pipeline. For more information on hydrogen storage technologies, see Production Study Appendix B.

4.5.2. Scenario Results

Eight scenarios were evaluated as potential systems to deliver clean renewable hydrogen from the primary production locations identified to potential demand centers in Central and Southern California. For conservative modeling purposes, it was assumed that most demand centers were concentrated in the LA Basin. Single-run and mixed-run configurations were evaluated for Scenarios 1-8 to provide a range of preliminary pipe and compressor sizes. Select pipelines were modeled as two-parallel pipes in the mixed-run configuration to provide operational flexibility. The single-run configuration results are summarized in Table 4 and were used to develop cost estimates for the Cost Effectiveness study to determine the potential levelized cost of clean renewable hydrogen to be delivered to end-users. The cost estimates were also provided to the Workforce Evaluation as the basis for the employment and economic impact analysis. Refer to Chapter 6 for Cost Estimate details.

Table 4 - Scenario 1-8 Single-Run Configuration Results

Scenario	Total Throughput, MMTPY	Primary Production Location(s)	Total Route Mileage	Range of Nominal Pipe Sizes	Total Compressor Station(s)	Compressor Station*
1	0.5	San Joaquin Valley (SJV)	355	12-in to 30-in	1	33,000 hp
2	0.5	Lancaster	314	12-in to 24-in	1	33,000 hp
3	0.5	Blythe	303	12-in to 30-in	1	33,000 hp
4	1.0	SJV, Lancaster	392	12-in to 36-in	2	33,000 hp (each)
5	1.0	Lancaster, Blythe	537	12-in to 30-in	2	33,000 hp (each)
6	1.0	SJV, Blythe	578	12-in to 30-in	2	33,000 hp (each)
7	1.5	SJV, Lancaster	390	16-in to 36-in	2	50,000 hp (each)
8	1.5	SJV, Lancaster, Blythe	616	12-in to 36-in	3	33,000 hp (each)

*Compressor station size specified for line packing operation.

In Scenario 1, the SJV production location was assumed to produce 0.5 MMTPY. The main pipeline from the SJV production location to the LA Basin was estimated to be 24-inch and 30-inch under a single-run configuration, and 16-inch and 20-inch under a mixed-run configuration. Under both single- and mixed-run configurations, the pipelines within the LA Basin were estimated to be 12-inch, 20-inch, and 24-inch. For both configurations, a 33,000 hp compressor station was calculated and assumed to be located near the SJV production area.

In Scenario 2, the Lancaster production location was assumed to produce 0.5 MMTPY. The main pipeline from the Lancaster production location to the LA Basin was estimated to be 24-inch under a single-run configuration, and 16-inch under a mixed-run configuration. Under both single- and mixed-run configurations, the pipelines within the LA Basin was estimated to be 12-inch, 16-inch, and 24-inch. For both configurations, a 33,000 hp compressor station was calculated and assumed to be located near the Lancaster production area.

In Scenario 3, the Blythe production location was assumed to produce 0.5 MMTPY. The main pipeline from the Blythe production location to the LA Basin was estimated to be 30-inch under a single-run configuration, and 20-inch under a mixed-run configuration. Under both single- and mixed-run configurations, the pipelines within the LA Basin was estimated to be 12-inch, 16-inch, and 24-inch. For both configurations, a 33,000 hp compressor station was calculated and assumed to be located near the Blythe production area.

Figure 3 illustrates where potential third-party production could be as well as potential storage locations which may be developed in the future to support regional hydrogen producers and end users. These are the assumptions for Scenarios 1 through 3. Scenario 1 has the highest total route mileage of the 0.5 MMTPY throughput scenarios evaluated and allows for the most direct access to potential depleted oil and gas fields for underground storage in the Central California. Scenario 2 presents the closest distance from a potential production location (Lancaster) to the LA Basin and is also relatively close to potential Central California underground storage access. Scenario 3 has the lowest total route mileage of the 0.5 MMTPY throughput scenarios and is closest to potential salt basin underground storage outside of California.

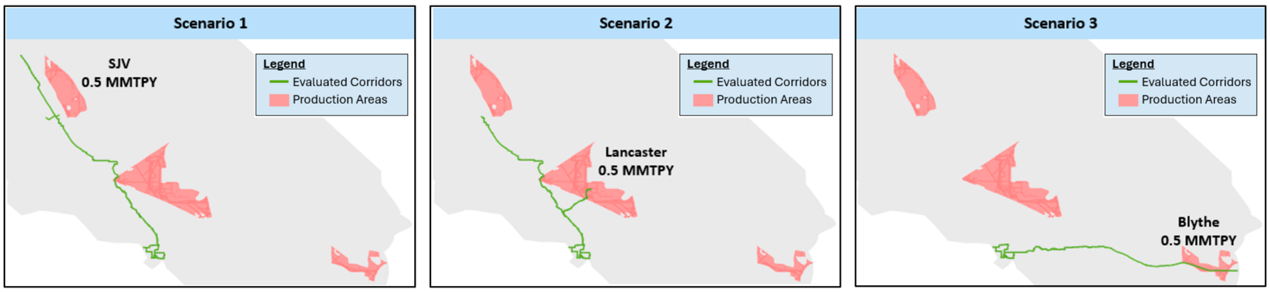


Figure 3 - Scenario 1-3

In Scenario 4, the SJV and Lancaster production locations were assumed to produce 0.5 MMTPY each resulting in a total of 1.0 MMTPY throughput. The main pipeline from the SJV production location to the junction combining with the pipeline from Lancaster was estimated to be 24-inch and 30-inch under the single-run configuration, and 16-inch and 20-inch under mixed-run configuration. The main pipeline from the Lancaster production location to the junction combining with pipeline from SJV was estimated to be 24-inch under the single-run configuration, and 16-inch under mixed-run configuration. The pipeline from the SJV and Lancaster juntion to the LA Basin was estimated to be 36-inch under the single-run configuration, and 24-inch under the mixed-run configuration. Under both single- and mixed-run configurations, the pipelines within the LA Basin were estimated to be 12-inch and 20-inch. For both configurations, a 33,000 hp compressor station was calculated and assumed to be located near each of the SJV and Lancaster production areas.

In Scenario 5, the Lancaster and Blythe production locations were assumed to produce 0.5 MMTPY each, resulting in a total of 1.0 MMTPY throughput. The main pipeline from the Lancaster production location to the LA Basin was estimated to be 24-inch under the single-run configuration, and 16-inch under the mixed-run configuration. The main pipeline from the Blythe production location to the LA Basin was estimated to be 24-inch and 30-inch under the single-run configuration, and 16-inch and 20-inch under mixed-run configuration. Under both single- and mixed-run configurations, the pipelines within the LA Basin was estimated to be 12-inch, 16-inch, 20-inch, and 24-inch. For both configurations, a 33,000 hp compressor station was calculated and assumed to be located near each of the Lancaster and Blythe production areas.

In Scenario 6, the SJV and Blythe production locations were assumed to produce 0.5 MMTPY each, resulting in a total of 1.0 MMTPY throughput. The main pipeline from the SJV production location to the LA Basin was estimated to be 30-inch under the single-run configuration, and 20-inch under the mixed-run configuration. The main pipeline from the Blythe production location to the LA Basin was estimated to be 30-inch under the single-run configuration, and 20-inch under mixed-run configuration. Under both single- and mixed-run configurations, the pipelines within the LA Basin were estimated to be 12-inch, 20-inch, and 30-inch. For both configurations, a 33,000 hp compressor station was calculated and assumed to be located near each of the SJV and Blythe production areas.

Figure 4 illustrates where potential third-party production could be as well as potential storage locations which may be developed in the future to support regional hydrogen producers and end users. These are the assumptions for Scenarios 4 through 6, which are also evaluated in the Cost Effectiveness Study. Scenario 4 has the lowest total route mileage of the 1.0 MMTPY throughput scenarios evaluated with potential depleted oil and gas fields for underground storage located approximately in the middle between the SJV and Lancaster production locations. Scenario 5 assumed Central California storage access for the Lancaster producion location, and storage access outside of California for the Blythe production location. Scenario 6 has the highest total route mileage of the 1.0 MMTPY throughput scenarios and assumed Central California storage access for the SJV production location, and storage access outside of California for the Blythe production location.

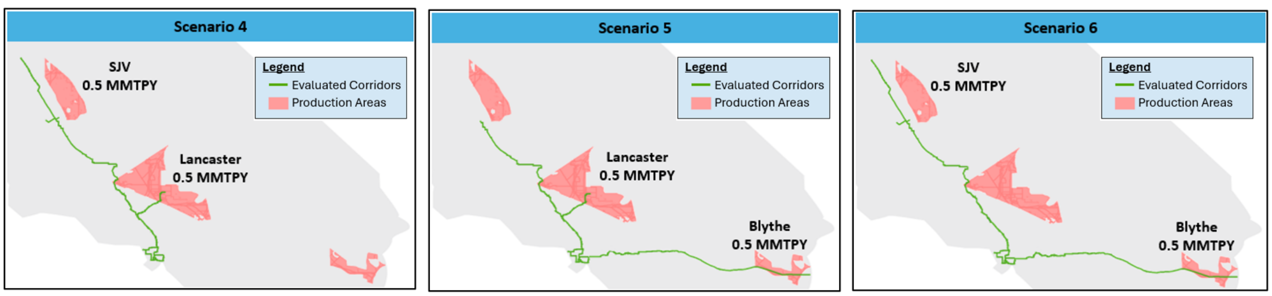


Figure 4 - Scenario 4-6

In Scenario 7, the SJV and Lancaster production locations were assumed to produce 0.75 MMTPY each resulting in a total of 1.5 MMTPY throughput, based on the availability of land identified within the Production Study. The main pipeline from the SJV production location to the junction combining with the pipeline from Lancaster was estimated to be 30-inch under the single-run configuration, and 20-inch under mixed-run configuration. The main pipeline from the Lancaster production location to the junction combining with pipeline frm SJV was estimated to be 24-inch under the single-run configuration, and 16-inch under mixed-run configuration. The pipeline from the SJV and Lancaster juntion to the LA Basin was estimated to be 36-inch under the single-run configuration, and 24-inch under the mixed-run configuration. Under both single- and mixed-run configurations, the pipelines within the LA Basin were estimated to be 16-inch, 20-inch, 24-inch, and 36-inch. For both configurations, a 50,000 hp compressor station was calculated and assumed to be located near each of the SJV and Lancaster production areas.

In Scenario 8, all three SJV, Lancaster, and Blythe production locations were assumed to produce 0.5 MMTPY each resulting in a total of 1.5 MMTPY throughput. The main pipeline from the SJV production location to the junction combining with the pipeline from Lancaster was estimated to be 30-inch under the single-run configuration, and 20-inch under mixed-run configuration. The main pipeline from the Lancaster production location to the junction combining with pipeline frm SJV was estimated to be 24-inch under the single-run configuration, and 16-inch under mixed-run configuration. The pipeline from the SJV and Lancaster juntion to the LA Basin was estimated to be 36-inch under the single-run configuration, and 24-inch under the mixed-run configuration. The main pipeline from the Blythe production location to the

LA Basin was estimated to be 24-inch and 30-inch under the single-run configuration, and 16-inch and 20-inch under mixed-run configuration. Under both single- and mixed-run configurations, the pipelines within the LA Basin were estimated to be 12-inch, 20-inch, 24-inch, and 30-inch. For both configurations, a 33,000 hp compressor station was calculated and assumed to be located near each of the SJV, Lancaster, and Blythe production areas.

Figure 5 illustrates where potential third-party production could be as well as potential storage locations which may be developed to support regional hydrogen producers and end users. These are the assumptions for Scenarios 7 and 8, which are also evaluated in the Cost Effectiveness Study. Scenario 7 has the lower total route mileage of the 1.5 MMTPY throughput scenarios evaluated, and access to potential depleted oil and gas fields for underground storage located approximately in the middle between the SJV and Lancaster production locations. Scenario 8 has the highest total route mileage of the 1.5 MMTPY throughput scenarios and assumed Central California storage access for the SJV and Lancaster production locations, and storage access outside of California for the Blythe production location.

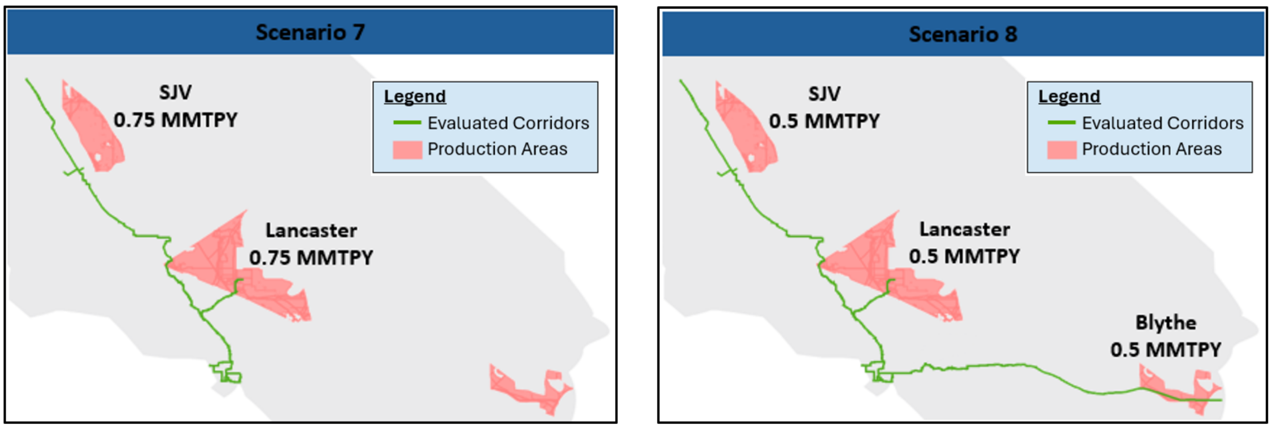


Figure 5 - Scenario 7 and 8

In all scenarios, the Central Zone (the area near the Ports of Los Angeles and Long Beach) has pipeline loops, allowing most of the lines in this area to be single lines. The Central Zone is represented in Figure 6. Once the main pipelines reach the Central Zone, the main pipeline(s) split, allowing them to cover more geographic areas that can serve as future demand takeoff points as hydrogen demand increases. Each side of the loop provides additional capacity, so if a portion of one pipeline becomes unavailable, flow could be supplied by the other pipeline sections forming the loop. This looping approach also allows for smaller pipe diameters that require less space for construction, which may be necessary in areas with high density of subsurface utilities and other congestion found within more populated and urban areas.

Figure 6 - Conceptual Central Zone Pipelines Modeled

4.6. Preferred Route Configurations

After evaluation of the routes, the Routing Analysis identified four Preferred Routes – A, B, C, and D – to be modeled and evaluated for preliminary sizing and system design. Scenario 7 reflects Preferred Route A.

4.6.1. Preferred Route Configuration Results

The following sections summarize the results for the Preferred Routes A, B, C, and D. In Table 5, the term "Normal" refers to the normal operating conditions the compressor station will experience based on the modeled throughput (or flow rate), and "Max" refers to operating compressor at MAOP of 1,200 psig during line packing operation.

Table 5 - Preferred Routes: Single and Mixed Run Result Comparison

	Configuration A		Configuration B		Configuration C		Configuration D*	
	Single Run	**Mixed Run**	**Single Run**	**Mixed Run**	**Single Run**	**Mixed Run**	**Single Run**	**Mixed Run**
Throughput	1.5 MMTPY	1.5 MMTPY	1.5 MMTPY	1.5 MMTPY	1.5 MMTPY	1.5 MMTPY	1.5 MMTPY	1.5 MMTPY
Mileage of Land Traversed	390 miles		406 miles		472 miles		481 miles	
Installed Pipe	390 miles	699 miles	406 miles	730 miles	472 miles	715 miles	481 miles	880 miles
Pipe Sizes	16”, 20”, 24”, 30”, 36”	16”, 20”, 24”	20”, 36”	20”, 24”	20”, 24”, 30”, 36”	20”, 24”	24”, 36”	24"
SJV Compressor Station								
Normal Outlet Pressure	725 psig	1,000 psig	815 psig	1,065 psig	825 psig	1,010 psig	950 psig	1,180 psig
Normal Power	19,500	38,000 hp	26,000	44,000 hp	26,500	39,000 hp	35,000	49,000 hp
Max Power	50,000 hp	50,000 hp	50,000 hp	50,000 hp	50,000 hp	50,000 hp	50,000 hp	50,000 hp
Lancaster Compressor Station								
Normal Outlet Pressure	800 psig	1,020 psig	700 psig	950 psig	700 psig	885 psig	775 psig	1,015 psig
Normal Power	25,000	39,500 hp	17,500	36,000 hp	17,500	30,500 hp	23,000	39,000 hp
Max Power	50,000 hp	50,000 hp	50,000 hp	50,000 hp	50,000 hp	50,000 hp	50,000 hp	50,000 hp

*Configuration D results does not include intermediate compression. Refer to Section 4.6.1.4 for intermediate compression results.

Preferred Route Configuration A (Route A)

Route A is the lowest mileage of all preferred route configurations and provides the most direct path to connect third-party production areas of SJV and Lancaster with the demand centers in Central California and Los Angeles Basin. The flow within the pipeline was modeled to split within the Los Angeles Basin as displayed in Figure 6. Locations along Route A are presented in Figure 7 with results from the hydraulic calculations shown in Figure 8. A summary of the labeled locations follows:

- Point 1 is the connection point modeled for SJV production location
- Point 2 is the connection point modeled for Lancaster production location
- Point 3 is the junction point where SJV and Lancaster flow combine
- Point 4 is the entry point to the Central Zone (beginning of the LA Basin)
- Point 5 is the Los Angeles Basin Demand Pressure location

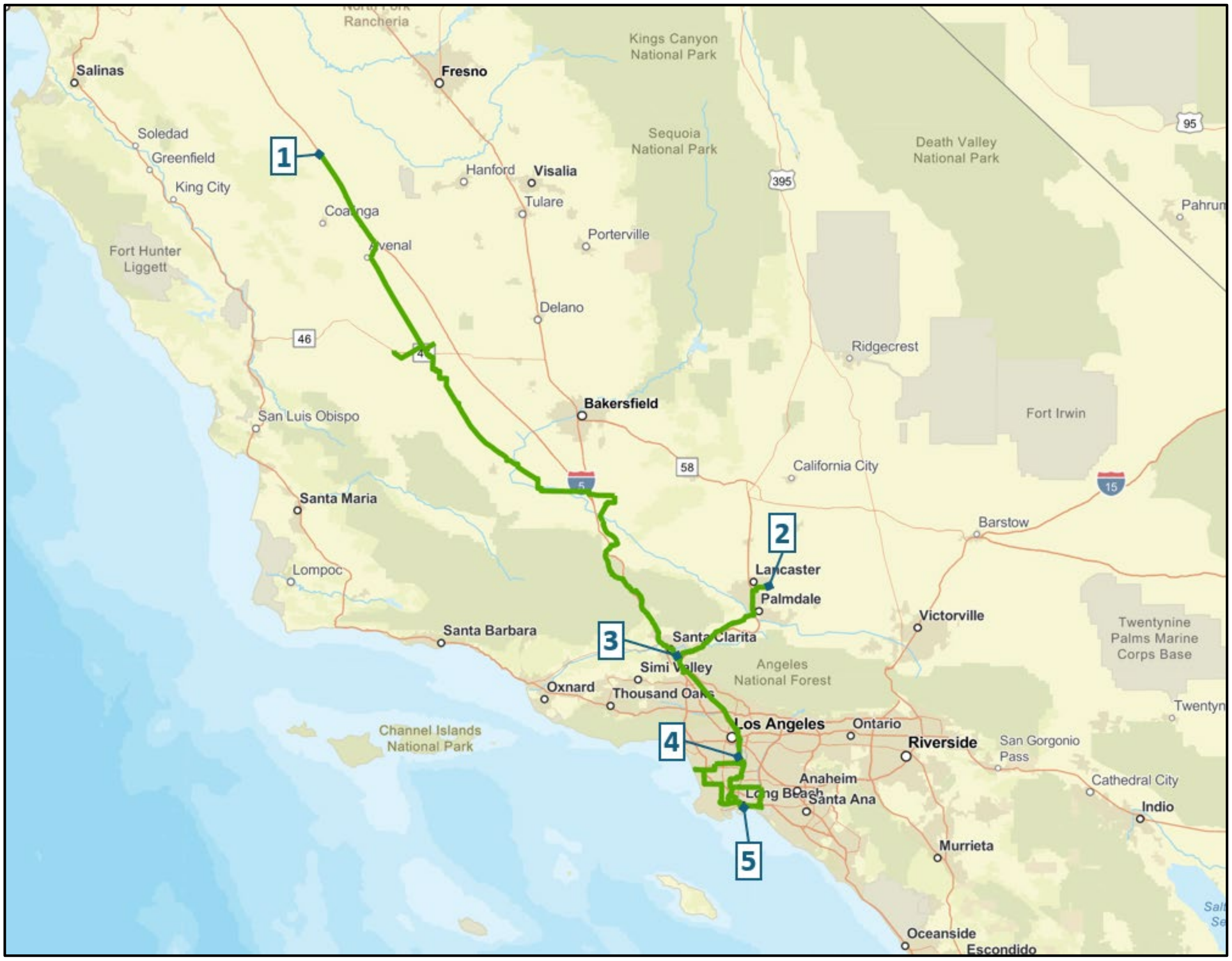
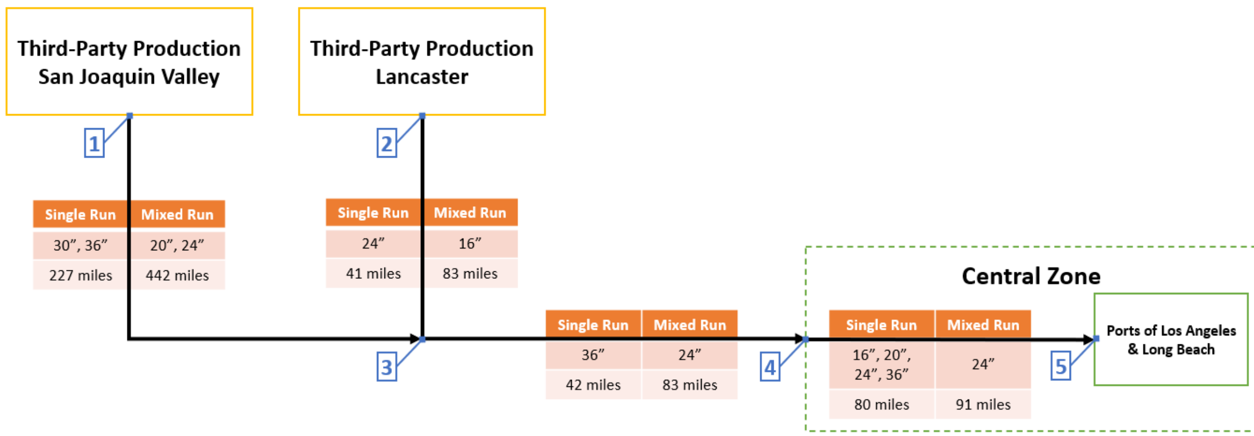


Figure 7 - Route A Map

Route A explores the most direct route from hydrogen production sites to the Los Angeles Basin demand center with the shortest overall pipeline distance. The pipeline from SJV to the junction (Point 1 to 3) was calculated to require 227 miles of 30- and 36-inch pipe for the single run configuration, and 442 miles of 20- and 24-inch for the mixed run configuration. The pipeline from Lancaster to the junction (Point 2 to 3) was calculated to require 41 miles of 24-inch pipe for the single run configuration, and 83 miles of 16-inch pipe for the mixed run configuration. The pipeline from the junction to the Central Zone (Point 3 to 4) was calculated to require 42 miles of 36-inch pipe for the single run configuration, and 83 miles of 24-inch pipe for the mixed run configuration. The pipelines within Central Zone to the Ports of Los Angeles and Long Beach (Point 4 to 5) was calculated to require 80 miles of 16-inch, 20-inch,24-inch, and 36-inch pipe for the single run configuration, and 91 miles of 24-inch pipe for the mixed run configuration. Figure 8 displays the flow rates and pressure results at various locations, including the range of potential pipeline sizes estimated using ProMax.



Normal Operating Data	1	2	3	4	5
Single Run Pressure (psig)	725	800	487	307	215
Mixed Run Pressure (psig)	1,000	1,020	614	325	218
Flowrate (MMTPY)	0.75	0.75	1.5	1.5	1.5

Figure 8 - Route A Hydraulic Results

Compressor discharge pressure affects the required pipe size and line packing capabilities. The normal operating horsepower is based on modeled flowrate, and the max horsepower is sized at MAOP of 1,200 psig to be used when line packing.

For the single run configuration, the normal outlet pressure at the SJV compressor station is 725 psig and 800 psig at the Lancaster compressor station outlet. This allows for an operating buffer of 475 psig at the SJV compressor station and 400 psig buffer at the Lancaster station to each compressor's MAOP.

For the mixed run configuration, the normal outlet pressure at the SJV compressor station is 1,000 psig and 1,020 psig at the Lancaster compressor station outlet. This allows for an operating buffer of 200 psig at the SJV compressor station and 180 psig buffer at the Lancaster station to each compressor's MAOP.

For both configurations, the max outlet pressure at the SJV and Lancaster compressor stations is 1,200 psig to allow for line packing operation. The system was designed to reduce compressor horsepower while maximizing the volume that can be gained from line packing. Table 6 displays the calculated compressor information for the normal and the maximum operations.

Table 6 - Route A Compressor Information

Route A - Compressors							
Configuration	**Location**	**Normal (hp)**	**Max (hp)**	**Inlet Pressure (psig)**	**Normal Outlet Pressure (psig)**	**Max Outlet Pressure (psig)**	**Flowrate (MMTPY)**
Single Run	SJV	19,500	50,000	500	725	1,200	0.75
	Lancaster	25,000	50,000	500	800	1,200	0.75
Mixed Run	SJV	38,000	50,000	500	1,000	1,200	0.75
	Lancaster	39,500	50,000	500	1,020	1,200	0.75

Preferred Route Configuration B (Route B)

Route B connects production sites in SJV and Lancaster with a single route without major laterals (or secondary pipelines branching from the main line) and continues onto the Los Angeles Basin with a single route and right-of-way. The overall pipeline distance is higher than Route A, but lower than Routes C and D. The flow within the pipeline was modeled to split within the Los Angeles Basin as displayed in Figure 6. Locations along Route B are presented in Figure 9 with results from the hydraulics calculations shown in Figure 10. A summary of the labeled locations follows:

- Point 1 is the connection point modeled for SJV production location
- Point 2 is the connection point modeled for Lancaster production location
- Point 3 is the entry point to the Central Zone (beginning of the LA Basin)
- Point 4 is the Los Angeles Basin Demand Pressure location

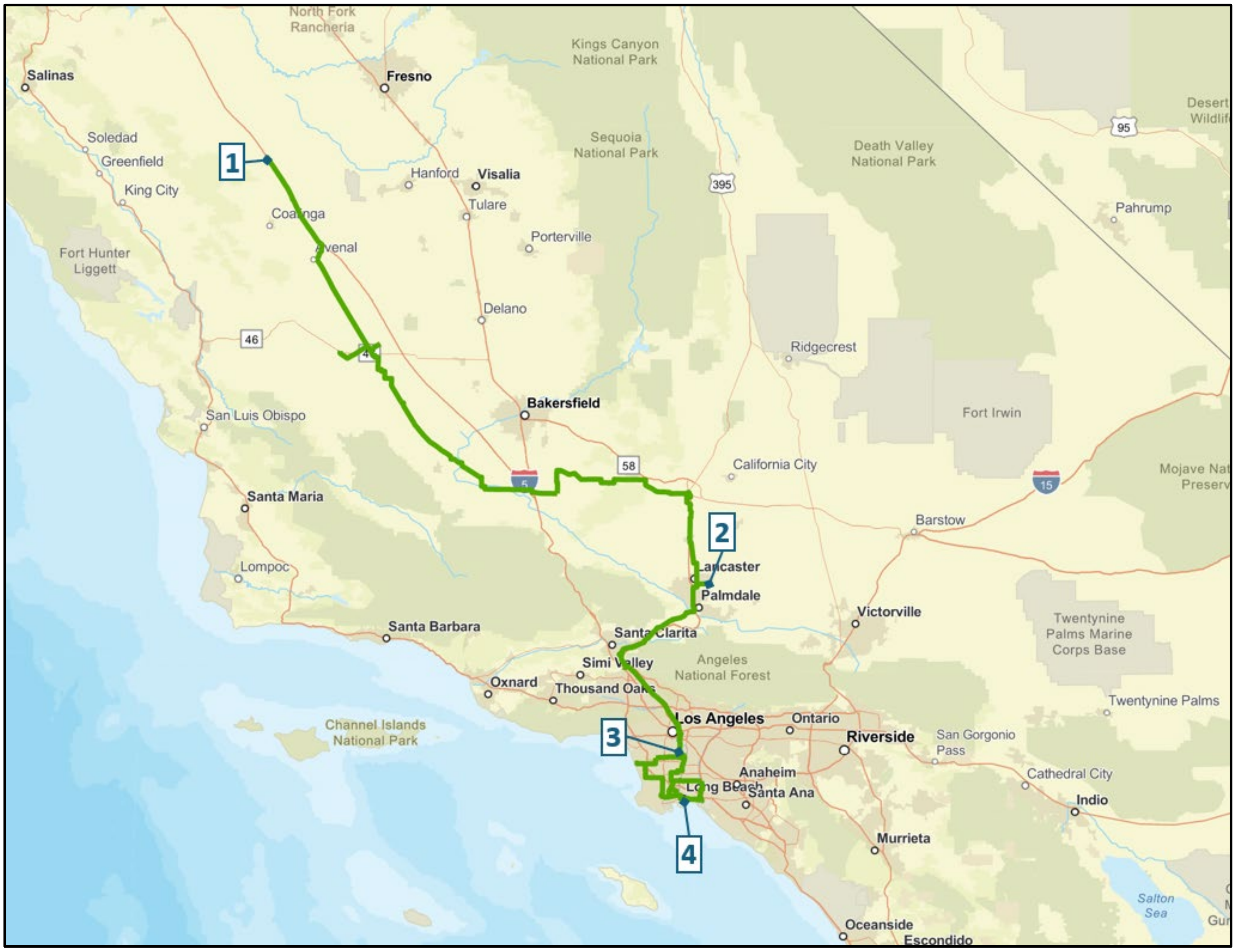
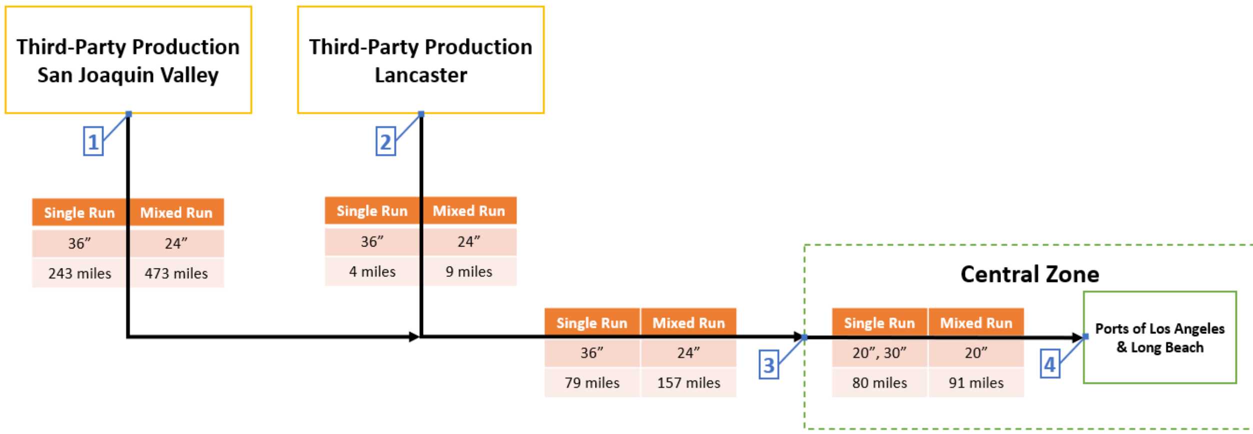


Figure 9 - Route B Map

Route B connects SJV and Lancaster production locations with a single route without major branching and continues onto the Los Angeles Basin with a single route. The pipeline from SJV to the Lancaster production connection (Point 1 to 2) was calculated to require 243 miles of 36-inch pipe for the single run configuration, and 473 miles of 24-inch for the mixed run configuration. The connection to the Lancaster production location (Point 2) was calculated to require 4 miles of 36-inch pipe for the single run configuration, and 9 miles of 24-inch pipe for the mixed run configuration. The combined SJV and Lancaster production pipeline (Point 2 to 3) was calculated to require 79 miles of 36-inch pipe for the single run configuration, and 154 miles of 24-inch pipe for the mixed run configuration. The pipelines within Central Zone to the Ports of Los Angeles and Long Beach (Point 3 to 4) were calculated to require 80 miles of 20-inch and 30-inch pipe for the single run configuration, and 91 miles of 20-inch pipe for the mixed run configuration. Figure 10 displays the flow rates and pressure results at various locations, including the range of potential pipeline sizes estimated using ProMax.



Normal Operating Data	1	2	3	4
Single Run Pressure (psig)	815	700	411	208
Mixed Run Pressure (psig)	1,065	950	447	207
Flowrate (MMTPY)	0.75	0.75	1.5	1.5

Figure 10 - Route B Hydraulic Results

For the single run configuration, the normal outlet pressure at the SJV compressor station is 815 psig and 700 psig at the Lancaster compressor station outlet. This allows for an operating buffer of 385 psig at the SJV compressor station and 500 psig buffer at the Lancaster station to each compressor’s MAOP.

For the mixed run configuration, the normal outlet pressure at the SJV compressor station is 1,065 psig and 950 psig at the Lancaster compressor station outlet. This allows for an operating buffer of 135 psig at the SJV compressor station and 250 psig buffer at the Lancaster station to each compressor’s MAOP.

For both configurations, the max outlet pressure at the SJV and Lancaster compressor stations is 1,200 psig to allow for line packing operation. Table 7 displays the calculated compressor information for the normal and the maximum operations.

Table 7 - Route B Compressor Information

Route B - Compressors							
Configuration	**Location**	**Normal (hp)**	**Max (hp)**	**Inlet Pressure (psig)**	**Normal Outlet Pressure (psig)**	**Max Outlet Pressure (psig)**	**Flowrate (MMTPY)**
Single Run	SJV	26,000	50,000	500	815	1,200	0.75
	Lancaster	17,500	50,000	500	700	1,200	0.75
Mixed Run	SJV	44,000	50,000	500	1,065	1,200	0.75
	Lancaster	36,000	50,000	500	950	1,200	0.75

Preferred Route Configuration C (Route C)

Route C includes a loop, which provides multiple flow paths. This allows fluid to follow the path of least resistance which can lower the overall pressure drop of the system. The flow within the pipeline was modeled to split within the Los Angeles Basin as displayed in Figure 6. Locations along Route C are presented in Figure 11 with results from the hydraulics calculations shown on a diagrammatic layout in Figure 12. A summary of the labeled locations follows:

- Point 1 is the connection point modeled for SJV production location
- Point 2 is the connection point modeled for Lancaster production location
- Point 3 is the north end of the pipeline loop where flow first splits from the main line(s)
- Point 4 is the south end of the pipeline loop where the flow combines to the main line(s).
- Point 5 is the entry point to the Central Zone (beginning of the LA Basin)
- Point 6 is the Los Angeles Basin Demand Pressure location

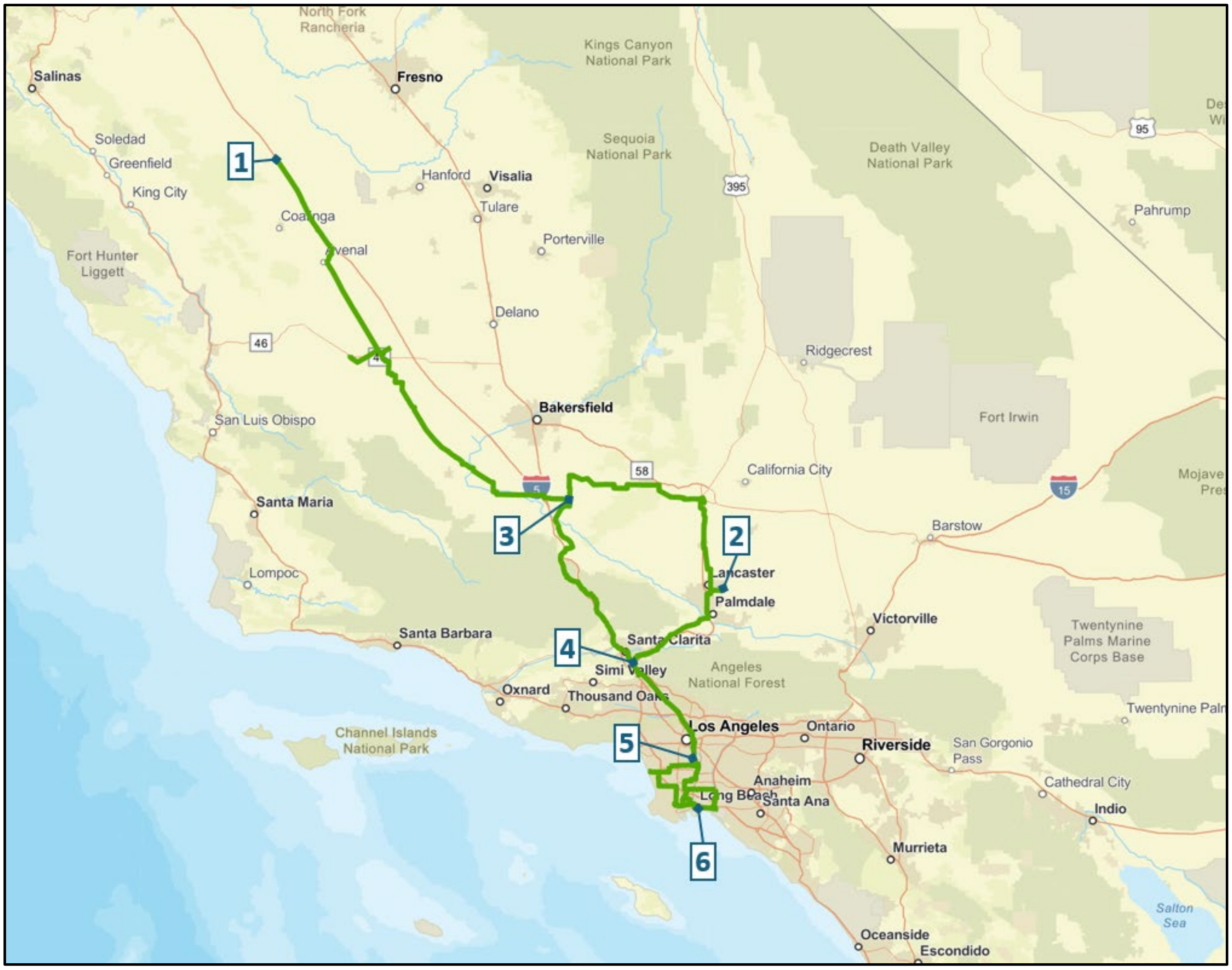
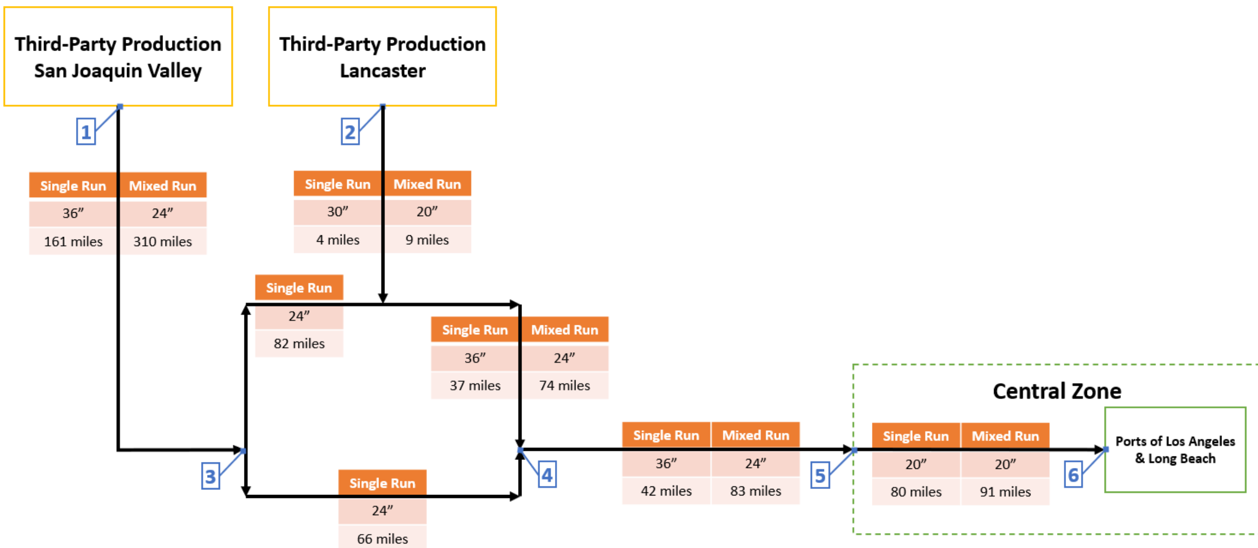


Figure 11 - Route C Map

Route C examines the impacts of having a pipeline loop between the production facilities and the Los Angeles Basin. This allows for flow to travel in both directions around the loop, offering greater system resiliency. Additionally, splitting flows within the pipeline loop results in lower flowrates in certain portions of the loop, therefore lowering the corresponding pressure drop in that specific portion.

The pipeline from SJV production location to the north end of the pipeline loop (Point 1 to 3) was calculated to require 161 miles of 36-inch pipe for the single run configuration, and 310 miles of 24-inch for the mixed run configuration. Due to the pipeline loop, a single 82 miles of 24-inch pipe was calculated from the point at which the SJV flow splits and combines with Lancaster production on the northern side of the loop (Point 3 to 2), and a single 66 miles of 24-inch pipe was calculated from the point that SJV flow splits and combined with Lancaster production on the southern side of the loop (Point 3 to 4). The pipeline from the Lancaster production to the loop was calculated to require 4 miles of 30-inch pipe for the single run configuration, and 9 miles of 20-inch pipe for the mixed run configuration. The point where Lancaster production enters the loop and combines with the flow split from the SJV production (Point 2 to 4) was calculated to require 37 miles of 36-inch pipe for the single run configuration, and 74 miles of 24-inch pipe for the mixed run configuration. The combined SJV and Lancaster production pipeline (Point 4 to

5) was calculated to require 42 miles of 36-inch pipe for the single run configuration, and 83 miles of 24-inch pipe for the mixed run configuration. The pipelines within Central Zone to the Ports of Los Angeles and Long Beach (Point 5 to 6) were calculated to require 80 miles of 20-inch pipe for the single run configuration, and 91 miles of 20-inch pipe for the mixed run configuration. The pipeline loop in Route C allowed for flow splitting and subsequently lower pressure drop, which resulted in smaller 20-inch diameter pipes within the Central Zone as compared to Routes A and B. Figure 12 displays the flow rates and pressure results at various locations, including the range of potential pipeline sizes estimated using ProMax.



Normal Operating Data	1	2	3	4	5	6
Single Run Pressure (psig)	825	700	870	560	412	215
Mixed Run Pressure (psig)	1,010	885	737	686	444	201
Flowrate (MMTPY)	0.75	0.75	0.75	1.5	1.5	1.5

Figure 12 - Route C Hydraulic Results

For the single run configuration, the normal outlet pressure at the SJV compressor station is 825 psig and 700 psig at the Lancaster compressor station outlet. This allows for an operating buffer of 375 psig at the SJV compressor station and 500 psig buffer at the Lancaster station to each compressor’s MAOP.

For the mixed run configuration, the normal outlet pressure at the SJV compressor station is 1,010 psig and 885 psig at the Lancaster compressor station outlet. This allows for an operating buffer of 190 psig at the SJV compressor station and 315 psig buffer at the Lancaster station to each compressor’s MAOP.

For both configurations, the max outlet pressure at the SJV and Lancaster compressor stations is 1,200 psig to allow for line packing operation. Table 8 displays the calculated compressor information for the normal and the maximum operations.

Table 8 - Route C Compressor Information

Route C - Compressors							
Configuration	**Location**	**Normal (hp)**	**Max (hp)**	**Inlet Pressure (psig)**	**Normal Outlet Pressure (psig)**	**Max Outlet Pressure (psig)**	**Flowrate (MMTPY)**
Single Run	SJV	26,500	50,000	500	825	1,200	0.75
	Lancaster	17,500	50,000	500	700	1,200	0.75
Mixed Run	SJV	39,000	50,000	500	1,010	1,200	0.75
	Lancaster	30,500	50,000	500	885	1,200	0.75

Preferred Route Configuration D (Route D)

Similar to Route B, Route D connects production sites in SJV and Lancaster with a single route without major branching and continues onto the Los Angeles Basin with a single route and right-of-way. Route D explored extending the Angeles Link system for potential connection with demand centers located in Riverside and San Bernardino counties. The overall pipeline distance for Route D is highest of all the preferred route configurations, which required evaluating an intermediate compressor station (also known as a booster compressor). As gas flows through pipelines, it experiences friction against the pipe walls leading to pressure loss. Intermediate compression helps maintain the pressure high enough to allow gas to continue moving efficiently across long distances.

Route D – Without Intermediate Compression

The flow within the pipeline was modeled to split within the Los Angeles Basin as displayed in Figure 6. Locations along Route D without intermediate compression are presented in Figure 13 with results from the hydraulics calculations shown in Figure 14. A summary of the labeled locations follows:

- Point 1 is the connection point modeled for SJV production location
- Point 2 is the connection point modeled for Lancaster production location
- Point 5 is the entry point to the Central Zone (beginning of the LA Basin)
- Point 6 is the Los Angeles Basin Demand Pressure location

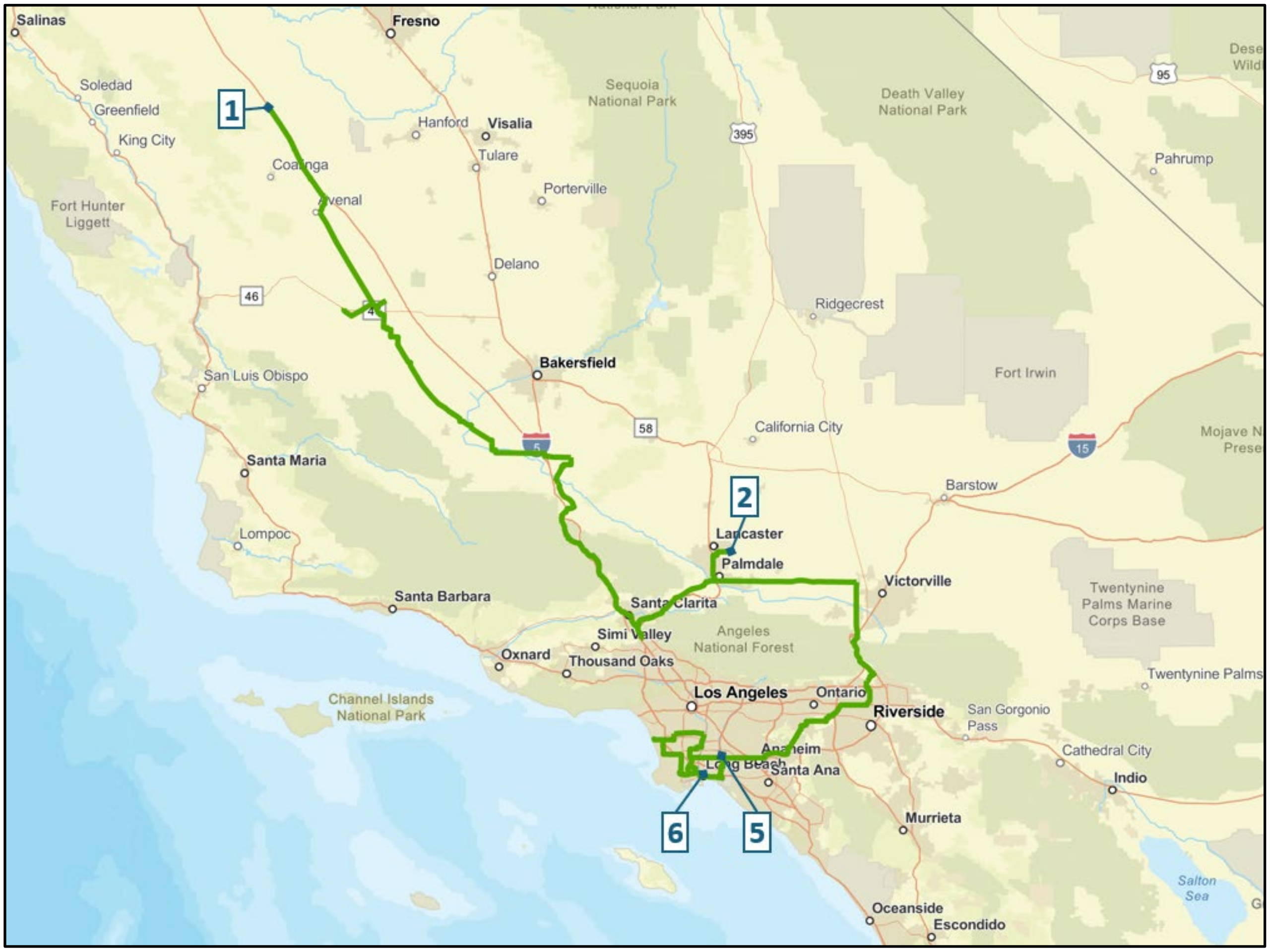
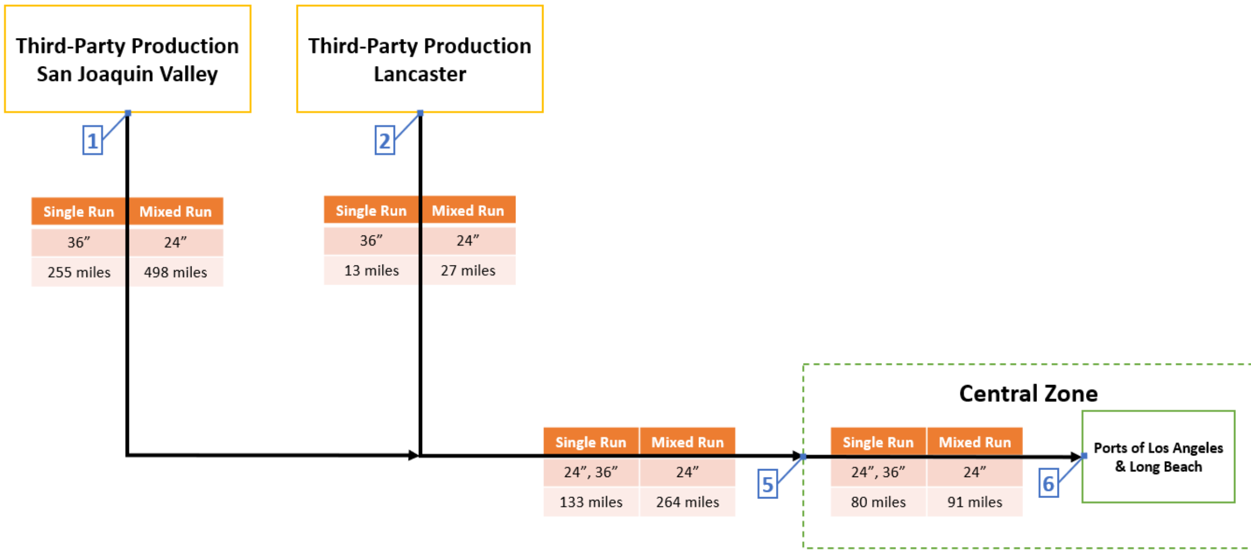


Figure 13 - Route D (Without Intermediate Compression) Map

Route D connects SJV and Lancaster production locations with a single route without major branching and continues onto the Los Angeles Basin with a single route. The pipeline from SJV to the Lancaster production connection (Point 1 to 2) was calculated to require 255 miles of 36-inch pipe for the single run configuration, and 498 miles of 24-inch for the mixed run configuration. The connection to the Lancaster production location (Point 2) was calculated to require 13 miles of 36-inch pipe for the single run configuration, and 27 miles of 24-inch pipe for the mixed run configuration. The combined SJV and Lancaster production pipeline (downstream of Point 2 to 5) was calculated to require 133 miles of 24-inch and 36-inch pipe for the single run configuration, and 264 miles of 24-inch pipe for the mixed run configuration. The pipelines within Central Zone to the Ports of Los Angeles and Long Beach (Point 5 to 6) were calculated to require 80 miles of 24-inch and 36-inch pipe for the single run configuration, and 91 miles of 24-inch pipe for the mixed run configuration. Figure 14 displays the flow rates and pressure results at various locations, including the range of potential pipeline sizes estimated using ProMax.



Normal Operating Data	1	2	5	6
Single Run Pressure (psig)	950	775	356	231
Mixed Run Pressure (psig)	1,180	1,015	328	202
Flowrate (MMTPY)	0.75	0.75	1.5	1.5

Figure 14 - Route D (without Intermediate Compression) Hydraulic Results

For the single run configuration, the normal outlet pressure at the SJV compressor station is 950 psig and 775 psig at the Lancaster compressor station outlet. This allows for an operating buffer of 250 psig at the SJV compressor station and 425 psig buffer at the Lancaster station to each compressor’s MAOP.

For the mixed run configuration, the normal outlet pressure at the SJV compressor station is 1,180 psig and 1,015 psig at the Lancaster compressor station outlet. This allows for an operating buffer of 20 psig at the SJV compressor station and 185 psig buffer at the Lancaster station to each compressor’s MAOP.

For both configurations, the max outlet pressure at the SJV and Lancaster compressor stations is 1,200 psig to allow for line packing operation. Table 9 displays the calculated compressor information for the normal and the maximum operations.

Table 9 - Route D (without intermediate compression) Compressor Information

Route D - Compressors							
Configuration	**Location**	**Normal (hp)**	**Max (hp)**	**Inlet Pressure (psig)**	**Normal Outlet Pressure (psig)**	**Max Outlet Pressure (psig)**	**Flowrate (MMTPY)**
Single Run	SJV	35,000	50,000	500	950	1,200	0.75
	Lancaster	23,000	50,000	500	775	1,200	0.75
Mixed Run	SJV	49,000	50,000	500	1,180	1,200	0.75
	Lancaster	39,000	50,000	500	1,015	1,200	0.75

Route D – With Intermediate Compression

For the mixed run configuration without intermediate compression, the SJV compressor must operate at nearly the MAOP of 1,200 psig to deliver hydrogen to the Central Zone demand centers. Adding an intermediate compressor station will allow the SJV compressor station to operate at a relatively lower operating pressure, which can potentially decrease strain on equipment and materials, provide margin for pressure and flow rate fluctuations, and increase the capacity for line packing. Therefore, an intermediate compressor configuration was modeled and evaluated for Route D with Figure 15 depicting locations and hydraulic results shown in Figure 16. A summary of the labeled locations follows:

- Point 1 is the connection point modeled for SJV production location
- Point 2 is the connection point modeled for Lancaster production location
- Point 3 is suction (inlet) modeled for the intermediate compression station
- Point 4 is discharge (outlet) modeled for the intermediate compression station
- Point 5 is the entry point to the Central Zone (beginning of the LA Basin)
- Point 6 is the Los Angeles Basin Demand Pressure location

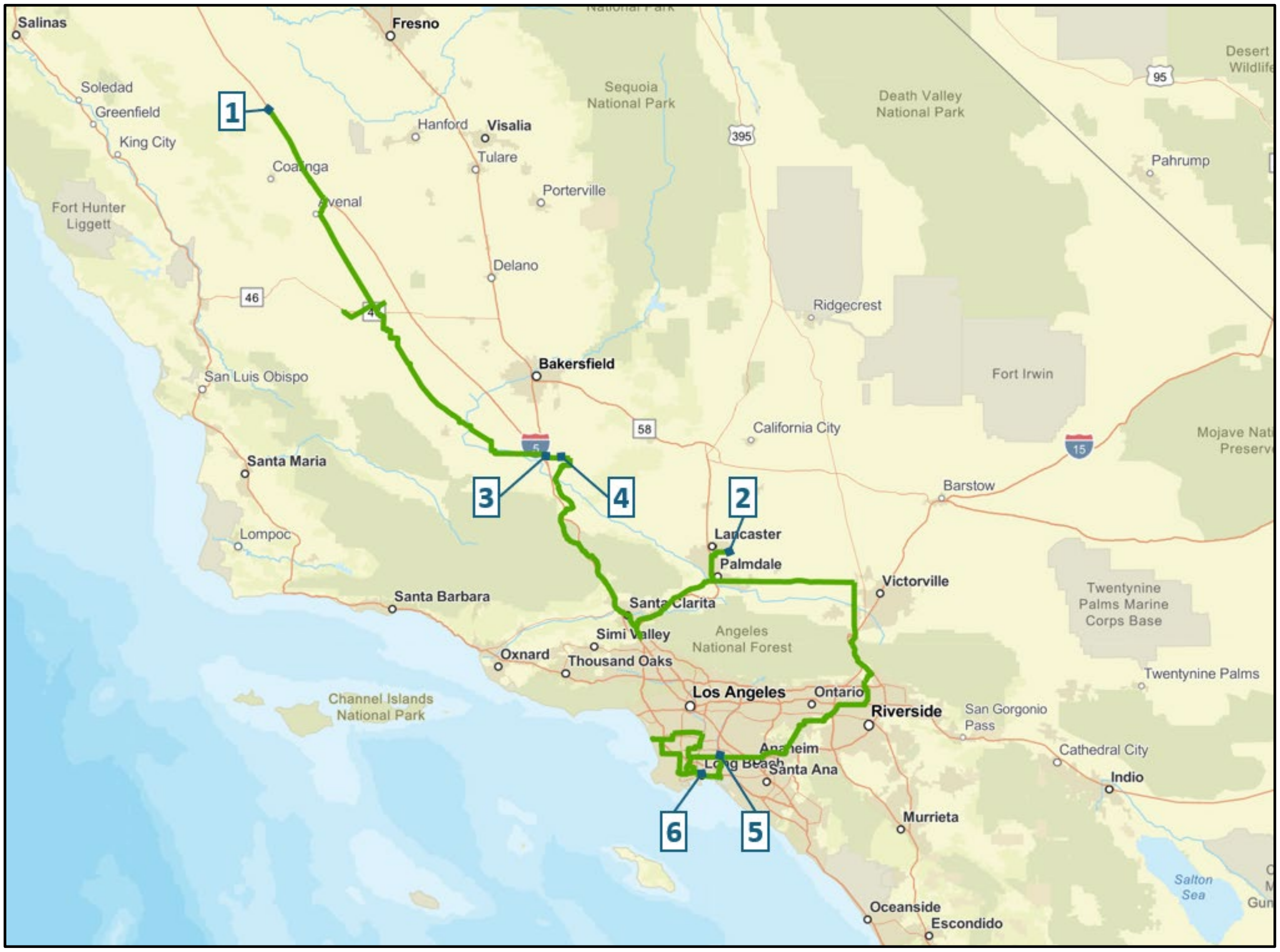
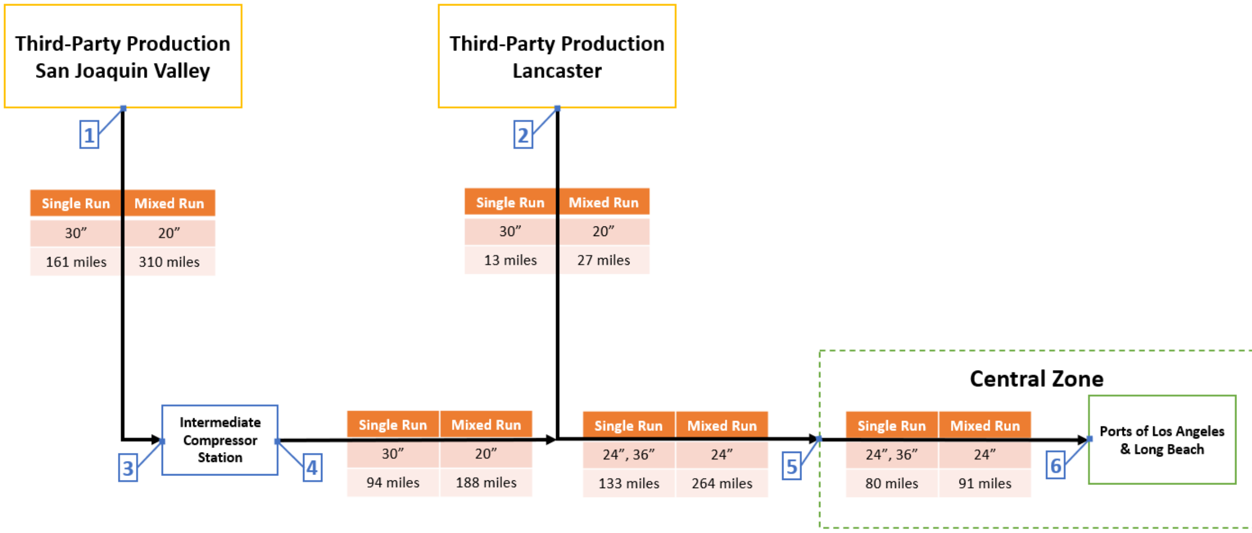


Figure 15 - Route D (With Intermediate Compression) Map

The pipeline from SJV to the intermediate compressor station inlet (Point 1 to 3) was calculated to require 161 miles of 30-inch pipe for the single run configuration, and 310 miles of 20-inch for the mixed run configuration. From the intermediate compressor outlet to the connection with the Lancaster production location (Point 4 to 2) was calculated to require 94 miles of 30-inch pipe for the single run configuration, and 188 miles of 20-inch pipe for the mixed run configuration. The connection to the Lancaster production location (Point 2) was calculated to require 13 miles of 30-inch pipe for the single run configuration, and 27 miles of 20-inch pipe for the mixed run configuration. The combined SJV and Lancaster production pipeline (downstream of Point 2 to 5) was calculated to require 133 miles of 24-inch and 36-inch pipe for the single run configuration, and 264 miles of 24-inch pipe for the mixed run configuration. The pipelines within Central Zone to the Ports of Los Angeles and Long Beach (Point 5 to 6) were calculated to require 80 miles of 24-inch and 36-inch pipe for the single run configuration, and 91 miles of 24-inch pipe for the mixed run configuration. Figure 16 displays the flow rates and pressure results at various locations, including the range of potential pipeline sizes estimated using ProMax.



Normal Operating Data	1	2	3	4	5	6
Single Run Pressure (psig)	775	780	475	900	341	208
Mixed Run Pressure (psig)	1,000	1,050	522	1,165	342	223
Flowrate (MMTPY)	0.75	0.75	0.75	0.75	1.5	1.5

Figure 16 - Route D (With Intermediate Compression) Hydraulic Results

For the single run configuration, the normal outlet pressure at the SJV compressor station is 780 psig, the Lancaster compressor station normal outlet pressure is 1,050 psig, and the intermediate compressor station outlet pressure is 900 psig. This allows for an operating buffer of 420 psig at the SJV compressor station and 150 psig buffer at the Lancaster station to each compressor’s MAOP.

For the mixed run configuration, the normal outlet pressure at the SJV compressor station is 1,000 psig, the Lancaster compressor station normal outlet pressure is 1,050 psig, and the intermediate compressor station outlet pressure is 1,165 psig. This allows for an operating buffer of 200 psig at the SJV compressor station and 150 psig buffer at the Lancaster station to each compressor’s MAOP.

For both configurations, the max outlet pressure at the SJV and Lancaster compressor stations is 1,200 psig to allow for line packing operation. Table 10 displays the calculated compressor information for the normal and the maximum operations.

Table 10 - Route D (with intermediate compression) Compressor Information

Route D - Compressors							
Configuration	**Location**	**Normal (hp)**	**Max (hp)**	**Inlet Pressure (psig)**	**Normal Outlet Pressure (psig)**	**Max Outlet Pressure (psig)**	**Flowrate (MMTPY)**
Single Run	SJV	23,000	50,000	500	775	1,200	0.75
	Lancaster	23,500	50,000	500	780	1,200	0.75
	Intermediate Compressor	35,000	53,500	475	900	1,200	0.75
Mixed Run	SJV	38,000	50,000	500	1,000	1,200	0.75
	Lancaster	41,000	50,000	500	1,050	1,200	0.75
	Intermediate Compressor	45,500	47,500	522	1,165	1,200	0.75

For the mixed run configuration, the intermediate compressor reduced the normal operating pressure of the SJV compressor station from 1,180 psig to 1,000 psig. The addition of the intermediate compressor for Route D can also decrease the required pipe sizes as the pressure drop will decrease, however this will result in increasing capital and operating expenses for installing and maintaining another compressor station with a maximum operating requirement of 47,500 horsepower. The benefits of reducing the SJV compressor station operating pressure were offset by the increased capital, maintenance, and utility costs of a third compressor station for Route D. Therefore, Route D with intermediate compression was not included in further analysis or cost estimate development.

5. MATERIALS REVIEW

Given hydrogen's unique properties, selecting appropriate materials is vital to mitigate potential issues such as hydrogen embrittlement. This section explores a range of potential material specifications based on hydraulic analyses, addressing key aspects such as pipeline wall thickness and pipe composition and physical properties (pipe grade) comparison. It also considers construction logistics and maintenance practices to improve pipeline longevity and reliability. Considerations to be explored in future phases of the Angeles Link project will include evaluation ofmaterial selection based on established operating parameters and integrity management technologies to further optimize the Angeles Link system.

5.1. Material Specification

The material specifications in this section are based on the latest edition of ASME B31.12 including applicable design factors. Preliminary calculations indicate that API 5L Grade X52 pipe appears to be suitable for the Angeles Link system based on the Hydraulic Analysis discussed in Chapter 4.

5.1.1. Pipeline Wall Thickness Calculation

The selection of pipeline sizes, pressures, and design factors directly influences the calculation of wall thickness and the resultant overall integrity of the system. Required pipeline sizes are determined through hydraulic calculations to meet operating parameters defined in the Design Parameters, Chapter 3. Temperature is controlled throughout the system by employing heat exchangers where necessary as determined through hydraulic calculations.

Pipeline wall thicknesses are calculated and provided in Table 11, Table 12, and Table 13 using the "Steel Pipe Design Formula" in ASME B31.12, PL-3.7.1 and the following assumed inputs:

- Design pressure (P) is 1,200 psig (Refer to Design Pressure, Section 3.2)
- Nominal outside diameter (D) is 16 to 36 inches (Refer to Hydraulic Analysis, Chapter 4)
- Temperature derating factor (T) is 1.000, for pipe up to 250 °F
- Quality Factor (E) is 1.00 based on using API 5L pipe, incorporated by reference into 49 CFR 192
- Design Factor (F) is 0.40 and is based on a Location Class 4
- These calculations do not include a corrosion allowance

The Design Factor (F) of 0.40 corresponds to a Location Class 4, which is defined by ASME B31.12, PL-3.2.2(d) to include areas where multistory buildings are prevalent, where traffic is heavy or dense, and where there may be numerous other utilities underground. Assuming Location Class 4 for the pipeline wall thickness calculation is consistent with ASME B31.12, GR-5.2.1 recommendations for any piping with a SMYS greater than 52,000 psi. This is a conservative assumption, as the Routing Analysis identified approximately 2 miles of initial corridors are within Location Class 4. Furthermore, ASME B31.12 allows pipelines operating less than or equal to 2,200 psig using materials with a SMYS of less than or equal to 52,000 psi to be considered in a Location Class 3 unless they are operating in Location Class 4 areas.

Other factors used to calculate potential wall thickness include the pipe grade and the resulting Material Performance Factor shown in Figure 17 and discussed below:

- Material stress value (S) is based on the SMYS for the chosen pipe grade. The values from Table IX-1B of ASME B31.12 follow:
    a. APL 5L Grade X52 has a SMYS of 52,000 psi (52 ksi)
    b. APL 5L Grade X60 has a SMYS of 60,000 psi (60 ksi)
    c. APL 5L Grade X70 has a SMYS of 70,000 psi (70 ksi)
- Material Performance Factor (H_f) is based on system design pressure and SMYS

Table IX-5A Carbon Steel Pipeline Materials Performance Factor, H_f

Specified Min. Strength, ksi		System Design Pressure, psig						
Tensile	Yield	≤1,000	2,000	2,200	2,400	2,600	2,800	3,000
66 and under	≤52	1.0	1.0	0.954	0.910	0.880	0.840	0.780
Over 66 through 75	≤60	0.874	0.874	0.834	0.796	0.770	0.734	0.682
Over 75 through 82	≤70	0.776	0.776	0.742	0.706	0.684	0.652	0.606
Over 82 through 90	≤80	0.694	0.694	0.662	0.632	0.610	0.584	0.542

Figure 17 - Carbon Steel Pipeline Materials Performance Factor, H_f

The following tables provide the calculated wall thickness at varying diameters for different grades of pipe. The pipe grades used in these calculations conform to API 5L and are distinguished by their specified minimum yield strength (SMYS), measured in psi (pounds-force per square inch).

Using API 5L Grade X52 pipe does not derate the pipe, the lower SMYS results in the greatest calculated wall thickness when compared to the higher grades. With the ability in ASME B31.12, GR-5.2.1 to apply a Location Class 3 to pipeline outside of Location Class 4, API 5L Grade X52 pipe offers the greatest flexibility in the latest edition of ASME B31.12.

Table 11 - Pipeline Wall Thickness Calculation (X52)

OD, NPS (in)	OD, Actual Pipe Size (in)	Calculated Wall Thickness (in), Class 4	Calculated Wall Thickness (in), Class 3
16	16.00	0.462	0.370
20	20.00	0.577	0.462
24	24.00	0.693	0.554
30	30.00	0.866	0.693
36	36.00	1.039	0.831

Using API 5L Grade X60 applies a derating factor of 0.874 resulting in a pipe wall thickness less than 1% lower than those calculated for API 5L Grade X52 despite the higher SMYS, when comparing Location Class 4 areas. Based on the guidance in ASME B31.12, GR-5.2.1, 36-inch pipe using API 5L Grade X60 would require a wall thickness greater than 1-inch. API 5L Grade X60 offers derating capability and slightly lower calculated wall thickness compared to API 5L Grade X52.

Table 12 - Pipeline Wall Thickness Calculation (X60)

OD, NPS (in)	OD, Actual Pipe Size (in)	Calculated Wall Thickness (in) Class 4
16	16.00	0.458
20	20.00	0.573
24	24.00	0.687
30	30.00	0.859
36	36.00	1.030

Using API 5L Grade X70 applies a derating factor of 0.776 resulting in a pipe wall thickness about 4% lower than those calculated for API 5L Grade X52 despite the higher SMYS, when comparing Location Class 4 areas. Based on ASME B31.12, API 5L Grade X70 is the only pipe grade reviewed in this study that resulted in a pipe wall thickness less than 1-inch when operating in a Location Class 4.

Table 13 - Pipeline Wall Thickness Calculation (X70)

OD, NPS (in)	OD, Actual Pipe Size (in)	Calculated Wall Thickness (in) Class 4
16	16.00	0.442
20	20.00	0.553
24	24.00	0.663
30	30.00	0.829
36	36.00	0.995

This study used recommendations in the latest edition of ASME B31.12, which was issued on December 29, 2023. Pipe manufacturers continue to test pipe to meet the stringent requirements of ASME B31.12. Manufacturers have qualified API 5L X65 per existing standards with testing of X70 grade occurring in various labs for conformance with ASME B31.12 and other standards to achieve full qualification for higher grades. Trial plans for heavy gauge up to 1-inch thickness have been developed based on pilot-scale trials to finalize alloy design and processing. A challenge for higher-grade line pipes in hydrogen applications is the Vickers hardness limitation (235 HV), which is being revised with standard committees. Higher grades of steel, like X70 and above, tend to have greater hardness and there is concern of embrittlement with these higher hardness steels. Finally, a new version ASME B31.12 is scheduled for publication in 2026 and "material performance factors will be reevaluated as materials research data are developed and understanding of hydrogen embrittlement of carbon and low alloy steels increases". ASME has published five editions of ASME B31.12 since December 2008 and has reduced derating and/or performance factors with each publication of ASME B31.12. In a future phase of the project, the Angeles Link pipeline system design will consider changes in publications from ASME, API, the CFR, and other codes and standards to remain current on the latest requirements and recommended practices.

5.2. Hydrogen Embrittlement

Hydrogen lowers the stress required to cause crack initiation and propagation. The related cracking is often referred to as hydrogen induced cracking (HIC). There are various mechanisms by which this occurs, including hydrogen enhanced decohesion (HEDE), hydrogen enhanced localized plasticity (HELP) and formation of brittle hydrides although hydride formation is uncommon in steel. Hydrogen embrittlement also reduces tensile ductility (reduced elongation in a tensile test) and the tensile strength of notched specimens.

In some steels, especially those with laminations or elongated nonmetallic inclusions, hydrogen atoms can collect at those features and recombine to form hydrogen molecules. Formation of hydrogen molecules from hydrogen atoms causes a large increase in hydrogen gas volume and a related increase of internal pressure of hydrogen gas within the wall of the steel until bulging (“hydrogen blistering”) and related extension of the blister occurs via crack formation and growth at the edges of the blister. Hydrogen blistering can occur in low strength steels, whereas hydrogen embrittlement is more frequently found in higher strength steels.

The rate at which hydrogen embrittlement occurs is closely related to how quickly hydrogen dissociates and enters the steel surface as H+. In severe conditions, such as electrochemical charging in a laboratory or, to a lesser extent, exposure to excessively negative cathodic protection potentials, detectable hydrogen embrittlement can occur within a day. In most hydrogen pipeline service, hydrogen embrittlement occurs much more slowly, if at all.[25] If a material is embrittled, it will remain that way regardless of time or exposure to more or less hydrogen. Angeles Link is planned to be a new pipeline system and mitigation of embrittlement will be considered as part of the primary design, monitoring, and development of future operations and maintenance procedures.

5.2.1. Effect of Gas Composition, Temperature, and Pressure

Susceptibility to hydrogen embrittlement and the rate of embrittlement are both related to the service conditions and to the metallurgical characteristics of the pipe. From the standpoint of the environment, the extent of the embrittlement is related to the partial pressure of hydrogen and, to a much lesser extent, the temperature. Hydrogen embrittlement is reduced at elevated temperatures (until at least 200°C when high temperature hydrogen attack[26] occurs) but is not greatly affected by the typical range of pipeline operating temperatures. Measurable reductions in toughness and related effects on fatigue life occur at

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[25] DOE Hydrogen Program FY 2005 Progress Report 449, Contract Number: DE-FC36-04GO14229, Start Date: 9/1/04, Projected End Date: 3/31/2006. See also Xiao Xing, Mengshan Yu, Olayinka Tehinse, Weixing Chen, Hao Zhang "The Effects of Pressure Fluctuations on Hydrogen Embrittlement in Pipeline Steels" Proc. ASME. IPC2016, Volume 1: Pipelines and Facilities Integrity, V001T03A025, September 26–30, 2016 Paper No: IPC2016-64478

[26] Hydrogen attack is the degradation of steel at elevated temperature due to atomic hydrogen travelling through the material and impacting impurities and defects.

partial pressures as low as 15 psia. However, embrittlement requires that some of the hydrogen molecules (H_2) dissociate to H^+ at the pipe surface so that the hydrogen can enter (“adsorption”) and diffuse through the pipe wall. Active corrosion, especially in the presence of hydrogen sulfide (H_2S), and unoxidized (actively growing) crack tips promote the entry of H^+.

5.2.2. Effect of Pipe Grade and Steel Metallurgy

There is broad consensus that susceptibility to embrittlement increases as pipe strength increases. However, the relationship is complicated by the interrelated effects of variations in metallurgical characteristics, including chemical composition and thermomechanical processing (i.e., details of the plate rolling procedure). ASME B31.12 notes that for a given pipe grade, susceptibility to embrittlement generally increases as carbon, manganese, sulfur, phosphorous, and chromium contents increase. Microalloying generally results in lower susceptibility to embrittlement.

ASME B31.12 recommends that steel pipe not have a grade greater than X52, even though higher strengths are permitted. However, for grades stronger than X52 the Materials Performance Factor (H_f) used for calculation of maximum allowable pressure for a given wall thickness decreases as strength increases. As a result, an increase in pipe strength is much greater than the corresponding decrease in required wall thickness when using grades stronger than X52 for pipe thickness determinations using ASMB B31.12 Option A. Table 14 illustrates that effect of increasing pipe strength on the required minimum wall thickness.

Table 14 - Effect of Hf on Required Wall Thickness for Pipelines Using B31.12 Option A

SMYS (ksi)	% Increase in SMYS vs. X52	% Decrease in H_f vs. X52	% Reduction in Required Wall Thickness vs. X52
52	0.0	0.0	0.0
56	7.7	12.6	- 4.9*
60	15.4	12.6	2.8
65	25.0	22.4	2.6
70	34.6	22.4	12.2
80	53.8	30.6	23.2

* 4.9% *greater* wall thickness is required compared to X52

5.3. Pipeline Integrity & Maintenance

Fitness for service is an important consideration as it is determined based on the ability of different types of facilities or individual components to satisfactorily perform their intended function, which is to safely and reliably deliver gas to customers.[27] In the absence of cracking or crack-like planar flaws, hydrogen embrittlement has little to no effect on long-term pipeline integrity. Fitness for service assessments need to account for the decrease in toughness that is expected to be associated with hydrogen embrittlement. The challenge is to accurately estimate the expected amount of toughness decrease resulting from exposure to hydrogen. The severity of embrittlement has been shown to be mostly related to hydrogen partial pressure, rather than to merely the percent of hydrogen present or to the total system pressure. The effect of hydrogen embrittlement on critical crack size can be illustrated by comparing flaw size versus failure pressure curves for a range of toughness values on a hypothetical pipeline.

Because critical crack sizes are smaller and cracks subjected to fluctuating stresses grow more quickly for steel exposed to pressurized hydrogen, inspection practices, including in-line inspection tools (ILI – aka smart pigs) need to be capable of reliably detecting and sizing planar flaws. Some elastomers and polymers used in ILI tools may not be compatible with high pressure hydrogen, so there may be a subset of existing inspection devices that are not suitable unless modified for hydrogen service. ILI service providers are aware of the increasing interest in inspections of hydrogen pipelines.

Simultaneously, design choices that minimize material stress will reduce the likelihood of cracks and reliance on inspection.

5.4. Repurposing Review

In alignment with stakeholder comments, a high-level evaluation of repurposing existing natural gas pipelines for 100% hydrogen gas service was conducted. The potential advantages and disadvantages to converting natural gas pipeline versus building new pipelines intended for hydrogen service are summarized below:

Advantages of conversion:

- Lower cost relative to building new pipelines
- Potential use of existing easements and rights of way
- Time required for conversion of existing pipelines can be less than installation of new pipelines

Disadvantages of conversion:

- Existing steel pipe may not match ideal properties (also, some existing pipelines may not have all of the preferred property data available, especially regarding toughness); uncertain properties of welds, especially pre-existing repairs and hot taps.
- Integrity of existing assets may be imperfect, i.e., pre-existing corrosion, pre-existing mechanical damage, stress corrosion cracking (SCC), fatigue, surface imperfections from manufacturing that would not exist in new pipe
- Some existing wall thickness may not be recommended by ASME B31.12. For example, for pipe greater than 4-inch diameter, the minimum wall thickness allowed in hydrogen service is 0.25-

[27] Report to America on Pipeline Safety. (2011). Determining natural gas distribution fitness for service. https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/docs/FFS-%20Distribution%20Technical%20Note%20Proposal%20Final%20%282%29.pdf

inch. That limit precludes the conversion of pipelines that may only be 0.156-inch, 0.188-inch, or 0.219-inch thick.

- Allowable MAOP in hydrogen service may be lower, depending upon location class, seam type, pipe grade, etc. The effect of pipe grade was previously described and illustrated in Table 14. The difference in design factor for Location Class 1 and 2 are shown in Table 15. While Table 15 shows the design factors applicable to ASME B31.12 Option B are the same as for ASME B31.8, ASME B31.12 Option B requires rigorous analysis of fatigue cycles and determination of embrittled toughness to determine the wall thickness required for a desired MAOP. As a result, the wall thickness could be significantly different than the thickness determined using ASME B31.8 for the same MAOP, or the MAOP may have to be reduced to achieve the desired fatigue life with the available or existing wall thickness.
- ASME B31.12 does not allow the use of pipe having butt welded longitudinal seams. Butt welded seam pipe (either furnace butt weld or continuous butt weld) is common in pipe sizes up to and including NPS 4.

Table 15 - Comparison of Design Factors from ASME B31.8 and ASME B31.12

Location Class	B31.8 Design Factor	B31.12 Option A Design Factor	B31.12 Option B Design Factor
1, Div. 1	0.80	NA	NA
1, Div. 2	0.72	0.50	0.72
2	0.60	0.50	0.60
3	0.50	0.50	0.50
4	0.40	0.40	0.40

5.4.1. Case Study of Retrofit Projects

In 2005 Air Liquide presented a summary of their experience converting two crude oil pipelines to hydrogen service[28] including:

- Corpus Christi Pipeline: An 8-inch diameter, Grade B pipe built in 1940-1950 was converted to hydrogen service at 700 psig for 6 months. It ruptured due to an unspecified form of corrosion in 1998, and then was derated to 350 psig. Currently, 65 miles of this retrofitted pipeline are still in service.

[28] Campbell, J. & Air Liquide. (2005, August 31). DOE Hydrogen Pipeline Working Group Meeting - Questions and issues on hydrogen pipelines. Office of Energy Efficiency & Renewable Energy. https://www.energy.gov/eere/fuelcells/articles/questions-and-issues-hydrogen-pipelines-pipeline-transmission-hydrogen

- Freeport to Texas City Pipeline: A 14-inch diameter pipeline built in 1979 with various grades and wall thickness, including X60, was converted to hydrogen service at 740 psig in 1996. No issues were reported, including the use of existing ball valves previously used for crude oil service.

A comparison of the specifications used in the Air Liquide retrofitted pipelines to a new pipeline suitable for 100% hydrogen service is shown in Table 16.

Table 16 - Air Liquide New and Converted Pipeline Characteristics[29]

Specification	New Pipeline	Retrofitted Freeport to Texas City Pipeline	Retrofitted Corpus Cristi Pipeline
Hardness	<250 HB	225 HB	178 HB
Carbon Equivalent	<0.43	0.63	0.325
Grade	<X52	X60	Grade B
Sulfur	<0.015%	0.015	0.036
Phosphorus	<0.015%	0.017	0.011
Charpy Impact	>35 J	>27 J	6 J
Heat Treatment	Normalized	N/A	N/A

There are several studies regarding the feasibility of converting existing pipelines to either 100% hydrogen service or to natural gas and hydrogen blends. For example, APA group (an Australian company) is studying the feasibility of converting a 0.219-inch and 0.312-inch thick API 5L X52 pipeline built in 1970 to ASME B31.8 code to 100% hydrogen service.[30] In the United Kingdom the H21 Programme is studying conversion of existing natural gas distribution pipelines to 100% hydrogen.[31]

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[29] Campbell, J. & Air Liquide. (2005, August 31). DOE Hydrogen Pipeline Working Group Meeting - Questions and issues on hydrogen pipelines. Office of Energy Efficiency & Renewable Energy. https://www.energy.gov/eere/fuelcells/articles/questions-and-issues-hydrogen-pipelines-pipeline-transmission-hydrogen

[30] APA Group. (2023, May). Parmelia Gas Pipeline: Hydrogen Conversion Technical Feasibility Study. https://www.apa.com.au/globalassets/our-services/gas-transmission/west-coast-grid/parmelia-gas-pipeline/3419_apa_public-pipeline-conversion_v6.pdf

[31] Switching a city from natural gas to hydrogen. (n.d.). https://www.dnv.com/oilgas/perspectives/switching-city-from-natural-gas-to-hydrogen/

6. COST ESTIMATES

SoCalGas developed cost estimates for the Scenarios and Preferred Route options using common practices associated with projects in development. SoCalGas utilized historical project information of constructed natural gas pipelines and compressor stations as the basis for developing unit costs for pipeline system features. The applicable project data was reviewed and selected based on certain variables such as common project types, pipeline installation length, geography, and right-of-way area. The estimate was organized into a standard project work breakdown structure where each category (e.g., Company Labor, Project Services, Environmental) was calculated using historical averages while also incorporating the estimating team's judgment. Contingency was also calculated incorporating the estimating team's judgment based on the level of design and known project uncertainties.

6.1. Basis of Estimate

SoCalGas utilized the recommended practices from Association for the Advancement of Cost Engineering International (AACEi) as guidelines for estimate development. AACEi is an internationally recognized organization that provides a structured framework, industry-specific guidance, and a focus on lifecycle costs—all of which contribute to enhancing cost and risk management for pipeline infrastructure projects. The Angeles Link project utilized the AACEi recommended practices (RP) of "Cost Estimate Classification Systems" to classify project cost estimates based on their purpose (e.g., evaluation, approval, funding). The following were adopted for Angeles Link preliminary cost estimates:

- "97R-18: Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Pipeline Transportation Infrastructure Industries" for pipeline costs
- "18R-97 Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries" for compressor station costs

For the Angeles Link Phase 1 feasibility study, Class 5 estimates were developed according to AACEi Recommended Practice 97R-18 and 18R-97 listed above.[32] Class 5 estimates are generally prepared based on limited information (typically 0-2% project scope definition) and have wide accuracy ranges. Typical accuracy ranges for Class 5 estimates are -20% to -50% on the low side, and +30% to +100% on the high side, depending on technological and system complexity, and appropriate reference information and other risks (after inclusion of an appropriate contingency determination). Ranges could exceed those shown if there are unusual factors including volatile commodity markets and escalation (i.e., because of the proportion of commodity material content such as steel). The intended end use for Class 5 estimates is to inform any number of strategic business purposes, including, but not limited to, market studies, engineering design, assessment of initial viability, evaluation of alternate schemes, project screening, routing studies, evaluation of resource needs and budgeting, and long-term capital planning.

[32] Class 5 estimates are the most preliminary class of estimate addressed in the AACEi classification system and are followed by Class 4 and Class 3 estimates as the project scope matures; the latter is considered the most appropriate for budget authorization, appropriation, and/or funding.

6.2. Scope of Estimate

The Class 5 estimates completed for the preliminary sizing results are based on historic SoCalGas construction project unit costs in SoCalGas service territory normalized to 2024 dollars, and include direct costs of the following:

- Contractor Costs for Construction
- SoCalGas Company Management, Union Labor and Non-Labor Costs, and Outreach & Public Affairs
- Engineering and Design Services
- Project Management and Project Services
- Material Procurement and Management
- Survey / As-Builts
- Pressure Test Certification Services
- X-Ray and Non-Destructive Examination
- Environmental Planning, Management, Monitoring, and Abatement Support
- Construction Management
- Inspection
- District Personnel (Management, Operations Manager, Union Labor, Instrumentation and Facilities Operation Supervisor)
- M&R (Meters and Regulation)
- Pipeline Integrity
- Water Storage
- Miscellaneous Services associated with hydrogen systems
- Outreach & Public Affairs
- Land Services
- City Permits
- Other Non-Labor Costs

The Class 5 estimates exclude the following:

- Future escalation (all costs are normalized to 2024 dollars)
- Indirect costs (overhead, administrative, insurance, taxes, etc.)
- New land purchasing and acquisition costs
- Point of Receipt costs
- Night work except for pipeline Tie-Ins / Isolations
- Weekend or Holiday Work
- Cultural resources (e.g., costs to remove, preserve, and/or handle unexpected discoveries)
- Dewatering
- Producer or customer connection costs
- Expected environmental remediation costs
- Any unexpected constructability costs

6.3. Scenarios 1-8 Cost Estimates

Class 5 estimates were completed for each of the scenarios based on the results described in Section 4.5. These estimates were developed for the Cost Effectiveness Study to determine the potential levelized cost of clean renewable hydrogen to be delivered to end-users. The cost estimates were also provided to the Workforce Evaluation as the basis for the employment and economic impact analysis.

6.3.1. Results/Discussion

Table 17 summarizes the Class 5 estimates for Scenarios 1 through 8. The costs developed are based on several factors such as land types (e.g. rural lands, urban areas, and mountainous terrain), and preliminary system design specifications. For estimating purposes, land types were assumed to be rural if greater than 75% of the pipeline were in Class 1 locations, and urban if greater than 75% of the pipeline were in Class 2, 3, or 4 locations as defined by Code of Federal Regulations, Title 49 CFR 192.5(b). The pipeline estimates assumed unit costs for valve stations, cathodic protection, launcher and receivers, fiber optic monitoring and SCADA (Supervisory Control and Data Acquisition) systems based on preliminary routing configurations. Preliminary pipeline material specifications were based on guidance from ASME B31.12, § PL-3.7.1 with corresponding hydraulic model sizing results and parameters. The compressor stations were estimated based on historic SoCalGas project estimates for reciprocating compressors at various operating requirements (horsepower).

The pipeline and compressor costs were combined to produce the total cost per scenario, which represents the estimated capital expenditures (CapEx). The annual operating expenditure (OpEx) was estimated to be 1% of the capital costs for fixed operation and maintenance activities.[33] Variable operating costs were developed by the Cost Effectiveness Study based on anticipated utility costs to operate the compressor stations.

[33] Khan, M.A., Young, C. and Layzell, D.B. (2021). The Techno-Economics of Hydrogen Pipelines. Transition Accelerator Technical Briefs Vol. 1, Issue 2, Pg. 1-40. ISSN 2564-1379.

Table 17 –Scenario Cost Estimate Summary

	Installed Pipe, miles	Range of Nominal Pipe Sizes	Approx Total Pipeline Cost*	No. of Compressor Station(s)	Approx Total Compressor Cost*	Approx Total Cost* (CapEx)
Scenario 1	355	12-in to 30-in	$5 B	1 @ 33,000 hp	$1B	$6 B
Scenario 2	314	12-in to 24-in	$4 B	1 @ 33,000 hp	$1 B	$5 B
Scenario 3	303	12-in to 30-in	$5 B	1 @ 33,000 hp	$1 B	$6 B
Scenario 4	390	12-in to 36-in	$4 B	2@ 33,000 hp (each)	$2 B	$6 B
Scenario 5	537	12-in to 24-in	$6 B	2@ 33,000 hp (each)	$2 B	$8 B
Scenario 6	578	12-in to 30-in	$7 B	2@ 33,000 hp (each)	$2 B	$9 B
Scenario 7	390	16-in to 36-in	$6 B	2 @ 50,000 hp (each)	$3 B	$9B
Scenario 8	616	12-in to 36-in	$9 B	3 @ 33,000 hp (each)	$3 B	$12B

*Cost based on Class 5 estimates, which have accuracy ranges of -20% to -50% on the low side, and +30% to +100% on the high side. See Section 6.1 for details.

6.4. Preferred Route Cost Estimates

Class 5 estimates were completed for each of the Preferred Route Configurations based on the results described in Section 4.6. This section supports the Routing Analysis by including cost as an additional factor for consideration and comparison for the Preferred Route Configurations.

6.4.1. Results/Discussion

Table 18 summarizes the Class 5 estimates for the single-run configuration for Preferred Routes A through D, which assumed the same preliminary land, pipeline, and compressor specifications as the Scenario 1-8 estimates.

Table 18 - Preferred Route Single-Run Configuration Cost Estimate Summary

Single-Run Configuration	Installed Pipe, miles	Pipe Sizes, inches	Approx Total Pipeline Cost*	No. of Compressor Station(s)	Approx Total Compressor Cost*	Approx Total Cost* (CapEx)
Route A	390	16”, 20”, 24”, 30”, 36”	$6 B	2 @ 50,000 hp (each)	$3 B	$9 B
Route B	406	20”, 36”	$7 B	2 @ 50,000 hp (each)	$3 B	$10 B
Route C	472	20”, 24”, 30”, 36”	$6B	2 @ 50,000 hp (each)	$3 B	$9 B
Route D	481	24”, 36”	$8 B	2 @ 50,000 hp (each)	$3 B	$11 B

*Cost based on Class 5 estimates, which have accuracy ranges of -20% to -50% on the low side, and +30% to +100% on the high side. See Section 6.1 for details.

As described in Section 4.6, single- and mixed-run configurations were modeled for the Preferred Routes to evaluate the system performance, operability, and resiliency, if portions of the system were temporarily removed from service for maintenance and other activities. The dual-run sections have smaller pipe diameters compared to the single-run equivalent, which is an important consideration since pipeline size impacts overall cost due to the increased material, weight, transportation, and constructability requirements associated with larger diameter pipes.

The single- and mixed-run Preferred Route Configuration cost comparison is presented in Table 19. The cost difference between the single- and mixed-run configurations range from 23% to 32%. The mixed-run configuration did not double the total installed pipe mileage, since only pipelines that were not part of a “looped” configuration were modeled as two-parallel lines (dual-run) to improve system resiliency, allow for continuous operation during potential disruptions, and increase storage capacity during peak usage periods.

Table 19 - Preferred Route Configuration: Single and Mixed Run Cost Estimate Comparison

	Approx. Total Cost*, Single-Run	Approx. Total Cost*, Mixed Run	Approx. Cost Difference	% Cost Difference
Route A	$9 B	$11 B	$2 B	23%
Route B	$10 B	$13 B	$3 B	27%
Route C	$9 B	$12 B	$3 B	31%
Route D	$11 B	$14 B	$3 B	32%

*Cost based on Class 5 estimates, which have accuracy ranges of -20% to -50% on the low side, and +30% to +100% on the high side. See Section 6.1 for details.

7. FUTURE CONSIDERATIONS

Angeles Link Phase 1 studies, including the Pipeline Sizing and Design, address the feasibility aspects and establish a foundation for the Angeles Link project. These feasibility studies serve as a precursor to more detailed analysis and refinement that underpin the subsequent stages of preliminary and Front End-Engineering Design (FEED) activities. FEED represents a detailed approach through which the project's specifications will be further defined. The future considerations identified within this chapter will be necessary to safely advance the engineering design, identify specific project requirements, safety and design factors, and support an efficient execution. These following considerations are important to the advancement of the project but were not considered part of the feasibility evaluation.

7.1. Hydraulic Performance and Modeling

7.1.1. Transient Hydraulic Analysis

A transient or dynamic hydraulic model focuses on studying the changes in flow conditions within a pipeline system over time. Analysis can be performed to examine the dynamic behavior of fluid flow within a pipeline when the flow conditions change rapidly. These changes can occur due to valve operations, changes in demand, or changes in supply. The analysis helps predict pressures exceeding normal operational levels and allows for a pipeline to be designed to the appropriate specifications for the characteristics of connected loads.

A hydraulic model of the pipeline will include all relevant pipeline system components like compression, valves, fittings, reservoirs, and pipeline geometries. Modeling software is then used to simulate different transient or dynamic scenarios. These tools use the method of characteristics or other numerical methods to solve the transient flow equations. This differs from static modeling where the models evaluate steady-state conditions where the flow parameters such as pressure, velocity, and flow rate are assumed to remain constant over time (as completed in Phase 1 of this study). The primary goal of static modeling is to evaluate the system under a normal operational state without considering changes over time. It is focused on efficiency and feasibility. By contrast, a dynamic analysis considers the time-dependent changes in the flow conditions caused by operations or disturbances. These models can capture how an event will affect variables such as pressure and flow rate over time. They are more complex and computationally intensive due to the need to solve the equations of motion and continuity for fluid dynamics, considering the elasticity of the fluid and the pipe wall. Transient modeling is used for understanding the pipeline's behavior under non-standard and emergency conditions, focusing on system integrity and how the system responds to changes.

Transient modeling allows for a variety of safety considerations to be made. First, as noted above, material selection requires transient modeling. It is additionally important in the development of design for protective measures such as pressure relief valves or the development of operational standards, monitoring thresholds, and system maximums/minimums.

In subsequent phases of Angeles Link, additional specific details regarding the pipeline connections can be determined as the route selection and material choice is narrowed. This additional detail will allow for the complexities of transient modeling to be performed.

7.1.2. System Requirements

The development of system requirements is also supported via transient hydraulic modeling and is an important component of system design on its own. The term "system requirements" for a pipeline refers to the specific operational and performance criteria that the pipeline must meet to function effectively and safely under various conditions, including extreme scenarios. These requirements are typically defined during the design phase of the pipeline and are crucial to the design process for adequacy during typical operating conditions but also during rare and challenging circumstances.

System requirements mandate that the design accounts for the most severe conditions anticipated during the pipeline's lifetime. For example, designing for a 1/35-year condition means that the pipeline must be able to withstand and operate during events that have a 2.86% chance of occurring in a given year. Operational margins are included to maintain the system's receipt and delivery objectives are achieved within a relatively wide variety of circumstances.

Materials must be chosen for their performance under normal conditions including for durability and resiliency under the specified extreme conditions. This might include selection of materials with higher corrosion resistance, greater mechanical strength, or enhanced flexibility. Engineering specifications such as wall thickness, diameter, and the type of joints and seals might be adjusted to cope with additional pressures or movements caused by extreme conditions.

Operational flexibility and performance standards are also defined via system requirements. This could include the amount of time expected for the system to quickly adjust operations in response to fluctuating demands, supply, or emergency events. Conversely, they may define the amount of time the system is expected to be operational and available for use without interruption, also known as "system up time". This metric allows for evaluation of the reliability and efficiency of the system and is part of the overall performance standards. It is typically expressed as a percentage of the total time over a specific period, often annually. For example, an expected up time of 99% annually means the system is expected to be operational for 99% of the time throughout the year, which translates to being "down", or non-operational, for no more than 3.65 days in a year. High up time requirements may necessitate redundancy in critical parts of the system architecture to support continuous operation and/or affect integrity maintenance planning strategies in order to prioritize performance of predictive maintenance with up time requirements in mind.

Service Level Agreements (SLAs) in a commercial context illustrate the expectations between service providers and customers. These SLAs stipulate the performance criteria, including up time, that must be met, and the penalties for failing to meet these criteria. As details of the project are developed, including hydrogen receipt and offtake, agreements such as SLAs would reflect corresponding system requirement features that allow for connection to the Angeles Link system.

7.1.3. Storage and Scalability

Hydraulic modeling is essential to the design of a system that is scalable and integrates storage solutions. The ability to evaluate changes over transient periods of time allows for evaluation of how to scale the system to meet current and future demands efficiently.

Long term planning options are developed as dynamic modeling simulates fluid flow over time, considering variations in supply and demand, compression operations, and other factors that affect flow and pressure in the system. Capacity planning, predicting how the pipeline will perform as demand increases or as new sources or sinks are integrated into the system, is essential in large infrastructure projects. Dynamic modeling allows for a simulation of what types of system changes may be adequate including installation of larger diameter pipes, adding parallel lines, or increasing the number and capacity of compressors. It also creates the capability to evaluate how an initial system may cope with future increases or decreases in flow to support informed decision making about system staging and growth.

By modeling different operational scenarios, it is possible to identify periods when the system may face excess supply or demand shortfalls. Storage facilities can be strategically located and sized to support regional hydrogen producers and end users to buffer these fluctuations, creating a steady supply and preventing system overload or underutilization. During periods of low demand, excess gas can be stored rather than reducing the pipeline's throughput drastically, which might be less efficient. Clean renewable hydrogen production and above ground and underground storage is not currently proposed as 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 packing, which refers to storing and then withdrawing gas supplies from the pipeline, can provide storage capacity while scale storage technologies are developed overtime to support regional hydrogen hub requirements.

The scalability of a pipeline system is another important mechanism in design given that the ability to respond to the growth of the supply and offtake, for which the pipeline acts as a transportation mechanism, is key. Clean renewable hydrogen production is currently not widespread but is anticipated to significantly increase as the shift toward sustainable energy sources gains momentum. Similarly, the demand for hydrogen is expected to rise as it becomes more integral to various industries seeking to decarbonize and meet State and Federal targets. See the Demand Study and the Production Study for further information on projected growth. In response to this emerging market, the development of a dedicated pipeline system for hydrogen transport is critical. Such a system must not only cater to current demands but must also be designed to accommodate future increases in production and consumption volumes. The time required to plan for installation of infrastructure necessitates that pipeline system components are anticipated in advance of when they may then be needed. This supports a smooth energy transition and a supply chain that is robust and responsive to the evolution of the energy landscape.

7.2. Design Development

Pipeline design is significantly influenced by the physical location of the pipeline as well as operational and maintenance considerations. These considerations are discussed below.

7.2.1. Material Selection & Corrosion Protection

Material selection is part of the design process and is heavily influenced by the route. Compatibility with environmental factors, such as soil and groundwater chemistry, can play a role in the material selected. Selection of materials that are robust and appropriate for the specific conditions of the pipeline's operation will minimize the risk of material degradation and failure due to corrosion. Corrosion is a natural process where materials made from metals deteriorate through an electrochemical reaction known as oxidation (rusting),[34] and can occur both internally and externally on a pipeline. It is critical to employ protection strategies and make material choices that are tailored to specific local geological and hydrological conditions as the rate of corrosion and susceptibility to it is influenced by these factors.

Corrosion – Different transported substances can have varying impacts on materials, potentially leading to corrosion or wear. Including integrity management involves the selection of materials that resist such degradation processes, thus maintaining the structural and functional integrity of the pipeline. This includes choosing corrosion-resistant alloys or applying protective coatings and linings both internally and externally.

Corrosion can be characterized by where and/or how it occurs. For example:

External corrosion occurs due to environmental conditions on the exterior surface of the steel pipe that can cause an electrochemical interaction between the exterior of the pipeline and the soil, air, or water surrounding it. Galvanic and atmospheric corrosion are common types of external corrosion.

Internal corrosion occurs due to a chemical attack on the interior surface of a steel pipe from the products transported in the pipe. This can be from either the commodity transported, or from other materials carried along with the commodity, such as water, hydrogen sulfide, and carbon dioxide.

Other types of corrosion can occur due to specific material defects or environments. These include stress corrosion cracking (SCC), microbiologically-influenced corrosion (MIC), stray current interference corrosion, and selective seam corrosion. These types of corrosion problems can be exacerbated by environmental conditions, manufacturing processes, pipe wall erosion from the transported commodity, physical location with respect to other structures, and applied stresses resulting from routine and normal pipeline operations.

Simultaneously, pipelines must also be designed for the fuel being carried. See the Materials Review Chapter of this Study for further detail into pipeline integrity (with regard to materials), hydrogen embrittlement, maintenance, and repurposing.

In subsequent phases of Angeles Link, more details will be available that will inform the development of specific integrity management practices for hydrogen infrastructure. Iteratively, integrity management needs will also drive material selection in the following ways.

Technology – Tools and equipment used to evaluate pipeline integrity, including devices such as smart in-line-inspection tools and others used to appropriately monitor and check pipeline health over time, are an important consideration in material selection. Part of the design process is to select materials that can be effectively inspected using commercially available equipment, and opting for standard sizes can enhance the availability of these tools and simplify integrity management practices. Materials that are compatible with advanced inspection and monitoring techniques, such as smart pigging and ultrasonic testing, enable more effective and less intrusive integrity checks.

Maintenance Practices – Material selection can also facilitate the ease of monitoring and maintenance of the pipeline. It may be more practical to select certain materials in areas that are challenging or difficult to physically access versus materials that require more frequent or invasive inspection.

[34] Pipeline Safety Stakeholder Communications. PHMSA. (n.d.-b). https://primis.phmsa.dot.gov/comm/FactSheets/FSCorrosion.htm

Cost-Effectiveness – Initial cost of materials is an important factor in the material selection process. Additionally, consideration must be given to the lifecycle cost of the pipeline. Selecting materials that require less maintenance, have longer lifespans, and have lower risk of failure can significantly reduce operational and repair costs over time.

Flow Velocity - Gas movement within a pipeline can be measured by its velocity. Pipeline erosion occurs when a fluid flowing within a pipeline gradually degrades small amounts of the inner pipeline surface through surface collisions with greater effect at higher fluid velocities. Gas velocities can be calculated to determine at what operating conditions erosion may occur in a pipeline using the Erosional Velocity Equation per ASME B31.12. The erosional velocity is a function of temperature and pressure and fluctuates throughout the system based on operating conditions. The fluid velocity is an important consideration for selecting pipe size and will be further analyzed in future phases when operating parameters throughout the Angeles Link system are established.

I-3.4.5 Hydrogen gas velocities in piping should not exceed the erosional velocity at peak conditions. Lower velocities are recommended. The erosional velocity, u_e, is calculated by:[1]

$$u_e = \frac{100}{\sqrt{\frac{29GP}{ZRT}}}$$

where

G = gas gravity (0.0695)
P = minimum pipeline pressure, psia
R = universal gas constant
= 10.73 $ft^3 \cdot psia/(lb\text{-}mol \cdot °R)$
T = flowing gas temperature, °R
u_e = erosional velocity, ft/sec
Z = compressibility factor at specified temperature and pressure, dimensionless

Figure 18 - Erosional Velocity Equation (ASME, 2024)

Sourcing Logistics – The availability of specific materials can vary greatly depending on geographic location, manufacturing capacity, and market demand. Materials that are readily available or can be delivered quickly from nearby suppliers may reduce lead times and assist in adherence to project schedules. Conversely, opting for materials that require long lead times or are subject to supply chain uncertainties can delay project timelines. The distance, means, and cost of transportation from the supplier to the project site can affect the total cost of the project. Heavy or bulky materials such as large-diameter pipes or heavy steel sections, might require special transportation arrangements. Additionally, some materials may have storage or handling constraints that complicate logistics.

As pipeline route, system needs, and design are further refined for Angeles Link, the selection of materials and corrosion protection features can be further developed. Due to the integration between these components, it is advisable to develop them after the project feasibility stage to allow for a more informed, accurate, and compliant approach. This creates a basis that is solid and founded on detailed project specifications to make them capable of addressing all operational and environmental requirements effectively.

7.2.2. Pipeline Routing[35], Construction & Maintenance

Pipeline routing influences the material selection of a pipeline as well as the overall design. Plans for construction and maintenance may also influence the design beyond the selection of materials. Cost, efficiency, weather, seismicity, and infrastructure proximity are all considerations that impact pipeline sizing and materials.

Cost – Routes that avoid natural obstacles like rivers, mountains, and protected ecosystems, sensitive habitats and potential wildlife habitats help to minimize environmental disruption, thereby reducing the amount of earth moved during construction and potential environmental mitigation requirements. Cost reductions or savings may result, which is also a key consideration achieved by shortening the overall length of the pipeline and the selection of routes that allow for easier construction and lower material costs. For example, construction within mountainous terrain can pose disadvantages due to potential for land movement, extreme or unpredictable weather, complexities in design, and ease of access for both installation and transportation of materials. These characteristics can result in higher design and installation costs.

Efficiency – Operational efficiency is another significant factor in route selection. The chosen route should consider facilitation of maintenance and surveillance to maximize ease of access in all seasons and conditions. This includes not only the construction timeframe when the ingress and egress of equipment to a work location will be important, but also includes consideration of future needs for pipeline inspection and repairs (e.g. potential rights-of-way or specific routing needs to accommodate maintenance equipment). The ability to surveil pipeline sites for safety and security must be incorporated into the route planning such that monitoring systems like patrol routes for aerial surveillance are effective and efficient.

Piggability – Designing pipelines to accommodate pipeline inspection gauges, or "pigs", is an important consideration for anticipated cleaning, inspection, and maintenance activities. General factors to consider include pipeline operating conditions, configuration, diameter changes, entry and exit points for the pig such as launchers and receivers, and fittings that include valves, bends, and elbows. Piggability also considers the materials specification depending on the type of pigging activity. Pigs that are equipped with sensors and data recording devices may only be compatible with certain material and pipe specifications. A variety of factors will need to be considered in subsequent design and project development to facilitate routine integrity management and maintenance activities.

Transportation – Material weight is increased as pipe diameter and wall thickness increases. This, in turn, affects how the pipe can be safely transported from the location where the steel is milled to the location where it will be stored or used for construction. Guidelines set forth by the U.S. Department of Transportation Federal Highway Administration for Freight Management and Operations[36] govern weight limitations for transportation by vehicle.

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[35] Refer to Routing Analysis for additional considerations not described in this chapter such as engineering, environmental, social, and geographic elements.
[36] Compilation of existing State Truck Size and Weight Limit Laws - Appendix A: State Truck Size and Weight Laws - FHWA Freight Management and Operations. (n.d.). https://ops.fhwa.dot.gov/freight/policy/rpt_congress/truck_sw_laws/app_a.htm

Weather – Weather related challenges significantly impact both the construction schedule and methodology of pipeline projects. Seasonal extremes must be considered, such as heavy rainfall or intense heat, which can influence when and how construction proceeds. Additionally, regions prone to freeze thaw cycles may require specific engineering solutions to manage soil instability that could involve deeper burial of the pipeline or the use of certain pipe materials. Areas prone to other transient environmental conditions like flooding may also require additional design considerations, which could include elevated structures or reinforced embankments to prevent erosion during heavy rains.

Infrastructure Proximity – Additional infrastructure within close proximity to the pipeline may have design implications. It is necessary to consider multiple components when siting an underground hydrogen pipeline with regard to other substructures, such as content carried, pressure, diameter, size, setback, and depth requirements, etc.[37] For aboveground infrastructure, proximity to other energy infrastructure, such as overhead electrical lines, is a site-specific consideration that may require rerouting or design adjustments. Design choices may be further affected by location with regard to zoning and land use. It is preferred to install operations and maintenance facilities in areas where noise and ingress or egress due to construction and operations will minimize disruption to local communities as feasible.

7.2.2.1 Geohazards[38]

Pipeline design and routing should consider geohazards, which can impact pipelines and related infrastructure. Frameworks typically consider the physical characteristics of geohazards and how the pipeline reacts to these hazards. A geohazard management program (GMP) incorporates methods and processes to systematically identify, evaluate, and manage geohazards, aiming to minimize the risk of pipeline damage and failure.[39] After establishing a pipeline route, it becomes possible to identify specific geohazards that need to be included in the GMP. The GMP can then be developed during detailed stages of the design process. Typical geohazard design considerations are as follows:

Seismic Fault

Pipeline design and routing should also consider the potential impacts of seismic activity or crossing of a fault. While many steps can be taken in response to a seismic event, proactive measures can also be engineered into the design. The installation of automatic valves on either side of known earthquake faults presents a proactive opportunity for real-time control should a pipeline failure occur. Valve set-back distance is conservatively determined through calculations that include the distance from the fault crossing where pipeline force is reduced to an acceptable level. Pipeline characteristics such as material and external site-specific conditions such as soil strength parameters assist in the valve-siting process. SoCalGas has designed and mitigated pipeline fault crossings on its existing natural gas system through

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[37] Global Designing Cities Initiative. (2022a, September 13). Underground Utilities Design Guidance - Global Designing Cities Initiative. https://globaldesigningcities.org/publication/global-street-design-guide/utilities-and-infrastructure/utilities/underground-utilities-design-guidance/

[38] PR-350-164501-R01 Guidance for Assessing Buried Pipelines after a Ground Movement Event: https://www.prci.org/162471.aspx

[39] Miller, A. (2023, November 6). IMCI 2.0 2023 framework for Geohazard Management. INGAA. https://ingaa.org/imci-2-0-2023-framework-for-geohazard-management/https://ingaa.org/wp-content/uploads/2023/11/2023_Framework-For-Geohazard-Management_Public.pdf

different measures such as geo foams, shallow trenches, increased wall thickness, and proper crossing design angles. As done today, the implementation of Finite Element Analysis to model the soil and pipe interaction can also be used to mitigate fault ruptures. In addition, both deterministic and probabilistic fault rapture analysis[40] can be used to further evaluate the proposed lines to make proactive design choices.

Liquefaction and Lateral Spreading

Soil conditions such as liquefaction and lateral spreading present another geohazard. SoCalGas manages this risk today in a way that can be leveraged for hydrogen pipelines through the use of California Geological Survey maps as well as historical operating data to identify areas where this geohazard may exist. Finite Element Models and mitigation measures such as piles can be used to mitigate against these geohazards.

Landslides

Proactive mitigation and monitoring are two main strategies to minimize landslide risk.[41] Publicly available maps and historical data used by SoCalGas today can be leveraged to identify areas of land movement; and to mitigate the hazard by either avoiding the hazard areas, using deeper burial depths, creating Best Management Practice measures that take this hazard into consideration, re-grading and benching the area, and/or using other civil engineering and geotechnical techniques and technologies to stabilize land movement.

Flooding and Debris Load

Hydrologic Engineering Center's River Analysis System (HEC-RAS) software, issued by the US Army Corps of Engineers, is used by SoCalGas today and can be further leveraged to calculate scour depth, flood height, and the velocity of flood events and associated debris loading. Deeper burial depths, deep foundation construction, and increasing the elevation of the pipe above the flood level are all methods currently employed to properly address potential flooding and debris loading. In addition, other techniques such as horizontal directional drilling, jack and bore, and/or the use of River-X software can be leveraged to design pipeline crossings over bodies of water.

Wildfire

SoCalGas utilizes post-wildfire data from USGS and CalFire. Once it's safe, geologists and/or geotechnical engineers perform field reconnaissance of the burnt area, followed by debris flow susceptibility analysis. This data could be utilized to minimize routing through wildfire prone areas, where feasible, and to inform pipeline design considerations such as soil conditions.

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[40] Nicee. (n.d.-b). https://www.wcee.nicee.org/wcee/article/16WCEE/WCEE2017-4570.pdf

[41] Guidelines for Management of Landslide Hazards for Pipelines. (n.d.-b). https://ingaa.org/wp-content/uploads/2020/08/38070.pdf

Subsidence, Expansive Soil and Other Geohazard Issues

SoCalGas will review the proposed pipeline route and design against other geohazards issues such as subsidence or expansive soil and provide different potential ways to mitigate these issues based on detailed geotechnical investigations, as needed.

7.2.3. Pressure & Flow Management

Design and pipeline route selection can also consider the potential effects of varying temperature and elevation on the chemical properties of the commodity being transported.

Topography - Pipeline design is impacted by the topography of the pipeline route. Elevation and temperature changes affect gas density.[42] If a pipeline passes through higher elevations, these factors must be considered to plan for necessary pressure and flow rates at other points along the pipeline which affect the size of the pipeline and MAOP.

Compression - In subsequent phases of Angeles Link, sites and design specifications will be developed for compressor stations. Compressor stations are essential for maintaining the pressure and flow of gas necessary for efficient transportation over long distances. Their size, location, and operational characteristics are inherently linked with route, materials, and system requirements.

The siting of compressor stations considers the pipeline route at intervals determined by the pressure drop in the pipeline. As discussed in previous chapters of this report, pressure drop in the pipeline is influenced by factors like pipeline diameter, roughness of the pipe interior, and the elevation changes along the route. There is an accessibility component for compression siting, specifically with regard to commercial power and utilities (water), construction, operation, and maintenance. While there are remote compressor stations the site must be accessible for construction equipment and emergency response. In addition, hydrogen compressor stations would be manned facilities requiring the necessary on-site accommodations such as an office building, operations room, maintenance shop and warehouse. Consideration of existing roads and the need for new road construction is crucial.

Valving – Valve stations manage operational conditions such as pressure and flow rate and allow for adjustments to be made based on system demand or operational conditions. Valve stations would be leveraged to perform an isolation of pipeline segments during routine maintenance or emergencies.

The size, pressure rating, and type of product being transported influence where valves are placed. Regulations often dictate minimum safety requirements, including the placement of valves at critical points such as populated areas, or near other infrastructure. The need for operational flexibility in terms of managing gas within the system also determines the design choices for the number, placement and type of valves selected. Design and siting of valve stations is also contingent upon geography and environmental elements identified over the course of the route. This could include water crossings or other natural barriers, seismic faults, ease of access for maintenance, or elevation changes. Environmental sensitivities of an area may further affect valve station placement because during emergencies or

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[42] Hydrogen density at different temperatures and pressures: H2tools: Hydrogen tools. H2tools. (n.d.). https://h2tools.org/hyarc/hydrogen-data/hydrogen-density-different-temperatures-and-pressures

maintenance operations, valves may need to be physically reached quickly and safely. Lastly, the cost of the valve station, including installation and maintenance, is an important consideration. Station placement seeks to optimally balance safety and functionality with cost-efficiency.

In subsequent phases of Angeles Link, additional design components will be identified and sited as appropriate for efficient and safe operation of the pipeline system.

7.2.4. Control System Design & Technology Integration

Integration of digitization, technology and controls are important for the reliable and efficient operation of a system and create the ability to manage and monitor a pipeline's operation. Control system design involves developing the automation and control mechanisms that enable the centralized monitoring and management of the pipeline.

Control systems design includes SCADA (Supervisory Control and Data Acquisition) systems, PLCs (Programmable Logic Controllers), communication infrastructure such as fiberoptics, safety systems such as ESDs (Emergency Shutdown systems), and Human-Machine Interfaces (HMIs). These will be critical components to the detailed design of a pipeline system. These control applications are currently used and integrated with existing infrastructure at SoCalGas and play a crucial role in leak detection and repair.

Technology integration involves the seamless incorporation of various technologies into the pipeline system to enhance performance, safety, and reliability. This may include sensors and instrumentation, data analytics, cybersecurity measures, and integration with other systems.

8. STAKEHOLDER COMMENTS

The input and feedback from stakeholders including the Planning Advisory Group (PAG) and Community Based Organization Stakeholder Group (CBOSG) has been essential to the development of this draft Design Study. Key themes from the feedback that has been received related to this Study are summarized and paraphrased below. All feedback received is included, in its original form, in the quarterly reports submitted to the CPUC and published on SoCalGas' website.[43] Feedback topics that were not addressed are also identified.

- **Comments made by: Communities for a Better Environment Comments, Environmental Defense Fund, Food and Water Watch, Los Angeles Department of Water and Power, Protect Playa Now, Public Advocates Office, and South Coast AQMD**
    - Emphasis should be on safety and leak prevention with regard to materials, monitoring technologies, proposed retrofits, siting, notification, and safety protocols.
    - Examine multiple scenarios for pipeline routing that include a hub model and different ways of disaggregating production. Inter-state options evaluated should be marked

[43] Angeles Link: SoCalGas, (n.d.a). https://www.socalgas.com/sustainability/hydrogen/angeles-link

distinctly from intra-state options and SoCalGas should identify regulatory uncertainties and assumptions.

- Assessment of repurposing existing gas pipelines, potential for leakage, material comparability, and the risk associated with repurposed pipelines. Prioritization of leak prevention, monitoring, detection, notification, and safety protocols.

- Assessment of proposed infrastructure with regard to power system reliability and resiliency. Concerns regarding increased reliance on electricity for end-use demand resulting in greater criticality of disruptions to electricity.

- Measures taken to address earthquakes.

- Reliability of renewable energy and hydrogen technologies should be assessed and additional analysis of existing energy infrastructure.

Summary of How Comments Were Addressed

- The evaluation of material leakage was discussed in Chapter 5 and includes potential embrittlement as well as pipeline integrity and maintenance. As described in Section 7.2, material selections are further refined and continued evaluation will be conducted.

- Multiple scenarios for varying routes and production quantities were evaluated, as Scenarios 1-8, and discussed in Section 4.5. Those scenarios that include reference to inter-state facilities are clearly marked.

- Evaluation of repurposing of existing natural gas pipelines was conducted at a high-level. The potential advantages and disadvantages to converting existing pipelines to dedicated hydrogen service versus building new pipelines intended for dedicated hydrogen service are discussed, as described in Section 5.4.

- A literature review was conducted on electric reliability that included identification of challenges, planning process and outlook, and the integration between reliability and hydrogen decarbonization, as described in Appendix B.

- Design measures that are considered for geohazard locations such as earthquake faults, are discussed, as described in Section 7.2.

9. GLOSSARY

Air Cooled Heat Exchangers - Heat transfer equipment typically found in transmission stations, used to cool the hot discharge gas from compressors to acceptable temperatures conducive to pipeline transportation.

American National Standards Institute (ANSI) – A private, non-profit organization that administers and coordinates the U.S. voluntary standards and conformity assessment system.[44]

American Petroleum Institute (API) - Formed in 1919 as a standards-setting organization and has developed more than 800 standards to enhance operational and environmental safety, efficiency and sustainability.[45]

American Society for Testing and Materials (ASTM) - A nonprofit organization that develops and publishes approximately 12,000 technical standards, covering the procedures for testing and classification of materials of every sort.[46]

American Society of Mechanical Engineers (ASME) - A nonprofit professional organization that enables collaboration, knowledge sharing, and skill development across all engineering disciplines, while promoting the vital role of the engineer in society.[47]

Association for the Advancement of Cost Engineering (AACE) - Advocates for its Body of Knowledge and the people who employ it through iteration and innovation of trusted technical guidance and meaningful collaboration.[48]

Butt Welding Steam Pipes - A joint where two pieces of metal are placed together in the same plane, and the side of each metal is joined by welding.[49]

California Public Utilities Commission (CPUC) – Regulates services and utilities, protects consumers, safeguards the environment, and assures Californians' access to safe and reliable utility infrastructure and services.[50]

Catalyst Poisoning - Metals like iron and potassium that are inherent in certain biomass feedstocks interact with the catalyst, poisoning it and causing loss of catalyst function.[51]

Centrifugal Compressors - Compressors increase the pressure by using the rotation of impeller blades to increase kinetic energy.

Compressor Drives - The mechanism or system responsible for powering the operation of a compressor, like an engine in an automobile.

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[44] American National Standards Institute. (n.d.). ANSI introduction. ANSI. https://www.ansi.org/about/introduction
[45] About API. Energy API. (n.d.). https://www.api.org/about
[46] ASTM International. ANSI Webstore. (n.d.). https://webstore.ansi.org/sdo/astm?msclkid=b5145c8e3c9110b215d53ac1f2f86bb8&utm_source=bing&utm_medium=cpc&utm_campaign=Standards-US&utm_term=ASTM+standards+store&utm_content=ASTM
[47] About ASME. ASME. (n.d.). https://www.asme.org/about-asme#:~:text=Founded%20in%201880%20as%20the%20American%20Society%20of,the%20vital%20role%20of%20the%20engineer%20in%20society.
[48] About Aace. (n.d.). https://web.aacei.org/about
[49] Welding joint types: Butt, lap, tee, Edge Joints & More: UTI. UTI Corporate. (n.d.). https://www.uti.edu/blog/welding/joint-types
[50] California Public Utilities Commission. (n.d.). What industries does the CPUC regulate? In California Public Utilities Commission. https://www.cpuc.ca.gov/-/media/cpuc-website/about-cpuc/documents/transparency-and-reporting/fact_sheets/cpuc_overview_english_030122.pdf
[51] Unlocking the mystery of Catalyst Poisoning | Department of Energy. (n.d.-g). https://www.energy.gov/eere/bioenergy/articles/unlocking-mystery-catalyst-poisoning

Compressor Stations - facilities that maintain the flow and pressure of a gas by receiving gas from the pipeline, re-pressurizing it, and sending it back into the pipeline system.

Compressors - Mechanical equipment, typically found in transmission stations used to increase the pressure of the hydrogen gas to adequate levels for transmission through the pipeline. They are essential for maintaining flow and overcoming frictional losses along the pipeline length.

Control & Monitoring Systems - Centralized systems that use field technology, sensors and communication methods to monitor and control the physical parameters of the pipeline.

Corrosion - A natural process where materials made from metals deteriorate through an electrochemical reaction known as oxidation (rusting).

Corrosion Protection Systems - Includes cathodic protection and protective coatings that are designed to prevent internal and external corrosion.

Derate - Also known as pipeline derating, is the process of reducing a pipeline's maximum allowable operating pressure (MAOP), allowable stress, or capacity under certain conditions.

Diaphragm Compressors - Driven by a reciprocating piston-crankshaft mechanism that separates hydraulic fluid/oil from process gas.

Electrolyzers - Electrolysis is a promising option for carbon-free hydrogen production from renewable and nuclear resources. Electrolysis is the process of using electricity to split water into hydrogen and oxygen. This reaction takes place in a unit called an electrolyzer.[52]

Emergency Shutdown Systems (ESDs) - Systems designed to rapidly shut down the pipeline operation in the event of a detected leak or other hazardous situations that will isolate sections of the pipeline to minimize risks.

Geographic Information System (GIS) - Geographic Information Systems (GIS) are systems that capture, store, analyze, and display spatial or geographic data. GIS can be used to create maps, models, and simulations that show the patterns, relationships, and trends of various phenomena that occur on the Earth's surface or in the atmosphere.

Hot Tapping - A procedure used to make a new pipeline connection while the pipeline remains in service, flowing natural gas under pressure.[53]

Hydrogen Embrittlement - A process resulting in a decrease in the fracture toughness or ductility of a metal due to the presence of atomic hydrogen.[54]

Inflation Reduction Act of 2022 (IRA) - Enhanced or created more than 20 tax incentives for clean energy and manufacturing.[55]

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[52] Hydrogen production: Electrolysis | Department of Energy. (n.d.-a). https://www.energy.gov/eere/fuelcells/hydrogen-production-electrolysis
[53] Environmental Protection Agency. (n.d.). EPA. https://www.epa.gov/natural-gas-star-program/pipeline-hot-taps
[54] Hydrogen embrittlement. (n.d.-d). https://ntrs.nasa.gov/api/citations/20160005654/downloads/20160005654.pdf
[55] Inflation reduction act. U.S. Department of the Treasury. (2024, May 8). https://home.treasury.gov/policy-issues/inflation-reduction-act

Inline Inspection (ILI) - A technique used to assess the integrity of natural gas transmission pipelines from the inside of the pipe and is used by Southern California Gas Company (SoCalGas) as part of its ongoing pipeline integrity program.[56]

Inside Diameter (ID) - Measured from top to bottom or left to right from the inside hole of the pipe. This measurement is important when calculating the flow of liquid.[57]

Intermediate Compressor/Booster - Maintains the pressure of natural gas as it flows through a pipeline.[58]

Leak Detection Systems - Technologies deployed along the pipeline to detect and locate leaks based on pressure, acoustic signals, or chemical sensors. These are components essential for the early detection of failures or breaches in pipeline integrity.

Line Packing - A method used for providing short-term gas storage in which natural gas is compressed in transmission lines, providing additional amounts of gas to meet limited peak demand.[59]

Location Class 1 - Any 1.6km (1 mile) section that has ten or fewer buildings intended for human occupancy. A Location Class 1 is intended to reflect areas such as wasteland, deserts, wetlands, mountains, grazing land, farmland and sparsely populated areas.[60]

Location Class 1, Division 1 - Not applicable to hydrogen service and not recognized in this Code.[61]

Location Class 1, Division 2 - Class 1 where the design factor of the pipe is equal to or less than .72 and has been tested to 1.1 times the maximum-operating pressure (ASME B31.12, PL-3.7.1-6 provides exceptions to design factor).[62]

Location Class 2 - Any 1.6 km (1 mile) section that has more than 10 but fewer than 46 buildings intended for human occupancy. A Location Class 2 is intended to reflect areas where the degree of the population is intermediate between Location Class 1 and Location Class 3, such as fringe areas around cities and towns, industrial areas, ranch or country estates, etc.[63]

Location Class 3 - Any 1.6 km (1 mile) section that has 46 or more building s intended for human occupancy, except when a Location Class 4 prevails. A Location Class 3 is intended to reflect areas such as suburban housing developments, shopping centers, residential areas, industrial areas, and other populated areas not meeting Class 4 requirements.[64]

Location Class 4 - Includes areas where multistory buildings are prevalent, where traffic is heavy or dense, and where there may be numerous other utilities underground. Multistory means four or more floors

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[56] In-line inspection of pipelines - SoCalGas. (n.d.-f). https://www.socalgas.com/documents/news-room/fact-sheets/In-LinePipelineInspection.pdf
[57] Simple guide to pipe size terminology. (n.d.-j). https://pandfglobal.com/wp-content/uploads/PFG-pipe-size-terminology-whitepaper-FA4.pdf
[58] UMN. (n.d.-k). https://mwc.umn.edu/wp-content/uploads/2021/01/compressor-station-pages1and2.11302020.pdf
[59] Apett.net. (n.d.). https://apett.net/cgi-sys/suspendedpage.cgi
[60] ASME B31.12, PL-3.2.2
[61] ASME B31.8
[62] ASME B31.12, PL-3.2.2
[63] ASME B31.12, PL-3.2.2
[64] ASME B31.12, PL-3.2.2

above ground, including the first or ground floor. The depth of basements or number of basement floors is immaterial.[65]

Lower Explosive Limit (LEL) - The minimum concentration of vapor in air below which propagation of a flame does not occur in the presence of an ignition source.[66]

Maximum Allowing Operating Pressure (MAOP) - maximum pressure at which the equipment may be operated

Metering & Regulation (M&R) - Track the volume of natural gas as it is transported and distributed. M&R stations use different meters and other equipment to continuously measure the flow and, if needed, reduce the pressure of gas as it moves through the station.[67]

Metering Stations - These stations measure the flow rate of hydrogen through the pipeline and are utilized for operational control and billing purposes.

Microalloying - Used in wrought steels to refine grain size during thermo-mechanical controlled processing.[68]

National Association of Corrosion Engineers (NACE) - Has become the global leader in developing corrosion prevention and control standards, certification and education.[69]

National Fire Protection Association (NFDPA) - Started as a Boston-based organization for fire sprinkler codes has grown to become the leading global advocate for the elimination of death, injury, property, and economic loss due to fire, electrical, and related hazards.[70]

Nominal Pipe Size Diameter (NPS) - Related to the inside diameter in inches, and NPS 12 and smaller pipe has outside diameter greater than the designated size.[71]

Non-Destructive Examination (NDE) - Used to inspect and evaluate materials, components, or assemblies without destroying their serviceability.[72]

Outside Diameter (OD) - Measured from top to bottom or left to right from the outside edges of the pipe – not the collar or socket end. The OD is often critical for joining pipes or getting the correct fitting that will fit over the pipe.[73]

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[65] ASME B31.12, PL-3.2.2
[66] 1915.11 - scope, application, and definitions applicable to this subpart. Occupational Safety and Health Administration. (n.d.). https://www.osha.gov/laws-regs/regulations/standardnumber/1915/1915.11
[67] Metering and regulating (M&R) stations. Earthworks. (n.d.). https://earthworks.org/issues/metering_and_regulating_mr_stations/
[68] Khalid, P. (2016, January 6). Overview of microalloying in steel. Academia.edu. https://www.academia.edu/20055864/6._Overview_of_Microalloying_in_Steel
[69] History. AMPP. (n.d.). https://www.ampp.org/about/nace-history
[70] Learn more about NFPA: The National Fire Protection Association. nfpa.org. (n.d.). https://www.nfpa.org/About-NFPA
[71] PI-21-0008. PHMSA. (2021, September 1). https://www.phmsa.dot.gov/regulations/title49/interp/pi-21-0008
[72] Discover nondestructive testing. (n.d.). https://www.asnt.org/MajorSiteSections/About/Discover_Nondestructive_Testing.aspx
[73] Simple guide to pipe size terminology. (n.d.-j). https://pandfglobal.com/wp-content/uploads/PFG-pipe-size-terminology-whitepaper-FA4.pdf

Pipeline Draft (drafting) – condition in a pipeline when the demand is greater than the supply resulting outflow of gas.

Pig Launchers & Receivers - Facilities used for the insertion and retrieval of pipeline inspection gauges (pigs) also known as in-line-inspection tools used to clean and inspect the pipeline.

Piggability - a pipeline or segment that has been constructed (or modified) to permit free passage of in-line inspection tools.[74]

Pipeline and Hazardous Materials Safety Administration (PHSMA) - Mission is to protect people and the environment by advancing the safe transportation of energy and other hazardous materials that are essential to our daily lives.[75]

Pipeline Erosion - Occurs when a fluid flowing within a pipeline gradually degrades small amounts of the inner pipeline surface through surface collisions with greater effect at higher fluid velocities.

Pipeline Pack (packing) - condition in a pipeline when supply is greater than demand resulting in excess gas accumulation.

Pressure Limiting Station (PLS) - Devices that regulate or limit the flow of gas at a specific set point to achieve or maintain a certain pressure to keep pipeline operations within the determined pressure limits.

Pressure Relief Valves (PRVs) - Safety devices designed to open at a predetermined pressure to prevent an excess pressure build-up that could jeopardize the pipeline's structural integrity.

Pressure Swing Adsorption - Used for separation of gases or vapors from air based upon their adsorption isotherms being a function of total pressure, as well as vapor pressure, and temperature. It is also used to separate pollutants from flue gases.[76]

Reciprocating Compressors - Utilize a piston and crankshaft to increase gas pressure at varying flow rates in high-pressure environments.

Reynolds Number - A dimensionless quantity that helps determine the flow regime based on pipe dimensions.

Service Level Agreements - Illustrate the expectations between service providers and customers.

Specified Minimum Yield Strength (SMYS) - SMYS is the minimum yield strength, expressed in pounds per square inch (psi) gage, prescribed by the specification under which pipe material is purchased from the manufacturer.[77]

Storage Facilities - Locations identified where quantities of gas are contained. Gas may be added or withdrawn from these facilities in a controlled manner.

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[74] Clark, T., Nestleroth, B., & Battelle. (2004). Topical report on gas pipeline pigability (DE-FC26-03NT41881). Battelle. https://netl.doe.gov/sites/default/files/2018-03/DE-FC26-03NT41881-topicalreport.pdf
[75] PHMSA's mission. PHMSA. (n.d.-a). https://www.phmsa.dot.gov/about-phmsa/phmsas-mission
[76] Choosing an adsorption system for VOC: Carbon, zeolite, ... (n.d.-b). https://www3.epa.gov/ttn/catc/dir1/fadsorb.pdf
[77] Pipeline Safety Stakeholder Communications. PHMSA. (n.d.-b). https://primis.phmsa.dot.gov/comm/glossary/index.htm?nocache=5217#SpecifiedMinimumYieldStrength

System Requirements (for a Pipeline) - The specific operational and performance criteria that the pipeline must meet to function effectively and safely under various conditions, including extreme scenarios.

Transient Modeling - Model focuses on studying the changes in flow conditions within a pipeline system over time. Analysis can be performed to examine the dynamic behavior of fluid flow within a pipeline when the flow conditions change rapidly.

Valves - Including isolation valves, control valves, and safety valves, these components regulate, direct, or control the flow of hydrogen by opening, closing, or partially obstructing various passageways.

Viscosity - A measure of a fluid's resistance to flow.[78]

Wall Thickness (WT) - The distance between one surface of an object and its opposite surface.

[78] Viscosity basics: What every engineer should know. AIChE. (2016, March 2). https://www.aiche.org/resources/publications/cep/editorial-calendar/viscosity-basics-what-every-engineer-should-know#:~:text=Viscosity%20%E2%80%94%20a%20measure%20of%20a%20fluid%E2%80%99s%20resistance,be%20used%20for%20both%20process%20and%20product-quality%20control.

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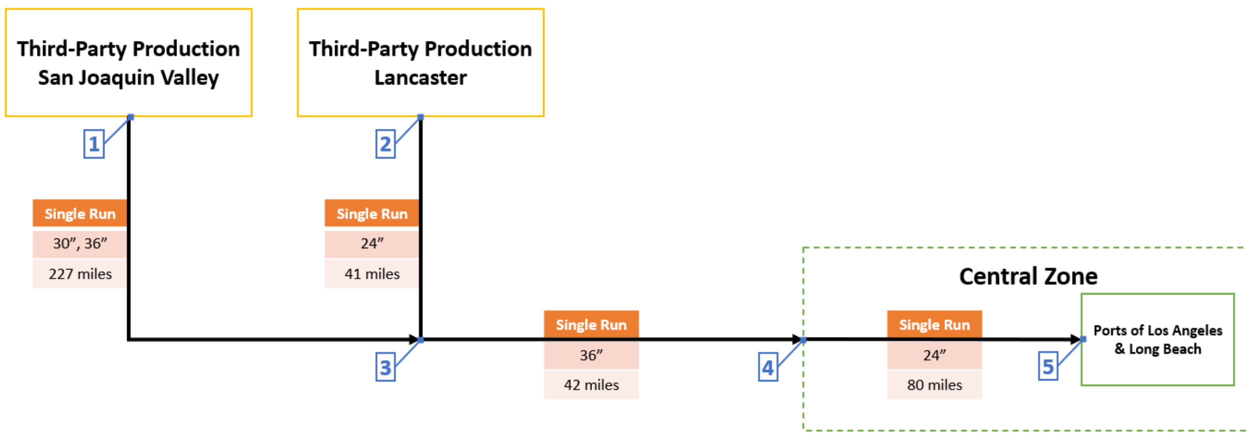
11. APPENDIX

11.1. Appendix A: Maximum Daily Production and Demand Rates

Steady-state hydraulic calculations were performed for Route A using the single-run configuration and daily maximum flowrates from the Production Study to support the Cost Effectiveness study sensitivity analysis. The flowrate at both SJV and Lancaster increased to 1.08 MMTPY, resulting in total throughput of 2.16 MMTPY to the Los Angeles Basin. The daily maximum flowrate is an approximately 44% increase from the average annual flowrate of 1.5 MMTPY.



Normal Operating Data	1	2	3	4	5
Single Run Pressure (psig)	1,035	1,060	685	405	215
Flowrate (MMTPY)	1.08	1.08	2.16	2.16	2.16

Figure 19 - Route A Maximum Daily Production Hydraulic Results

The pipeline sizes remained the same as the Preferred Routing Configuration A discussed in Section 4.6.1.1 at 1.5 MMTPY flowrate. The compression requirements at SJV and Lancaster increased by approximately 44%, which is proportional to the flowrate increase to 2.16 MMTPY. Table 20 displays the calculated compressor information for the normal and the maximum operations.

Table 20 - Maximum Daily Production Compressor Information

Maximum Daily Production - Compressors							
Configuration	**Location**	**Normal (hp)**	**Max (hp)**	**Inlet Pressure (psig)**	**Normal Outlet Pressure (psig)**	**Max Outlet Pressure (psig)**	**Flowrate (MMTPY)**
Single Run	SJV	58,000	72,000	500	1,035	1,200	1.08
	Lancaster	60,000	72,000	500	1,060	1,200	1.08

The preliminary results demonstrate a robust system capable of accommodating the maximum daily flowrates with increased compression and minimal piping adjustments. In a future phase of the project, transient modeling will be performed to thoroughly assess the Angeles Link system sizing requirements to accommodate variable production and demand flowrates.

11.2. Appendix B: Electric Reliability

In alignment with stakeholder comments,[79] a literature review of electric reliability was conducted to understand existing challenges, the planning process and outlook, and the integration between the electric and gas systems, with the purpose of informing the technical feasibility of Angeles Link as clean firm power in support of electrification and electric reliability.

11.2.1. Electric System Reliability Background

California's climate policy requires reducing statewide greenhouse gas (GHG) emissions to 40% of 1990 levels by 2030[80] and achieving carbon neutrality by 2045.[81] More recently, the California Air Resources Board's (CARB) 2022 Scoping Plan set a more aggressive trajectory of emission reductions to 48% by 2030.[82] Given the important role electrification will play in California's ability to achieve these goals, decarbonizing California's electric grid will be necessary and agencies and utilities across the State are working to achieve this objective. Meanwhile, statewide policies seek to electrify many sectors of the economy, expanding dependency on the electric grid. Advancements in technology, such as Artificial Intelligence (AI) and data centers, are anticipated to place even greater strain on electric demand. The increased adoption of electrification for critical activities such as light duty transportation is just one example of how the delivery of power to meet demand 24/7, 365 days a year will become increasingly critical. Thus, the collaboration of simultaneous electric grid decarbonization and electrification will need to prioritize electric reliability.

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[79] Appendix 1 - SoCalGas Responses to Comments Link: ALP1_Quarterly_Report_Appendices_Q3-2023.pdf (socalgas.com)
[80] Assembly Bill (SB) 32 (Ch. 249, 2016).
[81] Assembly Bill (AB) 1279 requires statewide carbon neutrality as soon as possible, but no later than 2045.
[82] California Air Resources Board (CARB). *2022 Scoping Plan*, dated November 16, 2022 at 116.

Existing reliability studies and analysis[83] largely estimate the reliability of proposed electric portfolios using less rigorous reliability screens as opposed to more robust analysis such as hourly loss of load modeling.

More recent awareness of the grid's increased sensitivity to reliability risks (e.g. blackouts, heatwaves, and higher penetration of intermittent resources) has resulted in utilization of more robust reliability analysis. These more recent studies, such as LA100,[84] SoCalGas Clean Fuels and Evolution of Clean Fuels studies, [85] and SDG&E's Path to Net Zero,[86] anticipate that higher amounts of "clean firm power,"[87] such as clean renewable hydrogen, will be required to support the State's reliability needs.

11.2.2. Electric Reliability Challenges

Increased Renewables and the Evolution of California's Electric Grid

Today's electric grid meets real-time energy needs by dispatching, increasing, or decreasing the generation of relatively quick-responding resources. These electric or power generation plants typically utilize natural gas generation[88] and can be called on to meet increased demand quickly for short to long periods of time, from a few hours to many days, depending on the electric grid's needs.

As the electric grid continues to increase capacity with intermittent renewable resources such as solar or wind, firm, dispatchable power such as that generated with clean renewable hydrogen will be necessary to maintain electric reliability. To illustrate, as the renewable electricity percentage from solar increases, the grid becomes more variable, challenging load growth, and necessitating flexible load following resources to balance the system. The increasing integration of solar is resulting in a growing number of days where daytime solar production is higher than electric load, resulting in mid-day excess energy. Later, as solar generation drops, dispatchable resources such as gas generation and battery energy storage systems (BESS) are called upon to quickly ramp up to balance the electric grid to maintain reliability. The operational characteristics of BESS form limitations on their duration and capacity, highlighting the essential need for firm, dispatchable gaseous generation.

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[83] For example: Energy and Environmental Economics' *Achieving Carbon Neutrality in California: PATHWAYS Scenarios Developed for the California Air Resources Board* and the *2021 SB 100 Joint Agency Report*.
[84] Cochran, Jaquelin, and Paul Denholm, eds. 2021. *The Los Angeles 100% Renewable Energy Study*. Prepared by National Renewable Energy Laboratory (NREL) for Los Angeles Department of Power and Water (LADWP).
[85] Southern California Gas. 2021. *The Role of Clean Fuels and Gas Infrastructure in Achieving California's Net Zero Climate Goal.* https://www.socalgas.com/sites/default/files/2021-10/Roles_Clean_Fuels_Full_Report.pdf. And Southern California Gas. 2023. *The Evolution of Clean Fuels in California.* *https://issuu.com/stfrd/docs/cleanfuelsreliabilityreportjuly23?fr=sNDA4OTYwNzQ4NTk*
[86] San Diego Gas & Electric. 2022. *The Path to Net Zero: A Decarbonization Roadmap for California*. Prepared by Boston Consulting Group and Black & Veatch. https://www.sdge.com/sites/default/files/documents/netzero2.pdf
[87] "Clean firm power" is defined as zero-carbon power that can be relied on whenever needed for as long as it's needed. As defined by Long, J. (n.d.). Also see, EDF: *California needs clean firm power, and so does the rest of the world*https://www.edf.org/sites/default/files/documents/SB100 clean firm power report plus SI.pdf
[88] Quick responding generation usually comes from peakers or simple cycle plants but can also be from increasing the output of larger steam plants that are not operating at full capacity. However, larger resources cannot typically go from cold start to generating at full capacity within a few minutes like a gas- or oil-fired simple cycle turbine.

The build-out of the future decarbonized electricity portfolio is expected to be comprised primarily of solar, wind, and BESS resources.[89] These resources along with firm and dispatchable resources are needed to meet peak demand. Additionally, future import availability may be constrained as neighboring states may require increased firm, dispatchable resources to address their own reliability needs and decarbonization efforts. The anticipated growth in electric demand, an increasingly intermittent electric supply portfolio, and aggressive decarbonization targets, will require clean firm and dispatchable resources that operate with critical system attributes such as load following and quick start capabilities.

Climate-Related Changes Present Grid Reliability and Resiliency Threats

The increasing impacts of climate change and natural disasters present challenges to California meeting its clean energy goals, particularly during severe weather events. Increasingly high temperatures contribute to droughts, wildfires, earthquakes, and heat waves that pose threats to humans, the environment, and reliability. Events such as extreme heat and wildfires, floods, jeopardize existing electric transmission and generation infrastructure, including those feeding the Los Angeles Basin.

2020 Extreme Heat Wave

In August 2020, an extreme heat wave across the West caused Californians to experience two days of rotating outages. Following the event, the California Independent System Operator (CAISO), California Public Utilities Commission (CPUC), and California Energy Commission (CEC) identified the following three main causes:

- The extended extreme heat wave—identified as being climate change-induced—created greater electricity demand on the electric grid than what was available or planned.
- Resource planning targets were not fully adapted to the grid's ongoing transition to clean energy resources and did not ensure sufficient capacity was available when needed, particularly in the evening hours.
- Market conditions in the day-ahead energy market magnified supply issues.[90]

The potential risks of having insufficient electric resources to meet demand were realized during this event, causing California to implement changes across the electric sector focused on planning, coordination, tracking, and greater attention to the changing needs of the grid as more variable resources are added in pursuit of climate goals.[91]

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[89] California Air Resources Board (CARB). 2022. *2022 Scoping Plan for Achieving Carbon Neutrality*. Prepared by the California Air Resources Board (CARB), https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf Page 203
[90] California Independent System Operator (CAISO), California Public Utilities Commission (CPUC), and California Energy Commission (CEC). Final-Root-Cause-Analysis-Mid-August-2020-Extreme-Heat-Wave (caiso.com) (January 2021), 1.
[91] Kootstra, M., and N. Barcic. 2023. *Joint Agency Reliability Planning Assessment.* Prepared by California Energy Commission (CEC) and California Public Utility Commission (CPUC), 1.

2022 Extreme Heat Wave

While reliability planning was enhanced following the 2020 heat wave, in late August and early September of 2022, California faced another 10-day extreme heat wave with record-setting temperatures and peak demand.[92] On August 31, 2022, Governor Gavin Newsom issued a Proclamation of a State of Emergency to increase energy supply and reduce demand as a result of the extreme heat and forecasting supply deficiencies.[93] On September 6, 2022, the State experienced the highest level of demand during the heatwave, prompting CAISO to issue a level 3 energy emergency alert (EEA), warning Californians of imminent blackouts.[94] Following this warning, CAISO sent an emergency text alert requesting Californians to conserve power. To increase supply, energy suppliers resorted to using backup gas generators.[95] While blackouts were avoided due to the actions taken by energy users, the need to rely on voluntary demand reductions and backup generation to maintain reliability may not always prove to be effective. The future for reliability points to the need for the electric grid to examine and address the planning and operational needs in light of expected future extreme weather events. As California moves toward its net GHG neutrality goal in 2045, reliability and resiliency risk management, implementing planning, forecasting, and tracking measures will need to continue to evolve with the transition.

11.2.3. Reliability and Hydrogen Decarbonization Studies

The existing electric resource planning of California's highly renewable grid may not fully address reliability and resiliency risks, as noted by the 2020 outages. Comprehensive reliability assessments should also include hourly modeling of multiple years for every iteration of each scenario examined. As a result, existing decarbonization studies may improperly account for renewable penetration and the growing impacts of climate change.

After the 2020 heatwaves, planners and modelers began more thoroughly analyzing reliability and resiliency risks when charting California's decarbonized future. Specifically, some more recent studies include robust reliability testing and some are using the industry-approved North American Electric Reliability Corporation (NERC) "one day in ten years" loss of load expectation (LOLE) testing.[96] The studies[97] that include this type of detailed reliability testing generally require or conclude the need for higher resource capacities across all technologies, including more clean, firm, dispatchable

[92] Q1 2022 Report on Market Issues and Performance. (n.d.-d). http://www.caiso.com/Documents/2022-First-Quarter-Report-on-Market-Issues-and-Performance-Sep-6-2022.pdf
[93] https://www.gov.ca.gov/wp-content/uploads/2022/08/8.31.22-Heat-Proclamation.pdf?emrc=78e3fc
[94] A level 3 EEA is issued when the grid operator is unable to meet minimum reliability reserve requirements. See https://www.caiso.com/Documents/Emergency-Notifications-Fact-Sheet.pdf
[95] CAISO September 6, 2022 generation data
[96] LOLE is defined as the expected number of days per time period (usually a year) for which the available generation capacity is insufficient to serve the demand at least once per day. LOLE counts the days having loss of load events, regardless of the number of consecutive or nonconsecutive loss of load hours in the day. The study applies the industry standard of 0.1 days per year, or one day in ten years.
[97] LA100, SoCalGas Clean Fuels and Evolution of Clean Fuels studies, and SDG&E's Path to Net Zero, anticipate requiring higher amounts of "clean firm power" to support the State's reliability needs, one of which is the use of clean renewable hydrogen.

resources like clean renewable hydrogen. While most of the published studies listed below applied the higher-level reliability screenings, the increased focus on reliability issues will likely result in some level of additional LOLE testing in the next iteration of these studies.

As future decarbonization studies further examine electric reliability issues and acknowledge the need for clean firm resources, it is expected that clean dispatchable resources like clean renewable hydrogen will play a key role.

2020 PATHWAYS Scenarios Developed for the California Air Resources Board (CARB) [98]

This CARB study is a high-level exploration of plausible PATHWAYS to economy-wide carbon neutrality. The report focuses on electrification and sector-wide carbon dioxide removal but does not specifically address how the electric sector could reliably support a decarbonized economy other than to acknowledge that some form of dispatchable generation is needed to maintain system reliability.

The study's Balanced Scenario and Zero-Carbon Scenario reduce the 2045 electric sector emissions to zero by maximizing variable renewables at 80-85% and **requiring 15-20% of firm resources, namely hydroelectric, geothermal and dispatchable clean fuels – either biomethane or hydrogen**.

2021 SB 100 Joint Agency Report, Achieving 100 Percent Clean Electricity in California: An Initial Assessment[99]

The 2021 SB 100 Report assumes much of the existing natural gas capacity is retained through 2045 to meet reliability and also agrees with the 2020 CARB PATHWAYS study on the importance of emerging technologies, noting that "(E)nergy storage technologies — including batteries, pumped hydro, **hydrogen**, and other emerging technologies — are expected to play a significant role in helping balance the grid as the state implements SB 100."[100]

Despite alignment with the CARB PATHWAYS study, the SB 100 report's list of modeled technologies for their Core Scenario excludes many emerging firm clean dispatchable generation, including "green" hydrogen[101] combustion. However, the 2021 SB 100 report included the clean "generic dispatchable" and "generic baseload" resource categories in its additional Study Scenarios. These

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[98] Energy and Environmental Economics, Inc. 2020. *Achieving Carbon Neutrality in California: PATHWAYS Scenarios Developed for the California Air Resources Board*. Prepared by Energy and Environmental Economics, Inc (E3) for the California Air Resources Board (CARB) https://ww2.arb.ca.gov/sites/default/files/2020-10/e3_cn_final_report_oct2020_0.pdf

[99] Liz Gill, Aleecia Gutierrez, Terra Weeks. 2021. *2021 SB 100 Joint Agency Report, Achieving 100 Percent Clean Electricity in California: An Initial Assessment*. Prepared by the California Air Resources Board (CARB), the California Energy Commission (CEC), and the California Public Utilities Commission (CPUC), https://www.energy.ca.gov/publications/2021/2021-sb-100-joint-agency-report-achieving-100-percent-clean-electricity

[100] Page 108 2021 SB 100 Report

[101] Page B-8 2021 SB 100 Report; the 2021 SB100 Report defined green hydrogen as "hydrogen gas that is not produced from fossil fuel feedstock sources and does not produce incremental carbon emissions during its primary production process."

categories include a wide variety of emerging technologies such as green hydrogen combustion. The SB 100 report notes inadequate supply and cost data, and/or lack of commercial availability of green hydrogen in California at the time of the report publication. The Report concludes that reaching 100% carbon-free retail sales by 2045 is technically achievable but provides that additional work is needed, including modeling to "ensure reliability for all hours of the year in line with state planning requirements while meeting clean energy and climate goals."

At the 2025 SB 100 Inputs and Assumptions Workshop, CEC staff noted the Investment Reduction Act's (IRA) federal incentives on clean hydrogen production and listed hydrogen technologies that are available in California as proposed eligible resources for 2025 SB100 report modeling.[102]

The CEC has committed to complete a LOLE reliability analysis,[103] which is expected to result in the need for higher amounts of clean firm power resources. If hydrogen resources become SB100-eligible, the upcoming modeling would be able to analyze how clean hydrogen resources can help meet clean firm power needs. Further, federal incentives can also lower the cost of hydrogen, increasing the likelihood that SB100 portfolios would include hydrogen resources.

2022 CARB Scoping Plan for Achieving Carbon Neutrality[104]

The 2022 Scoping Plan updates prior statewide plans to reach California's economy-wide greenhouse gas (GHG) reduction targets. It also outlines a path to achieving the State's 2045 carbon neutrality goals. However, like the SB 100 Report, the 2022 Scoping Plan does not include sensitivities, such as loss of load evaluations in its reliability modeling, which may lead to implementation differences from the plan.

The final Scoping Plan modeling assumed retention of existing natural gas capacity and added 9 GW of hydrogen combustion for reliability purposes.

2021 EDF and CATF: California needs clean firm power, and so does the rest of the world[105]

The Environmental Defense Fund (EDF) and the Clean Air Task Force (CATF) commissioned three distinct and independent modeling efforts, each producing distinct pathways for California to achieve carbon neutrality by 2045. These models relied on prior analyses to estimate the loss of load of each portfolio. Each model produced similar conclusions, indicating that the most feasible and cost-effective pathway involves sustained investment in wind and solar energy, complemented by a diverse mix of clean firm power sources. The study stated: "Our modeling concludes an ambitious but achievable investment in clean firm power capacity, essentially replacing the gas fleet with 25-40 gigawatts of clean firm power will minimize costs while maintaining reliability and substantially and

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[102] Mark Koostra of the CEC at the February 16, 2024 SB 100 Input and Assumptions Workshop
[103] Ibid.
[104] California Air Resources Board (CARB). 2022. *2022 Scoping Plan for Achieving Carbon Neutrality*. Prepared by the California Air Resources Board (CARB), https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf
[105] Long, JCS, et al. 2021. *California needs clean firm power, and so does the rest of the world*. Prepared for EDF and CATF.
https://www.edf.org/sites/default/files/documents/SB100%20clean%20firm%20power%20report%20plus%20SI.pdf

reduce the amount of renewable energy capacity that must be deployed."[106] While the study does not select a specific clean firm power mix, clean fuels such as clean renewable hydrogen are listed as potential technologies.

At the time of this study's modeling, the lower cost scenario primarily consisted of clean firm power technologies such as carbon capture and sequestration and nuclear, with relatively smaller amounts of clean fuel generation.[107] However, at the August 22, 2023, SB 100 Kick-Off workshop, EDF indicated that potential future modeling would select more clean fuel generation such as hydrogen due to expected reductions in hydrogen costs from IRA incentives.[108]

2021 NREL: The Los Angeles 100% Renewable Energy Study for LADWP (LA100)[109]

The LA100 is a comprehensive analysis of a clean electricity future for Los Angeles that focused particular attention on the potential for climate change risks affecting the Los Angeles Basin, specifically elevated wildfire risks that can result in de-energization of critical transmission lines coupled with energy demand increases from increased use of air conditioning.[110] The National Renewable Energy Laboratory (NREL) modeled Los Angeles Department of Water and Power's (LADWP) customer electricity demand, local solar adoption, power system generation, and transmission and distribution networks. The LA100 explores these options through four scenarios, each assessed under varying levels of load electrification and with robust reliability testing that assesses all hours of the year for five years. The LA100 Study notes challenges upgrading the city's local electric transmission infrastructure, which would be needed to help import utility scale renewable energy to some areas of Los Angeles, and thus the LA100 scenarios require in-basin renewably fueled generation. The study shows that pathways to 100% decarbonization diverge on how to meet the last 10%–20% of energy demand that cannot be met by existing renewable and conventional storage technologies, and that the main solution currently available to maintain a reliable system that can withstand extreme events is to store and use renewable fuels, with hydrogen and biofuels being the key alternatives. The LA100 also emphasizes the need for research and development in hydrogen power, alongside the development of renewable firm capacity resources.

2022 SDG&E: The Path to Net Zero: A Decarbonized Roadmap for California[111]

This study investigates decarbonization pathways for California and includes how San Diego Gas & Electric (SDG&E) can expand on technologies and approaches to encourage decarbonization. The

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[106] Ibid

[107] Ibid

[108] 08-22-23; EDF's comments during their presentation at the SB 100 Kickoff Workshop

[109] Cochran, Jaquelin, and Paul Denholm, eds. 2021. *The Los Angeles 100% Renewable Energy Study*. Prepared by National Renewable Energy Laboratory (NREL) for Los Angeles Department of Power and Water (LADWP). https://maps.nrel.gov/la100/.

[110] Cochran, *The Los Angeles 100%*, NREL, Ch 12, 24.

[111] San Diego Gas & Electric. 2022. *The Path to Net Zero: A Decarbonization Roadmap for California*. Prepared by Boston Consulting Group and Black & Veatch. https://www.sdge.com/sites/default/files/documents/netzero2.pdf

roadmap utilizes economy-wide modeling of the State with LOLE reliability modeling of the electric sector. Several priority areas are highlighted in this study, notably electric sector reliability. A three-pronged approach for achieving decarbonization in California focuses on clean electricity, carbon removal, and clean fuels.

The study notes that, "Clean dispatchable electric generators are most critical for keeping the electricity grid reliable while meeting emissions reduction goals. They can both quickly provide electricity to meet customer needs and use a clean fuel source such as green hydrogen."[112] The study also acknowledges current barriers and the need for clean fuels infrastructure to enable clean dispatchable resources.

This study's focus on reliability highlighted a need for flexible and dispatchable generation for which the study includes 20 GW of dispatchable clean hydrogen generation by 2045.

2021 and 2023 SoCalGas: The Role of Clean Fuels and Gas Infrastructure in Achieving California's Net-Zero Climate Goal and The Evolution of Clean Fuels in California[113]

SoCalGas's Clean Fuels Study (CFS) is a technical analysis that explores achieving decarbonization in California, examining the potential role that clean fuels and a supporting clean fuels network could play in achieving carbon neutrality. The study examined cross-sector optimization across electric, fuels, and transport. With electricity demand expected to double by 2045,[114] there is no established blueprint for widescale decarbonization. Thus, the study examined four corner case scenarios designed to pull different decarbonization levers to different degrees and highlight distinctions for evaluation as no one scenario can reliably predict and forecast future developments. Three of the scenarios assume that fuels are delivered to end uses. All four scenarios were evaluated against a set of criteria that support public welfare, including energy system reliability and resiliency. The analysis found that the scenarios that met the criteria of reliability and resiliency retain the fuels network with approximately 35 – 50 GW of thermal generation capacity. This thermal generation was supported by a blend of clean fuels including biogas and hydrogen.

In 2023, SoCalGas published a supplemental analysis to the CFS, The Evolution of Clean Fuels in California. This updated analysis utilized an hourly LOLE reliability evaluation to model the potential for electric system outages, producing more refined results that led to concluding the need for incremental capacity for all resource types: batteries, wind, solar, and clean hydrogen generation as a clean firm power resource. The impact of this additional reliability testing found that up to 10 GW of

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[112] SDG&E's *The Path to Net Zero: A Decarbonization Roadmap for California*, p. 11, available at: https://www.sdge.com/sites/default/files/documents/netzero2.pdf

[113] Southern California Gas. 2021. *The Role of Clean Fuels and Gas Infrastructure in Achieving California's Net Zero Climate Goal.* https://www.socalgas.com/sites/default/files/2021-10/Roles_Clean_Fuels_Full_Report.pdf. And Southern California Gas. 2023. *The Evolution of Clean Fuels in California.* *https://issuu.com/stfrd/docs/cleanfuelsreliabilityreportjuly23?fr=sNDA4OTYwNzQ4NTk*

[114] Southern California Gas. 2021. *The Role of Clean Fuels and Gas Infrastructure in Achieving California's Net Zero Climate Goal.* https://www.socalgas.com/sites/default/files/2021-10/Roles_Clean_Fuels_Full_Report.pdf at 3.

incremental clean hydrogen generation capacity was needed to meet the LOLE reliability requirement.

11.2.4. Conclusion - Reliability

Reliability and resiliency are essential components of a dependable energy system and must include consideration of future decarbonization goals. Clean firm power resources will play a key role in overcoming strains from climate-induced weather events and the growing number of intermittent resources to meet the growing demands of electricity users whose dependence on grid reliability will grow over time.

The most widely used firm power resource in California is currently natural gas generation, which has the capability to ramp up or down when called upon, enabling the integration of renewables, and providing both short duration and seasonal long duration storage supported by a network of gas pipelines. Pipelines provide reliable and resilient underground infrastructure that is shielded from many extreme weather conditions. The resiliency, reliability, and local resource adequacy provided by the existing natural gas generation fleet can be transitioned to clean firm power by replacing natural gas with clean fuels such as clean renewable hydrogen, retaining the local reliability and resiliency attributes.

Many of the decarbonization studies described herein identified clean renewable hydrogen as a clean firm power resource that could help decarbonize California while supporting grid reliability. Moreover, as noted by ARCHES, "renewable clean hydrogen is also 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."[115] Similarly, the Biden-Harris Administration recognized that "Achieving commercial-scale hydrogen deployment is a key component of President Biden's Investing in America agenda, and critical to building a strong clean energy economy while enabling our long-term decarbonization objectives."[116]

A hydrogen pipeline system such as Angeles Link would provide the connective infrastructure to enable the use of clean renewable hydrogen at the bulk scale to support the decarbonization of the power generation sector, among others.

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

[116] DOE, Biden-Harris Administration Releases First-Ever National Clean Hydrogen Strategy and Roadmap to Build a Clean Energy Future, Accelerate American Manufacturing Boom (June 5, 2023), available at: https://www.energy.gov/articles/biden-harris-administration-releases-first-ever-national-clean-hydrogen-strategy-.

ANGELES LINK PHASE 1

PRELIMINARY ROUTING/CONFIGURATION ANALYSIS

DRAFT

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

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

Abbreviation	Term/Phrase/Name
AFC	Alternative Fuel Corridors
AFDC	Alternative Fuels Data Center
ARCHES	Alliance for Renewable Clean Hydrogen Energy Systems
Burns & McDonnell OR BMcD	Burns & McDonnell Engineering Company, Inc.
CARB	California Air Resources Board
CBOSG	Community Based Organization Stakeholder Group
CPCN	Certificate of Public Convenience and Necessity
CPUC	California Public Utilities Commission
DACs	Disadvantaged Communities
DOE	United States Department of Energy
DOT	United States Department of Transportation
ESJ	Environmental Social Justice
EHB	European Hydrogen Backbone
EV	Electric vehicle
FEED	Front-End-Engineering and Design
FEP	Front-End Planning
FHWA	Federal Highway Administration
GIS	Geographic Information Systems
HCA	High Consequence Areas
HDD	Horizontal Directional Drill
HSR	High Speed Rail
IIJA	Infrastructure Investment and Jobs Act
MNV	Mainline Valve
NHS	National Highway System
NPMS	National Pipeline Mapping System
NRHP	National Register of Historic Places
OCED	Office of Clean Energy Demonstrations
PAG	Planning Advisory Group
PHMSA	Pipeline and Hazardous Materials Safety Administration
ROW	Right-of-Way
SJV	San Joaquin Valley
SoCalGas	Southern California Gas Company
UOM	Unit of Measure

EXECUTIVE SUMMARY

Southern California Gas Company (SoCalGas) is proposing to develop a clean renewable hydrogen[1] pipeline system to facilitate transportation of clean renewable hydrogen from multiple regional third-party production sources and potential storage sites to various delivery points and end users in Central and Southern California, including in the Los Angeles Basin. CPUC Decision (D.) 22-12-055 (Phase 1 Decision) approved the Memorandum Account for SoCalGas's proposed Angeles Link. Pursuant to D.22-12-055, SoCalGas identified and compared routes and configurations for Angeles Link. The Preliminary Routing/Configuration Analysis (Routing Analysis) evaluates a wide range of pipeline pathways in Central and Southern California and identifies several preferred routes and one variation to consider for further evaluation in subsequent phases.

The objective of this Routing Analysis is to evaluate and determine several possible preferred routes during the feasibility stage of Angeles Link. Subsequent Pre-FEED and FEED activities in Phase 2 will select one preferred route. This preliminary Routing Analysis was conducted at a high-level and sought to identify broad directional pathways with the highest potential of achieving the purpose of the Angeles Link pipeline system. In addition to determining the directional pathways, this Routing Analysis identified features and characteristics of the area around the potential pipeline route that would be considered and analyzed in more detail in future phases, including the identification of Disadvantaged Communities, and features related to engineering, social and environmental considerations.

This analysis integrated information from other Phase 1 feasibility studies, and the outputs from this analysis also informed other studies. Specifically, data was integrated into this analysis from the following studies, including: Production Planning & Assessment (Production Study), the Demand Study, and the Pipeline Sizing & Design (Design Study). Data from this study was also noted in the following studies: the Design Study, the Greenhouse Gas Emissions Evaluation (GHG Evaluation), the Nitrogen Oxide (NOx) and Other Air Emissions Assessment (NOx Assessment), the High-Level Feasibility Assessment and Permitting Analysis (Permitting Analysis), the Environmental Analysis, and the Environmental Social Justice Plan (ESJ Plan).

Routing Analysis Framework

The Routing Analysis evaluated potential directional pathways for the Angeles Link pipeline system implementing the following framework:

- Consider the locations of potential third-party clean renewable hydrogen producers and the potential consumers of clean renewable hydrogen, including in the mobility, power generation, and industrial sectors, so clean renewable hydrogen can be effectively carried to entities looking to decarbonize.

[1] In the California Public Utilities Commission (CPUC)'s Angeles Link Phase 1 Decision (D).22-12-055 (Phase 1 Decision), clean renewable hydrogen refers to hydrogen that does not exceed 4 kilograms of carbon dioxide equivalent (CO_2e) produced on a lifecycle basis per kilogram of hydrogen produced and does not use fossil fuels in the hydrogen production process, where fossil fuels are defined as a mixture of hydrocarbons including coal, petroleum, or natural gas, occurring in and extracted from underground deposits.

- Consider the potential hydrogen production locations and offtake sites identified by California's hydrogen hub consortium—the Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES)[2]. ARCHES is California's public-private hydrogen hub consortium that applied for federal funding from the U.S. Department of Energy (DOE) for a California H2Hub. SoCalGas joined ARCHES in October 2022 and was included on the ARCHES application to the DOE for the federal funding made available under The Regional Clean Hydrogen Hubs Funding Opportunity DE-FOA-0002779.[3] ARCHES published information siting the location of hydrogen production projects and offtake sites in California included in its application submitted to the DOE.
- Compare multiple potential routes from inputs from other Angeles Link Phase 1 feasibility studies and external data sources to identify three principal categories of information: (i) the initial route corridors for consideration; (ii) the routes of highest potential for Angeles Link; and (iii) characteristics and features along the routes of highest potential for further evaluation.

Results of Routing Analysis

Routes presented are preliminary and subject to change based on the final alignment in subsequent phases of Angeles Link. Based on the evaluation contained in this Routing Analysis, SoCalGas identified four (4) potential preferred routes that share the general characterizations below:

- Connect potential regional producers and end-users as identified by the Production and Demand studies, which includes 1.5 MMT/Y throughput
- Connect potential ARCHES production and offtake sites
- Connect two SoCalGas segments within ARCHES to support the California H2Hub
- Route Variation 1 identified for evaluation in Phase 2, reducing route mileage through communities considered to be Disadvantaged, as identified by the ESJ Screening Tool
- Identify certain engineering, environmental, social, and environmental justice features along the potential preferred routes
- Traverse various land types including, but not limited to, urban areas, rural lands, and mountainous terrain

Stakeholder Input

The input and feedback from stakeholders including the Planning Advisory Group (PAG) and Community Based Organization Stakeholder Group (CBOSG) has been helpful to the development of this Routing Analysis. For example, the study clarifies that pipeline corridors initially considered focused on routes that are all intra-state. Additionally, the Routing study evaluated certain Engineering, Environmental, and Social attributes, including DAC, cultural sites, land use, zoning, seismic activity, endangered species,

[2] ARCHES is co-founded by the Governor's Office of Business and Economic Development, the University of California, a statewide labor coalition organized by the State Building and Construction Trades Council of California, and the Renewables 100 Policy Institute. *See* https://archesh2.org/wp-content/uploads/2024/03/ARCHES-FAQ-Basic-1.pdf

[3] Refer to DOE Regional Clean Hydrogen Hubs at: https://www.energy.gov/oced/regional-clean-hydrogen-hubs-0

and ROW. The total mileage within these areas was identified, and a summary of the Pivvot[4] results were included in the Appendix. The feedback that has been received to-date related to this Study and how those comments are addressed is summarized in more detail in Chapter 7. All feedback received is included, in its original form, in the quarterly reports submitted to the CPUC and published on SoCalGas' website.[5]

1. INTRODUCTION – PIPELINE ROUTING

The Angeles Link pipeline system is envisioned as a non-discriminatory pipeline system that is dedicated to public use and aims to facilitate transportation of clean renewable hydrogen from multiple regional third-party production sources and storage sites to various delivery points and end users in Central and Southern California. The system route is expected to consist of transmission pipeline(s), compressor station(s), and other related system components and appurtenances. The system will transport clean renewable hydrogen from regional third-party production and storage sources to various delivery points in Central and Southern California, including the Los Angeles Basin (LA Basin) which encompass the concentrated commercial and industrial area in and around the Ports of Los Angeles and Long Beach.

In accordance with D.22-12-055, OP 6 (i), SoCalGas identified and compared possible routes and configurations for Angeles Link. The Routing Analysis is a critical step in the development of the Angeles Link system and seeks to preliminarily (i) identify possible preferred routing/configurations; (ii) evaluate technical considerations, major crossings, elevations, terrain types, and other potential geographical and urban challenges; and (iii) identify existing SoCalGas Direct Land Rights and Rights-of-Way.

Gaseous hydrogen can be transported safely by pipeline much in the same way natural gas is today, as detailed in the Plan for Applicable Safety Requirements (Safety Study). Approximately 1,600 miles of pure hydrogen pipeline are currently operating in the United States.[6] At the time of this analysis, there are no known open access non-discriminatory pipelines transporting pure hydrogen. Hydrogen pipelines today are owned by merchant hydrogen producers.[7] As discussed in the Project Options & Alternatives (Alternatives Study), the High-Level Economic Analysis and Cost Effectiveness (Cost Effectiveness Study) studies and recognized by an Atlantic Council Global Energy Center report[8], pipelines are the safest and least costly means to move energy products. PHMSA acknowledges that the efficiency of volumes transported by pipeline are beyond the capacity of other forms of transportation[9], and furthermore DOE

[4] Pivvot is a third-party cloud-based application that consolidates a vast library of public information such as jurisdictional boundaries, social and community data, physical infrastructure locations, and environmental considerations such as hydrology, geography, and ecology.

[5] Angeles Link: SoCalGas, (n.d.-a). https://www.socalgas.com/sustainability/hydrogen/angeles-link

[6] Hydrogen pipelines | Department of Energy. (n.d.-b). https://www.energy.gov/eere/fuelcells/hydrogen-pipelines.

[7] Ibid.

[8] Quarterman, C. (2021, July 21). Hydrogen Policy Brief 3: Hydrogen Transportation and Storage. Atlantic Council Global Energy Center. https://www.atlanticcouncil.org/wp-content/uploads/2021/07/AC_HydrogenPolicySprint_3.pdf

[9] General Pipeline Faqs. PHMSA. (n.d.-a). https://www.phmsa.dot.gov/faqs/general-pipeline-faqs

concludes that dedicated hydrogen pipelines moving large volumes over long distances are critical to achieving economies of scale.[10]

1.1. Analysis Overview

Pipeline routing traditionally starts at a feasibility stage before moving into Front End Engineering Design (FEED) level of analysis, then transitioning into the final stages of design, permitting and construction. Consistent with that process, Angeles Link is expected to be developed and further refined in multiple Phases. Phase 1 focuses on a feasibility level analysis and study, including this Routing Analysis. For purposes of the Routing Analysis, Phase 2 will focus on pre-FEED and FEED activities specific to the preferred routes and variations identified in Phase 1, development of information to lead to selection of a preferred route, and further refinement of the chosen alignment. This multiphase approach creates multiple opportunities for incorporating stakeholder feedback and refinement of the associated proposed system route.

Pipeline routing generally begins by connecting two specific or known points, first focusing on the shortest distance between the two. For purposes of this feasibility stage, the Routing Analysis first defined an area of study, focusing on points of connection between the potential production areas and potential areas of offtake for the clean renewable hydrogen that Angeles Link would transport. Criteria was then applied to the study areas to inform the potential pipeline routes, including largely known geographical constraints such as mountain ranges or water bodies. In addition, other elements traditionally considered in pipeline routing and applied to this analysis included:[11]

- Cost efficiency
- Disadvantaged communities
- Land use limitations
- Impact to environment
- Pipeline integrity
- Public security
- Proximity to the facilities

Route features are categorized into Environmental, Social, or Engineering elements and are considered as the routing analysis seeks to identify potential pathways that, where possible, follow the most direct route between supply and offtake, avoid densely populated areas, areas that are environmentally sensitive or have cultural significance, and minimize new environmental and community impacts.[12]

In Phase 2 of Angeles Link, pre-FEED activities and a FEED study would be conducted. These activities would build on Phase 1 feasibility studies currently underway. Multiple alignment variations of the

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[10] Office of Technology Transitions, Office of Clean Energy Demonstrations, Hydrogen & Fuel Cell Technologies Office, Elgowainy, A., Penev, M., Crane, D., Cummins, K., Klembara, M., Chan, V., Tian, L., Shah, J., & Wagner, J. (2023). Pathways to commercial liftoff: Clean hydrogen. https://liftoff.energy.gov/wp-content/uploads/2023/05/20230523-Pathways-to-Commercial-Liftoff-Clean-Hydrogen.pdf

[11] Optimization of gas pipeline route selection with goal ... - IEOM. (n.d.-l). http://www.ieomsociety.org/gcc2019/papers/132.pdf

[12] Routing. Pipeline 101. (2024, May 30). https://pipeline101.org/topic/routing/

preferred route will be considered in Phase 2 to allow. Stakeholder and community input would be solicited during the Phase 2 analysis and would be considered when making alignment decisions. Once a preferred system route is identified, SoCalGas would advance development of the preferred system route, including technical design, planning and engineering, to develop the information needed to complete a FEED study for the preferred system route.

This Routing Analysis identifies several possible preferred routes and Route Variation 1 at a feasibility level for further consideration and evaluation. These findings support Phase 2 pre-FEED and FEED work, to develop more detailed refinement of the Angeles Link pipeline system. The subsequent more detailed route evaluation, alignment, and scoring to be conducted in the future is discussed further below in Chapter 6, Future Considerations, of this report.

1.2. Phase 1 Feasibility Study Integration

This Routing Analysis incorporates information from other Angeles Link Phase 1 feasibility studies. In addition, information from this Routing Analysis informed other Angeles Link Phase 1 feasibility studies. A summary of how information related to the routing was informed by and/or incorporated into other Phase 1 studies includes:

- The Production Planning & Assessment Study (Production Study) identified three primary areas within Central and Southern California for potential third-party clean renewable hydrogen production. This informed the Routing Analysis by determining how pipeline routes could access to production facilities.
- The Demand Study identified potential hydrogen users and offtake across Central and Southern California. This informed the Routing Analysis by identifying where higher concentrations of demand are anticipated to exist and grow, by sector, and this characterization can be applied to better understand the advantages to certain routes.
- The Pipeline Sizing & Design Criteria (Design Study) received mileage information from the Routing Analysis to evaluate the sizing and design of combinations of potential third-party production and storage locations to meet a corresponding proposed throughput, referred to as Scenarios. The Scenarios informed the potential Preferred Routes analyzed in this Routing Study. The Design Study also completed high-level cost estimates for the Scenarios and preferred routes that are identified in this Routing Analysis.
- The Environmental Social Justice Plan received the potential corridors for consideration throughout Central and Southern California that were evaluated in this Routing Analysis for screening of the potential environmental social justice impacts associated with the construction and operation of Angeles Link in those potential pipeline corridors. Screening results informed the creation of Route Variation 1.
- The Greenhouse Gas Emissions Evaluation (GHG Evaluation) received approximate route length from this Routing Analysis to evaluate the upper range of benefits from potential GHG reductions associated with Angeles Link.
- The Nitrogen Oxide (NOx) and Other Air Emissions Assessment (NOx Assessment) received approximate route length from this Routing Analysis to evaluate the range of impacts from potential air emissions associated with Angeles Link.

- The High-Level Feasibility Assessment & Permitting Analysis (Permitting Analysis) received the potential corridors for consideration throughout Central and Southern California that were evaluated in this Routing Analysis. Information regarding permitting is considered in the characterization of the preferred routes.
- The Environmental Analysis received the potential corridors for consideration throughout Central and Southern California evaluated in this Routing Analysis to provide a high-level analysis of the potential environmental impacts associated with the construction and operation of Angeles Link and to provide a high-level comparison of potential impacts of identified alternatives.

1.3. Routing Analysis Process

The methodology employed in conducting the Routing Analysis was based in two parts: System Evaluation and Route Evaluation. The process was inherently iterative, as it required the integration of a continuous influx of information received from various sources over the duration of this study. To effectively manage and incorporate this evolving data, the methodology was designed to be highly adaptable to allow for periodic evaluation and adjustment. This approach allowed each step to be informed by the most current and comprehensive data available, thereby enhancing the accuracy and relevance of the findings.

As illustrated in Figure 1, System Evaluation assessed the overall layout and pathways to safely transport clean renewable hydrogen by examining (1) the role of the system, (2) zone development, and (3) identifying initial corridors for consideration. Leveraging the role of Angeles Link and foundational information about expected supply and demand for clean renewable hydrogen in Central and Southern California, the basis for a system was identified. Three functional zones – Connection, Collection, and Central – were then developed to allow for a systematic approach to the creation of potential routes that considers both short term and long-term operational needs and reliability.

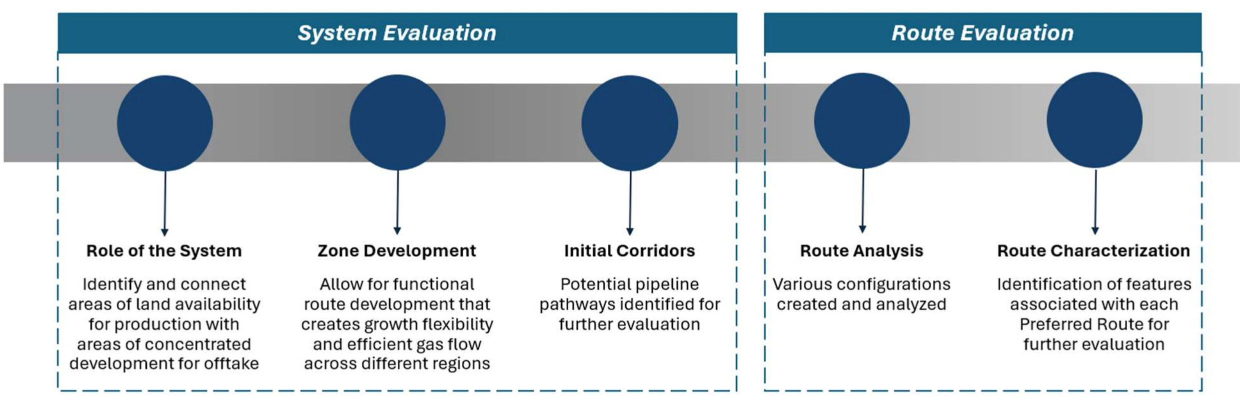

Figure 1. Routing Analysis Process: System and Route Evaluation

Preliminary pipeline feature analysis of a variety of route options was completed during the route evaluation and several potential preferred routes were selected and characterized. Route analysis included the preliminary siting of potential routes for Scenarios identified within the Design Study. An assessment was completed from a functional standpoint, examining operational characteristics that the potential route supports within a conceptual fully built-out clean renewable hydrogen system. As information was gathered and evaluated, additional data was integrated from external sources as well as from other Angeles Link Phase 1 activities. Routes were characterized using certain features, such as access to potential production, demand, common route attributes and permitting considerations.

2. SYSTEM EVALUATION

2.1. The Role of the System

As a non-discriminatory pipeline system dedicated to public use, Angeles Link is proposed to play a critical role in efficiently and safely providing the infrastructure to transport clean renewable hydrogen from one region to another (e.g., from multiple third-party production and storage sites to various delivery points and end users). Pipelines are capable of moving large volumes of gas resulting in connectivity that can be crucial for the seamless operation of many industrial, energy, and technology systems. Within this Analysis, Preferred Routes are routes which connect areas of clean renewable hydrogen production with areas of concentrated demand***.***

Angeles Link is intended to fulfill several underlying purposes, including the following:

1. To support the State of California's decarbonization goals, including the California Air Resources Board's (CARB) 2022 Scoping Plan for Achieving Net Neutrality, which identifies the scaling up of renewable hydrogen for the hard-to-electrify sectors as playing a key role in the State achieving carbon neutrality by 2045 or earlier. [13]
2. To support the State of California's decarbonization goals in the mobility sector, including the Governor's Executive Order N-79-202[14], which seeks to accelerate the deployment of zero-emission vehicles; CARB's implementation of the Advanced Clean Fleets regulation, which is a strategy to deploy medium- and heavy-duty zero-emission vehicles;[15] as well as the implementation of the March 15, 2021 Advanced Clean Truck regulation[16], which aims to accelerate a large-scale transition of zero-emission medium-and heavy-duty vehicles.
3. To optimize service to all potential end-users in the project area by operating an open access, common carrier clean renewable hydrogen transportation network dedicated to public use.
4. To support improving California's air quality by displacing fossils fuel for certain hard -to-electrify uses, including the mobility sector.
5. To enhance energy network reliability, resiliency, and flexibility as California industries transition fuel usage to achieve the State's decarbonization goals.

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[13] California Air Resources Board's 2022 Scoping Plan for Achieving Carbon Neutrality (November 16, 2022), at pp. 9-10, available at https://ww2.arb.ca.gov/sites/default/files/2022-12/2022-sp.pdf.
[14] NEWSOM, G. (2020). EXECUTIVE ORDER N-79-20. In STATE OF CALIFORNIA. https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf
[15] Advanced Clean Fleets | California Air Resources Board. (n.d.). https://ww2.arb.ca.gov/our-work/programs/advanced-clean-fleets/about
[16] California Air Resources Board. (n.d.). Advanced Clean Trucks Regulation. In FINAL REGULATION ORDER. https://ww2.arb.ca.gov/sites/default/files/2023-06/ACT-1963.pdf

6. To enable long duration clean energy storage that can further accelerate renewable development and minimize grid curtailments.
7. To provide a cost effective and affordable open access clean renewable hydrogen transportation network at just and reasonable rates.
8. To provide efficient and safe clean renewable energy transportation in support of the State's decarbonization goals.
9. Over time and combined with other current and future clean energy projects and reliability efforts, to help reduce reliance on natural gas use served by the Aliso Canyon storage facility, while continuing to provide reliable and affordable energy service to the region.

Initial Awareness of Demand

The Los Angeles Basin (LA Basin), as a major urban and industrial hub, represents a significant demand center for clean renewable hydrogen. Many potential end-users in the hard-to-electrify sectors evaluated in the Demand Study can be identified using public resources, several of which are listed below. ARCHES, discussed in further detail in later chapters, also identified anticipated off-take sites in Central and Southern California that are part of a diverse portfolio of clean hydrogen projects and infrastructure to advance California's ambitious clean energy goals. The major industrial activity in the LA Basin and anticipated ARCHES projects were considered in the System Evaluation for the Angeles Link pipeline system.

Listed below are public resources available to identify potential off takers in the LA Basin include, but are not limited, to:

- **Alternative Fuel Corridors**, designated by the Federal Highway Administration, aim to support installation of electric vehicle (EV) charging, hydrogen, propane, and natural gas fueling infrastructure at strategic locations along major national highways.[17] These corridors are also aligned with the heavy-duty trucks, transit vehicles, and fuel cell and battery electric vehicles identified in Mobility sector per the Demand Study.
- **California Oil Refineries and Terminals**, designated by the California Energy Commission[18], are currently the largest industrial consumers of hydrogen which is primarily produced via steam methane reformation and other non-renewable methods.[19] Refineries and shipping terminals are aligned with the Industrial and Mobility sectors evaluated in the Demand Study.
- **California Power Plants**, designated by the California Energy Commission[20], and the power generation sector could become the anchor hydrogen infrastructure driver, per the Demand Study.

[17] Alternative fuel corridors. (n.d.). https://hepgis-usdot.hub.arcgis.com/pages/alternative-fuel-corridors
[18] California Energy Commission. (n.d.). California's oil refineries. https://www.energy.ca.gov/data-reports/energy-almanac/californias-petroleum-market/californias-oil-refineries
[19] Alternative Fuels Data Center: Hydrogen production and distribution. (n.d.). https://afdc.energy.gov/fuels/hydrogen-production#:~:text=Natural%20gas%20reforming%20using%20steam,with%20lower%20carbon%20dioxide%20emissions.
[20] California power plants. (n.d.). https://cecgis-caenergy.opendata.arcgis.com/datasets/CAEnergy::california-power-plants/about

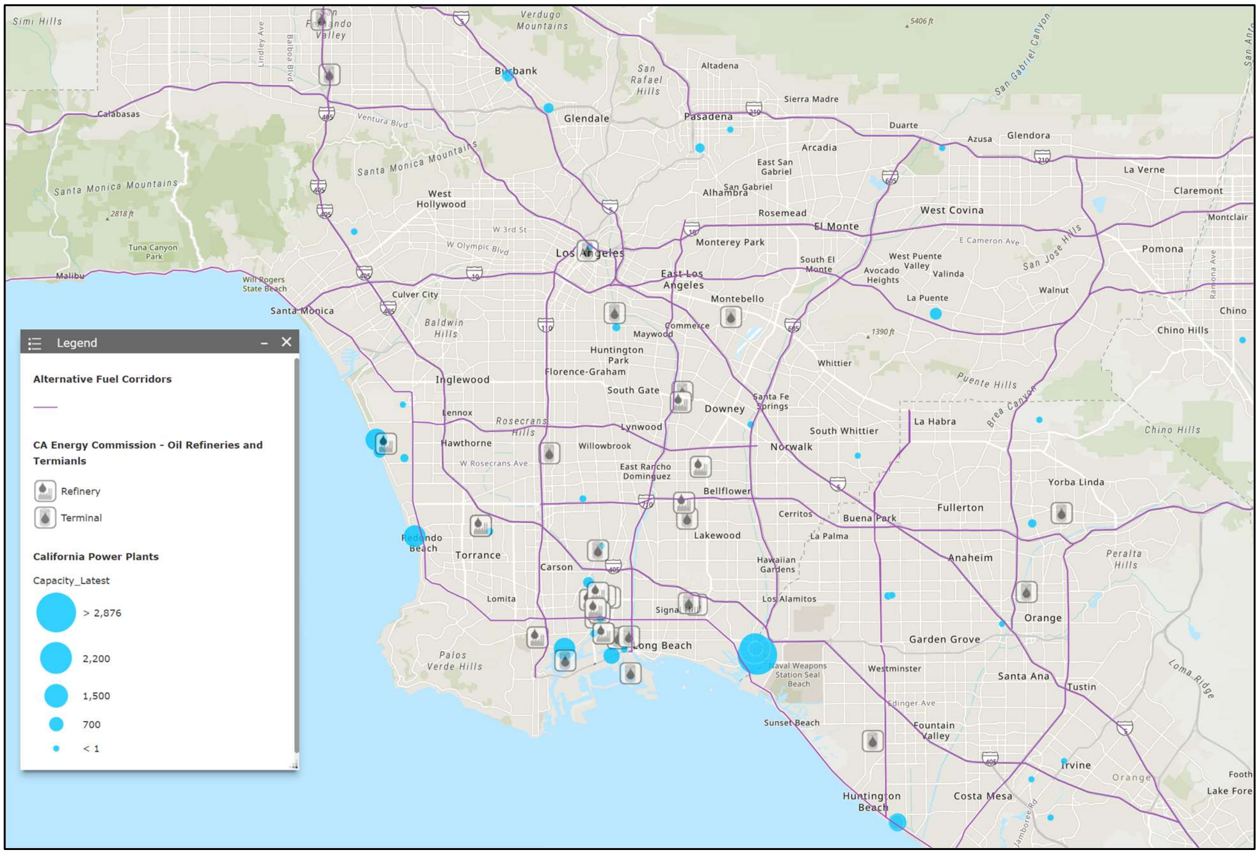

Figure 2. Illustration of Alternative Fuel Corridors, Refineries, and Power Plants in the LA Basin

Figure 3. Illustration of Anticipated ARCHES Projects[21]

[21] ARCHES H2, *Meet ARCHES* (October 2023), *available at:* https://archesh2.org/wp-content/uploads/2023/10/Meet-Arches_October-2023.pdf; DOE – Office of Clean Energy Demonstrations

Initial Awareness of Production

Areas of production for clean renewable energy are typically located where renewable energy resources – such as wind and solar, are abundant and can be harnessed efficiently. These are often rural or less densely populated regions with favorable conditions for renewable energy generation. The less densely populated regions shown in Figure 4 also coincide with the potential ARCHES projects identified in Central and Southern California, shown in Figure 3, and the areas of highest likelihood to generate large-scale clean renewable hydrogen analyzed in the Production Study. See Production Study for further details.

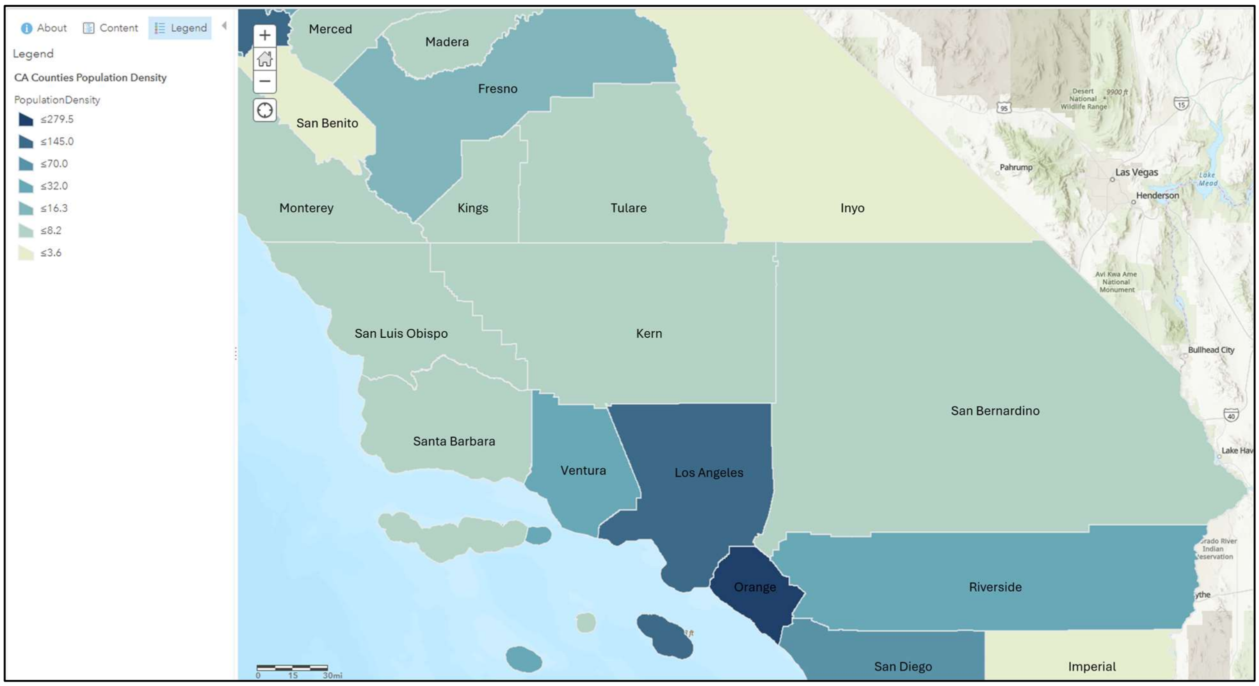

Figure 4. Illustration of Population Density calculated as Total Population Per Square Mile[22]

As the connective infrastructure between the demand and production components, potential pipeline routes for Angeles Link would connect production sites to demand centers, incorporating the following considerations:

- Geographical Directness: Selecting the most direct routes that efficiently connect the production sites with end users in Central and Southern California, including the LA Basin

[22] Population_Density_2020_California_Counties (FeatureServer). (n.d.). https://services1.arcgis.com/ZIL9uO234SBBPGL7/arcgis/rest/services/Population_Density_2020_California_Counties/FeatureServer

- Topographical Feasibility: Avoidance of natural barriers like extensive mountain ranges or protected areas that could complicate construction and increase costs.

2.2. Zone Development

A systematic approach was critical for identifying and developing preliminary routing options for Angeles Link as this pipeline would be a new system. In contrast to a traditional pipeline project where a pipeline is routed between two identified points within an established system, Angeles Link would be a new gas transportation system. Identification of preferred system routes must be based on operational resiliency and energy reliability in order for the system to successfully help decarbonize the identified sectors of California's industry and economy. Zone development allows for designing a system that is functionally diverse to support cohesive, efficient long-term operation.

SoCalGas established three zones within the Central and Southern California region that each reflected different aspects of hydrogen delivery[23]. Each Zone has a primary, but not exclusive, function which allows for system versatility. The Central Zone is primarily the area known as LA Basin, the Collection Zone is located outside the LA Basin, where regional hydrogen production and demand centers are likely located, and the Connection Zone is the region where pipelines are needed to connect producers and end-users furthest away from the LA load center. Refer to Figure 5 for an illustration of the three zones.

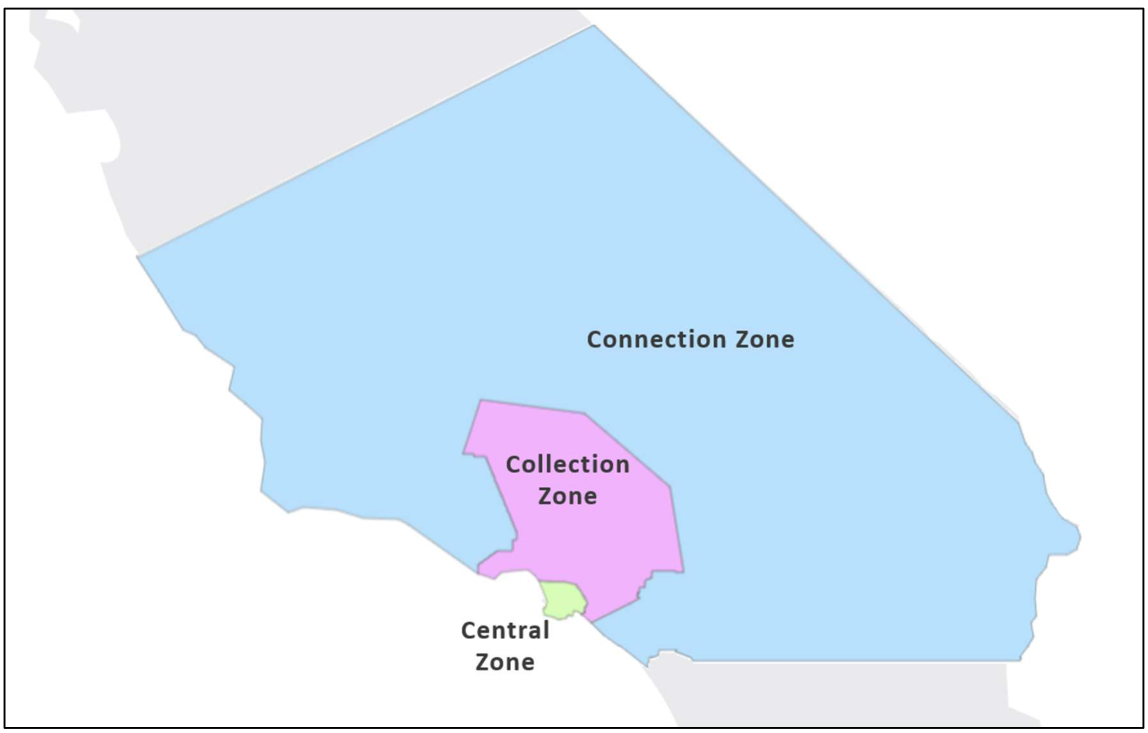

Figure 5. Illustration of Connection, Collection, and Central Zones

[23] Zone boundaries are approximate and subject to change.

While each zone serves a specific purpose – delivery, supply, and a combination of both – a pipeline system that interconnects these zones allows the gas to be efficiently transferred from the likely points of supply (Connection Zone) through the areas of collection (where gas might also be used, sourced or stored) to the points of demand in the delivery areas (primarily in the Central Zone, although broader offtake is anticipated throughout Central and Southern California. See the Demand Study for additional details). This integration helps in managing the flow of gas according to the needs and capacities of each zone, enhancing the overall system functionality. Within this Analysis, Preferred Routes are routes which have pipeline passing through all three zones.

Key characteristics and the anticipated function of the different zones is as follows:

Central Zone. The LA Basin area is anticipated to contain the densest area of potential offtake given the concentration of demand from the hard-to-electrify sectors. The Angeles Link system in this area would serve as pipeline delivery system to Power Generation, Mobility, and Commercial/Industrial Manufacturing sectors. The primary role of the Central Zone is to support large-scale delivery of clean renewable hydrogen.

Collection Zone. Pathways within this zone bridge the more focused functionality of the Central Zone and the Connection Zone by taking on a dual nature. Pipeline in this area is anticipated to serve multiple roles simultaneously, both allowing for collection of gas from hydrogen suppliers but also supporting gas delivery to end users.

Connection Zone. Pathways in this zone present opportunities for connection to other hydrogen networks in-state and/or out-of-state. These pathways allow for connectivity and reduce the possibility for isolating access to critical energy infrastructure. While Angeles Link is envisioned to be an intrastate system, interconnectivity is pivotal for establishing a resilient system, furthering the operator's ability to weather challenges, unexpected events, and maintain a steady supply. The primary role of the Connection Zone is to support supply and reliability.

Connections between different hydrogen networks, both in- and out-of-state, allow for a more reliable supply by providing multiple sources of clean renewable hydrogen. This redundancy can be critical for preventing supply disruptions that may occur due to maintenance issues, unanticipated events, or natural disasters affecting one part of the network. Broad ability to source hydrogen gas can also create flexibility in load balancing between supply and demand across broader regions more effectively. If one area experiences a spike in demand or a drop in supply, gas can be rerouted from areas with a surplus, creating a stable supply and preventing local shortages.

Potential for market integration is also a potential aspect of this zone. The Connection Zone would allow for the creation of a more integrated clean renewable hydrogen gas market. Integration enables more efficient trading and price stabilization across different regions by smoothing out local price volatility due to isolated supply or demand shocks.

The potential integrated hydrogen gas market that the Connection Zone may create is similar to hydrogen "backbone" networks currently under exploration and planning globally as the hydrogen economy seeks to expand and the co-location of supply with demand is not always viable. For example, the European Hydrogen Backbone (EHB) Initiative[24] has taken a coordinated approach toward the identification of infrastructure needs and minimization of barriers, driving forward the rapid deployment of an efficient hydrogen network in Europe. Locally, the initiation of a North American Hydrogen Backbone collaborative, driven by Guidehouse and Rocky Mountain Institute (RMI)[25], underscores the need for this connection in the form of transparency between midstream infrastructure development.

2.3. Initial Corridors for Consideration

As a basis was created for route evaluation, corridors were narrowed based on factors such as geological structure and features. Access to the LA Basin area is constrained by geology, including several mountain ranges: Sierra Madre Mountains, San Gabriel Mountains, and the Santa Rosa Mountains. Additionally, there are multiple National Forests that also surround the LA Basin. Given these features, there is a limitation of potential pathways that enter the LA Basin from the lands that surround it.

Figure 6. Illustration of Potential Pathways to Enter the LA Basin

[24] The European Hydrogen Backbone (EHB) initiative. EHB European Hydrogen Backbone. (n.d.). https://ehb.eu/
[25] Mills, R. (2023, December 20). An urgency for connective hydrogen infrastructure. RMI. https://rmi.org/an-urgency-for-connective-hydrogen-infrastructure/

The Angeles Forest and San Gabriel Mountains have highly variable terrain in terms of elevation changes and dense vegetation cover. To limit disturbance to these natural areas and prevent construction and operational challenges associated with variable topography, routes outside of established transportation corridors were eliminated from consideration.

Coastal routes present specific challenges in terms of access limitations, coastal weather conditions, and limitation in space. Routes accessing LA Basin along the Central California coast and leading to LA Basin from the Southern region of the state, face these complexities. In addition, the extensive mountainous terrain and numerous protected lands make it more likely that hydrogen production facilities would be located further away, necessitating significantly longer routes. This combination of coastal conditions, unsuitable terrain, and increased distances made these regions less viable for preliminary route exploration.

During this initial evaluation, focus was placed on corridors that reside in close proximity to the potential demand sectors for Angeles Link to connect that demand with potential areas for clean renewable hydrogen production. Information generated by SoCalGas during the pre-feasibility SPEC Reports, coupled with other public data including National Pipeline Mapping System (NPMS), Alternative Fuels Data Center (AFDC) Corridors, and Federal Corridors was used to create a variety of different pipeline pathways that fall North-to-South and East-to-West.

2.3.1. Agency Data Sets

SoCalGas identified potential opportunities for routing that include energy corridors on federal lands, federal interstate corridors, Alternative Fueling Corridors, and industrial areas with high demand to minimize impacts to the community and the environment.

Energy Corridors on Federal Lands. SoCalGas utilized the United States Department of Energy (DOE) Energy Corridors on Federal Lands resource that provides a map of corridors on Federal Lands throughout the United States.[26,27] SoCalGas reviewed the data to identify federal corridors as a method of addressing increasing energy demands of oil, gas, hydrogen pipelines, electricity transmission, and distribution facilities in the coming future. Moreover, the map supports the creation of the Connection Zone by designating energy corridors in the High, Low, and Southern Desert areas that contact federal land, as well as corroborating the Collection and Central Zone by designating areas with fewer sensitive and federal land concerns that are more suitable for pipeline networks instead of long, transmission pipelines.

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[26] Energy Corridors on Federal Lands | Department of Energy. (n.d.-c). https://www.energy.gov/gdo/energy-corridors-federal-lands

[27] West-wide energy corridor information center. West-wide Energy Corridor Information Center. (n.d.). https://corridoreis.anl.gov/

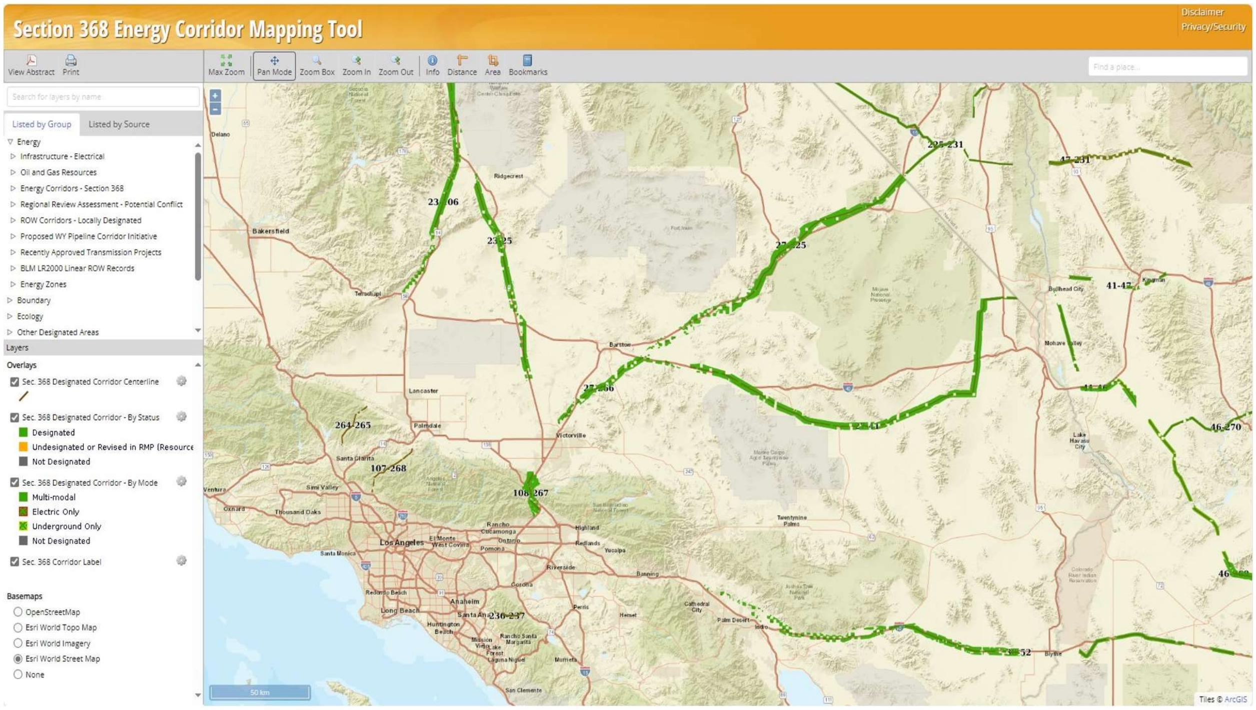

Figure 7. Illustration of Section 368[28] Energy Corridor Public Viewer[29]

National Pipeline Mapping System (NPMS). The NPMS is a resource published by the Pipeline and Hazardous Materials Safety Administration (PHMSA).[30] The mapping system details a network of existing corridors, including gas transmission and hazardous liquid pipelines that are under the jurisdiction of the United States Department of Transportation (DOT) and PHMSA.[31] Resulting observations from these corridors aided in the development of the Central Zone by identifying existing locations of oil and gas refineries, and analyzing industrial activity data in that region. Initial corridor siting also considered proximity of existing SoCalGas high pressure pipeline facilities.

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[28] As summarized by the U.S. Department of Energy, Section 368 of the Energy Policy Act of 2005 (EPAct) "directs the Secretaries of Agriculture, Commerce, Defense, Energy, and Interior to designate, under their respective authorities, corridors for oil, gas, and hydrogen pipelines and electricity transmission and distribution facilities on Federal lands in the 11 contiguous Western States (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming), to perform any required environmental reviews, and to incorporate the designated corridors into relevant agency land use and resource management plans or equivalent plans. Section 368 also directs the agencies to take into account the need for upgraded and new infrastructure and to take actions to improve reliability, relieve congestion, and enhance the capability of the national grid to deliver energy. EPAct also calls for identifying corridors in the other 39 states and to expedite processes for future projects in these energy corridors." *See* https://www.energy.gov/gdo/energy-corridors-federal-lands.

[29] Section 368 Energy Corridor Mapping Tool. (n.d.). https://bogi.evs.anl.gov/section368/portal/

[30] Home. NPMS. (n.d.). https://www.npms.phmsa.dot.gov/

[31] Learn About the Public Map Viewer. About public map viewer. (n.d.). https://www.npms.phmsa.dot.gov/AboutPublicViewer.aspx

Figure 8. Illustration of SoCalGas Transmission Pipelines (part of National Pipeline Mapping System)[32]

Alternative Fuels Data Center (AFDC). The AFDC is a joint effort between the United States Department of Energy (DOE) and the United States Department of Transportation (DOT) to establish a national network for alternative fueling and electric vehicle charging infrastructure along national highway network corridors. The AFDC website provides a public source of data surrounding alternative and renewable fuels within each state.[33] Furthermore, the Alternative Fuel Corridors (AFC) noted by the Data Center were designated by the Federal Highway Administration (FHWA) to support installation of electric vehicle charging, hydrogen, propane, and natural gas fueling infrastructure at strategic locations along major highways.[34]

For the Routing Analysis, AFC was utilized to identify approximately 200 miles of the initial corridors considered. This data characterizes where the Routing Analysis identifies pipelines could potentially transport hydrogen from producers to fueling station demand centers. The AFC also displays potential hydrogen consumers.

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[32] SoCalGas Internal GIS has been used for illustrative purposes and user readability.

[33] EERE: Alternative fuels data center home page. EERE: Alternative Fuels Data Center Home Page. (n.d.). https://afdc.energy.gov/

[34] Alternative Fuel Corridors - Environment - FHWA. (n.d.). https://www.fhwa.dot.gov/environment/alternative_fuel_corridors/

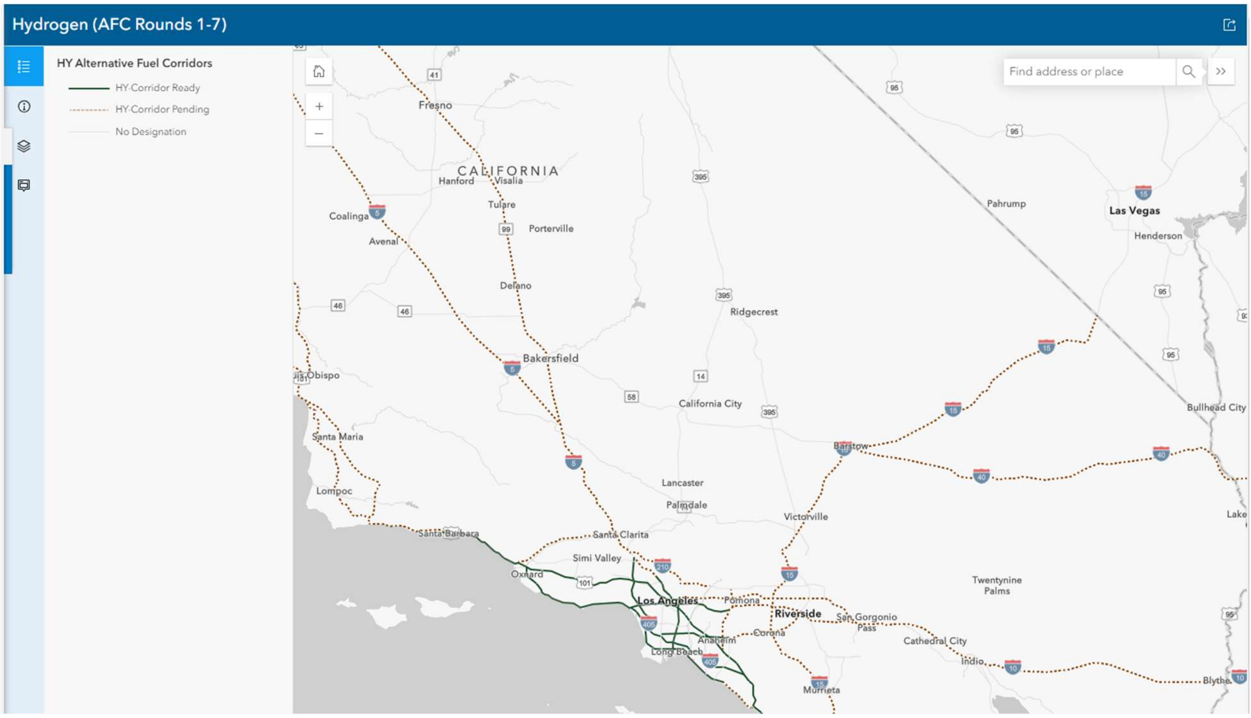

Figure 9. Illustration of Alternative Fuels Corridors[35]

2.3.2. Initial Corridors

This initial map identifies potential corridors for a new pipeline system, considering a range of developed and undeveloped lands and terrains. This includes urban, rural, and mountainous terrain features, while also including different ecological conditions. Since a single pipeline often traverses land with varied features, it will be crucial to conduct detailed evaluation and analysis in subsequent phases of the project.

The development of a new pipeline system rather than a route in an already established system, necessitated a broad approach that allowed for comprehensive assessment of the Central and Southern California regions. When combined, these initial corridors traverse a total of approximately 1,300 miles, providing a wide range of options within which to narrow down the routes for the Angeles Link system. The illustration in Figure 10 presents this wide range of options for evaluation and multiple pathways for the incorporation of new data. Of the approximately 1,300 miles of initial corridors evaluated, 500 miles were estimated to be within Section 368 Federal Energy Corridors, 200 miles were estimated to be aligned with the Alternative Fuel Corridors, and approximately 950 miles were within 50 feet of existing SoCalGas high pressure pipeline facilities. The approach lays a strong foundation for the Routing Analysis and allows data and other related information to be applied. As the Routing Analysis developed, the initial set of pathways were progressively narrowed down to the most preferred routes.

[35] Alternative fuel corridors. (n.d.-b). https://hepgis-usdot.hub.arcgis.com/pages/alternative-fuel-corridors

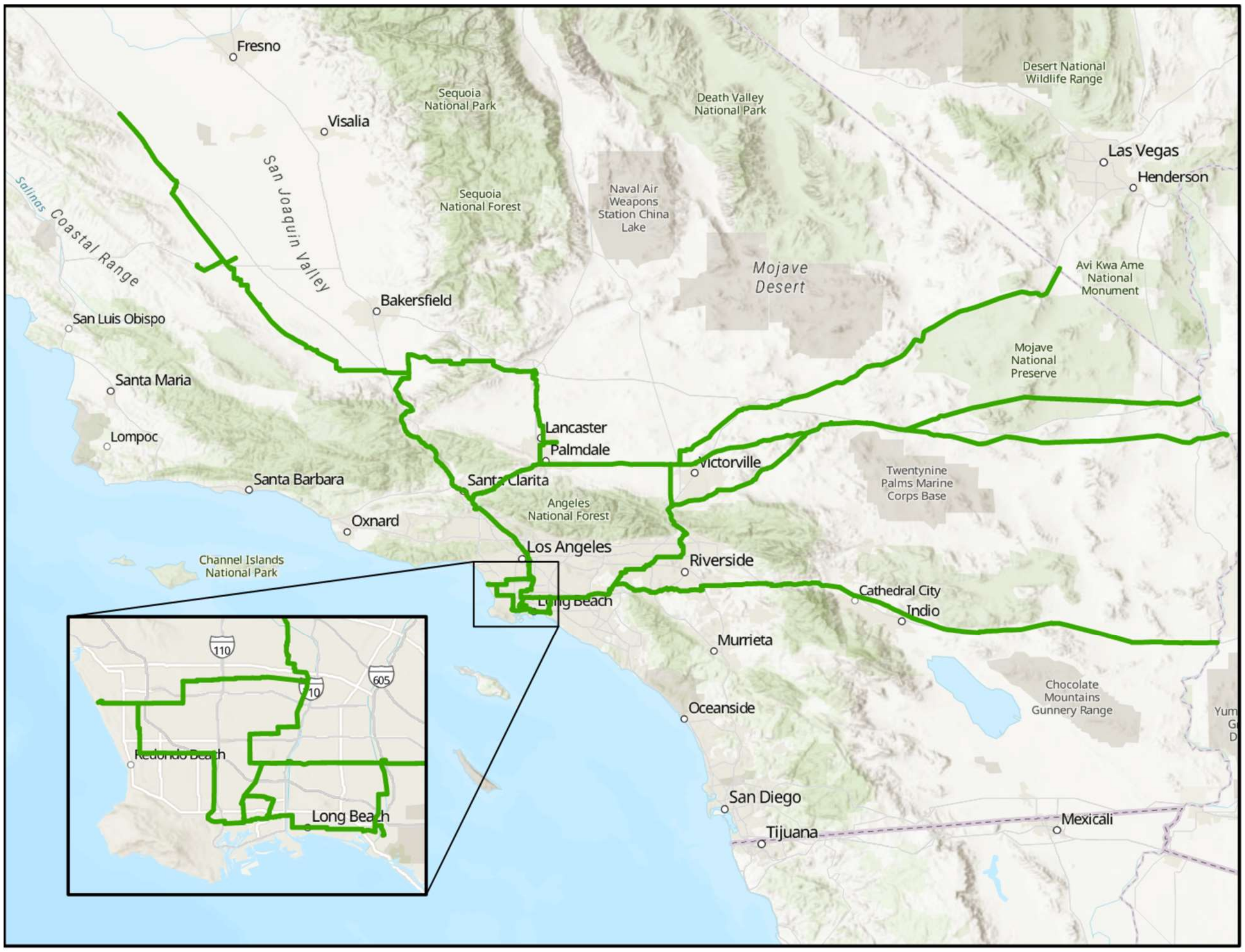

Figure 10. Initial Corridors Evaluated

2.3.3. Corridor Segmentation

All initial corridors identified were broken down into smaller pieces for more practical evaluation. These segments, identified by letter designations, were evaluated for characteristics and attributes. By analyzing these smaller sections individually, work could be conducted in an organized structure. As the routing evaluation proceeded, the segments could be used to craft a variety of different routes.

These twenty-five pipeline segments represent conceptual routing within available corridors for consideration in a preferred routing configuration and made up the initial potential options for Angeles Link. The illustration of these segments is displayed in Figure 11 below.

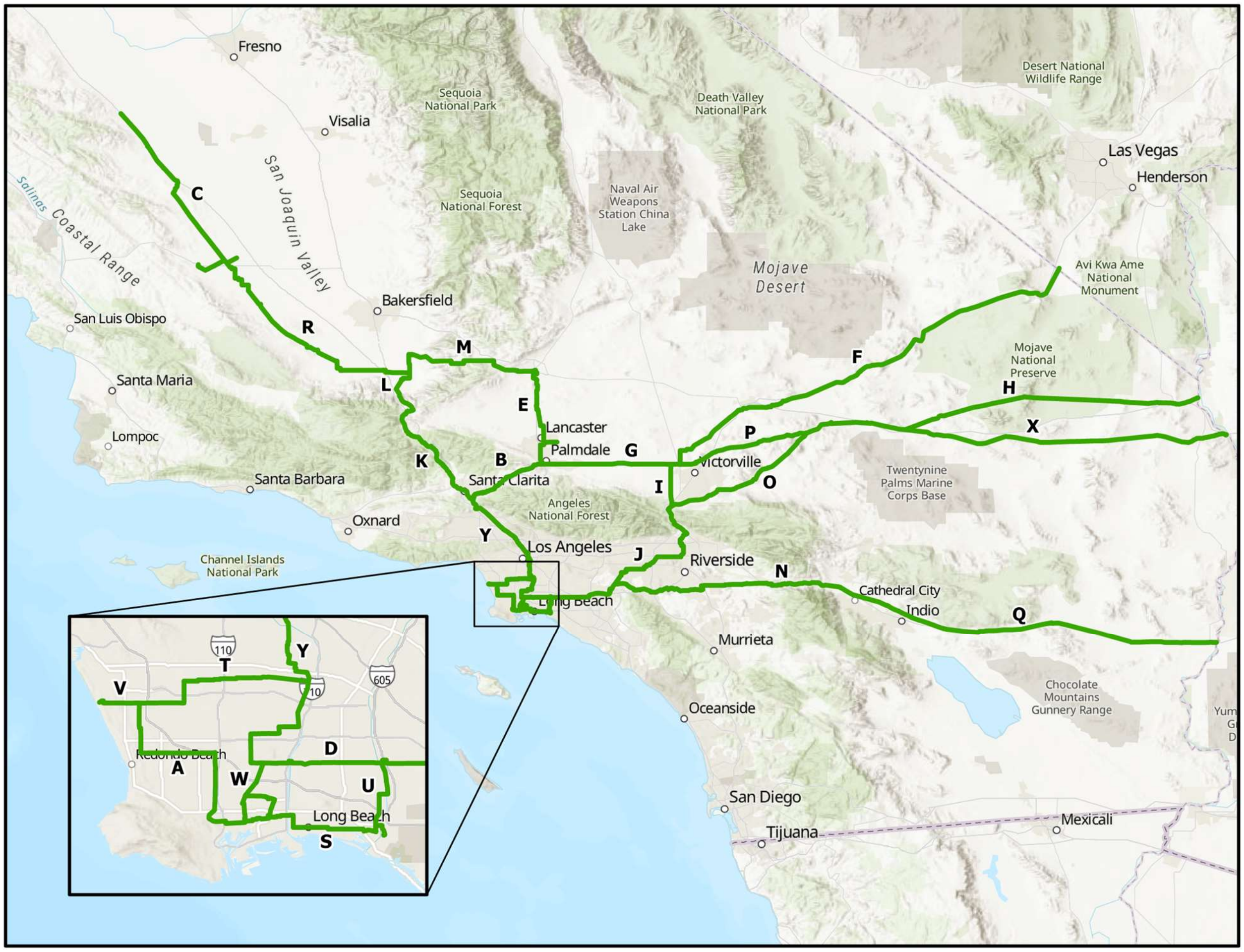

Figure 11. Evaluated Corridors by Segment

3. ROUTE EVALUATION

3.1. Feature Evaluation

3.1.1. Segment Analysis & Evaluation

As selected routes are further explored in subsequent phases, information about the routes will be essential for detailed alignments that seek to minimize potential impacts on the community and the environment. Cataloging the network by segments allowed for an efficient and systematic approach to routing analysis. A comprehensive approach was utilized to build assessment matrices and to develop the following three categories for routing analysis for each segment:

- Engineering: constructability factors that can create logistical problems or excessive costs to pipeline construction, operation, or maintenance. For example, incorporating construction staging considerations involves evaluating potential routes for compatibility with the logistical requirements of construction staging. Staging areas must be established along the selected route where materials such as pipes, valves, and fittings can be efficiently received, stored, and accessed. The proximity of these staging areas to existing infrastructure like major roads and railways significantly reduces the time and cost associated with transporting materials to the construction sites.

- Environmental: challenging topography that may prevent construction or regulated lands that may require additional permits or mitigation before construction activities would be allowed. For example, choosing routes that require less intensive land clearing and grading to minimize ecological disruption.
- Social Category: factors that may have direct or indirect effects on people. Routes that include sensitive crossing areas, such densely populated areas, might require advanced techniques like horizontal directional drilling to minimize surface disturbance. Supplementary analysis was performed related to Disadvantaged Communities or DACs (see Chapter 4 of this analysis), as well as the Environmental and Social Justice Analysis.

Within each of the three categories, attributes were identified as a component to measure routing characteristics, each measured with relative units (see Appendix for full matrix details, including attribute definitions). For each of the segments, a matrix was developed that indexed individual attributes, equating to characteristics relative to each specific segment. The segment characterization was used to identify features that provide additional insight into the preferred routes in Sections 5.1.1. The attributes identified for each segment are displayed in Table 1 below:

Table 1. Matrix Categories Used for Segment Characterization

CATEGORY	ATTRIBUTE	GIS DATA LAYER OWNER*
ENGINEERING	49 CFR 192 Class Location	SoCalGas GIS
ENGINEERING	Adverse Soil Conditions	Pivvot
ENGINEERING	Centerline (CL) length with 15% Slope	Pivvot
ENGINEERING	Fault Areas	Pivvot
ENGINEERING	High Consequence Areas (HCA)	N/A, BMcD Engineering Assessment
ENGINEERING	Mainline Valve (MLV)	N/A, BMcD Engineering Assessment
ENGINEERING	Number of Overhead Utility Crossings	Pivvot
ENGINEERING	Physical Conflict	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary Workspace	N/A, BMcD Engineering Assessment
ENGINEERING	Railroad Crossings	Pivvot
ENGINEERING	Road Crossings	Pivvot
ENGINEERING	Route Length	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Pivvot
ENVIRONMENTAL	Coastal Zone	Pivvot, BMcD Engineering Assessment
ENVIRONMENTAL	Conservation Areas	Pivvot
ENVIRONMENTAL	Federal Endangered or Threatened Species Critical Habitat	Pivvot
ENVIRONMENTAL	Floodplain	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Pivvot
ENVIRONMENTAL	Stream Crossings	Pivvot
ENVIRONMENTAL	Wetlands	Pivvot
SOCIAL	Agricultural/Pastureland	Pivvot
SOCIAL	Commercial Land	Pivvot
SOCIAL	Cultural & Tribal Resources	Pivvot
SOCIAL	Federal Land/Property	Pivvot
SOCIAL	Industrial Land	Pivvot
SOCIAL	Institutional Land	Pivvot
SOCIAL	Maintained Public & Recreational Areas	Pivvot
SOCIAL	National Register of Historic Places (NRHP) locations	Pivvot
SOCIAL	Proximity to Buildings	Pivvot

*BMcD “Engineering Assessment” was a desktop user analysis.

The importance of the feature characterization is to serve as a quantitative method of cataloging routing characteristics. In addition, the matrices developed for each segment are intended to be used as the foundation to further engineering, design, planning, permitting, and stakeholder outreach in Phase 2 that will be required to achieve feasible routes that are constructible and sustainable. Each of the evaluation criteria listed in Table 1 correlates with one or multiple GIS data sources, as detailed below.

3.1.2. Route Feature Evaluation

The initial segment criteria were identified and used to develop characteristics for the preferred routes. The full matrices and a summary table of the length for each segment is shown in Appendix B and C.

3.1.3. Data Sources & Attribute Measurement Approach

The Pivvot software was utilized in the segment analysis efforts to efficiently streamline data collection and measurement. Pivvot is a GIS software program that allows a pipeline route to be identified, studied, reviewed, and updated based on hundreds of data sources available within the software. GIS Data Layer Sources are shown in Appendix B. Routes were uploaded to Pivvot for analysis based on the attributes listed in Table 1 above. Pivvot's database comprised of the following data:

Table 2. Evaluation Criteria and Data Source

JURISDICTIONAL DATA	HYDROLOGY DATA	BOUNDARY DATA	GEOTECHNICAL DATA
County Boundary	Aquifer	Congressional District	Depth to Bedrock
Dept. of Transportation Districts	Commercially Navigable Waterway	Electric Retail Service Territories	Elevation
Municipal Boundary	EPA Protected Waterbody	Energy Regulatory Region	Fault Area
State Boundary	100-Year Flood Plain	Natural Gas Service Territories	Fault Lines
U.S. ACE Districts	500-Year Flood Plain	Oil & Gas Production Area	Geological Unit
U.S. BIA Regions	Levee	Organizational Boundary	Enhanced Karst Topography (Terracon)
U.S. BLM Admin. Units	NHD Flowline	PHMSA Populated Places	Landslide Risk
U.S. BOR Regions	NDH Waterbody	Public Land Survey	Peak Ground Acceleration
U.S. EPA Regions	NWI Wetlands	Public Safety Answering Point	Percent Slope
U.S. FEMA Regions	Watershed	School Districts	Depth to Water
U.S. Federal Lands	Wild & Scenic Rivers	State Legislative Districts	Hydric Soils (Potential Wetland Soil Landscape)
U.S. FWS Regions	USGS Stream Gauges		Hydrologic Soil Groups
U.S. FS Regions			Prime Farmland (Terracon)
U.S. NMFS Regions			Soil Behavior Class (Terracon)
U.S. NRCS Regions			Soil Corrosivity (Terracon)
U.S. Tribal Lands			Soils
			Steel Corrosivity
WEATHER DATA	**ENERGY & INFRASTRUCTURE DATA**	**ECOLOGY & ENVIRONMENTAL DATA**	**LAND USE DATA**
Hail Events	Communication Towers & Obstacles	Critical Species Habitat	Property Parcel
Lightning Strikes	Contaminated Sites	Species/Habitat Range	Land Cover
Tornado Events	Electric Transmission Powerline	Ecosystem Region Boundary	Land Ownership Conflicts
Wind Events	Electric Transmission Substations	Species Habitat	Community & Society Data
	Existing Pipeline		Environmental Justice
	Fifty Foot Structure Buffer		Social Vulnerability
	Greenhouse Gas Emitters		
	Interconnect Queue		
	Points of Interest		
	Cemeteries		
	Federal Registered Sites		
	Railroads		
	Roads		
	Trails		
	Wind Turbines		

3.2. Land Rights

A preliminary analysis of existing Direct Land Rights and rights to use Rights of Way pursuant to a municipal franchise agreement (described below) was performed to inform the Routing Analysis. This information is based on the current preliminary alignment of the routes and will be a basis for further exploration in subsequent phases as preferred routes are evaluated from a more granular perspective and new alignments options are determined.

3.2.1. Franchise Rights

SoCalGas operates and maintains a significant portion of its pipeline system in Rights of Way pursuant to local ordinances (i.e., franchise agreements) that generally grant SoCalGas the right to construct, operate, and maintain in Rights of Way pipeline infrastructure to transmit and distribute gas for any and all purposes consistent with applicable law. Sixty-four (64) municipalities were identified that are crossed by the potential pipeline segments, sixty (60) of which have some form of franchise agreement with SoCalGas. Certain terms and conditions of the 60 franchise agreements (which vary by city and county) were reviewed, as well as relevant applicable local codes and state statutes (i.e., the Broughton Act, the Franchise Act and the regulations of the CPUC) for those city and county jurisdictions crossed by the proposed 25 routing segments.

3.2.2. Existing Direct Land Rights

Sites within each of the 25 routing segments where its linear pipeline facilities are located in relation to the proposed routes were identified using GIS and SoCalGas facility maps to preliminarily evaluate those portions of the segments in, or in proximity to, its existing Direct Land Rights, and, as available, retrieved copies of the relevant easements, rights-of-way and licenses. (SoCalGas fee-owned land was not included.).[36] Each segment was reviewed on a parcel-by-parcel basis, each "parcel" having a county-assigned tax identification number.

Once the parcels in each segment were identified, research was conducted on publicly available data to obtain ownership from property detail reports, county tax roll databases and real estate data service providers. Note that neither detailed title review (e.g., review of relevant preliminary title reports or property surveys to identify complex ownership interests, title exceptions, concurrent usage or specific land use restrictions) nor physical surveys or inspections of existing SoCalGas or third-party facilities were performed for this analysis. The evaluation of property ownership and SoCalGas Direct Land Rights agreements included:

- Identification of parcels traversed by the proposed segments owned by federal, state or local governmental agencies, railroads, other utilities, and certain private parties (e.g., state or local conservation agencies, oil and gas entities) that typically present acquisition challenges due to long lead time or permitting requirements
- Identification of defined widths permitted to construct and maintain pipeline facilities

[36] Fee owned land refers to real property owned by SoCalGas.

3.3. Route Analysis

Various route configurations were created and analyzed, and relevant information was integrated from the Production, Demand, and Design Studies, in addition to incorporating ARCHES-related information as it became available.

3.3.1. Scenarios

The Phase 1 Production Study[37] identified three potential areas—referenced in this section as "San Joaquin Valley" (SJV), "Lancaster", and "Blythe"—with the highest likelihood to generate large-scale clean renewable hydrogen by third parties. Angeles Link is proposed to transport up to 1.5 million metric tons per year (MMTPY) by the Demand Study. Combinations of the identified potential production locations were analyzed to achieve a range of 0.5 MMTPY, 1.0 MMTPY, and 1.5 MMTPY total throughput (See Production and Design studies for further detail). These combinations are identified as Scenarios 1-8, which provide potential pathways to deliver hydrogen from the primary potential production locations to demand centers in the Central and Southern California, including the LA Basin.

Table 3 - Scenario 1-8 Results

Scenario	Total Throughput, MMTPY	Primary Production Location(s)	Total Route Mileage*
1	0.5	San Joaquin Valley (SJV)	355
2	0.5	Lancaster	314
3	0.5	Blythe	303
4	1.0	SJV, Lancaster	392
5	1.0	Lancaster, Blythe	537
6	1.0	SJV, Blythe	578
7	1.5	SJV, Lancaster	390
8	1.5	SJV, Lancaster, Blythe	616

*Single-Run configuration mileage. Refer to the Design Study for more details.

[37] Clean hydrogen production and above-ground and underground storage are 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.

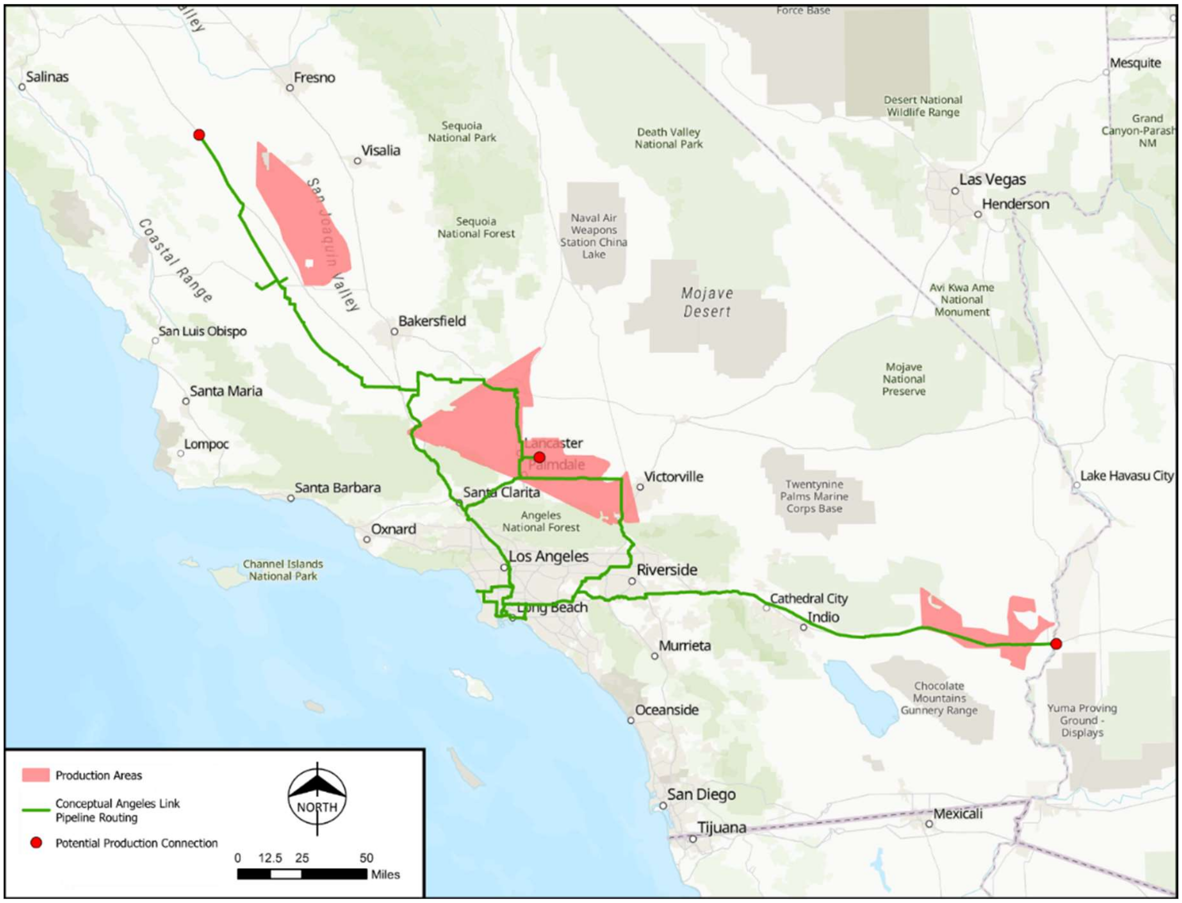

Figure 12. Conceptual Production Areas and Pipeline Routing

Figure 12 depicts the conceptual production areas and pipeline routing for Scenarios 1-8, which are further described in this section.

As described in previous sections, one objective of this Routing Analysis was to develop an efficient pipeline network that could transport up to 1.5MMTPY. To access this volume, based on the Production Study, it was determined that at least two of the areas identified for potential production may be necessary. Initial corridors evaluated pipelines that extend East from the Lancaster Production Area to the California and Nevada border. These corridors were not pursued in Scenarios 1-8 as the excessive mileage and land disturbance of these potential corridors are not necessary to reach an identified Production Area. Scenarios 5, 6, and 7 all illustrate potential routes that connect to at least two of the potential production areas. Averaged, these scenarios indicate that a route that traverses up to 500 miles may be necessary to achieve this. Therefore, within this Analysis, Preferred Routes traverse 500 miles in distance or less.

Scenario 1: San Joaquin Valley (SJV)

Scenario 1 consists of a pipeline system that initiates in the SJV Production Area in the Connection Zone, before heading south through the Connection and Collection Zones to potential storage and delivery to end users and ending in the Central Zone. The total mileage for this scenario is 355 miles, with approximately 165 miles in the Connection Zone, 110 miles in the Collection Zone, and 80 miles in the Central Zone. Of the 0.5 MMTPY throughput scenarios, Scenario 1 has the longest total distance and allows for the most direct access to potential depleted oil and gas fields for underground storage in Central California. Figure 13 illustrates the potential production location, zones, and conceptual pipeline routing for this scenario.

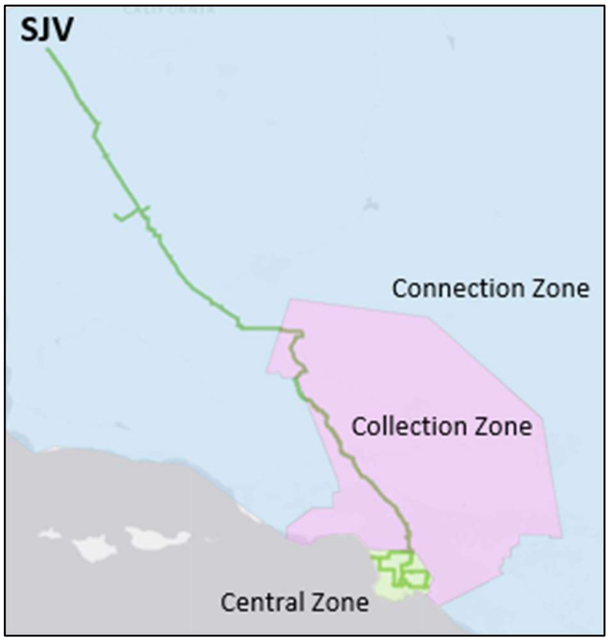

Figure 13. Scenario 1 Illustration

Scenario 2: Lancaster

Scenario 2 consists of a pipeline system that initiates in the Lancaster Production Area in the Collection Zone, before heading southwest within the Collection Zone to deliver hydrogen to potential end users and ending in the Central Zone. There is also a portion of this system heading north into the Connection Zone to accommodate potential storage and delivery to end users in the Connection Zone. The total distance for this scenario is 314 miles, with approximately 87 miles in the Connection Zone, 147 miles in the Collection Zone, and 80 miles in the Central Zone. Of the 0.5 MMTPY throughput scenarios, Scenario 2 presents the shortest distance from a potential production location (Lancaster) to the LA Basin and is located relatively close to potential Central California underground depleted oil and gas fields storage access. Figure 14 illustrates the potential production locations, zones, and conceptual pipeline routing for this scenario.

Figure 14. Scenario 2 Illustration

Scenario 3: Blythe

Scenario 3 consists of a pipeline system that initiates in the Blythe Production Area in the Connection Zone, before heading west through the Connection and Collection Zones to deliver hydrogen to potential users, and ending in the Central Zone. The total distance for this scenario is 303 miles, with approximately 200 miles in the Connection Zone, 23 miles in the Collection Zone, and 80 miles in the Central Zone. Of 0.5 MMTPY throughput scenarios, Scenario 3 has the shortest total distance and is located closest to potential underground salt basin storage outside of California. Figure 15 illustrates the potential production locations, zones, and conceptual pipeline routing for this scenario.

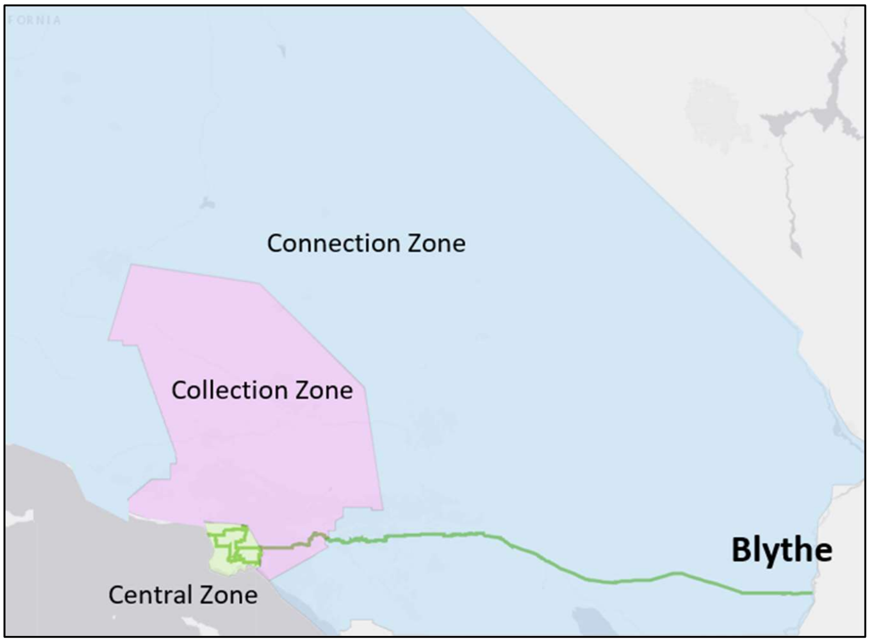

Figure 15. Scenario 3 Illustration

Scenario 4: SJV and Lancaster

Scenario 4 consists of a pipeline system that combines flow from the SJV and Lancaster Production Areas in the Connection and Collection Zones to potential storage and delivery end users, and ending in the Central Zone. The total mileage for this scenario is 392 miles, with approximately 165 miles in the Connection Zone, 147 miles in the Collection Zone, and 80 miles in the Central Zone. Of the 1.0 MMTPY throughput scenarios, Scenario 4 has the shortest total distance and provides potential access to underground storage located between the SJV and Lancaster production locations. Figure 16 illustrates the potential production locations, zones, and conceptual pipeline routing for this scenario.

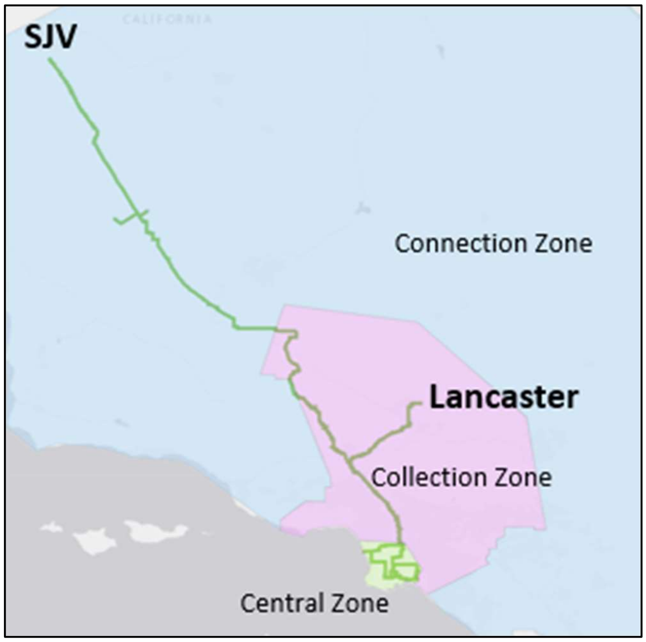

Figure 16. Scenario 4 Illustration

Scenario 5: Lancaster and Blythe

Scenario 5 consists of a pipeline system where flow from the Lancaster and Blythe Production Areas are combined in the Central zone to deliver hydrogen to potential users. The pipeline from the Lancaster Production Area is located in the Collection Zone and splits south towards the Central Zone to deliver hydrogen to Southern California, and north towards potential access to storage and delivery to end users in the Connection Zone. The pipeline from the Blythe Production Area travels west through the Connection and Collection Zones to transport hydrogen to the Central Zone. The total mileage for this scenario is 537 miles, with approximately 286 miles in the Connection Zone, 171 miles in the Collection Zone, and 80 miles in the Central Zone. Of the 1.0 MMTPY throughput scenarios, Scenario 5 assumed potential depleted oil and gas fields storage access in Central California for the Lancaster production location, and storage access outside of California for the Blythe production location. Figure 17 illustrates the potential production locations, zones, and conceptual pipeline routing for this scenario.

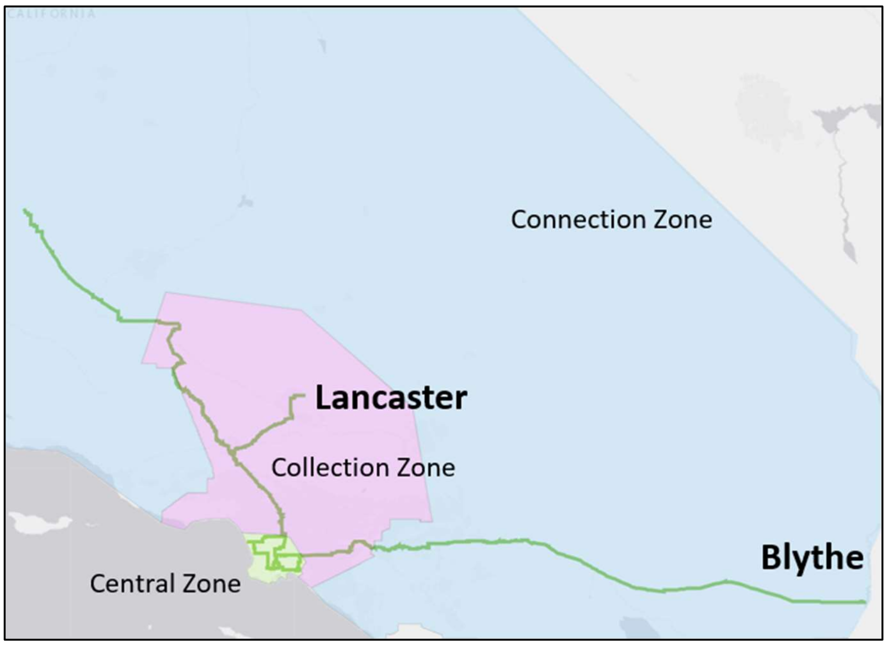

Figure 17. Scenario 5 Illustration

Scenario 6: SJV and Blythe

Scenario 6: SJV and Blythe

Scenario 6 consists of a pipeline system where flow from SJV and Blythe Production Areas are combined in the Central Zone to deliver hydrogen to potential users. The pipeline from the SJV Production Area is located in the Connection Zone and travels south towards potential storage access and delivery to end users in Central and Southern California, ending in the Central Zone. The pipeline from the Blythe Production Area travels west through the Connection and Collection Zones to transport hydrogen to the Central Zone. The total mileage for this scenario is 578 miles, with approximately 364 miles in the Connection Zone, 134 miles in the Collection Zone, and 80 miles in the Central Zone. Of the 1.0 MMTPY throughput scenarios, Scenario 6 has the longest total distance and assumed Central California storage access for the SJV production location, and storage access outside of California for the Blythe production location. Figure 18 illustrates the potential production locations, zones, and conceptual pipeline routing for this scenario.

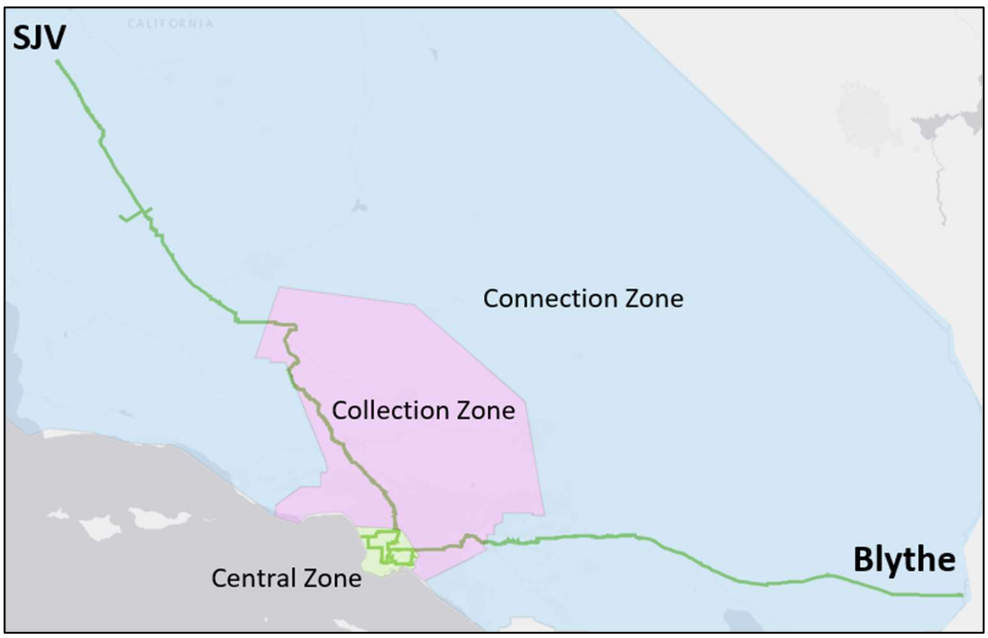

Figure 18. Scenario 6 Illustration

Scenario 7: SJV and Lancaster

Scenario 7 consists of a pipeline system combining flow from the SJV and Lancaster Production Areas in the Connection and Collection Zones to potential storage and delivery to end users, ending in the Central Zone. The total mileage for this scenario is 390 miles, with approximately 164 miles in the Connection Zone, 146 miles in the Collection Zone, and 80 miles in the Central Zone. This pipeline route is identical to Scenario 4 but with increased production capacity of 0.75 MMTPY at each location, resulting in the 1.5 MMTPY throughput. Of the 1.5 MMTPY throughput scenarios, Scenario 7 has the shortest total distance and provides access to potential in-state underground storage located between the SJV and Lancaster production locations. Figure 19 illustrates the potential production locations, zones, and conceptual pipeline routing for this scenario.

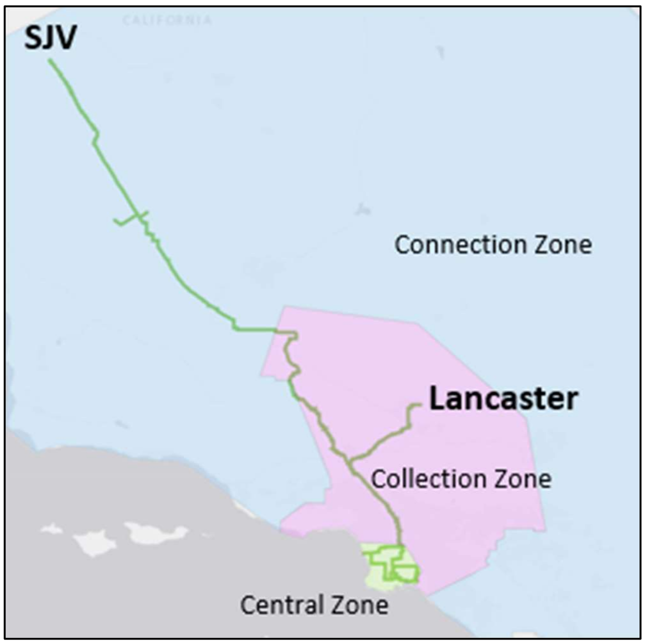

Figure 19. Scenario 7 Illustration

Scenario 8: SJV, Lancaster, and Blythe

Scenario 8 consists of a pipeline combining flow from the SJV and Lancaster Production Areas, and a separate pipeline from the Blythe Production Area to deliver hydrogen to end users, ending in the Central Zone. The total mileage for this scenario is 616 miles, with approximately 364 miles in the Connection Zone, 171 miles in the Collection Zone, and 80 miles in the Central Zone. Of the 1.5 MMTPY throughput scenarios, Scenario 8 has the longest total distance and assumed Central California storage access for the SJV and Lancaster production locations, and storage access outside of California for the Blythe production location. Figure 20 illustrates the potential production location, zones, and conceptual pipeline routing for this scenario.

Figure 20. Scenario 8 Illustration

3.3.2. Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES)

In October 2022, SoCalGas partnered with ARCHES[38], which is a public-private partnership to create a sustainable, statewide, clean hydrogen hub in California utilizing local renewable resources. ARCHES's objective is to fully decarbonize the regional economy, while prioritizing environmental justice, equity, economic leadership and workforce development.

In September 2022, DOE's Office of Clean Energy Demonstrations (OCED) issued Funding Opportunity Announcement DE-FOA-0002779 (FOA) to solicit applications from six to ten regional H2Hubs to receive federal funding from the 2021 Infrastructure Investment and Jobs Act (IIJA). The stated purpose of this program is to "catalyze investment in the development of H2Hubs that demonstrate the production, processing, delivery, storage, and end-use of clean hydrogen, in support of the Biden Administration's goal to achieve a carbon-free electric grid by 2035 and a net zero emissions economy by 2050."[39] As explained in the FOA, each H2Hub is to be executed over approximately 8-12 years, or sooner, depending on the size and complexity of the H2Hub.[40]

SoCalGas coordinated with ARCHES throughout the development of ARCHES's application for federal funding for the California H2Hub, and Angeles Link was included as part of ARCHES's application in April 2023. On October 13, 2023, DOE announced that the California H2Hub was selected for an award up to $1.2 billion. DOE and ARCHES are currently in negotiations to determine the award amount as well as project milestones.

Two segments of Angeles Link are part of this foundational California H2Hub. One segment will be an approximately 80-mile pipeline near existing SoCalGas pipeline rights-of-way, expected to connect various producers in the San Joaquin Valley in Central California.

[38] ARCHES is co-founded by the Governor's Office of Business and Economic Development, the University of California, a statewide labor coalition organized by the State Building and Construction Trades Council of California, and the Renewables 100 Policy Institute. *See* ARCHES-FAQ-Basic-1.pdf (archesh2.org)
[39] DOE, FOA (September 22, 2022) at 6, *available at:* https://oced-exchange.energy.gov/FileContent.aspx?FileID=40a1ff87-622d-4ef5-8d7c-89bfe089fd11.
[40] *Id.* at 18.

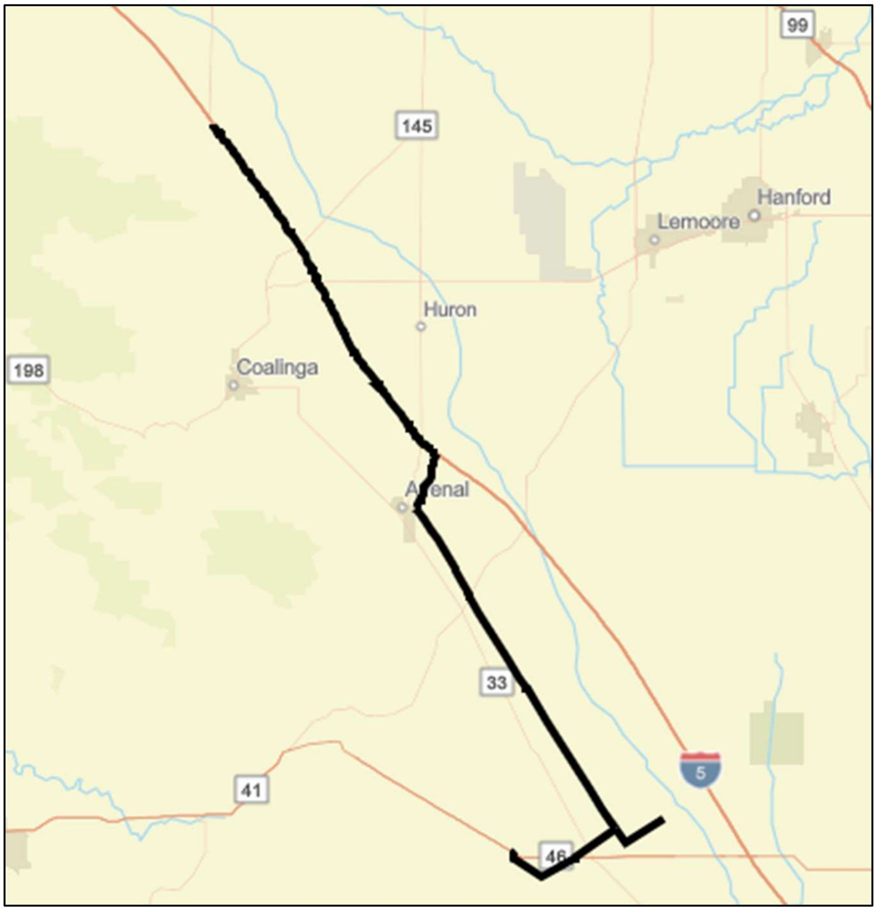

Figure 21. Illustration of ARCHES, Segment C

The second segment would run approximately 45 miles from Lancaster to the Los Angeles Basin with proposed routing configured near existing pipeline rights-of-way and previously disturbed corridors, as feasible, and would transport clean renewable hydrogen from producers in the Lancaster area directly to end users in the Los Angeles Basin.

Figure 22. Illustration of ARCHES, Segment B

The broader Angeles Link project would connect both segments within a pipeline system and provide backbone infrastructure dedicated to public use to allow the efficient movement of clean renewable hydrogen from producers to end users to support California's initiative to accelerate renewable hydrogen projects.[41] Within this Analysis, Preferred Routes are routes which connect Segments B and C.

3.3.3. Configuration Narrowed

To achieve the vision of Angeles Link to connect clean renewable hydrogen production sources to various delivery points anticipated in Central and Southern California, including the LA Basin, the pipeline network was evaluated holistically, leading to a route evaluation. This information was integrated in the following ways within this Analysis to identify those routes of highest possible potential to achieve the objectives of Angeles Link:

- Preferred Routes are routes which connect areas of clean renewable hydrogen production with areas of concentrated demand (Section 2.1 – The Role of the System)

[41] ARCHES Mission, available at: https://archesh2.org/about/

- Preferred Routes are routes which have pipeline passing through all three zones (Section 2.2 – Zone Development).
- Preferred Routes are routes traverse 500 miles in distance or less (Section 3.3.1 – Scenarios)
- Preferred Routes are routes which connect SoCalGas's ARCHES Projects, Segments B and C (Section 3.3.2 – Alliance for Renewable Clean Hydrogen Energy Systems).

The objective of this Routing Analysis in Phase 1 is to evaluate and determine several possible preferred routes during the feasibility stage of Angeles Link. Subsequent Pre-FEED and FEED activities in Phase 2 will select one preferred route and will assess the routes on a more granular level.

3.3.4. Preferred Routes Identified

Preliminary pipeline segments were assembled in various configurations to meet the established criteria for preferred route. Following the previously described evaluation efforts, four preferred route configurations emerged. The four Preferred Route Configurations titled: A, B, C, and D, are shown in Figure 23 below. Route Variation 1 was also added after evaluating ESJ Screening information and in response to stakeholder feedback as a variation for further evaluation in Phase 2 as it has the potential to minimize route mileage traversing disadvantaged communities in the LA Basin. Chapter 4 of this Analysis includes more detailed information about Route Variation 1. These configurations represent high-level preliminary pathways of highest potential to connect clean renewable hydrogen production with concentrated areas of demand and the routes and variation will be evaluated in further detail in subsequent Phases.

These four Preferred Route Configurations share the common characteristic of delivering up to 1.5 MMTPY of clean renewable hydrogen from third-party production locations in San Joaquin Valley and Lancaster to Central and Southern California, including the Los Angeles Basin, while passing through the Connection, Collection, and Central Zone and supporting connection between the two ARCHES segments. On average, they traverse approximately 450 miles.

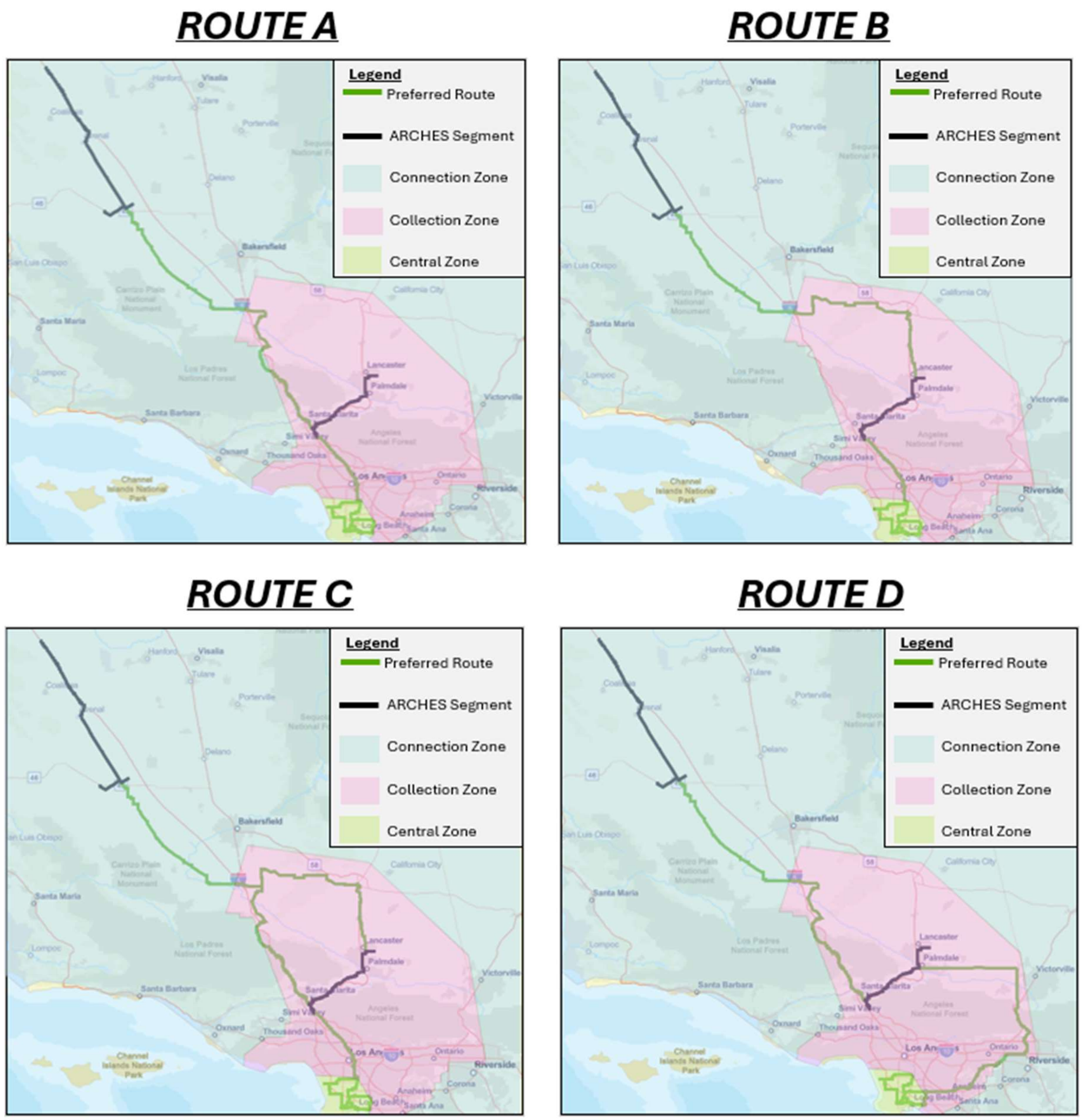

Figure 23. Preferred Route Configurations with Zones

Figure 24, below, illustrates LA Basin and includes Routes A, B, and C, as a solid line from their access point into LA Basin. Route Variation 1 would be a part of these routes in their entirety and is depicted as a dashed line for differentiation in the below image. Route D can also be seen in the Figure as it accesses LA Basin from the East.

Figure 24. Illustration of Preferred Route and Route Variation 1

4. DISADVANTAGED COMMUNITIES AND ENVIRONMENTAL SOCIAL JUSTICE

SoCalGas's Angeles Link Environmental Social Justice Community Engagement Plan (ESJ Plan) describes how SoCalGas proposes to work with community-based organizations and Disadvantaged Communities (DACs) in Phase 2 to prioritize community engagement activities in order to inform route selection and alignment, mitigate potential impacts, and maximize Project benefits (subject to CPUC approval).

This Routing Analysis describes how DACs and Environmental Social Justice (ESJ) communities were evaluated in Phase 1 (selection of initial routing corridors) and will be taken into consideration when selecting a single preferred route in Phase 2.

4.1. Preliminary Route Identification and ESJ/DAC Considerations

As part of this initial route identification process, SoCalGas used information from its ESJ Plan to identify DAC and ESJ communities via a desktop GIS analysis. SoCalGas used two datasets to identify DACs:

- CalEnviroScreen (managed by the California Office of Environmental Health Hazard Assessment) which uses environmental, health, socioeconomic information to produce scores for every census tract in the state
- Climate and Economic Justice Screening Tool (Biden administration directed the Council on Environmental Quality to develop tool) which has datasets that are indicators of burdens in eight categories: climate change, energy, health, housing, legacy pollution, transportation, water and wastewater, and workforce development.

SoCalGas then considered evaluating hydrogen corridors that would avoid DAC and ESJ communities entirely. However, as described in Section 2.3, access to the LA Basin area from the San Joaquin Valley is constrained by geological features, including several mountain ranges and National Forests. Given these features, there are limitations to the potential pathways that enter the LA Basin from the areas that surround it. Figure 25 also illustrates that large areas in the San Joaquin Valley and LA Basin are designated as DACs or ESJ communities.

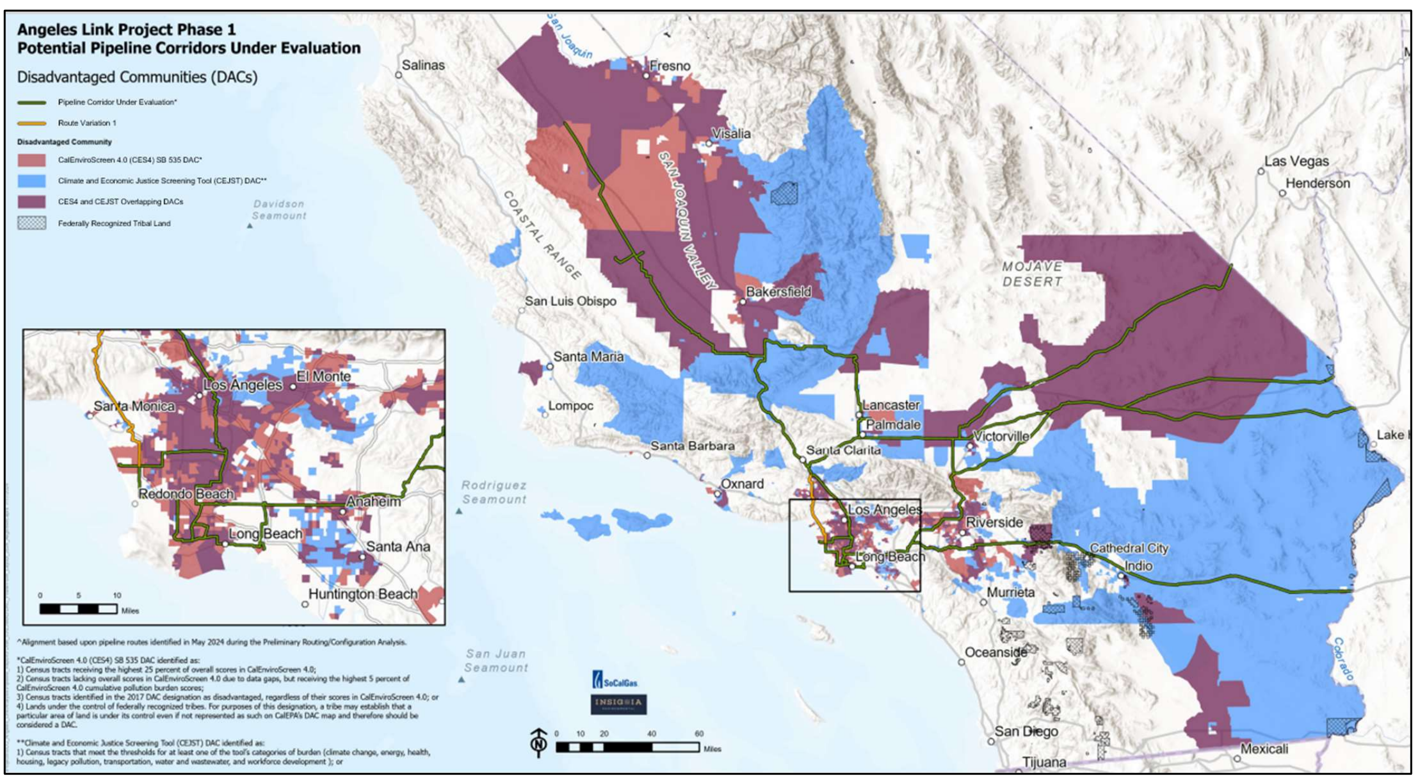

Figure 25. Illustration of Preferred Routes A, B, C, D and DACs

Routing completely out of DACs may not be feasible due to various factors including technical challenges and operational considerations that may compromise system efficiency, safety, affordability, and reliability. As described in the Chapter 2, initial selection of the corridors considered was primarily driven by the need to efficiently connect hydrogen production facilities to off taker. Many of the potential off takers Angeles Link intends to serve are concentrated within DACs. However, locating Angeles Link near these off takers could result in localized air quality improvements. For example, as demonstrated by the Nitrogen Oxide (NOx) and Other Air Emissions Assessment Draft Report (NOx Report), the zip codes closest to ports, goods movement corridors, electric generation, and other industrial activities that Angeles Link would serve benefit the most from NOx reductions in the study area. Refer to the NOx Report for information about NOx reductions by sector and geography.

4.1.1. Route Variation – DAC Avoidance

During the initial refinement process of the routes completed during Phase 1, adjustments were made to avoid instances of overlap between the corridors evaluated within 1000-ft of disadvantaged communities. As more detailed DAC data became available as part of ESJ Plan and based on PAG and CBOSG feedback, SoCalGas made further changes to its potential routes by adding a Route Variation 1. As illustrated above in Figure 25 and below in Figure 26, the Route Variation 1 is an alternative routing for the pipeline segment that runs parallel to the Interstate 5 (I-5) in the LA Basin, which traverses through densely populated DACs. This is an example of a specific evaluation for Preferred Routes A, B, and C[42] which would be studied further in Phase 2 when alignment evaluation at the street-level is conducted to determine how DAC impacts may be avoided and benefits maximized.

The Route Variation 1 presents a potential pipeline pathway for Preferred Routes A, B, and C that would potentially reduce main pipeline route mileage traversing DACs in the LA Basin. The percentage of Preferred Routes A, B, and C that traverse disadvantaged communities was found to range from 76-81%. Based on preliminary desktop analyses and following existing SoCalGas pipeline alignment, the potential Route Variation 1, if feasible, may reduce the distance that traverses DACs to approximately 67-73% of the total route distance, a decrease of approximately 8% by route and overall decreases the percentage of pipeline traversing DACs within LA Basin for these routes by approximately 20%.

Preferred Route D presents another option to reduce DAC impacts. As shown in Section 3.3.4, Preferred Route D does not contain pipelines that parallel I-5 in the LA Basin thereby avoiding the corresponding DACs in the area. The percentage of Preferred Route D that traverse disadvantaged communities was found to be approximately 69%, which is within the potential Route Variation 1 range.

In Phase 2, additional considerations will be needed to evaluate changes to accessibility, environmental impacts, and other logistic factors. SoCalGas emphasizes that preferred routes are not final and will implement its ESJ Plan in Phase 2 to incorporate community feedback into its final preferred route selection process.

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[42] Preferred Route D does not contain pipeline segments in LA Basin parallel to the I-5, as described in Section 4.1.3.

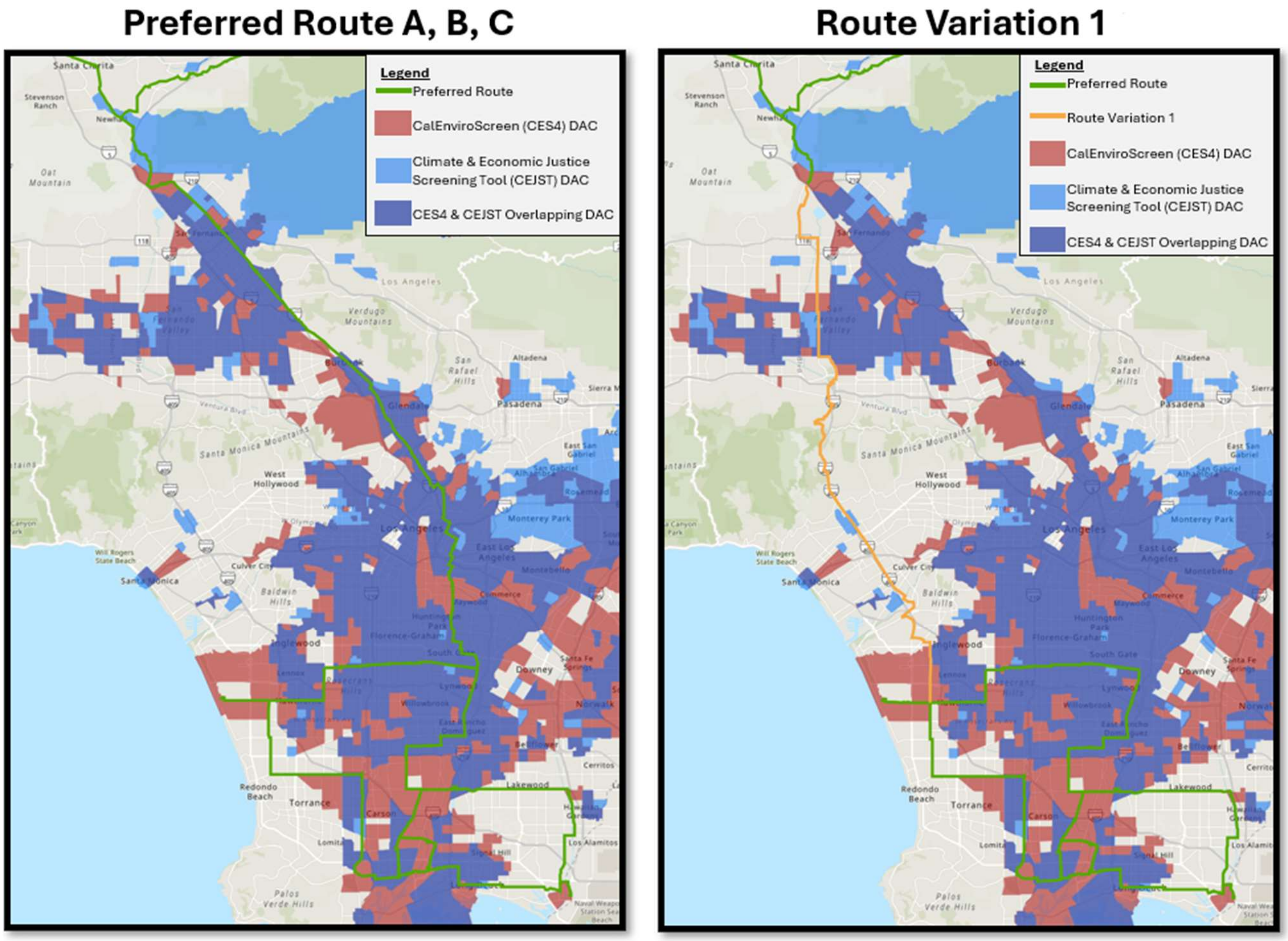

Figure 26. Illustration of Route Variation 1 and DAC[43]

4.2. Future Route Refinement and ESJ/DAC Considerations

As described in its ESJ Plan, SoCalGas proposes to meet with a broader range of stakeholders and utilize more community engagement strategies in Phase 2 to collaborate and seek input from DACs on route alignment. SoCalGas intends to convene route-specific regional stakeholder groups composed of community-based and environmental justice organizations, as well as other stakeholders who live, work, or own businesses in the community; public health organizations and local health departments; schools; labor organizations; academic researchers; additional technical experts; federal, state, and tribal decision-making bodies; and local representatives.

[43] DAC information extracted from ESJ Plan described in Section 4.1.

5. ROUTE CHARACTERIZATION

5.1. Overview

The preferred routes selected have the potential to achieve the objectives Angeles Link and can be characterized in multiple ways based on the route and its integration to the other Phase 1 Feasibility Studies. This information will be used for further evaluation in subsequent phases of Angeles Link.

5.1.1. Preferred Routes – Descriptions

Engineering Design Characteristics. Based on hydraulic analyses conducted in the Design Study, the preferred routes may have pipe diameters ranging from 16" to 36" and may require 2-3 compressor stations at 50,000 horsepower (hp) each to transport the throughput of 1.5 MMTPY. These preliminary design results were used to develop Class 5 estimates for the preferred routes that range from approximately $9-$14B. Refer to the Cost Estimates Chapter in the Design Study, for additional details.

Geographic Characteristics & Land. The Feature Evaluation described in Section 3.1 concluded that each preferred route, on average, is currently composed of approximately 40% urban areas, 53% rural land, and 7% mountainous terrain. The overall range of land type composition for the preferred routes are 38-45% for urban area, 48-56% rural land, and 6-8% mountainous terrain. Another geographic consideration is the class location, which can be used to guide pipeline design for varying population density and nearby infrastructure occupancy.[44] On average, a preferred route is composed of approximately 35% Class 1[45] location, 0.5% Class 2[46] location, 64% Class 3[47] location, and 0.5% Class 4[48] location. The overall range of class location composition for the preferred routes are 32-37% Class 1 location, 0.5% Class 2 location, 62-67% Class 3 location, and 0.5% Class 4 location.

A high-level desktop review of the SoCalGas transmission system concluded that, on average, approximately 96% of the total mileage of each preferred route was within approximately 50 feet of an existing SoCalGas high pressure pipeline asset. For each of the preferred routes, the percentage of the route that was identified in close proximity existing SoCalGas high pressure pipeline assets ranged from 94-98% of the total mileage of each route.

Based on the preliminary land rights analysis described in Section 3.2 and the current alignment of the routes, on average, approximately 41% of the total mileage of each preferred route was identified as

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[44] 49 CFR 192.5 -- Class locations. (n.d.-b). https://www.ecfr.gov/current/title-49/subtitle-B/chapter-I/subchapter-D/part-192/subpart-A/section-192.5
[45] Per 49 CFR 192.5(b)(1), Class Location 1 is any area that extends 660-feet on either side of the centerline of any continuous 1-mile length of onshore pipeline that has 10 or fewer buildings for human occupancy
[46] Per 49 CFR 192.5(b)(2), Class Location 2 is any class location unit that has more than 10 but fewer than 46 buildings intended for human occupancy
[47] Per 49 CFR 192.5(b)(3), Class Location 3 is any class location unit that has 46 or more buildings intended for human occupancy or any area where the pipeline lies within 300-feet of either a building or a small, well-defined outside area (such as a playground, recreational area, outdoor theater, or other place of public assembly) that is occupied by 20 or more persons on at least 5 days a week for 10 weeks in any 12-month period. (The days and weeks need not be consecutive.)
[48] Per 49 CFR 192.5(b)(4), Class Location 4 is any class location unit where buildings with four or more stories are prevalent.

potentially able to be located parallel to facilities for which SoCalGas has existing Direct Land Rights. For each of the preferred routes, the percentage of the route that was identified as potentially able to be located parallel to facilities for which SoCalGas has existing Direct Land Rights ranged from 36-48% of the total mileage of such route. If a broader spectrum of public rights of way within each of the preferred routes were considered,[49] the range of the preferred routes' percentage of total mileage within existing rights of way could potentially increase to 53-76% and would be on average, approximately 63% of the total mileage of each preferred route. These percentages are preliminary and subject to change based on the final alignment in subsequent phases of Angeles Link. Refer to Section 3.2 for additional Land Rights details and discussion.

The Production Study identified potential third-party underground storage locations in Central California, near the San Joaquin Valley (SJV) to balance projected fluctuations in production and demand. Since the preferred routes include the same potential SJV and Lancaster third-party hydrogen producers, they also share the same potential Central California storage prospects.

Social Characteristics. The Feature Evaluation described in Section 3.1 concluded that the preferred routes avoid physical conflicts with existing infrastructure and buildings, most landfills and hazardous waste sites, cultural and tribal resource areas,[50] and historic locations designated by the National Register of Historic Places.

An evaluation was also conducted to determine the distance of the preferred pipeline route alignments that traverses census tracts designated as disadvantaged communities (DACs) as defined by CalEnviroScreen and Climate & Economic Justice Screening Tool data. The distance of each preferred route that traverses DAC census tracts range from 69-81%. Rerouting the pipeline configuration in the LA Basin using the Route Variation 1 reduces the percentage of pipeline that traverse DAC census tracts to 67% - 73%. The Route Variation 1 will be studied in more detail in Phase 2. Refer to Chapter 4 for details on Disadvantaged Communities (DACs) and Environmental Social Justice (ESJ) analyses, including proposed routing variation that would reduce the main pipeline distance routed through these communities.

System Zones. Table 4 below shows the various composition of the four preferred routes. As evaluated, each route is composed of preliminary segments that fall within the Connection, Collection, and Central Zones. Both potential production and demand may be accessed in every Zone.

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[49] Analysis inclusive of public rights of way, conducted separately as part of the Feature Evaluation.
[50] Cultural and tribal areas identified by Tribal Nations, Bureau of Indian Affairs, or State Historic Preservation Office. Refer to the Segment Attribute Glossary in Appendix A.

Table 4. Preferred Routes A, B, C, D Segments and Zones

Zone	Segment	Preferred Routes A	B	C	D
Connection	C *(ARCHES Segment)*	✓	✓	✓	✓
	R	✓	✓	✓	✓
Collection	B *(ARCHES Segment)*	✓	✓	✓	✓
	E		✓	✓	
	G				✓
	I				✓
	J				✓
	K	✓		✓	✓
	L	✓		✓	✓
	M		✓	✓	
	Y	✓	✓	✓	
Central	A	✓	✓	✓	✓
	D	✓	✓	✓	✓
	S	✓	✓	✓	✓
	T	✓	✓	✓	✓
	U	✓	✓	✓	✓
	V	✓	✓	✓	✓
	W	✓	✓	✓	✓
	Y	✓	✓	✓	✓

ARCHES Production and Offtake Sites. Each preferred route can be evaluated within the context of sites identified by ARCHES for potential hydrogen production or offtake. Table 5 below summarizes the number of preliminary production sites identified by ARCHES[51] that are in close proximity to each configuration. Preferred Route Configurations A, B, and C can potentially access 5 ARCHES production sites located primarily in SJV and Lancaster areas. Preferred Route Configuration D can potentially access 7 sites located in SJV, Lancaster, and Riverside County areas. Figures 27 through 30 show the proximity of Preferred Route Configurations A, B, C, D to the ARCHES production sites.

[51] ARCHES H2, *Meet ARCHES* (October 2023), *available at:* https://archesh2.org/wp-content/uploads/2023/10/Meet-Arches_October-2023.pdf; DOE – Office of Clean Energy Demonstrations

Table 5. Preferred Route Specific Characterization Comparison

	Route Configuration			
Characterization	**A**	**B**	**C**	**D**
ARCHES Production Sites	5	5	5	7
ARCHES Offtake Sites	8	8	9	15
Demand Access, %	83%	83%	83%	92%

The number of preliminary offtake sites identified by ARCHES[52] located near each configuration is also summarized in Table 5. Preferred Route Configurations A, B, and C can potentially access 8 and 9 ARCHES offtake sites located primarily in southern SJV, Lancaster, and the LA Basin. Preferred Route Configuration D can potentially access 15 sites located in southern SJV, Lancaster, LA Basin, and Riverside County. Figures 26 through 29 shows the proximity of Preferred Route Configurations A, B, C, D to the ARCHES offtake sites.

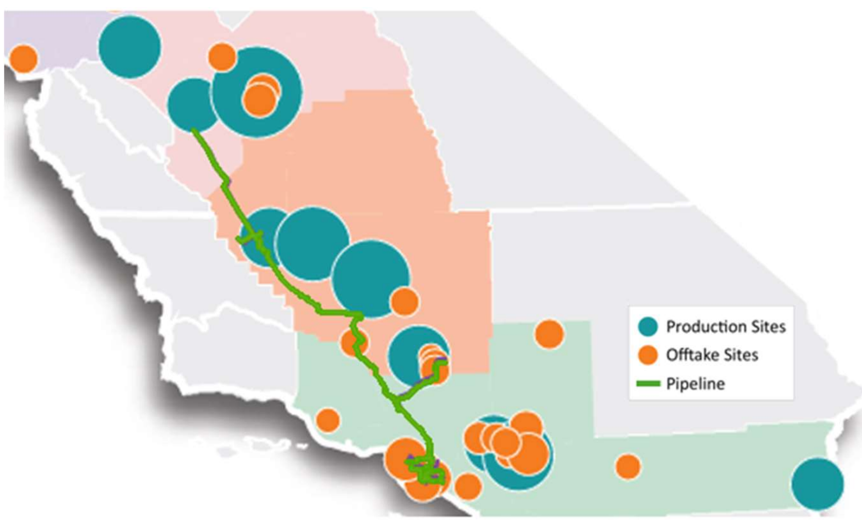

Figure 27. Preferred Route Configuration A and ARCHES Map

[52] Ibid.

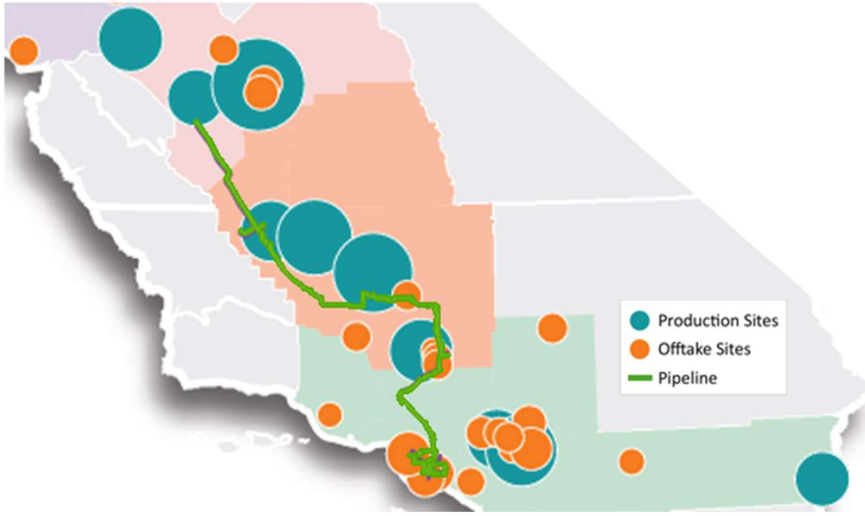

Figure 28. Preferred Route Configuration B and ARCHES Map

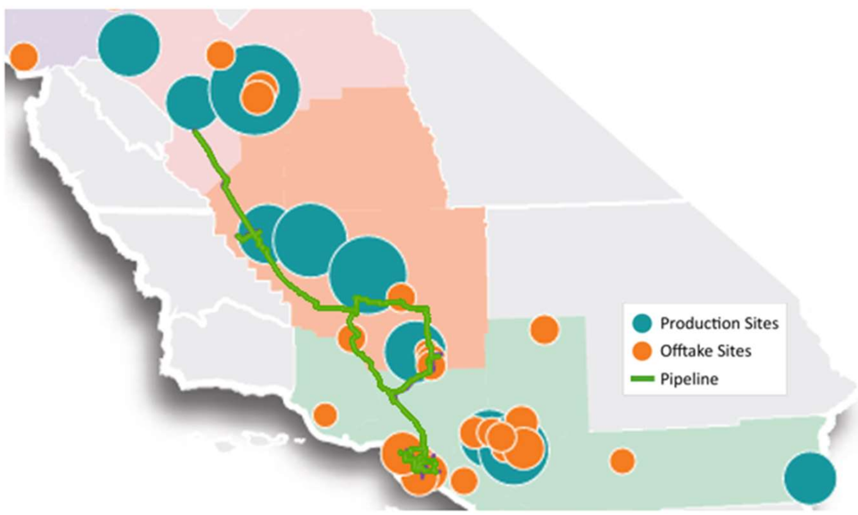

Figure 29. Preferred Route Configuration C and ARCHES Map

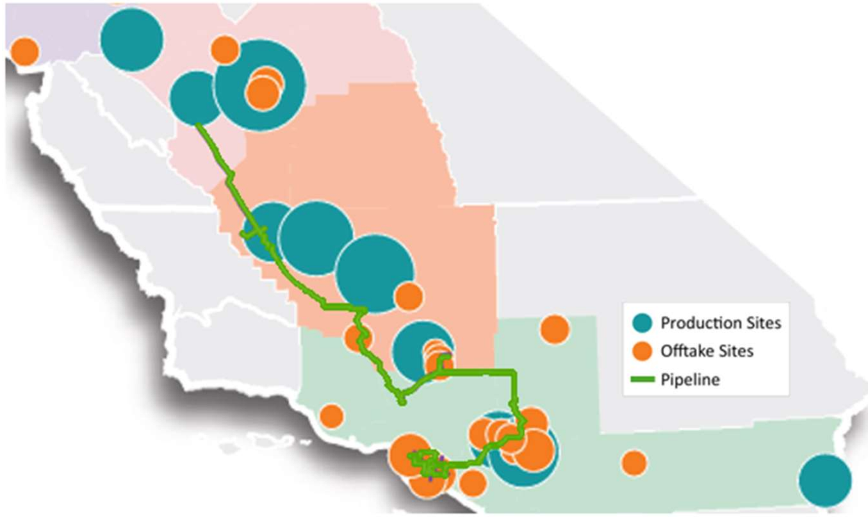

Figure 30. Preferred Route Configuration D and ARCHES Map

Demand Access. The Demand Study identified potential clean renewable hydrogen demand in Central and Southern California. The geographic distribution of this demand – specifically the 2045 Ambitious Demand Case – is illustrated below by percentage into geographic regions. Preferred Route Configurations A, B, and C are capable of accessing 83% of the total 2045 high demand projected in the Bakersfield, Lancaster, and Los Angeles geographic regions. Preferred Route Configuration D is capable of accessing 92% of the total 2045 high demand projected in the Bakersfield, Lancaster, Los Angeles, and Riverside geographic regions. Figure 31 shows a map of the Demand breakdown by geographic region and these percentages, as they apply per route, are included in Table 5.

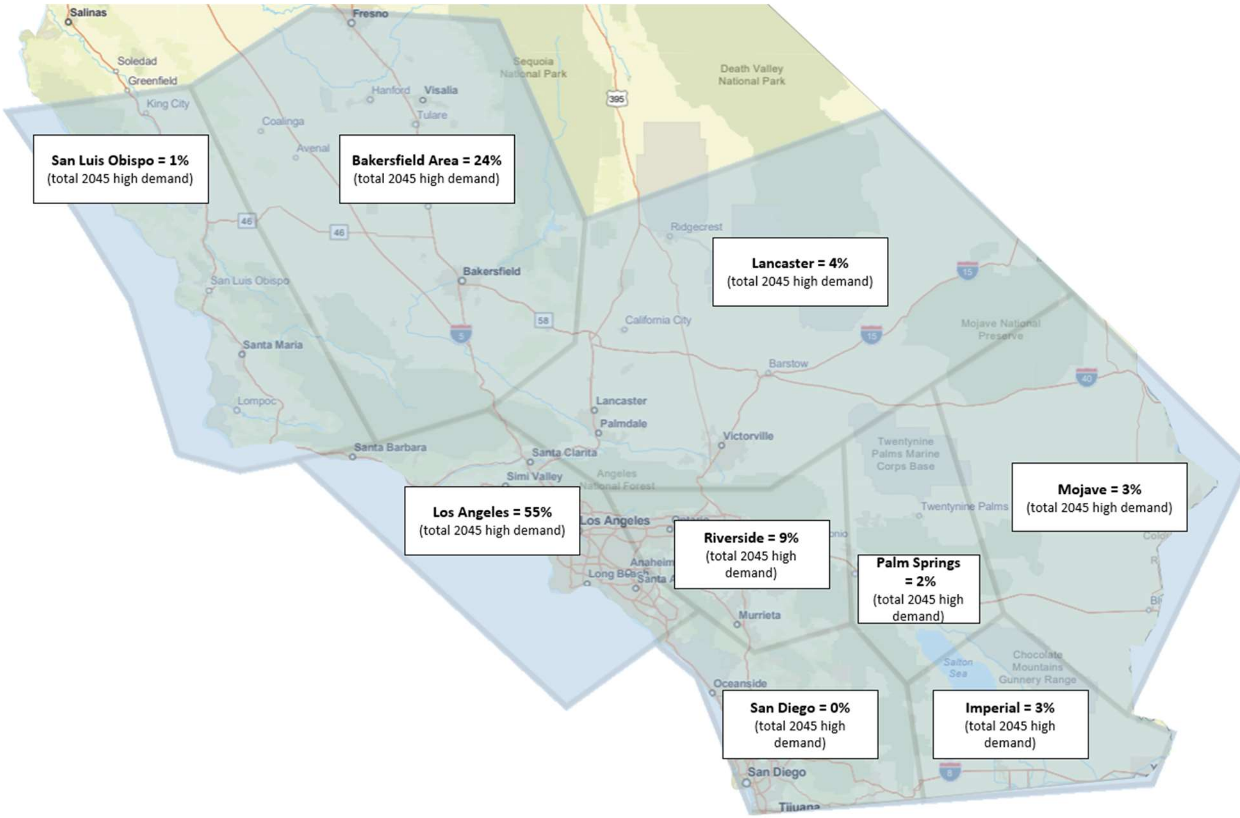

Figure 31. Demand by Geographic Region

5.1.2. Preferred Route – Geography

Preferred Route A

Preferred Route A starts in the San Joaquin Valley, approximately 40 miles southwest of Fresno, CA, near Interstate 5 and US 33. It heads southeast, roughly paralleling I-5 for 30 miles, then turns southwest near Avenal. Continuing southeast through Valley Acres and the San Gabriel Mountains, it roughly parallels I-5 to Valencia and Santa Clarita. Another section starts in Lancaster, goes south through Palmdale, and roughly parallels US 14 to Santa Clarita, connecting to the main route. The route then goes through Sylmar and Burbank, heading south to South Gate. It branches off, with one segment heading west to El Segundo, Lawndale, Carson, and ending in Wilmington, and the other through Compton and Long Beach, ending at the Port of Long Beach. Total route mileage is approximately 390 miles.

Figure 32. Preferred Route A Map

Preferred Route B

Preferred Route B also begins in the San Joaquin Valley, approximately 40 miles southwest of Fresno, CA, near I-5 and US 33. It heads southeast, roughly paralleling I-5 for 30 miles, then turns southwest near Avenal. Continuing southeast through Valley Acres, it then turns east for 25 miles to Lancaster. From there, it heads south through the San Gabriel Mountains to Valencia and Santa Clarita. It continues through Sylmar and Burbank, heading south to South Gate. It branches off, with one segment heading west to El Segundo, Lawndale, Carson, and ending in Wilmington, and the other through Compton and Long Beach, ending at the Port of Long Beach. Total route mileage is approximately 406 miles.

Figure 33. Preferred Route B Map

Preferred Route C

Preferred Route C combines routing from configurations A and B in a loop. One side roughly parallels I-5 through the San Gabriel Mountains to Valencia and Santa Clarita. The other side roughly parallels US 14 to Santa Clarita. The route begins in the San Joaquin Valley and ends at the Ports of Los Angeles and Long Beach. Total route mileage is approximately 472 miles.

Figure 34. Preferred Route C Map

Preferred Route D

Preferred Route D starts in the San Joaquin Valley and branches at Lancaster, heading further east to Victorville, then south to Cajon Junction, roughly paralleling I-15. It turns west near Fontana, southwest through Ontario Ranch and Chino Hills, then west through Yorba Linda and Anaheim. It continues west through Lakewood and Long Beach, ending at the Ports of Los Angeles and Long Beach. An additional branch starts in South Gate, heads west to El Segundo, then south through Lawndale and Carson, ending in Wilmington. Total route mileage is approximately 481 miles.

Figure 35. Preferred Route D Map

Route Variation 1

Route Variation 1 starts in Northern San Fernando Valley as a continuation of Preferred Routes A, B, and C[53], and replaces a portion of 42 miles of segment Y in the previously identified routes. Starting at approximately the Newhall Pass, the route variation roughly parallels I-405 and proceeds South through the Sepulveda Pass. In Hawthorne, the route rejoins the pipeline pathways identified in the Central Zone. Total route variation mileage is approximately 43 miles.

Figure 36. Route Variation 1 Map

6. FUTURE CONSIDERATIONS

6.1. Route Optimization

Route optimization is the process of determining the most efficient path for a pipeline, with consideration to a variety of factors that seek to avoid, minimize, and mitigate potential environmental and social impacts, costs, and risks while maximizing operational efficiency and safety. The key elements

[53] Preferred Route D does not contain pipeline segments parallel to the I-5, as described in Section 5.1.2.

of route optimization include: stakeholder impacts and land use, environmental considerations, safety and risk management, cost minimization, logistical and operational efficiency, technical feasibility, and future scalability. A street-level alignment evaluation of each pipeline was not conducted in Phase 1 and is expected to occur in subsequent phases of Angeles Link.

Consistent with these overarching elements and the purpose and need set forth for Angeles Link, future analysis would consider the following factors to further optimize the Angeles Link preferred pipeline route and execute refinement through efficient use of resources and to minimize potential impacts to communities. These factors would be incorporated in the proposed routing criteria utilized to evaluate route variations and ultimately to further refine a preferred route in Phase 2.

- Follow generally accepted principles for siting infrastructure.
- Avoid unnecessary impacts to the DAC and the environment, where feasible.
- Allow for safe and efficient construction and testing activities.
- Provide all-weather accessibility for operations, maintenance, and emergency response.
- Meet current and near-term energy needs

A pipeline system like Angeles Link consists of many interconnected components that are designed to safely work together. During pre-FEED and FEED, these various components will be evaluated holistically to define a system route and develop a 30% engineering design of the route and associated facilities.

In Phase 2 of the Project, Pipeline routing will be advanced to a level of progressively higher detail and definition during pre-FEED and FEED activities. Detailed routing information supports the specification of critical pipeline characteristics such as diameter, grade, and wall thickness. During pre-FEED and FEED, the pipelines will be designed to meet or exceed applicable pipeline operating and safety standards, including those that may impact routing decisions, such as consideration of population density/class location, or material selection.[54]

Pipeline routing will be refined throughout Phase 2 following an iterative engineering process. Preferred routes identified within this report are relatively high-level and may look like bold lines on a map. In Phase 2, during pre-FEED, SoCalGas will identify a preferred system route, and refine the routing to identify the potential specific alignments where the pipeline and related facilities may be located. During FEED, the pipeline route will be further refined to identify the pipeline and facilities placement within that alignment within tens of feet.

Potential route variations, which were not part of the initial corridors considered, would be further explored in subsequent phases of Angeles Link as appropriate. During the feasibility analysis conducted in Phase 1, data points were identified and PAG/CBOSG feedback received that that led to the inclusion of a Route Variation 1. Although route alignment was not an objective of this Feasibility Analysis, subsequent phases of Angeles Link will focus on determining pipeline alignment and minimizing impacts at a street-level using multiple siting features – social, engineering, and geological. An example of one of these areas identified for further exploration is in LA Basin.

Route Variation 1 follows the footprint of existing SoCalGas high pressure pipeline facilities from San Fernando Valley to Hawthorne. The initial Preferred Route alignment of the route along I-5 South was

[54] Refer to the Angeles Link Phase 1 - Plan for Applicable Safety Requirements

chosen for evaluation as it is located closer to potential offtake facilities and passes through more level terrain. During Phase 2, the Route Variation 1 and other potential routes that differ in alignment from what is currently identified in this report, will be studied for siting potential.

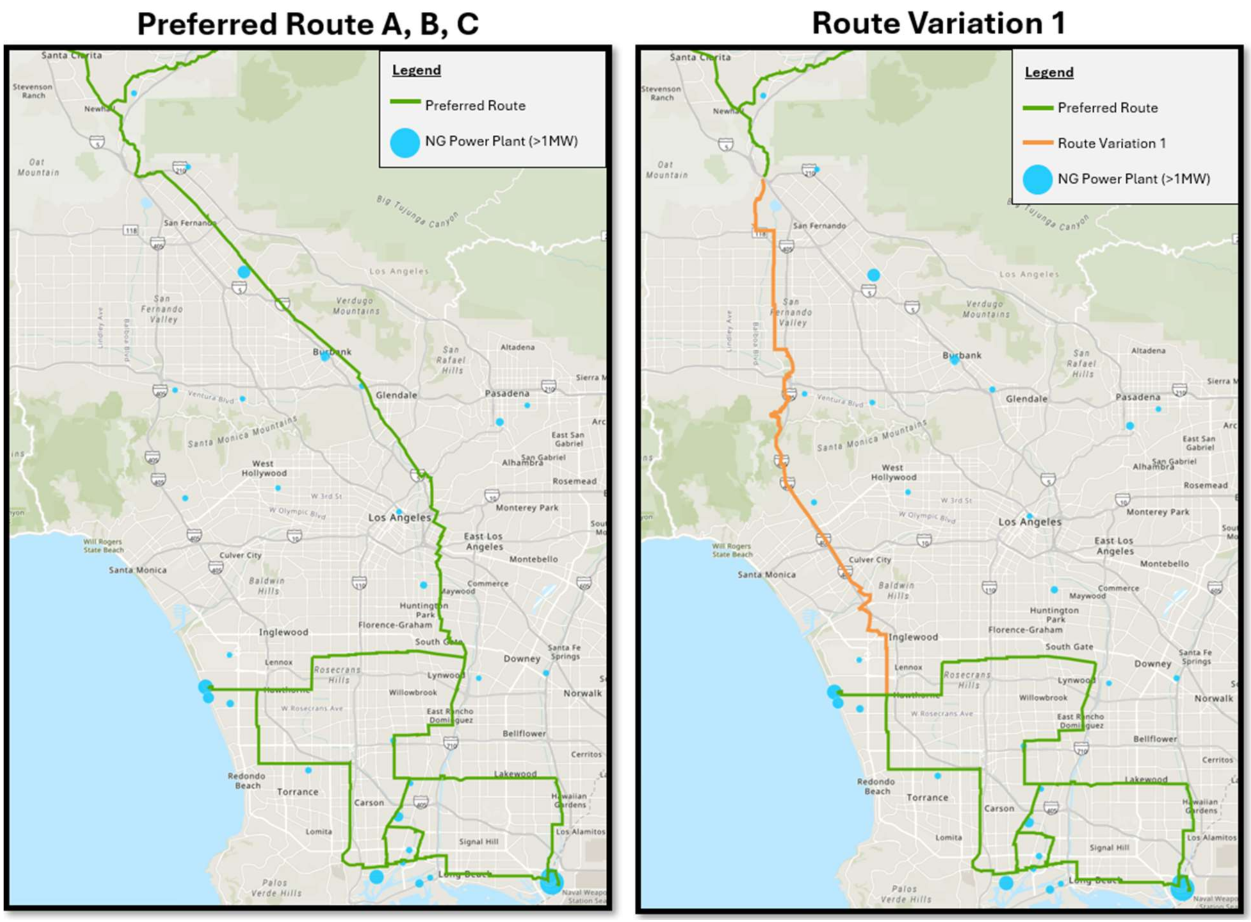

Figure 37. Illustration of Route Variation 1 and Power Plants (Natural Gas as Primary Energy Source)[55]

While this section identifies potential route variation, it is important to note that other viable options may exist that were not identified in this analysis. The identification of this variation does not imply it is the only or most advantageous option available. Numerous factors, including social and environmental impact, cost, safety, technical engineering, and logical considerations, must be thoroughly evaluated before final siting of a route.

[55] California power plants. (n.d.-b). https://gis.data.ca.gov/datasets/4a702cd67be24ae7ab8173423a768e1b_0/about

6.2. Future Siting Analysis

In Phase 2, as a preferred route is selected, a detailed analysis of pipeline siting and land rights options (e.g., Rights of Way, Direct Land Rights, as well as new easements or licenses) for the proposed pipeline will be conducted for the selected configuration and any route variation(s). Future considerations will evaluate existing land rights and infrastructure, identify potentially complex ownership interests, title exceptions, concurrent usage or specific land use restrictions, and additional title due diligence and property surveys may be performed to develop further detailed refinement and a preliminary land acquisition plan.

6.3. Weighted Evaluation

This Routing Analysis conducted during the feasibility stage of Angeles Link, evaluated potential routes from a broad system perspective to identify those with the highest overall potential of connecting clean renewable hydrogen production with potential offtake. A weighted ranking system was not employed to evaluate the potential routes as the level of detail was premature for an accurate down-selection process to be employed and would have increased the risk of potentially overlooking options of greater performance ability.

In subsequent phases of the project, analysis of more detailed and precise data will allow ranking and scoring to be conducted based on specific features. This approach delivers a higher degree of accuracy and will allow for continued engagement with stakeholders for feedback and revision.

6.4. Large-Scale Local Infrastructure Initiatives

The identification and consideration of other on-going or planned large-scale infrastructure projects or initiatives expected to occur over the next five years holds value to the planning of Angeles Link. A comprehensive understanding of these events and projects will allow for strategic planning, coordination, collaboration, and risk management.

Resource allocation planning is an important consideration, as substantial labor, equipment, and materials are typically needed for infrastructure projects. Awareness of other project plans creates the ability to anticipate demand and strategically plan for appropriate resource allocation, including identifying and addressing any potential conflicts or opportunities with regard to physical project siting during the early stages of project planning.

Another important factor is the opportunity for coordination and identifying overlapping construction zones. Multiple projects planned in close proximity or within the same timeframe may lead to opportunities to share infrastructure such as access roads or staging areas. Identification of potential conflicts, such as overlapping construction zones allows for additional flexibility to be built into the project for adaptability, thereby managing risks more effectively throughout the execution of projects. This collaborative approach can lead to significant cost savings and reduced potential environmental and social impacts. It may also support synchronization of timelines and logistics to minimize disruption for local communities and more seamless project execution.

For example, known future infrastructure projects and events local to Central and Southern California could include the following:

- **Los Angeles 2028 Olympics**[56]
- **Brightline West**[57]
- **CA High-Speed Rail**[58]
- **LA Metro –** D Line Subway Extension Project[59]
- **LA Metro –** K Line Northern Extension[60]
- **LA Metro –** Sepulveda Transit Corridor[61]

7. STAKEHOLDER COMMENTS

The input and feedback from the Planning Advisory Group (PAG) and Community Based Organization Stakeholder Group (CBOSG) has been helpful to the development of this Routing Analysis. A high-level summary of feedback that has been received to date related to the Routing Analysis is summarized below, along with a summary of how that feedback was incorporated into this analysis. All feedback received is included, in its original form, in the quarterly reports submitted to the CPUC and published on SoCalGas's website.[62]

- **Comments made by: Defend Ballona Wetlands, Environmental Defense Fund, Food and Wat Watch, Physician for Social Responsibility – Los Angeles, Protect Playa Now, Public Advocates Office, South Coast AQMD, and Southern CA Water Coalition**
  - Consider current knowledge of seismic issues not known or understood when the original rights of way of existing pipelines were established. Study and consider sacred site locations and engage in much greater involvement with the Indigenous Tribal Leaders of our region as well as flora and fauna potentially impacted by the Project.

  - The routing study should focus on intra-state routing options. Inter-state options evaluated should be marked distinctly from intra-state options and SoCalGas should identify regulatory uncertainties and assumptions. Results from Pivvot should include both the results from and assumptions used in the tool. Examine multiple scenarios for

[56] Los Angeles will host the 2028 US Summer Olympic Games
[57] Project Overview | Brightline West. (n.d.). https://www.brightlinewest.com/overview/project - A 218-mile passenger rail service planned to operate from Rancho Cucamonga, California to Las Vegas.
[58] About California High-Speed Rail | California High-Speed Rail Authority. (n.d.). https://hsr.ca.gov/about/high-speed-rail-authority/ - The California High-Speed Rail (HSR) project is a transportation initiative aimed at connecting Northern California to Southern California.
[59] D Line Subway Extension Project | LA Metro. (n.d.). https://www.metro.net/projects/westside/ - Extension of the subway from Wilshire/La Brea Station through Westwood/UCLA Station and is located in Central LA and Westside Cities
[60] Metro K Line Northern Extension | LA Metro. (n.d.). https://www.metro.net/projects/kline-northern-extension/ - Connect existing systems between Baldwin Hills and Hollywood
[61] Sepulveda Transit Corridor Project | LA Metro. (n.d.). https://www.metro.net/projects/sepulvedacorridor/ - Project evaluates the Sepulveda Pass for creation of transit options
[62] Angeles Link: SoCalGas, (n.d.-a). https://www.socalgas.com/sustainability/hydrogen/angeles-link

pipeline routing that include a hub model and different ways of disaggregating production.

Provide a list of potential pipeline routes and list of manufacturers and supplies. Identify existing pipelines corridors or rights-of-way along with potential new rights-of-way.

- Concerns about how the potential pathways laid out in this study affect already overburdened communities
- Perform additional analysis of existing energy infrastructure and potential land use and zoning constraints for both pipeline and hub scenarios.
- Indicate what outreach to Disadvantaged Communities (DACs) is planned as part of the analysis
- Describe how routing siting and easement is affected by hydrogen production locations.

Summary of How Themes were Incorporated into the Analysis

- The Routing Analysis evaluated certain engineering, environmental, and social attributes, including DAC, cultural sites, zoning, seismic activity, endangered species, and land type and rights. The total mileage within these areas was identified, and the Pivvot results were included in the Appendix.
- The Route Variation 1 was included to illustrate how rerouting can be achieved to avoid siting the main pipeline route within DACs in the LA Basin. In subsequent phases of Angeles Link, when siting evaluation is conducted, further analysis and community engagement will be conducted to establish appropriate pipeline alignments.
- SoCalGas has three members of its CBOSG who represent tribal communities. In response to PAG and CBOSG feedback, SoCalGas has also reached out to other organizations who represent tribal communities in Los Angeles and the Central Valley and will extend opportunities for them to join the PAG and/or CBOSG in Phase 1 or subsequent phases of the project. SoCalGas is preparing an Environmental Analysis study that evaluates cultural and tribal cultural resources based on a records search and desktop information. During future phases, SoCalGas will also perform a detailed cultural and tribal cultural resources assessment, including field surveys, to identify locations of sensitivity along the preferred pipeline routes.
- The pipeline corridors initially considered were identified and four potential preferred routes were developed and identified through this analysis. Focus was placed on routes that are all intra-state. A list of manufacturers and suppliers was not part of this feasibility analysis and will be studied in subsequent stages.
- The potential preferred routes are illustrated with regard to areas of potential clean renewable hydrogen production, as identified within the Production Study. The various routes considered within the Scenarios also include access to different locations and quantities of production. Those scenarios that include reference to inter-state facilities are clearly marked.

8. CONCLUSION

Angeles Link is proposed to support California's transition towards sustainable energy infrastructure by laying down the first steps of a pipeline network to transport clean renewable hydrogen from various production sources to delivery points in the Los Angeles Basin, which span from the Ports of Los Angeles and Long Beach, to the broader Central and Southern California region.

The Routing Analysis is crucial to identify preliminary hydrogen pipeline route pathways. To reflect a connected analysis, information from other feasibility studies were incorporated, such as from the Production and Demand Studies. Results of this Routing Analysis will aid in developing a preferred system route in Phase 2, including engineering designs based on one preferred route configuration. SoCalGas estimated direct pathways for connecting clean renewable hydrogen producers to consumers, which concluded that preferred routing configurations would be approximately 450 miles in length[63].

Further, aligning with the ARCHES mission to develop hydrogen infrastructure and a state-wide hydrogen hub, SoCalGas considered how the Angeles Link aligns with ARCHES hydrogen infrastructure placement to determine hydrogen pipeline locations in this Routing Analysis. As a result, the Routing Analysis aligned multiple segments of the proposed pipeline routing configurations with those Angeles Link segments included in ARCHES.

Integral to the planning process were the matrices developed for each of the 25 pipeline segments, which served as comprehensive tools for evaluating route development, assessing high-level engineering, environmental, and geographical attributes. These matrices incorporated a range of factors, including geological conditions, regulatory requirements, stakeholder suggestions, and potential community impacts.

Preliminary routes A, B, C, and D emerged as preferred route configurations as follows:

- Their alignment with the purpose and need of Angeles Link is supported by their ability to connect areas of high clean renewable hydrogen production potential to areas of concentrated demand;
- The layout of these routes supports reliability and resiliency of system planning in alignment with regional zones, alignment with ARCHES, and connect SoCalGas's ARCHES Projects, Segments B and C;
- Routes traverse less than 500 miles (and on average span 450 miles), to efficiently access and deliver a capacity up to 1.5 MMTPY; and
- Route Variation 1 was also added for further analysis in Phase 2 due to its potential to minimize traversing disadvantaged communities in the LA Basin.

These route alignments will be refined in subsequent phases to reduce disruptions to communities and ecosystems while maximizing accessibility to key demand centers and existing infrastructure with potential for hydrogen use. The data compiled, analyzed, and evaluated within this report serves as the basis for pre-FEED and FEED evaluation for Angeles Link in Phase 2.

[63] Average route mileage of final four preferred routes identified.

9. GLOSSARY

Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES) – A public-private partnership to create a sustainable, statewide, clean hydrogen hub in California utilizing local renewable resource to produce hydrogen with the objective to fully decarbonize the regional economy, while prioritizing environmental justice, equity, economic leadership and workforce development.

Alternative Fuel Corridors (AFC) – Federal Highway Administration designated alternative fuel corridors to support installation of EV charging, hydrogen, propane, and natural gas fueling infrastructure at strategic locations along major national highways. These corridors are updated and redesignated on an annual basis by soliciting nominations from State and local officials. This recurring process responds to the rapidly evolving state of vehicle technology, increased market adoption, and installation of infrastructure related to the use of alternative fuels.[64]

Alternative Fuels Data Center (AFDC) – A joint effort between the United States Department of Energy (DOE) and the United States Department of Transportation (DOT) to establish a national network for alternative fueling and electric vehicle charging infrastructure along national highway network corridors.

California Public Utilities Commission (CPUC) – Regulates services and utilities, protects consumers, safeguards the environment, and assures Californians' access to safe and reliable utility infrastructure and services.[65]

Corridors – A linear geographic pathway where existing utilities are already installed or have the potential to be installed in the future. In the context of this report, corridors are pathways that may contain existing or future rights-of-way (see definition below) that have been identified for preliminary evaluation plan the installation of hydrogen gas transmission lines.

Direct Land Rights – For purposes of this report, easements, licenses or other rights to use the surface of, and the space above and below land owned or controlled by a private individual or entity, a public entity or a public utility for the purpose of installing, operating, repairing, and maintaining pipelines and related facilities and equipment.

Disadvantaged Communities (DACs) - Areas disproportionately affected by environmental pollution and other factors that can lead to negative public health, concentrations of people that are of low income, high unemployment, low levels of home ownership, high rent burden, sensitive populations, or low levels of educational attainment.

Federal Highway Administration (FHWA) - An agency within the U.S. Department of Transportation that supports State and local governments in the design, construction, and maintenance of the Nation's highway system (Federal Aid Highway Program) and various federally and tribal owned lands (Federal Lands Highway Program).[66]

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[64] Alternative Fuel Corridors - Environment - FHWA. (n.d.-b). https://www.fhwa.dot.gov/environment/alternative_fuel_corridors/

[65] California Public Utilities Commission. (n.d.). What industries does the CPUC regulate? In California Public Utilities Commission. https://www.cpuc.ca.gov/-/media/cpuc-website/about-cpuc/documents/transparency-and-reporting/fact_sheets/cpuc_overview_english_030122.pdf

[66] About FHWA. (n.d.). FHWA. https://highways.dot.gov/about/about-fhwa

Front-End Planning (FEP) - A critical process for uncovering project unknowns while also developing adequate scope definition and a structured approach for the project execution process. For infrastructure projects, the FEP process assists in identifying and mitigating risks stemming from issues such as right-of-way concerns, utility adjustments, environmental hazards, logistic problems, and permitting requirements. [67]

Front-End-Engineering and Design (FEED) - The process through which the engineering design of the system route identified during pre-FEED is advanced to 30% design level, which would support a Class 3 estimate.

Geographic Information Systems (GIS) - Geographic Information Systems (GIS) are systems that capture, store, analyze, and display spatial or geographic data. GIS can be used to create maps, models, and simulations that show the patterns, relationships, and trends of various phenomena that occur on the Earth's surface or in the atmosphere.

Hard-to-electrify sectors - Those sectors of the economy that are difficult or costly to switch from fossil fuels to electricity as a source of energy. These sectors include heavy industry, aviation, shipping, and long-distance road transport. These sectors account for a significant share of California's greenhouse gas emissions and pose a challenge for achieving the state's decarbonization goals.

High Consequence Areas (HCA) -Unusually sensitive environmental areas (defined in 49 CFR 195.6), urbanized areas and other populated places (delineated by the Census Bureau), and commercially navigable waterways. [68]

High Speed Rail (HSR) - Definition of high-speed rail is relative and varies from country to country. The U.S. Federal Railroad Administration uses a speed of 110 miles per hour as the threshold for its minimum high-speed designation. [69]

Horizontal Directional Drill (HDD) - Construction contractors attach steerable drill bits, reamers, tracking and monitoring devices and other tools to the end of a drill pipe string, then slowly drill a hole underneath an obstacle from one side to the other along a path that has been carefully evaluated, permitted, and designed by engineers and scientists. [70]

Matrix - A table that lists various evaluation criteria for determining the best route for a pipeline. In the context of this report, each matrix evaluates a specific segment of the overall ALP pipeline network.

National Highway System (NHS) - Consists of roadways important to the nation's economy, defense, and mobility. [71]

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[67] Infrastructure project SCOPE DEFINITION USING project definition rating index | request PDF. (n.d.-f). https://www.researchgate.net/publication/305788839_Infrastructure_Project_Scope_Definition_Using_Project_Definition_Rating_Index

[68] HL Im fact sheet. PHMSA. (n.d.-b). https://www.phmsa.dot.gov/pipeline/hazardous-liquid-integrity-management/hl-im-fact-sheet

[69] Environmental and Energy Study Institute (EESI). (n.d.). High speed rail: Benefits, costs, and challenges. EESI. https://www.eesi.org/briefings/view/high-speed-rail-benefits-costs-and-challenges

[70] Horizontal directional drilling HDD operations white Paper.pdf. (n.d.-d). https://www.api.org/-/media/APIWebsite/oil-and-natural-gas/primers/Horizontal Directional Drilling HDD Operations White Paper.pdf

[71] National Highway System. FHWA. (n.d.). https://www.fhwa.dot.gov/planning/national_highway_system/

National Pipeline Mapping System (NPMS) - A dataset containing locations of and information about gas transmission and hazardous liquid pipelines and Liquefied Natural Gas (LNG) plants which are under the jurisdiction of the Pipeline and Hazardous Materials Safety Administration (PHMSA).

Non-discriminatory – In reference hydrogen pipeline infrastructure, this describes that it is accessible to all potential hydrogen end-users consistent with a published tariff. Accordingly, the term could be used interchangeably with the term "open access". When contracting with an open access, non-discriminatory pipeline system, customers have access to similar contracts. An alternative to this could be a "private carrier".

Open Access - Refers to a regulatory mandate to allow others to use a utility's transmission and distribution facilities to move bulk power from one point to another on a nondiscriminatory basis for a cost-based fee[72]. Accordingly, the term could be used interchangeably with the term "non-discriminatory". When contracting with an open access, non-discriminatory pipeline system, customers have access to similar contracts. An alternative to this could be a "private carrier".

Pipeline and Hazardous Materials Safety Administration (PHMSA) - Mission is to protect people and the environment by advancing the safe transportation of energy and other hazardous materials that are essential to our daily lives.

Pivvot - A third-party cloud-based application that allows a pipeline route to be identified, studied, reviewed, and refined based on hundreds of data sources available within the software.

Private Carrier - Would agree to transport goods under particular circumstances and would contract with each customer - without the assumption that a similar contract will be available to the next customer.

Rights-of-Way (ROW) - For purposes of this report, Rights-of-Way refer to the surface of, and the space above and below, any public street, alley, bridge, or other route of public travel or utility transport, for which a municipality (city or county) can grant rights of use for the purpose of installing, operating, repairing, and maintaining a pipeline system and related facilities and equipment.

Route - A pathway that a pipeline system or segment may follow. In the context of this report, routes represent potential pathways for a pipeline from third-party production and storage of clean renewable hydrogen to the delivery point, or customer. Routes may vary in level of detail.

Segment - In the context of this report, a segment represents a potential portion of the Angeles Link pipeline system. Typically, a segment is referenced to discuss the engineering analysis and siting evaluation performed with respect to that specific length of pipeline.

United States Department of Energy (DOE) - Manages the United States' nuclear infrastructure and administers the country's energy policy. [73]

[72] Auth, T. (n.d.-c). Glossary of Acronyms and other Frequently used terms. https://www.cpuc.ca.gov/news-and-updates/newsroom/glossary
[73] U.S. Department of Energy (DOE): Usagov. U.S. Department of Energy (DOE) | USAGov. (n.d.). https://www.usa.gov/agencies/u-s-department-of-energy

United States Department of Transportation (DOT) - A federal agency of the United States government that oversees the transportation system of the country. The DOT aims to ensure the safety, efficiency, accessibility, and sustainability of various modes of transportation, such as air, road, rail, water, and transit. The DOT also supports the development and innovation of transportation infrastructure, technology, and policy.

10. APPENDICES

Appendix A: Segment Attribute Glossary

Appendix B: Segment Matrices

Appendix C: Segment Mileage Summary Table

Table C.1. Approximate Segment Mileage

Segment	Phase 1 Preliminary Segment Mileage
Segment A	28
Segment B	46
Segment C	80
Segment D	8
Segment E	31
Segment F	153
Segment G	39
Segment H	92
Segment I	32
Segment J	60
Segment K	55
Segment L	10
Segment M	51
Segment N	78
Segment O	53
Segment P	51
Segment Q	123
Segment R	82
Segment S	9
Segment T	9
Segment U	7
Segment V	3
Segment W	5
Segment X	125
Segment Y	49
Total	**1,277**

Feature Characterization Matrix - Glossary

CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	ATTRIBUTE - DETAILED DEFINITION
ENGINEERING	**49 CFR 192 Class Location 1**	Length within 49 CFR 192 Class Location 1	Federal pipeline safety regulations defines Class Location 1 as any area that extends 660-feet on either side of the centerline of any continuous 1-mile length of onshore pipeline ("class location unit") that has 10 or fewer buildings for human occupancy. (See 49 CFR 192.5(b)(1).) In general, Class Location 1 is SoCalGas' most preferred Class Location for new pipeline construction.
ENGINEERING	**49 CFR 192 Class Location 2**	Length within 49 CFR 192 Class Location 2	Federal pipeline safety regulations defines Class Location 2 as any class location unit that has more than 10 but fewer than 46 buildings intended for human occupancy. (See 49 CFR 192.5(b)(2).)
ENGINEERING	**49 CFR 192 Class Location 3**	Length within 49 CFR 192 Class Location 3	Federal pipeline safety regulations defines Class Location 3 as any class location unit that has 46 or more buildings intended for human occupancy or any area where the pipeline lies within 300-feet of either a building or a small, well-defined outside area (such as a playground, recreational area, outdoor theater, or other place of public assembly) that is occupied by 20 or more persons on at least 5 days a week for 10 weeks in any 12-month period. (The days and weeks need not be consecutive.) (See 49 CFR 192.5(b)(3).)
ENGINEERING	**49 CFR 192 Class Location 4**	Length within 49 CFR 192 Class Location 4	Federal pipeline safety regulations define Class Location 4 as any class location unit where buildings with four or more stories are prevalent. (See 49 CFR 192.5(b)(4).) Where possible, SoCalGas intends to seek to avoid this Class Location for new pipeline construction.
ENGINEERING	**Adverse Soil Conditions**	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	Installation of a pipeline within adverse soil conditions, such as acid sulfate soils, expansive soils or clays, fine textured saturated soils in seismic zones, organic soils, water-saturated soils or wetlands, gravel to boulder sized rock or high bedrock, can challenge the construction, operation, and maintenance of the pipeline. Non-standard construction equipment may be required, increasing cost, and damage over time from adverse soils may decrease the lifespan of the pipeline, requiring more frequent or more extensive maintenance.
SOCIAL	**Agricultural/Pasture Land**	Agricultural/pasture land use within 50 feet of centerline	Installation and operation of the pipeline within agriculture/pastureland (e.g., prime farmland, unique farmland, or other farmland of statewide or local importance) use can offer advantages over other developed land use due to fewer limitations from existing infrastructure and construction efficiencies. Note, this criterion does not take into account land that is under deed restriction or subject to a Williamson Act contract, which would be evaluated in more detail in a future phase.
ENGINEERING	**CL Length with 15% Slope**	Length of centerline with slope greater than 15 percent (%)	Constructability access and workspace must be considered for installation of a pipeline on sloped terrain. A centerline perpendicular to and/or parallel to the slope increases the complexity which equates to slower construction productivity. When slopes exceed 15%, there is greater potential for grading, shoring, and/or benching of the construction corridor, reduced access points to the construction corridor, and soil instability, all leading to additional construction costs.
ENVIRONMENTAL	**Coastal Zone**	Length within Coastal Zone Boundary	The Coastal Zone is a legislatively-defined geographic region that establishes the area regulated under the Coastal Act Section 30103, encompassing both land and water areas along the length of the California coastline from the Oregon border to the Mexico border.
SOCIAL	**Commercial Land**	Commercial land within 50 feet of centerline	Commercial land is land designated for use by businesses that provide services to the public, such as offices, retail stores, hotels, and restaurants. Installation and operation of the pipeline within commercial land use can present constructability challenges and delays due to potential impacts to businesses when the pipeline is being installed (such as customer parking and access). There may also be an increased potential for future third party line strikes due to proximity to potential future land disturbing activities.
ENVIRONMENTAL	**Conservation Areas**	Conservation areas within 50 feet of centerline	Protected species are more commonly found in conservation areas. Planning phase timing anticipated to increase due to environmental permitting/approvals, and construction/maintenance restrictions for land use in these areas. Slower construction production due to restrictions in clearing and high potential for construction phase re-routing around the sensitive species locations.
SOCIAL	**Cultural & Tribal Resources**	Length of CL within Cultural & Tribal Resource areas	This criterion encompasses areas or sites that have been identified as potential cultural resource locations by Tribal Nations, Bureau of Indian Affairs, or State Historic Preservation Office with data from the TIGER (Topologically Integrated Geographic Encoding and Referencing) system and Line Census American Indian areas for the United States. Boundary details are reported by the federally recognized tribal governments through the Census Bureau, or the Bureau of Indian Affairs (BIA), or based on treaty or other historical document.
SOCIAL	**Disadvantaged Communities**	Total Length within Disadvantaged Communities per Senate Bill 535	As identified by Senate Bill 535 CalEnviroScreen data, disadvantaged communities are areas disproportionally affected by environmental pollution and other hazards that can lead to negative public health effects, exposure, or environmental degradation. In general, SoCalGas will seek to minimize routing new pipeline through disadvantaged communities.

Feature Characterization Matrix - Glossary			
CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	ATTRIBUTE - DETAILED DEFINITION
ENVIRONMENTAL	**Federal Endangered or Threatened Species Critical Habitat**	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	Defined as the specific areas within a geographical area occupied by a species, at the time a species was listed, that contain the physical or biological features essential to the conservation of federal endangered or threatened species that may need special management or protection. In locations where current conceptual routing encroaches on or within 500 feet of endangered or sensitive species' critical habitat, BMcD will request advisement from SoCalGas Environmental team to determine if rerouting is needed. In general, SoCalGas will seek to minimize routing new pipeline through federal endangered or threatened species critical habitats.
SOCIAL	**Federal Facility/Property**	Length within Federal Facility/Property	Installation of a pipeline within federal property presents additional permitting, constructability, and O&M considerations, such as those associated with heavy equipment loads, vibrations, and site access during planning, operation, construction and post-commissioning maintenance activities.
ENVIRONMENTAL	**Floodplain**	Length within 100-Year Floodplain Area	Aggregation of FEMA floodplain data derived to the 100 year boundary for flood risk. A 100 year flood is a flood event that has a 1 in 100 chance (1% probability) of being equaled or exceeded in any given year. Based on the expected 100 year flood flow rate, the flood water level can be mapped as an area of inundation.
ENGINEERING	**HCA**	Length within High Consequence Areas (HCA)	High Consequence Areas (HCA) identifies specific locales and areas where a release could have the most significant adverse consequences, as identified in accordance with federal pipeline safety regulations. (See CFR §192.903.)
SOCIAL	**Industrial Land**	Industrial land within 50 feet of the centerline	Industrial land generally refers to land designated for use by businesses, but the public does not tend to visit these facilities, such as manufacturing and distribution centers.
SOCIAL	**Institutional Land**	Institutional land (schools, educational facilities, hospitals, churches, daycares, nursing homes) within 100 feet of centerline	Locating the pipeline within institutional land use is generally less preferred due to potential conflicts during construction related to heavy traffic and use at these facilities.
SOCIAL	**Landfills & Hazardous Waste Sites**	Landfills & Hazardous Waste Sites	Installation of a pipeline within a landfill or known hazardous waste site is not feasible due to unknown soil properties of waste, contaminants, and unanticipated soil movement from compaction. In locations where current conceptual routing encroaches on or within landfills or known hazardous waste sites, pipeline routing is to be refined/rerouted to avoid these locations where possible. In general, SoCalGas will seek to minimize routing new pipeline through landfills and hazardous waste sites.
ENGINEERING	**Mainline Valve (MLV)**	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	Mainline valve locations are based on Federal pipeline safety regulations 49 CFR 192 Class Location and are as follows: Class 1 Location: all points in Class 1 within 10 miles of MLV (Mainline Valve every 20 miles) Class 2 Location: all points in Class 2 within 7 1/2 miles of MLV (Mainline Valve every 15 miles) Class 3 Location: all points in Class 3 within 4 miles of MLV (Mainline Valve every 8 miles) Class 4 Location: all points in Class 4 within 2 1/2 miles of MLV (Mainline Valve every 5 miles)
SOCIAL	**Maintained Public & Recreational Areas**	Maintained Public and Recreational Areas within 50 feet of centerline	Maintained land that is being used for public and recreational purposes (state, local and federal parks per United States Fish and Wildlife Service (U.S.F.W.S), sports fields, golf courses). Must be evaluated with consideration to length of Class 3 Location and HCA.
SOCIAL	**NRHP historic locations**	Number of NRHP historic locations within 100 feet of centerline	The NRHP (National Register of Historic Places) is the official list of the Nation's historic places worthy of preservation. In locations where current conceptual routing results in encroaching on or within a registered historic place, pipeline routing is to be refined/rerouted to avoid these locations where possible. In general, SoCalGas will seek to minimize routing new pipeline through NRHP historic locations.
ENGINEERING	**Number of Overhead Utility Crossings**	Number of overhead utilities within 25 feet and/or crossing centerline	Pipelines installed near overhead high-voltage AC transmission power lines are subject to AC interference, which has the potential to adversely impact the pipeline's cathodic protection. Also, installation of a pipeline beneath overhead utilities may reduce construction productivity due to height restrictions and require additional safety measures for construction personnel. Additional costs in pipeline design and construction should be expected for AC mitigation engineering and installation.
ENGINEERING	**Physical Conflict**	Physical conflict with known existing structures	Physical conflicts with pipeline routing may include but are not limited to, man-made structures like buildings, retaining walls, stormwater canals, electrical transmission towers, or natural terrain features like cliffs and fissures. In general, SoCalGas will seek to minimize routing new pipeline in locations where current conceptual routing encroaches on a physical conflict.

Feature Characterization Matrix - Glossary			
CATEGORY	**ATTRIBUTE - TITLE**	**ATTRIBUTE - DESCRIPTION**	**ATTRIBUTE - DETAILED DEFINITION**
ENGINEERING	**Pipeline Constructability - Inadequate Temporary Workspace**	Inadequate Workspace for Pipeline construction	Different pipe size diameters and single versus multiple pipeline installations require different size temporary workspaces for pipeline construction, due to size of equipment, size of trench, amount of spoil excavated, and quantity of equipment pieces, etc. In general, urban locations are more space constrained, equating to a slower construction production rate, often requiring traffic control. On the other hand, rural locations often have fewer space constraints, allowing for larger workspaces and increased construction productivity. Additional workspaces at trenchless crossings consider numerous constructability factors, including but not limited to, larger excavations, pullback pipe string areas, parking, equipment passing lanes, directional drill pads, etc. In locations where current conceptual routing results in inadequate temporary construction workspace, pipeline routing is to be refined/rerouted to a feasible constructible route.
SOCIAL	**Proximity to Buildings**	Number of building within 100 feet of Centerline	Where possible, and in consideration of other technical, environmental, and social factors, SoCalGas will strive to minimize locating new pipeline within 100 feet of residences.
ENGINEERING	**Railroad Crossings**	Number of Railroad Crossings	Railroad crossings may present additional permitting and/or right-of-way considerations and may also require trenchless crossing construction methods.
ENGINEERING	**Road Crossings**	Number of road crossings	Road crossings may present additional permitting and/or right-of-way considerations and may also require trenchless crossing construction methods and traffic control/mitigation plans.
ENGINEERING	**Route Length**	Total Route Length	Typically, shorter routes are less complex and have the potential to reduce overall environmental disturbance, construction cost, and timeframe. However, in some scenarios, there may be opportunities to increase the pipeline route's length to avoid sensitive areas or other constraints. Therefore, pipeline route length must be balanced against other technical, environmental, and social considerations.
ENVIRONMENTAL	**Stream Crossings**	Number of streams crossed (Including Headwaters)	Stream crossings can present permitting and constructability considerations, including the need for trenchless crossings (HDDs or Auger Bores), uncertain soil conditions, flooding potential, and overall delays to construction timeline.
ENGINEERING	**Trenchless Crossings**	Number of Trenchless Crossings	Trenchless Crossings (HDDs or Auger Bores) can present permitting and constructability considerations, including uncertain soil conditions, flooding potential, and space constraints (particularly for larger diameter HDDs) and overall delays to construction timeline.
ENGINEERING	**Trenchless Crossings length**	Total length of Trenchless crossings	Trenchless Crossings (HDDs or Auger Bores) can present permitting and constructability considerations, including uncertain soil conditions, flooding potential, and space constraints (particularly for larger diameter HDDs).
ENGINEERING	**Underground Foreign Utilities**	Number of foreign utility crossings	Utility owners/operators may have different requirements for crossing methods and clearances. In construction, may require deep crossings where engineered trenches would be needed.
ENVIRONMENTAL	**Wetlands**	Wetlands crossed within 50 feet of centerline	Locating pipeline in wetland areas presents additional environmental, permitting, and constructability considerations, which could impact overall project schedule and cost.

Feature Characterization Matrix - Segment A					
CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	27.58	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	0.00	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	0.00	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	2586.50	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	1.93	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	12.83	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	3.13	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	9.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	16.89	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	0.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	1.91	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	27.58	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	24.33	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares,	1.18	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	4.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	17.13	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	69.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary Workspace	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	1590.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	18.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	271.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	27.60	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	0.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	15.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	12,650.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	340.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	0.72	ACRES	Pivvot

Feature Characterization Matrix - Segment B					
CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	10.08	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	1.25	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	35.57	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric	246.82	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	97.82	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	8864.80	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	25.41	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	31.66	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	30.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	171.67	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	1481.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	11.16	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	46.90	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	10.38	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares,	2.63	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	7.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	34.53	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	63.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary Workspace	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	608.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	2.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	289.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	45.73	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	60.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	9.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	5615.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	240.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	4.57	ACRES	Pivvot

Feature Characterization Matrix - Segment C					
CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	75.81	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	4.04	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	23,532.60	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	811.42	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	11,951.80	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	0.00	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	2.00	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	15.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	0.00	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	1,055.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	206.26	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	79.85	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	0.00	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares,	0.00	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	7.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	2.40	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	28.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary Workspace	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	9.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	0.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	168.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	79.85	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	79.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	23.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	7,870.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	78.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	4.85	ACRES	Pivvot

Feature Characterization Matrix - Segment D					
CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	7.62	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric	0.00	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	0.00	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	4,725.70	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	2.84	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	2.29	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	6.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	0.00	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	0.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	1.65	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	7.62	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	3.01	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares,	0.44	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	1.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	4.92	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	18.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary Workspace	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	382.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	4.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	68.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	7.52	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	6.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	7.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	2745.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	47.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	2.49	ACRES	Pivvot

Feature Characterization Matrix - Segment E					
CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	30.50	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	0.00	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	117.28	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	3,030.80	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	11.24	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	1.92	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	7.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	0.00	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	3,782.30	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	101.09	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	22.40	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	10.41	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares,	0.02	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	4.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	3.91	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	17.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary Workspace	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	353.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	3.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	170.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	30.51	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	56.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	3.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	1,640.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	53.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	1.24	ACRES	Pivvot

Feature Characterization Matrix - Segment F

CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	137.50	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	15.28	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	18,909.30	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	7.31	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	7,073.30	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	12.19	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	953.90	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	6.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	78.49	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	444,687.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	23.53	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	0.00	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	4.34	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares,	0.00	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	9.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	1,056.43	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	48.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary Workspace	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	46.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	6.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	212.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	152.78	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	440.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	17.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	7,945.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	144.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	98.18	ACRES	Pivvot

Feature Characterization Matrix - Segment G

CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	27.94	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	1.50	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	10.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	0	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	74.31	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	685.30	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	0.47	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	3.70	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	6.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	149.86	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	2344.90	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	49.84	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	10.59	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	22.82	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares,	0.04	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	198.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	4.91	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	4.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary Workspace	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	189.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	2.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	172.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	39.46	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	52.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	2.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	410.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	50.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	14.04	ACRES	Pivvot

Feature Characterization Matrix - Segment H

CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	92.07	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	0.00	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	0.00	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	9,781.20	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	0.00	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	1059.26	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	2,779.60	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	5.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	0.00	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	0.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	0.00	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	0.00	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	0.00	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares,	0.00	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	7.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	1,066.32	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	7.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary Workspace	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	3.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	2.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	115.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	92.08	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	355.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	3.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	1,560.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	39.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	16.14	ACRES	Pivvot

Feature Characterization Matrix - Segment I

CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	8.80	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	2.50	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	20.59	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	2228.50	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	0.00	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	4674.10	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	0.25	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	91.62	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	9.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	381.73	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	0.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	21.21	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	31.89	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	1.86	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares,	0.00	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	5.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	0.00	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	16.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary Workspace	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	36.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	6.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	116.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	31.91	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	52.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	10.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	4555.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	43.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	1.64	ACRES	Pivvot

Feature Characterization Matrix - Segment J					
CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	4.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	56.29	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	3,459	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	14.45	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	11,074.00	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	17.19	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	33.75	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	13.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	39.53	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	0.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	15.25	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	44.20	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	16.99	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares,	0.39	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	9.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	41.90	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	220.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary Workspace	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	2,120.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	11.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	386.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	60.28	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	39.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	36.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	16,540.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	200.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	5.57	ACRES	Pivvot

Feature Characterization Matrix - Segment K					
CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	35.03	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	1.10	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	19.26	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	0	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	162.25	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	13,217.80	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	6.43	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	307.12	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	39.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	538.00	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	0.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	41.67	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	42.90	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	11.27	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares,	0.00	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	112.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	648.55	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	58.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	199.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	1.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	234.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	55.41	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	103.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	13.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	8,650.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	492.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	5.12	ACRES	Pivvot

Feature Characterization Matrix - Segment L					
CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	10.44	FEET	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	0.00	FEET	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	FEET	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	584	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	106.07	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	0.00	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	0.00	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	0.00	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	9.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	15.93	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	0.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	82.96	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	4.87	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	0.00	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares,	0.00	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	1.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	0.00	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	4.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	3.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	0.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	21.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	10.44	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	7.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	2.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	2,300.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	7.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	0.53	ACRES	Pivvot

Feature Characterization Matrix - Segment M

CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	43.75	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	7.37	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	4,212.00	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	404.90	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	12,518.00	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	0.74	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	6.90	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	12.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	138.93	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	0.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	49.16	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	7.37	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	0.78	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares,	0.00	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	4.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	4.49	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	35.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary Workspace	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	63.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	1.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	142.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	51.18	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	131.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	5.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	830.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	18.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	9.82	ACRES	Pivvot

Feature Characterization Matrix - Segment N

CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	77.92	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	13,728.90	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	114.17	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	4,798.00	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	30.14	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	98.19	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	16,381.96	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	23.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	240.46	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	4,307.50	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	49.48	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	0.00	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	11.96	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares,	0.55	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	10.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	134.93	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	42.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary Workspace	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	1144.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	4.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	355.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	77.95	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	139.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	24.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	10,435.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	155.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	14.83	ACRES	Pivvot

Feature Characterization Matrix - Segment O					
CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	52.73	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	5,205.70	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	0.00	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	7649.00	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	0.00	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	219.72	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	7.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	183.33	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	0.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	7.35	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	0.00	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	0.00	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares,	0.00	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	4.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	220.84	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	25.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary Workspace	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	55.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	6.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	193.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	52.75	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	97.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	7.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	1,800.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	67.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	31.02	ACRES	Pivvot

Feature Characterization Matrix - Segment P

CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	45.09	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	8.09	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	0.50	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	0.00	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	0.00	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	8483.90	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	0.42	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	371.20	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	4.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	109.23	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	0.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	2.67	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	0.00	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	2.41	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares, nursing	0.00	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	5.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	357.06	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	18.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	11.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	3.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	136.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	50.79	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	186.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	8.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	2,040.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	82.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	10.20	ACRES	Pivvot

Feature Characterization Matrix - Segment Q					
CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	104.11	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	18.37	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	24,104.20	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	316.14	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	6593.30	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	9.76	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	636.75	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	17201.30	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	12.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	867.10	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	0.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	176.30	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	18.37	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	0.61	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares,	0.44	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	9.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	571.31	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	76.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	116.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	2.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	136.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	122.51	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	329.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	24.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	10,730.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	171.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	28.80	ACRES	Pivvot

Feature Characterization Matrix - Segment R					
CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	81.69	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	164,404.50	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	827.55	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	4199.20	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	1.36	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	73.81	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	17.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	0.00	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	0.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	211.01	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	81.69	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	0.55	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares,	0.00	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	11.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	35.50	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	37.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	14.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	1.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	190.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	81.68	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	118.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	19.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	6,420.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	18.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	9.62	ACRES	Pivvot

Feature Characterization Matrix - Segment S					
CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	9.08	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	0.00	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	0.00	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	21.20	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	6.79	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	2.50	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	0.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	58.68	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	16.23	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	9.08	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	9.63	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares, nursing	0.73	ACRES	Pivvot
ENGINEERING	Pipeline Constructability - Inadequate Temporary	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	2.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	3.26	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	13.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	909.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	2.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	137.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	9.15	MILES	N/A, BMcD Engineering Assessment
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	862.50	FEET	Pivvot
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	39.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	3.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	4200.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	32.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	1.99	ACRES	Pivvot

Feature Characterization Matrix - Segment T

CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	8.63	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	0.00	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	0.00	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	140.40	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	5.75	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	2.93	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	0.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	21.09	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	0.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	0.00	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	8.63	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	0.10	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares, nursing	0.48	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	2.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	6.32	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	13.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	1070.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	2.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	173.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	8.63	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	0.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	3.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	975.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	29.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	0.00	ACRES	Pivvot

Feature Characterization Matrix - Segment U

CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GISDATALAYEROWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	0.00	FEET	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	0.00	FEET	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	7.03	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	FEET	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	0.00	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	0.00	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	292.40	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	4.30	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	5.11	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	23.06	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	0.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	0.00	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	0.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	1.25	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	7.03	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	0.03	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares, nursing	0.00	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	1.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	56.76	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	21.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	140.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	0.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	34.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	7.11	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	3.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	6.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	3100.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	21.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	1.86	ACRES	Pivvot

Feature Characterization Matrix - Segment V

CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	2.90	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	0.00	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	0.00	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	623.90	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	1.14	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	0.03	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	0.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	0.00	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	0.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	0.00	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	2.90	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	6.87	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares, nursing	0.23	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	1.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	0.02	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	9.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary Workspace	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	95.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	1.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	13.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	2.90	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	6.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	0.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	0.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	33.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	0.00	ACRES	Pivvot

Feature Characterization Matrix - Segment W

CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GISDATALAYEROWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	5.35	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	0.00	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	0.00	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	222.40	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	0.93	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	0.78	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	0.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	0.00	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	0.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	0.66	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	5.35	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	9.32	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares,	0.17	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	1.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	1.40	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	14.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	230.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	1.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	46.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	5.23	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	14.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	2.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	1275.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	141.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	0.46	ACRES	Pivvot

Feature Characterization Matrix - Segment X					
CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GIS DATA LAYER OWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	118.56	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	6.24	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	0.00	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	58.40	MILES	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	0.00	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	4402.80	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	0.00	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	1390.67	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	7.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	112.82	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	0.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	1.75	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	6.24	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	0.00	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares,	0.00	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	7.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	1396.46	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	0.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	8.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	4.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	5.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	67.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	124.77	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	441.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	12.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	5,970.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	141.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	29.93	ACRES	Pivvot

Feature Characterization Matrix - Segment Y

CATEGORY	ATTRIBUTE - TITLE	ATTRIBUTE - DESCRIPTION	MEASURE	UNIT OF MEASURE	GISDATALAYEROWNER
ENGINEERING	49 CFR 192 Class Location 1	Length within 49 CFR 192 Class Location 1	0.03	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 2	Length within 49 CFR 192 Class Location 2	0.00	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 3	Length within 49 CFR 192 Class Location 3	46.71	MILES	SCG GIS
ENGINEERING	49 CFR 192 Class Location 4	Length within 49 CFR 192 Class Location 4	1.90	MILES	SCG GIS
ENGINEERING	Adverse Soil Conditions	Length within Adverse Soil Conditions (Soil Behavior Class 0-2' & 2-6', Hydric Soils)	0.00	FEET	Pivvot
SOCIAL	Agricultural/Pasture Land	Agricultural/pasture land use within 50 feet of centerline	0.00	ACRES	Pivvot
ENGINEERING	CL Length with 15% Slope	Length of centerline with slope greater than 15 percent (%)	538.70	FEET	Pivvot
ENVIRONMENTAL	Coastal Zone	Coastal Zone Boundary Area within 50' of CL	0.00	ACRES	Pivvot, BMcD Engineering Assessment
SOCIAL	Commercial Land	Commercial land within 50 feet of centerline	19.44	ACRES	Pivvot
ENVIRONMENTAL	Conservation Areas	Conservation areas within 50 feet of centerline	8.66	ACRES	Pivvot
SOCIAL	Cultural & Tribal Resources	Length of CL within Cultural & Tribal Resource areas	0.00	FEET	Pivvot
ENVIRONMENTAL	Endangered/Sensitive Species Critical Habitat	Endangered/Sensitive Species Critical Habitat within 500 feet of the centerline	26.00	QTY	Pivvot
ENGINEERING	Fault Areas	Fault Area within 500 feet of centerline	134.36	ACRES	Pivvot
SOCIAL	Federal Facility/Property	Length within Federal Facility/Property	0.00	FEET	Pivvot
ENVIRONMENTAL	Floodplain	100 Year Floodplain Area within 50' of CL	11.84	ACRES	Pivvot
ENGINEERING	HCA	Length within High Consequence Areas (HCA)	48.64	MILES	N/A, BMcD Engineering Assessment
SOCIAL	Industrial Land	Industrial land within 50 feet of the centerline	27.30	ACRES	Pivvot
SOCIAL	Institutional Land	Institutional land (schools, educational facilities, hospitals, churches, daycares,	3.83	ACRES	Pivvot
ENVIRONMENTAL	Landfills & Hazardous Waste Sites	Landfills & Hazardous Waste Sites	0.00	FEET	Pivvot
ENGINEERING	Mainline Valve (MLV)	Mainline Valve (MLV) quantity per 49 CFR 192 Class Location	8.00	QTY	N/A, BMcD Engineering Assessment
SOCIAL	Maintained Public & Recreational Areas	Maintained Public and Recreational Areas within 50 feet of centerline	15.19	ACRES	Pivvot
SOCIAL	NRHP historic locations	Number of NRHP historic locations within 100 feet of centerline	1.00	QTY	Pivvot
ENGINEERING	Number of Overhead Utility Crossings	Number of overhead utilities within 25 feet and/or crossing centerline	94.00	QTY	Pivvot
ENGINEERING	Physical Conflict	Physical conflict with known existing structures	0.00	QTY	Pivvot, BMcD Engineering Assessment
ENGINEERING	Pipeline Constructability - Inadequate Temporary	Inadequate Workspace for Pipeline construction	0.00	FEET	N/A, BMcD Engineering Assessment
SOCIAL	Proximity to Buildings	Number of buildings within 100 feet of Centerline	3,101.00	QTY	Pivvot
ENGINEERING	Railroad Crossings	Number of Railroad Crossings	13.00	QTY	Pivvot
ENGINEERING	Road Crossings	Number of road crossings	562.00	QTY	Pivvot
ENGINEERING	Route Length	Total Route Length	48.57	MILES	N/A, BMcD Engineering Assessment
ENVIRONMENTAL	Stream Crossings	Number of streams crossed (Including Headwaters)	4.00	QTY	Pivvot
ENGINEERING	Trenchless Crossings	Number of Trenchless Crossings	27.00	QTY	N/A, BMcD Engineering Assessment
ENGINEERING	Trenchless Crossings length	Total length of Trenchless crossings	11,610.00	FEET	N/A, BMcD Engineering Assessment
ENGINEERING	Underground Foreign Utilities	Number of foreign utility crossings	208.00	QTY	Pivvot
ENVIRONMENTAL	Wetlands	Wetlands crossed within 50 feet of centerline	1.60	ACRES	Pivvot