ANGELES LINK PHASE 1
PROJECT OPTIONS & ALTERNATIVES STUDY
FINAL REPORT – DECEMBER 2024

SoCalGas commissioned this Project Options & Alternatives Study from Wood Mackenzie. The analysis was conducted, and this report was prepared, collaboratively.

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0. Acronyms, Glossary, Tables & Figures

0.1. Acronyms and Abbreviations

ALMA	Angeles Link Memorandum Account
AQMD	Air Quality Management District
ARCHES	Alliance for Renewable Clean Hydrogen Energy Systems
BAU	Business as Usual
BCF	Billion Cubic Feet
BESS	Battery Energy Storage Systems
BEV	Battery Electric Vehicle
CARB	California Air Resources Board
CAES	Compressed Air Energy Storage
CAISO	California Independent System Operator
CapEx	Capital Expenditure
CBOSG	Community Based Organization Stakeholder Group
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilization and Storage
CEC	California Energy Commission
CEQA	California Environmental Quality Act
CHP	Combined Heat and Power
CPUC	California Public Utilities Commission
CO_2	Carbon Dioxide
DOE	Department of Energy
GHG	Greenhouse Gases
FCEB	Fuel Cell Electric Bus
FCEV	Fuel Cell Electric Vehicle
GW	Gigawatt
IEA	International Energy Agency
IIJA	Infrastructure Investment and Jobs Act
IRA	Inflation Reduction Act
HDV	Heavy-Duty Vehicle
LADWP	Los Angeles Department of Water & Power
LCOE	Levelized Cost of Electricity
LCOH	Levelized Cost of Delivered Hydrogen
LDES	Long Duration Energy Storage
LDV	Light-Duty Vehicle
MDV	Medium-Duty Vehicle
MTPA/MMT	Million Tonnes per Annum
NEPA	National Environmental Policy Act
O&M	Operations and Maintenance
OEM	Original Equipment Manufacturers
OpEx	Operating Expenses
PAG	Planning Advisory Group
PPA	Power Purchase Agreement
PTC	Production Tax Credit
RNG	Renewable Natural Gas
PSIG	Per Square Inch Gauge
SC	Scheduling Coordinator
SoCalGas	Southern California Gas Company
SJV	San Joaquin Valley
SMR	Steam Methane Reformers
T&D	Transmission and Distribution
VRFB	Vanadium Redox Flow Batteries
ZEV	Zero-emission Vehicle

0.2. Glossary of Terms

The following terms are used in this report. For the purposes of this report, the terms are used as follows:

Carbon capture and sequestration (CCS) – A set of technologies that remove CO_2 either from the atmosphere or from point sources. The captured CO_2 is then compressed and injected into deep underground geological formations (that may include depleted oil and gas reservoirs or saline formations) for permanent storage.[1] For purposes of this report, CCS alternatives are those that include the removal of CO_2 from point sources and permanent sequestration (not for use in oil and gas recovery).

Clean firm power - Zero-carbon power generation sources that can be relied on whenever and for as long as needed. Clean firm power sources do not depend on the weather like solar and wind do, and do not have limitations in duration of power production capabilities (as long as fuel is available).[2]

Clean renewable hydrogen – For purposes of Angeles Link Phase 1 studies, clean renewable hydrogen refers to hydrogen that is produced through a process that results in a lifecycle (i.e., well-to-gate) greenhouse gas (GHG) emissions rate of not greater than four kilograms of carbon dioxide-equivalent per kilogram of hydrogen produced and does not use any fossil fuel in its production process.[3]

Cogeneration – Combined heat and power (CHP), also referred to as cogeneration, is the simultaneous generation of useful heat and electricity from a single fuel source.[4]

Dispatchable energy/dispatchable generation – Resources that are classified as dispatchable by the scheduling coordinator (SC) or the California Independent System Operator (CAISO) and could include a variety of technologies: steam turbines; combustion turbines; combined cycle gas turbines; reciprocating engines; energy storage; dispatchable CHP; biomass and geothermal resources.[5]

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[1] https://www.congress.gov/bill/117th-congress/senate-bill/799/text

[2] https://www.edf.org/sites/default/files/documents/SB100%20clean%20firm%20power%20report%20plus%20SI.pdf p. 5.

[3] As defined in CPUC Decision (D.) 22-12-055.

[4] CPUC Combined Heat and Power (CHP) https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/electric-power-procurement/combined-heat-and-power-program-overview

[5] CPUC https://www.cpuc.ca.gov/-/media/cpuc-website/files/legacyfiles/q/6442466773-qc-manual-2020.pdf

Electrification – Electrification refers to a combination of system level[6] transformation and use case level[7] technology changes including the grid infrastructure required to support growing electric load. The purpose of electrification in California is to reduce GHG emissions in carbon-intensive demand sectors by powering these sectors with electricity produced using zero-carbon technologies over time.[8]

Electrolyzer – Electrolysis is the process of using electricity to split water into hydrogen and oxygen. This reaction takes place in a unit called an electrolyzer.[9]

Energy density – The amount of energy that can be stored per unit of volume or mass; higher energy density means more energy can be stored in a smaller volume or mass.[10]

***Levelized Cost of Electricity* (*LCOE*) –** Represents the average revenue per unit of electricity generated that would be required to recover the return on capital related to costs of building and operating a generating plant. LCOE is a summary metric to measure of the overall competitiveness of different generating technologies.[11]

Linepack – Gas linepack refers to the gas stored in gas pipelines due to the compressibility of the gas. As a form of gas energy storage, linepack can enhance system flexibility.[12]

Long-duration energy storage (LDES) – A portfolio of technologies that store energy over long periods for future dispatch and marked by duration of dispatch (e.g., multi-day and seasonal).[13]

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[6] System level electrification includes the incremental electricity generation, storage, and supporting upstream grid infrastructure requirements to meet wide-scale end use electrification needs.

[7] Use-case level electrification refers to replacing technologies or processes that use fossil fuels, like internal combustion engines and gas boilers, with electrically powered equivalents, such as electric vehicles or heat pumps. More details at https://www.iea.org/energy-system/electricity/electrification

[8] California Air Resources Board, https://ww2.arb.ca.gov/our-work/programs/ab-32-climate-change-scoping-plan/2022-scoping-plan-documents

[9] https://www.energy.gov/eere/fuelcells/hydrogen-production-electrolysis DOE Office of Energy Efficiency & Renewable Energy.

[10] Department of Energy Vehicle Technology Office definition, available at https://www.energy.gov/eere/vehicles/articles/fotw-1234-april-18-2022-volumetric-energy-density-lithium-ion-batteries

[11] As defined in EIA https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf

[12] As defined in https://www.sciencedirect.com/science/article/abs/pii/S2352152X2303116X Wu et al.

[13] DOE https://liftoff.energy.gov/long-duration-energy-storage/

Levelized Cost of Delivered Hydrogen (LCOH) – Reflects the unit cost of hydrogen based on the return on capital related to the cost of production, transmission, storage, and distribution. When used in this study, LCOH refers to the delivered cost of hydrogen.

Reliability and resiliency – Reliability refers to a system having sufficient resources to adequately meet demand while accounting for commonly-expected events (e.g., equipment failure, short-duration outages). Resilience focuses on the ability of a system to withstand/recover from high-impact, low-frequency events that are often unexpected and can result in long duration outages.[14]

Renewable energy – Renewable energy uses energy sources that are continually replenished by nature — the sun, the wind, water, the Earth's heat, and plants. Renewable energy technologies turn these fuels into usable forms of energy—most often electricity, but also heat, chemicals, or mechanical power.[15]

Renewable natural gas (RNG) – Also known as "biomethane," 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 a gas pipeline. Major sources of biomethane include non-hazardous landfills, wastewater treatment facilities, organic waste, and animal manure. The California Public Utilities Commission (CPUC) has recognized that "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."[16]

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[14] CPUC https://www.cpuc.ca.gov/-/media/cpuc-website/industries-and-topics/meeting-documents/vorlumen20230321resiliency-definitionsfinal.pdf

[15] Per NREL's https://www.nrel.gov/docs/fy01osti/27955.pdf report for the Department of Energy.

[16] More details on definition available at https://www.cpuc.ca.gov/industries-and-topics/natural-gas/renewable-gas

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1. Executive Summary

1.1. Project Options & Alternatives Study Overview

Southern California Gas Company (SoCalGas) proposes to develop a hydrogen pipeline system (Angeles Link) to transport clean renewable hydrogen[17] from regional third-party production sources and storage sites to end users in Central and Southern California, including in the Los Angeles Basin (L.A. Basin). The Angeles Link pipeline system is anticipated to extend across approximately 450 miles.

Angeles Link is intended to support California's decarbonization goals[18] through the significant reduction of greenhouse gas (GHG) emissions in hard-to-electrify sectors of the economy, including dispatchable power generation, mobility[19] and industrial sectors. Additionally, Angeles Link seeks to enhance energy system reliability and resiliency and enable the development of third-party long duration energy storage (LDES) resources, as California works to achieve the State's decarbonization goals.

On December 15, 2022, the California Public Utilities Commission (CPUC) approved Decision (D.) 22-12-055, which authorized SoCalGas to establish the Angeles Link Memorandum Account (ALMA) to track expenses related to conducting Phase 1 feasibility studies.[20] The Project Options & Alternatives Study (hereafter referred to as the Alternatives Study)[21] was prepared pursuant to D.22-12-055, Ordering Paragraph (OP) 6(d), which required SoCalGas to consider and evaluate project alternatives, including a localized hydrogen hub and electrification. As described in more detail in Step 6 below, the Alternatives Study incorporates findings from the High-Level Economic Analysis & Cost Effectiveness Study (Cost Effectiveness Study) and Environmental Analysis.

Input and feedback from stakeholders, including the Planning Advisory Group (PAG) and Community Based Organization Stakeholder Group (CBOSG), was helpful in the development of this study. For example, in response to stakeholder input to the preliminary findings, as the draft report was being prepared the study expanded discussion around the selection and assessment criteria used to evaluate alternatives in this report. Section 6 below provides

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[17] As defined in https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M499/K891/499891989.PDF

[18] For example, https://ww2.arb.ca.gov/our-work/programs/ab-32-climate-change-scoping-plan/2022-scoping-plan-documents see at pp. 9-10, and Senate Bill 100 (SB 100).

[19] https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf , also Advanced Clean Fleets | California Air Resources Board

[20] https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M499/K891/499891989.PDF

[21] Project options refer to various routing scenarios as described in the Pipeline Sizing and Design Criteria Study. The Alternatives Study integrates those options as part of the overall evaluation of Angeles Link and alternatives.

additional details on how stakeholder feedback was incorporated into the development of this report. All feedback received is included, in its original form, in the quarterly reports submitted to the CPUC and published on SoCalGas' website.[22]

1.2. Study Approach

The Alternatives Study used a six-step evaluation framework to identify and assess potential alternatives to Angeles Link as described below. The methodology and interim results of each step are detailed throughout this study.

- Step 1: Identify potential alternatives.
- Step 2: Evaluate potential alternatives against identified criteria.
- Step 3: Dismiss alternatives that fail to satisfy Step 2 criteria.
- Step 4: Select alternatives to carry forward for further analysis.
- Step 5: Provide alternatives to cost effectiveness and environmental studies.
- Step 6: Incorporate findings from the Cost Effectiveness Study and Environmental Analysis and evaluate each alternatives' fulfilment of the purpose and need for Angeles Link. [23]

The Alternatives Study aimed to evaluate Angeles Link and alternatives across a specific set of objectives as identified below:

Hydrogen Delivery Alternatives: *How does Angeles Link compare to alternative methods for delivering clean renewable hydrogen to end users in the region across power generation, mobility, and industrial sectors?*

Non-Hydrogen Alternatives: *How does clean renewable hydrogen delivered by Angeles Link compare to alternative, non-hydrogen decarbonization pathways for key use cases across power generation, mobility, and industrial sectors?*

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

[23] See Section 3.2 for additional detail on the Purpose and Need for Angeles Link.

Given these objectives, alternatives were evaluated across two categories—Hydrogen Delivery Alternatives and Non-Hydrogen Alternatives. As mentioned previously, the portfolio of potential alternatives identified for this study (see Table 1) considered the various stakeholder comments received from the PAG and CBOSG.

Table 1: Portfolio of Potential Alternatives Identified for Evaluation

Category	Selected for Consideration in Step 2	Not Selected for Consideration in Step 2[24]
Potential Hydrogen Delivery Alternatives	• Localized hub • Power transmission & distribution (T&D) with in-basin hydrogen production • Liquid hydrogen trucking • Gaseous hydrogen trucking • Liquid hydrogen shipping • Methanol shipping • Ammonia shipping[25] • Intermodal transport (liquid hydrogen trucking and liquid hydrogen rail)[26]	• No alternative was excluded
Potential Non-Hydrogen Alternatives	• Electrification • Carbon Capture & Storage (CCS)	• Renewable Natural Gas (RNG) • Energy efficiency • Nuclear power generation • Hydro power generation • Geothermal power generation • Plug-in hybrid vehicles • Biofuel vehicles • Ethanol vehicles

Each of the alternatives explored has the potential to play a role as a complementary solution within a broader portfolio of technologies deployed to address California's decarbonization

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[24] These other clean fuels and technologies were considered in Step 1 but screened out for further evaluation. See Section 4.2 for details on the rationale.

[25] Ammonia shipping and intermodal transport (liquid hydrogen trucking and liquid hydrogen rail) were evaluated in Step 3 (of the six-step process as discussed above) but not selected for

goals. However, for the purposes of this study, each alternative is addressed on a standalone basis. This approach was taken to evaluate each alternative's ability to meet the purpose and need for Angeles Link. Alternatives that could not meet the equivalent energy demand serviced by Angeles Link or could not meet the defined set of scoring criteria were not carried forward for further evaluation in Step 2. Angeles Link and the selected portfolio of alternatives that moved to Step 2 (of the six-step evaluation framework) were assessed against a set of identified criteria based on the type of alternative as shown in Table 2 and

Table **3** below.

Table 2: Criteria Used to Assess Hydrogen Delivery Alternatives[27]

Hydrogen Delivery Alternatives	Assessment Criteria				
1. Localized hub 2. Power transmission & distribution (T&D) with in-basin hydrogen production 3. Liquid hydrogen trucking 4. Gaseous hydrogen trucking 5. Liquid hydrogen shipping 6. Methanol shipping 7. Ammonia shipping 8. Intermodal transport[28]	**State Policy**	**Range**	**Reliability & Resiliency**	**Ease of Implementation**	**Scalability**

Table 3: Criteria Used to Assess Non-Hydrogen Alternatives

Non-Hydrogen Alternatives	Assessment Criteria				
1. Electrification 2. CCS	**State Policy**	**Tech. Maturity**	**Reliability & Resiliency**	**End User Requirements**	**Scalability**

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further analysis in the Cost Effectiveness Study or Environmental Analysis. See Appendix 7.3 for more details.

[26] Ibid.

[27] See Section 4.3 for definitions of criteria and the methodology used to assess alternatives.

[28] Intermodal transport includes a combination of Liquid Hydrogen Trucking and Liquid Rail transportation.

1.3. Key Findings

The evaluation of Angeles Link compared to Hydrogen Delivery Alternatives found that Angeles Link is the best suited option to meet the evaluation criteria for the delivery of clean renewable hydrogen at scale across Central and Southern California, including the L.A. Basin. As estimated in the Demand Study, and as discussed further in Section 4.3.2, Angeles Link has the potential to serve the clean dispatchable power generation, heavy-duty transportation, and hard-to-electrify industrial sectors at scale in support of California's decarbonization objectives. Other alternatives, such as a localized hub or hydrogen trucking, could serve a portion of the estimated clean renewable hydrogen demand; however, neither of these alternatives has the ability to meet the throughput volumes, transport distances, or cost-effectiveness[29] of a pipeline system at the scale needed to meet California's decarbonization targets. Similarly, while shipping alternatives such as liquid hydrogen and methanol can be used for long-distance transportation of hydrogen at scale, they are not suitable for transporting intrastate hydrogen production throughout Central and Southern California, including the L.A. Basin. Finally, power transmission and distribution with in-basin hydrogen production would require more extensive and complex infrastructure development compared to pipelines. The transmission of enough power to produce 1.5 Mtpa[30,31] of hydrogen could require the development of more than twenty high-capacity electric transmission circuits[32] that

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[29] See Angeles Link Cost Effectiveness Study for additional information.

[30] The acronym Million Tonnes Per Annum (Mtpa) or Million Metric Tonnes (MMT) is used interchangeably across multiple Angeles Link studies.

[31] 1.5 Mtpa refers to Scenario 7 Preferred Configuration A (Scenario 7) in the Design Study.

[32] A circuit refers to a specialized cable that carries power from one location to another. A transmission line can be defined as single or double circuit, depending on the number of circuits. The number of circuits and lines required depends on the power generation capacity and carrying capacity for the distance from supply to sub-station. A 500kV AC transmission system was selected in order to meet the capacity requirements for the Delivery Alternative. The 500kV system is largely compatible with the CAISO grid, which is mostly AC. 26.6 GW is the electricity need for the electrolysis process. Total generation also accounts for transmission losses of 1.8 GW for the scope configuration of Scenario 7 of the in-basin hydrogen production with power T&D alternative. Total installed solar capacity is estimated at 43 GW in the Production Study to account for intra-day availability. Refer to the Cost Effectiveness Study Appendix 7.2.2 and 7.3.1 for additional details.

are less cost-effective,[33] [34] and less reliable and resilient[35] than an underground pipeline system.

The evaluation of Angeles Link compared to Non-Hydrogen Alternatives found Angeles Link is best suited to meet the operational requirements of long-haul, high payload, high duty-cycle vehicles such as long-range trucks and buses when compared to electrification. Carbon capture and sequestration (CCS) is not a technically viable alternative that could be deployed at scale to capture tailpipe emissions for the mobility sector. In the dispatchable power sector, hydrogen meets the criteria to serve as a source of clean firm generation and LDES. While battery storage as a standalone solution is mature and can be deployed at scale, it is cost-prohibitive to overbuild for system reliability needs without advances in other LDES technologies. Additionally, in several industrial subsectors, industrial retail electricity tariffs in California would make the cost of hydrogen supplied by Angeles Link competitive with electrification, especially for higher heat industrial applications.

The evaluation also showed that CCS could offer a cost-effective pathway for the decarbonization of certain industrial sectors such as cement.[36] However, CCS may face challenges in terms of maturity, scalability, and the ability to meet end-user requirements[37] in power and other industrial sectors. The adoption of CCS for capturing CO_2 is highly site, sector, and location specific, and will therefore require the consideration of site, sector, and regional factors beyond the scope of this study, including access to CO_2 transport and sequestration infrastructure near point sources. Proximity and access to CO_2 transport and sequestration infrastructure is crucial to the development of CCS projects, particularly for point sources that do not have the scale to support integrated infrastructure development on their own.

The California Air Resources Board's (CARB) 2022 Scoping Plan identified clean renewable hydrogen as key to achieving California's decarbonization objectives, particularly in hard-to-electrify sectors of the economy.[38] Angeles Link is intended to support the CARB's Scoping Plan and California's decarbonization goals through the delivery of clean renewable hydrogen to serve consumers in hard-to-electrify sectors. The evaluation of Angeles Link and potential

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[33] See Angeles Link Cost Effectiveness Study for additional information.

[34] https://www.publicadvocates.cpuc.ca.gov/-/media/cal-advocates-website/files/press-room/reports-and-analyses/230612-caladvocates-transmission-development-timeline.pdf

[35] For example, electric companies may need to temporarily turn off power to specific areas to reduce the risk of fires caused by electric infrastructure. See, e.g., https://www.cpuc.ca.gov/psps/

[36] SB 596 requires CARB to develop a comprehensive strategy for the cement industry to achieve net-zero emissions by 2045, see: https://ww2.arb.ca.gov/our-work/programs/net-zero-emissions-strategy-cement-sector

[37] Refer to the definition of criteria in Table 10.

[38] See https://ww2.arb.ca.gov/resources/documents/2022-scoping-plan-documents at pp. 9-10, 64, 73-74, 77-78, 186-187, 204, 207, 212. See also Senate Bill 100 (SB 100).

alternatives for the delivery of clean renewable hydrogen at scale across Central and Southern California, including the L.A. Basin, identified Angeles Link as the best suited option for achieving the criteria identified in this study. Angeles Link also performed well with respect to the criteria defined for the evaluation of Non-Hydrogen Alternatives and is well positioned to serve dispatchable electric generation, heavy-duty transportation, and hard-to-electrify industrial consumers in Central and Southern California.

2. Study Background

2.1. Purpose and Objectives of Study

The Alternatives Study identifies potential alternatives to Angeles Link, establishes criteria to evaluate the alternatives, performs an assessment of Angeles Link and alternatives against these criteria, and performs a summary evaluation for Phase 1 purposes of Angeles Link and alternatives against the purpose and need for Angeles Link (described in Sections 3.2 and 4.4.3). Alternatives were grouped into two categories:

- **Hydrogen Delivery Alternatives** address the question: “How does Angeles Link compare to alternative configurations for producing and delivering clean renewable hydrogen to end users in the region?” These alternatives include various other hydrogen production configurations and modes of transportation, such as a localized hydrogen hub, trucking, shipping, and in-basin production supported by out-of-basin renewable electricity and power transmission and distribution (T&D) infrastructure.
- **Non-Hydrogen Alternatives** address the question: “How does Angeles Link compare to alternative, non-hydrogen decarbonization pathways for key use cases across power, mobility, and industrial sectors?” These alternatives include various non-hydrogen decarbonization pathways and technologies, including electrification and CCS.

The criteria for assessing alternatives were defined in consideration of the need for Angeles Link. The Alternatives Study evaluated each alternative with respect to the defined criteria, including compatibility with state policy, technological maturity, range of deliverability, reliability and resiliency, ease of implementation, end user requirements, and scalability. The criteria also included cost, which was evaluated in the Cost Effectiveness Study, and high-level environmental impacts, which were evaluated in the Environmental Analysis. The main output of this evaluation was a high-level summary of the relative strengths and weaknesses of alternatives across the identified criteria.

2.2. Relationship with Other Studies

The Alternatives Study both informed and was informed by other Angeles Link Phase 1 studies as follows:

- The Production Study provided the potential hydrogen production regions and the associated production and storage costs to inform the delivery capacity required of potential Hydrogen Delivery Alternatives.
- The Pipeline Routing/Sizing & Design Study informed the Angeles Link routing, sizing, and design criteria, and Angeles Link system costs to enable the selection and definition of potential Hydrogen Delivery Alternatives based on relatively consistent sizing and geographic considerations.
- The Demand Study provided information on the total addressable market and relevant use cases for hydrogen across mobility, power, and industrial sectors, which informed the use cases selected for analysis of Non-Hydrogen Alternatives.
- The Cost Effectiveness Study evaluated the alternatives identified in this study and performed cost analysis, the high-level results of which have been incorporated into this study.
- The Environmental Analysis evaluated the potential environmental impacts associated with Angeles Link and the Hydrogen Delivery Alternatives and Non-Hydrogen Delivery identified in this study.

3. Description of Angeles Link

This section provides a high-level description of Angeles Link and its stated purpose and need to enable a comparison of Angeles Link to the identified alternatives.

3.1. Project Description

Angeles Link is proposed to include the following characteristics:

- A non-discriminatory pipeline system that is dedicated to public use.
- Transports clean renewable hydrogen from regional third-party production and storage sites to end users in Central and Southern California, including the L.A. Basin (inclusive of the Ports of Los Angeles and Long Beach).
- Extends across approximately 450 miles.
- Includes two pipeline segments (San Joaquin Valley, or SJV, and Lancaster) within the Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES).[39]
- Ranges from approximately 200 to 1200 pounds per square inch gauge (psig).
- Has pipeline diameter(s) that may be up to 36 inches.
- Routed to maximize use of existing rights-of-way, as feasible.
- Sized for an annual total throughput of approximately 0.5 to 1.5MMT over time.
- May be constructed in stages.

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

Figure 1: Illustrative Map of Angeles Link Infrastructure[40]

3.2. Purpose and Need for Angeles Link

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

1. To support California's decarbonization goals, including CARB's 2022 Scoping Plan for Achieving Net Neutrality, which identifies the scaling up of renewable hydrogen for the decarbonization of hard-to-electrify sectors as playing a key role in the State achieving carbon neutrality by 2045 or earlier.[41]
2. To support California's decarbonization goals in the mobility sector, including the Governor's Executive Order N-79-202,[42] 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;[43] as well as the implementation of the March 15, 2021 Advanced Clean

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[40] Note, the Angeles Link conceptual corridor reflects one potential configuration of Angeles Link. Please see the Preliminary Routing Configuration Study for more information on preliminary preferred routes. These routes could evolve and are subject to refinement in Phase 2 of Angeles Link.

[41] California Air Resources Board's 2022 Scoping Plan for Achieving Carbon Neutrality, at pp. 9-10, available at https://ww2.arb.ca.gov/sites/default/files/2022-12/2022-sp.pdf

[42] https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf

[43] Advanced Clean Fleets Regulation Summary: https://ww2.arb.ca.gov/our-work/programs/advanced-clean-fleets

Truck regulation,[44] 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 system dedicated to public use.
4. To support improving California's air quality by displacing fossil fuels for certain hard-to- electrify sectors, including the mobility sector.
5. To enhance energy system reliability, resiliency, and flexibility as California industries transition fuel usage to achieve the State's decarbonization goals.
6. To enable long duration clean energy storage that can further accelerate renewable energy development, minimize grid curtailments, and enhance energy system resiliency.
7. To provide a cost effective, transparent, and affordable open access clean renewable hydrogen transportation system 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 natural gas use served by the Aliso Canyon natural gas storage facility while continuing to provide reliable and affordable energy service to the region.

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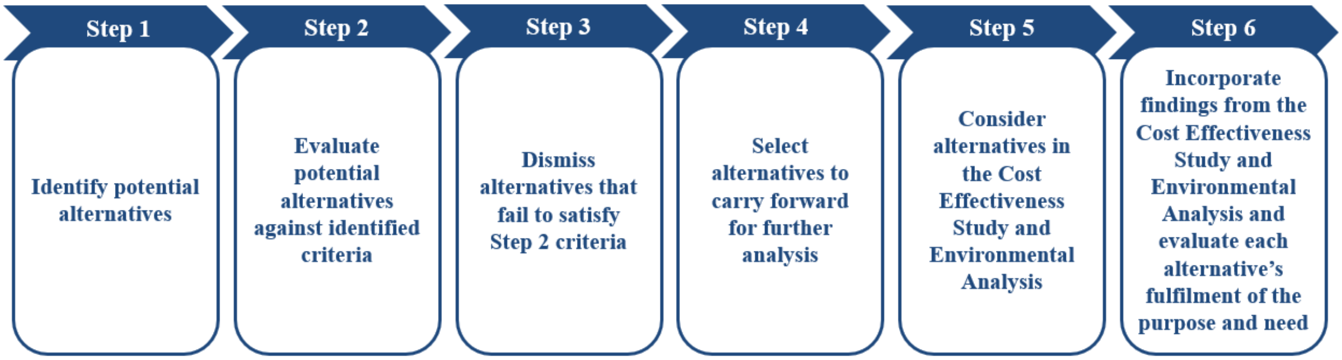
[44] Advanced Clean Trucks Regulation: https://ww2.arb.ca.gov/our-work/programs/advanced-clean-trucks

4. Framework for Evaluation of Project Alternatives

4.1. Overview of the Six-Step Evaluation Process

The Alternatives Study followed six-steps to assess Angeles Link and its alternatives and efficiently integrate findings from other relevant studies. These six-steps informed the study's methodology and are reflected in the structure of this report.

Figure 2: Overview of Six-Step Evaluation Process



Step 1: Identify potential alternatives.

At the onset of the Alternatives Study, a portfolio of potential alternatives was identified, including the specific alternatives identified in D.22-12-055 (localized hub and electrification).[45] The initial portfolio of potential alternatives was developed and pre-screened based on the technical requirements provided in the Decision (e.g., clean renewable hydrogen production), geographic alignment with ARCHES for hydrogen infrastructure development within California, and a high-level alignment with the purpose and need for Angeles Link.

A screening list of potential alternatives (see Table 4 below) was grouped into two categories: Hydrogen Delivery Alternatives and Non-Hydrogen Alternatives.

- **Hydrogen Delivery Alternatives** comprised various alternative clean renewable hydrogen modes of transportation, in addition to the localized hydrogen hub alternative.[46] This included power T&D with in-basin hydrogen production, liquid hydrogen trucking, gaseous hydrogen trucking, liquid hydrogen shipping, methanol and ammonia shipping (as hydrogen derivates), and intermodal transport (liquid hydrogen trucking and liquid hydrogen rail). All alternatives were selected for further evaluation in Step 2.

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[45] D.22-12-055.

[46] See Appendix 7.1.1 for additional information on the localized hub.

- **Non-Hydrogen Alternatives** were defined to address specific use cases within the priority sectors identified in the Demand Study across the mobility, power, and industrial sectors (e.g., within the mobility sector, battery electric vehicles (BEV) for the heavy-duty, long-haul trucking use case). Non-Hydrogen Alternatives comprised alternative decarbonization technologies, including electrification[47,48] and CCS. Other potential alternatives not selected for further evaluation in Step 2 (of the six-step evaluation framework) include renewable natural gas (RNG), energy efficiency, nuclear power generation, hydro power generation, geothermal power generation, plug-in hybrid vehicles, bio-fuels, and ethanol vehicles. See Section 4.2.2 for additional information.

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[47] Electrification refers to a combination of system level transformation and use-case level technology changes including the grid infrastructure required to support growing electric load. System level electrification includes the incremental electricity generation, storage, and supporting upstream grid infrastructure requirements to meet wide-scale end use electrification needs. Use-case level electrification refers to "*replacing technologies or processes that use fossil fuels, like internal combustion engines and gas boilers, with electrically powered equivalents, such as electric vehicles or heat pumps*." (https://www.iea.org/energy-system/electricity/electrification).

[48] The Alternatives Study evaluated the electrification alternative on a systemwide basis at a high level, and on an end use-case basis for more in-depth comparison of the alternatives.

Table 4: Portfolio of Potential Alternatives Identified for Evaluation

Category	Selected for Consideration in Step 2	Not Selected for Consideration in Step 2[49]
Potential Hydrogen Delivery Alternatives	- Localized hub - Power transmission & distribution (T&D) with in-basin hydrogen production - Liquid hydrogen trucking - Gaseous hydrogen trucking - Liquid hydrogen shipping - Methanol shipping - Ammonia shipping[50] - Intermodal transport (liquid hydrogen trucking and liquid hydrogen rail)[51]	- No alternative was excluded
Potential Non-Hydrogen Alternatives	- Electrification - Carbon Capture & Storage (CCS)	- Renewable Natural Gas (RNG) - Energy efficiency - Nuclear power generation - Hydro power generation - Geothermal power generation - Plug-in hybrid vehicles - Biofuel vehicles - Ethanol vehicles

Steps 2-4: Evaluate alternatives, dismiss those that fail to satisfy Step 2 criteria, and select alternatives to carry forward for further analysis.

The Alternatives Study conducted an initial assessment of each group of pre-screened alternatives. The purpose of the initial assessment was to determine which alternatives met the criteria before carrying forward the selected alternatives for further analysis in the Cost Effectiveness Study and the Environmental Analysis.

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[49] These other clean fuels and technologies were considered in Step 1 but screened out for further evaluation. See Section 4.2 for details on the rationale.

[50] Ammonia shipping and Intermodal transport (liquid hydrogen trucking and liquid hydrogen rail) were evaluated in Step 3 (of the six-step process as discussed above) but not selected for further analysis in the Cost Effectiveness Study or Environmental Analysis. See Appendix 7.4.3 for more details.

[51] Ibid.

Once alternatives were established, a set of key assessment criteria were identified and tailored to each category of alternatives. These criteria included state policy, technological maturity, range of deliverability (distance), reliability and resiliency, ease of implementation, end-user requirements, and scalability. These criteria were developed in consideration of the need for Angeles Link, among other factors, and provided a framework to select which alternatives should be carried forward for cost and environmental impact assessments in accordance with D.22-12-055's requirements to evaluate the associated costs and environmental impacts of alternatives.[52] The criteria were applied to each category of alternative based on the applicability of the criteria as shown in Table 5 below for Hydrogen Delivery Alternatives and Table 6 for Non-Hydrogen Alternatives. For example, range of deliverability can be a critical driver for Hydrogen Delivery Alternatives as some alternatives (e.g., gaseous, and liquid hydrogen trucking) may have optimal range requirements to achieve commercial viability based on the volume and distance (range) of hydrogen transported. This consideration is not applicable to the use case level assessment of Non-Hydrogen Alternatives like electrification and CCS.

Table 5: Criteria Used to Assess Hydrogen Delivery Alternatives

Hydrogen Delivery Alternatives	Assessment Criteria				
1. Localized hub 2. Power transmission & distribution (T&D) with in-basin hydrogen production 3. Liquid hydrogen trucking 4. Gaseous hydrogen trucking 5. Liquid hydrogen shipping 6. Methanol shipping 7. Ammonia shipping 8. Intermodal transport[53]	**State Policy**	**Range**	**Reliability & Resiliency**	**Ease of Implementation**	**Scalability**

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[52] D.22-12-055.

[53] Intermodal transport includes a combination of Liquid Hydrogen Trucking and Liquid Rail transportation.

Table 6: Criteria Used to Assess Non-Hydrogen Alternatives

Non-Hydrogen Alternatives	Assessment Criteria				
1. Electrification 2. CCS	**State Policy**	**Tech. Maturity**	**Reliability & Resiliency**	**End User Requirements**	**Scalability**

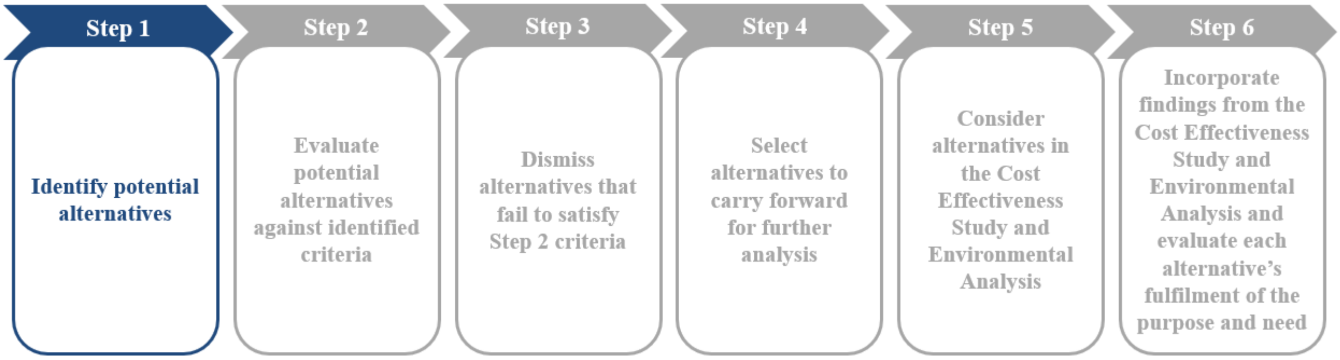
After the alternatives were evaluated against the criteria, any alternatives that were determined not to meet the criteria were dismissed from further analysis, while all other alternatives were carried forward to the Cost Effectiveness Study (to evaluate the cost-effectiveness of the alternatives) and the Environmental Analysis (to evaluate associated environmental impacts of the alternatives). A more detailed discussion explaining why certain alternatives were not carried forward for further analysis is provided in Section 4.3 of this report.

Steps 5-6: Consider alternatives in the Cost Effectiveness Study and Environmental Analysis, incorporate findings from the Cost Effectiveness Study and Environmental Analysis, and evaluate alternatives' fulfillment of the purpose and need.

Summary findings from the Cost Effectiveness Study and the Environmental Analysis have been incorporated into this Alternatives Study. Angeles Link and alternatives were also evaluated relative to the specific elements of the purpose and need for Angeles Link. More information on the economic and environmental results and the purpose and need evaluation is included in Section 4.4 of this report. Additionally, key findings reflecting the overall strengths and weaknesses of the alternatives relative to Angeles Link based on all criteria evaluated are included in Section 5 of this report.

4.2. Identification of Alternatives

Figure 3: Six-Step Evaluation Process: Identification of Alternatives



This section describes Step 1, the identification of potential alternatives, including descriptions of identified alternatives and reasons certain alternatives (e.g., RNG) were not carried forward for further consideration. As the identification and pre-screening process incorporated different considerations for each category of alternatives, the findings for Step 1 are discussed in two sections—Hydrogen Delivery Alternatives and Non-Hydrogen Alternatives.

4.2.1. Hydrogen Delivery Alternatives

The process to determine the Hydrogen Delivery Alternatives to be evaluated entailed identifying potentially feasible hydrogen delivery modes, focusing specifically on existing solutions for delivering clean renewable hydrogen. For the potential delivery alternatives, production and delivery configurations incompatible with the defined parameters of Angeles Link (as discussed in the Production, Demand, and Pipeline Sizing and Design Studies (Design Study)), such as transporting high-carbon-intensive hydrogen or hydrogen produced outside California, were not analyzed.

To align with the purpose and need for Angeles Link, and to meet end-user requirements, the definition of Angeles Link and alternatives for the purposes of this study and the Cost Effectiveness Study included hydrogen transportation as well as some baseline assumptions about third-party production, storage,[54] and specialized handling that is likely to be

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[54] Clean hydrogen production and above-ground and underground storage is not currently part of the design of Angeles Link. As the design for Angeles Link is further developed, and system requirements are more clearly defined, 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 as larger scale storage technologies mature and are deployed over time to support regional hydrogen hub

incorporated at full system build out. In addition, the alternatives were defined to make them comparable on a like for like basis, meaning they must all achieve the same scale; transport hydrogen produced in similar locations and via similar technology where possible; be limited to California; and have access to storage that could help support energy system reliability and resiliency in the longer term. As an exception to the requirement for all alternatives to achieve a similar production and delivery capacity, a localized hydrogen hub was considered as a Hydrogen Delivery Alternative pursuant to the CPUC's direction in D.22-12-055 to consider a localized hydrogen hub among Angeles Link alternatives.

The Design Study evaluated the conceptual development of clean renewable hydrogen pipeline routes based on the potential third-party production and storage that could be developed for the larger hydrogen economy in California as illustrated in Figure 4 below.

For purposes of this study, assumptions include the following:

- Third-party production resources located broadly in SJV, Lancaster, and Blythe areas.[55]
- Delivery in Southern California, including to the Port of Los Angeles and Port of Long Beach with the ability to support demand in Central California.
- Development of third-party storage resources, such as above/below ground storage facilities.

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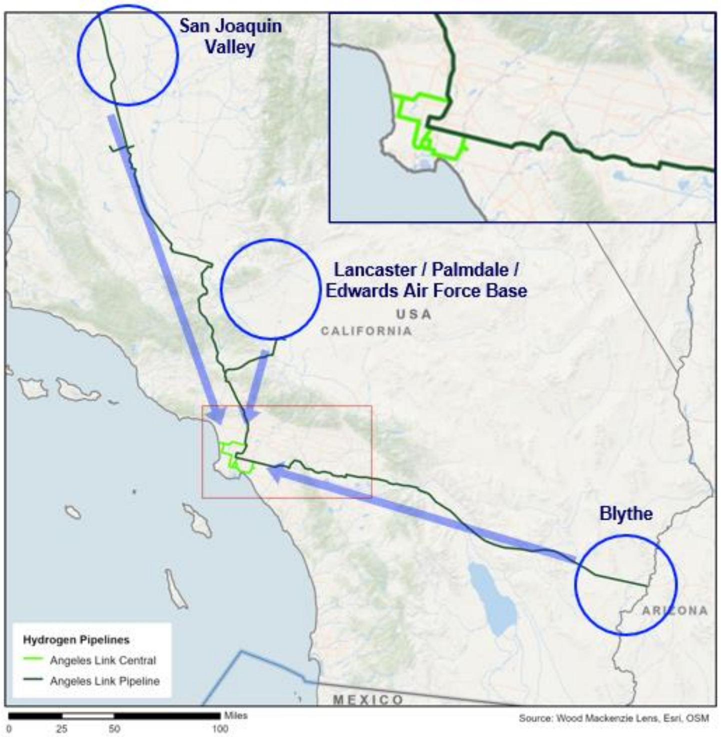
requirements. For additional storage considerations see the Cost Effectiveness Study Appendix 7.5.1.

[55] The Design Study and Preliminary Routing/Configuration Analysis prepared as separate Angeles Link Phase 1 analyses concluded Angeles Link could be designed to deliver the total 1.5 Mtpa of clean renewable hydrogen to end users from production located near San Joaquin Valley and Lancaster, excluding Blythe.

Figure 4: Illustrative Map of Angeles Link and Delivery Alternatives Key Locations[56]



Source: Wood Mackenzie Lens, Esri, OSM

4.2.1.1. Hydrogen Delivery Alternatives Selected for Further Evaluation

The Alternatives Study identified six delivery methods and nine Hydrogen Delivery Alternatives as descried in Table 7 below. This included hydrogen transport using a pipeline system, hydrogen transport using trucks (as compressed gas and as liquid), rail, ship (liquid hydrogen, and derivatives such as methanol, and ammonia), power T&D with in-basin hydrogen production, and a localized clean renewable hydrogen hub.

As mentioned previously, scope configurations for each delivery alternative were customized based on their inherent technical and operational requirements and constraints. Specifically for several alternatives, solar generation, hydrogen production, and storage sites were adjusted to reduce logistical complexity, while still achieving scale, supporting system reliability and resiliency to the extent possible.

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[56] The systems would be designed to serve demand along their routes.

Table 7: Hydrogen Delivery Alternatives Descriptions[57]

Delivery Method	Delivery Alternative	Description
Pipeline	Angeles Link	A dedicated pipeline system designed to transport clean renewable hydrogen gas from third-party production sites to end-users in Central and Southern California, including the L.A. Basin. Full Project Description in Section 3.1.
Truck	Liquid Hydrogen Trucking	Hydrogen produced at the defined production locations is liquefied and loaded at each production site to liquid hydrogen trucks and then transported to end users. Each truck can transport up to 4 tonnes (metric tons) of hydrogen per load, while loading bays can dispatch 4 trucks per day. Assumes vehicle stock turnover from diesel trucks to fuel cell electric drive trains in the 2030s to meet California's decarbonization goals. Trucks would use existing highways, following corridors similar to conceptual pipeline routes. This alternative assumes the use of underground storage (such as depleted oil fields), which would be connected via liquid trucks. Assumes a distribution pipeline is developed in the L.A. Basin with interconnection to end users, including the Ports of Los Angeles and Long Beach (Ports).
	Gaseous Hydrogen Trucking	Hydrogen produced at the identified production locations is compressed and loaded at production facilities, then transported to end users via compressed hydrogen trucks. Each truck can transport up to 1 tonne of hydrogen per load, while loading bays can dispatch 5 trucks per day. Assumes vehicle stock turnover from diesel trucks to fuel cell electric drive trains in the 2030s to meet California's decarbonization goals. Trucks would use existing highways, following corridors similar to conceptual pipeline routes. This alternative assumes the use of underground storage (such as depleted oil fields), which would be connected via gaseous trucks. Assumes a distribution pipeline is developed in the L.A. Basin with interconnection to end users, including the Ports.
Ship	Liquid Hydrogen Shipping	Production of hydrogen in Central and Northern California is transported via a pipeline to a liquefaction terminal in the nearby port. Liquid hydrogen is loaded into 10,000 cubic meter vessels (~700

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[57] Refer to Cost Effectiveness Study for additional information, including maps.

Delivery Method	Delivery Alternative	Description
		tonnes). These vessels transport the hydrogen to L.A. Ports, which are transferred into liquid storage vessels and then regasified at the terminal to be directly serviced at the interconnection point at the Ports. Assumes a distribution pipeline is developed in the L.A. Basin with interconnection to end users, including the Ports.
	Methanol Shipping	Production of hydrogen in Central and Northern California is transported via a pipeline to a methanol conversion plant in nearby ports. The methanol is transferred onto a methanol vessel intended to transport hydrogen as methanol to L.A. Ports. Methanol is then transferred into a methanol-to-hydrogen reconversion facility. After reconversion, the hydrogen is stored as liquid hydrogen before being regasified to be directly serviced at the interconnection point at the Ports. Assumes a distribution pipeline is developed in the L.A. Basin with interconnection to end users, including the Ports.
	Ammonia Shipping	Production of hydrogen in Central and Northern California is transported via a pipeline to an ammonia conversion plant in nearby ports. The ammonia is transferred into an ammonia vessel intended to transport hydrogen as ammonia to L.A. Ports. Ammonia is then transferred into an ammonia-to-hydrogen reconversion facility. After reconversion, the hydrogen is stored as liquid hydrogen before being regasified to be directly serviced at the interconnection point at the Ports. Assumes a distribution pipeline is developed in the L.A. Basin with interconnection to end users, including the Ports.
Power T&D with In-Basin Production	Power T&D with In-Basin Production	Involves transmitting renewable energy as electrons through multiple 500 kV AC electric power lines, connecting solar production to the L.A. Basin from the same production sites and generally via the same potential conceptual Angeles Link pipeline corridors. Hydrogen production would occur in-basin, with a distribution pipeline interconnection to end users, including the Ports. This assumes all new transmission lines with no interconnection to the existing grid. To meet reliability requirements, this option assumes liquid storage in-basin.
Localized Hub	Localized Hub	Production is located in the L.A. Basin, within a 40-mile radius centered at the Port of Los Angeles and Port of Long Beach and

Delivery Method	Delivery Alternative	Description
		expanding inland, in close proximity to end users. Hydrogen production assumes small-scale solar and production in-basin. The alternative also includes pipelines for distribution in the L.A. Basin, as well as in-basin above-ground liquid storage.[58]
Intermodal Transport	Liquid Truck / Liquid Rail	Hydrogen produced is liquefied at production facilities, then transferred to rail cars via trucks to loading terminals. A liquid hydrogen truck fleet would transport the hydrogen to the nearest railroad loading terminal, where it would be transferred into rail cars. Once in the terminal, each rail car can transport up to 4.5 tonnes of hydrogen.[59] Hydrogen is transported in liquid form along rail routes to ports, then stored in liquid state, before being regasified to be directly serviced at the interconnection points at the ports. Assumes a distribution pipeline with interconnection to the ports.

4.2.1.2. Hydrogen Delivery Alternatives Not Advanced for Further Evaluation

All the potential Hydrogen Delivery Alternatives, including the localized hub, were advanced for further evaluation.

4.2.2. Non-Hydrogen Alternatives

The process for selecting Non-Hydrogen Alternatives for evaluation was informed by the Demand Study, which provided end-use cases across the mobility, power, and industrial sectors. The Demand Study found that projected hydrogen demand in these sectors ranged from ~0.02 Mtpa in the cement sector to 1.7 Mtpa in the power generation sector by 2045.[60] The selection process prioritized non-hydrogen decarbonization alternatives that could support the purpose and need for Angeles Link. Electrification was considered as a Non-Hydrogen Alternative pursuant to the CPUC's direction in D.22-12-055 to consider electrification among Angeles Link alternatives.[61] Other potential Non-Hydrogen Alternatives identified for screening

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[58] Detailed definition for Localized Hub is described in Appendix 7.1.1.

[59] 4.5 tonnes of hydrogen were estimated assuming the same energy density of a liquid truck and adjusting to the volume of a rail car. More detail on the capacity and sources of a liquid truck is available in the Cost Effectiveness Study Appendix 7.3.1.2.2.

[60] Based on "Moderate Case". See Demand Study for additional information.

[61] This study is being prepared pursuant to the CPUC Decision (D.22-12-055, Ordering Paragraph [OP] 6 (d)), which states SoCalGas shall share findings from the Phase 1 feasibility

align with the CARB 2022 Scoping Plan objectives to meet California’s decarbonization goals. The identified Non-Hydrogen Alternatives include electrification, CCS, and other clean fuel sources and technologies. These other fuels and technologies included: (i) RNG, (ii) energy efficiency (EE), (iii) ethanol and plug-in hybrids and biofuels specifically in the mobility sector, and (iv) nuclear power generation, hydro power generation, and geothermal power generation specifically in the power sector as identified in Table 8.

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studies that consider and evaluate project alternatives, including a localized hydrogen hub or electrification.

Table 8: Mapping of Non-Hydrogen Alternatives to Use Cases[62]

Sector[63]		Electrification	CCS	Other Technologies and Fuels
Mobility (long-haul, heavy-duty) ○ *1.0 Mtpa*		Battery electric vehicles	Not applicable to use case	RNG, EE, ethanol, and biofuel vehicles
Power (clean reliable) ○ *1.7 Mtpa*		Battery energy storage	Gas + CCS power plant[64]	RNG, EE, nuclear, hydro, geothermal
Industrial ○ *1.2 Mtpa*	Cogeneration ○ *0.4 Mtpa*	Not applicable to use case	Gas + CCS cogeneration facility	RNG, EE
	Refineries (process H_2) ○ *0.7 Mtpa*	Not applicable to use case	Unabated hydrogen from SMR + CCS	EE
	Cement (fuel switching) ○ *0.02 Mtpa*	Electric kiln	Gas + CCS kiln	RNG, EE
	Food & Beverage (fuel switching) ○ *0.03 Mtpa*	Electric oven/fryer	Not applicable to use case	RNG, EE

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[62] The use case categories considered for the evaluation of Non-Hydrogen Alternatives were informed by the Demand Study.

4.2.2.1. Non-Hydrogen Alternatives Selected for Further Evaluation

Based on an initial screening of the potential Non-Hydrogen Alternatives to determine their ability to meet the purpose and need for Angeles Link as a standalone alternative, the following were selected for further assessment in this study:

Electrification refers to a combination of system level[65] transformation and use case level[66] technology changes including the grid infrastructure required to support growing electric load. The assessment of electrification was primarily conducted on a use case level for the purposes of this study (e.g., fuel cell electric vehicle (FCEV) vs. BEV for heavy-duty vehicles for the mobility sector). A broader evaluation of system-level electrification considerations was also conducted based on a high-level review of existing research, third-party studies, and California's decarbonization goals. These considerations are summarized in Section 4.3.2.1.1, with additional details in Appendix 7.3.3.

CCS refers to carbon capture and sequestration technology, which is the process of storing carbon dioxide in underground geologic formations. The assessment of CCS was conducted on a use case level for the purposes of this study (e.g., hydrogen vs. CCS for power generation), and certain system-level considerations and assumptions were incorporated into the use case level assessments, including the implications of the CO_2 storage and transportation infrastructure needed to support CCS applications.

4.2.2.2. Non-Hydrogen Alternatives Not Advanced for Further Evaluation

The following alternatives were considered in the Step 1 pre-screening process but not advanced for further assessment. While these solutions may play important roles in support of California's decarbonization targets, they were found to be unlikely to fully address the energy equivalent of Angeles Link's hydrogen demand requirements as standalone alternatives.

RNG derived from organic waste has been identified as an important clean fuel alternative in supporting California's ambitious decarbonization and methane emission reduction goals,

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[63] Circles reflect 2045 projected hydrogen demand (in Mtpa) in the Demand Study "Moderate Case", with the exception of refineries, for which demand was only projected in the "Ambitious Case". See Demand Study for additional information.

[64] Gas + CCS refers to a CO_2 capture technology that captures emissions from an existing natural gas facility.

[65] System level electrification includes the incremental electricity generation, storage, and supporting upstream grid infrastructure requirements to meet wide-scale end use electrification needs.

[66] Use-case level electrification refers to replacing technologies or processes that use fossil fuels, like internal combustion engines and gas boilers, with electrically powered equivalents, such as electric vehicles or heat pumps. More detail at https://www.iea.org/energy-system/electricity/electrification

aligning with the State's legislative policies and mandates, such as Senate Bill (SB) 1440[67] and SB 1383.[68] As discussed in the 2022 CARB Scoping Plan, RNG (biomethane) can help offset usage of traditional fuels to meet California's decarbonization objectives.[69] SB 1440 specifically requires RNG procurement of 17.6 billion cubic feet (BCF) annually by 2025, and 72.8 BCF by 2030, which represents 12% of the current residential and small business gas usage in 2020.[70] Organic waste feedstock-derived RNG provides a lower-carbon alternative (or a negative carbon alternative for some feedstocks) to conventional natural gas, creating an opportunity to utilize existing gas infrastructure for cleaner energy applications. Its role is crucial in the initial phases of California's low-carbon transition, particularly in sectors where direct electrification is challenging. RNG plays a key role in meeting the SB 1440 procurement targets, SB 1383 procurement requirements, and the voluntary market (e.g., customers seeking to procure RNG to help meet their sustainability goals). However, RNG's potential to fully address the energy equivalent of Angeles Link's hydrogen demand requirements as a standalone alternative is tempered by statewide supply availability.

Energy efficiency is a key decarbonization tool in nearly every sector, as it allows for the overall reduction in energy inputs required to serve growing future energy demand. As defined by the Department of Energy (DOE), energy efficiency is the use of less energy to perform the same task or produce the same result.[71] Energy efficiency is a partial decarbonization solution on its own and cannot be evaluated on a standalone basis relative to Angeles Link and other alternatives from an energy equivalency perspective.

In the **mobility** sector, the following fuels were considered but not advanced for further analysis as they each produce tailpipe emissions and are therefore not compliant with California's Advanced Clean Trucks and Advanced Clean Fleets regulations:[72]

- **Ethanol,** also known as flex fuel, is a gasoline-ethanol blend containing 51%-83% ethanol and capable of serving flexible fuel vehicles in the mobility sector.[73] Ethanol is a sustainable fuel produced from various plant components known as biomass. Ethanol is

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[67] SB 1440 (Hueso, Chapter 739, Statutes of 2018) sets Biomethane (RNG) procurement targets for gas utilities to reduce GHG emissions in remaining pipeline gas and reduce methane emissions from organic waste.

[68] http://www.leginfo.ca.gov/pub/15-16/bill/sen/sb_1351-1400/sb_1383_bill_20160919_chaptered.htm

[69] https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf

[70] https://www.cpuc.ca.gov/news-and-updates/all-news/cpuc-sets-biomethane-targets-for-utilities

[71] https://www.energy.gov/eere/energy-efficiency-buildings-and-industry

[72] https://ww2.arb.ca.gov/our-work/programs/advanced-clean-fleets

[73] https://afdc.energy.gov/vehicles/flexible-fuel

an alcohol that is blended with gasoline to boost octane while reducing carbon monoxide and other smog-causing pollutants.[74]

- **Plug-in hybrids** use batteries to power an electric motor, as well as another fuel, such as gasoline or diesel, to power an internal combustion engine or other propulsion source.[75] Several light-duty plug-in hybrids are commercially available, and medium-duty vehicles are beginning to enter the market. Medium- and heavy-duty vehicles can also be modified into plug-in hybrid vehicles.[76]
- **Biofuels**, such as biodiesel, are renewable, biodegradable fuels produced from vegetable oils, animal fats, or recycled restaurant grease.[77]

In the **power** sector, the following technologies were considered but not advanced for further analysis for the following reasons:

- **Nuclear power generation** is the energy harnessed to produce electricity through nuclear fission inside a reactor. Due to the absence of state plans for new-build units and the planned retirement of Diablo Canyon Power Plant in 2030,[78] nuclear power was not considered for further evaluation.
- **Hydro power generation** is a clean and renewable source of energy allowing for power generation from the natural flow of water by using the elevation difference created by a dam or a water diversion system.[79] Due to limited new capacity additions forecasted in the CARB Scoping Plan,[80] hydro units (including pumped hydro storage) were screened out from further consideration in this study.
- **Geothermal power generation** uses the heat energy extracted from the geothermal resources from underground geologic reservoirs of hot water to produce electricity.[81] Even though geothermal energy has the potential to play a role in supporting decarbonization goals in California, new geothermal capacity is expected to be minimal, as CARB's Scoping Plan forecasts only up to 1 GW of geothermal capacity additions by 2045.[82]

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[74] https://www.energy.gov/eere/bioenergy/biofuel-basics

[75] https://afdc.energy.gov/vehicles/electric-basics-phev

[76] https://afdc.energy.gov/vehicles/electric-basics-phev

[77] https://afdc.energy.gov/fuels/biodiesel-basics

[78] California Energy Commission - https://www.energy.ca.gov/news/2023-02/cec-determines-diablo-canyon-power-plant-needed-support-grid-reliability

[79] https://www.energy.gov/eere/water/hydropower-basics

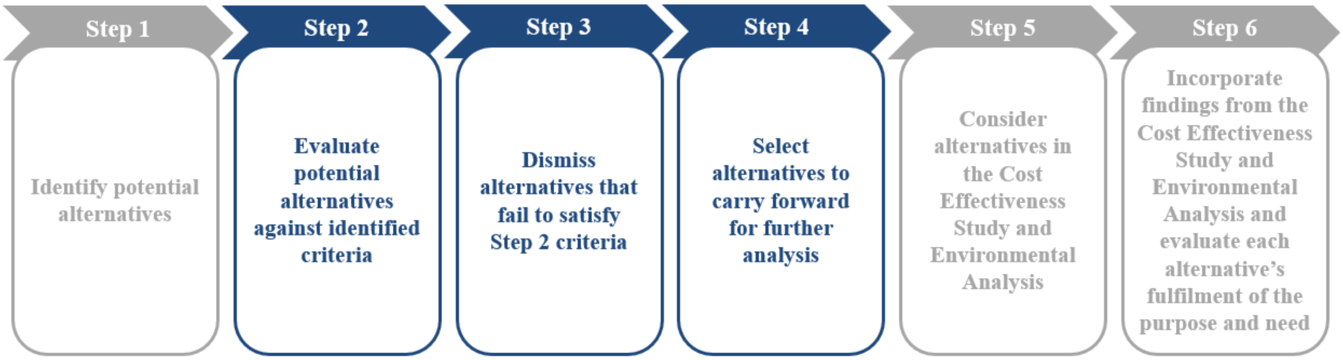
[80] https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf

[81] https://www.nrel.gov/research/re-geo-elec-production.html

[82] https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf

4.3. Evaluation of Alternatives

Figure 5: Six-Step Evaluation Process: Evaluation of Alternatives



This section describes the evaluation criteria, methodology, and key findings from the evaluation alternatives in Steps 2-4 of the six-step evaluation framework (as illustrated in Figure 5 above). Considering the criteria are distinctive to each category of alternatives, the findings for Steps 2-4 are categorized into two sections—Hydrogen Delivery Alternatives and Non-Hydrogen Alternatives.

4.3.1. Evaluation of Hydrogen Delivery Alternatives

Five assessment criteria were applied to evaluate Hydrogen Delivery Alternatives for advancement to the next steps in the analysis: (i) state policy; (ii) range; (iii) reliability and resiliency; (iv) ease of implementation; and (v) scalability, summarized in

Table 9 below. A 4-point assessment rubric (high, good, moderate, low) was used to evaluate the extent to which each Delivery Alternative may achieve or be consistent with each criterion.

Table 9: Criteria Definitions and Assessment Rubric for Step 2 Evaluation

Criteria Selected for Screening	Definition	High	Good	Moderate	Low
State Policy	Level of alignment with California's clean energy and environmental policies	Alignment with state policy, including specific incentives or initiatives	Alignment with state policy but potential conflicts with decarbonization goals	No alignment with state policy and potential conflicts with decarbonization goals	Explicit misalignment with state policy and conflicts with decarbonization goals

Criteria Selected for Screening	Definition	High	Good	Moderate	Low
Range	The distance or range of deliverability the transportation method can effectively cover for delivering hydrogen	Capable of efficiently transporting hydrogen at least the length of California	Capable of covering at least 450[83] miles or is optimal given its location - but might face inefficiencies (losses)	Moderate range with the ability to efficiently cover fewer than 450 miles in a day	Limited range due to technical or other type of constraints
Reliability and Resiliency	The capability to provide uninterrupted and/or consistent hydrogen supply and adapt to reduce the duration/magnitude of disruptive events[84]	Guarantees hydrogen supply and unparalleled adaptability to reduce duration/ magnitude of disruptive events	Infrequent hydrogen supply disruptions due to adaptability to mitigate the duration/ magnitude of disruptive events	Expected and unavoidable hydrogen supply disruptions and limited adaptability to manage disruptive events	Constant hydrogen supply disruptions and limited adaptability to manage disruptive events

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[83] Length of Angeles Link Project description.

[84] https://www.cpuc.ca.gov/-/media/cpuc-website/industries-and-topics/meeting-documents/vorlumen20230321resiliency-definitionsfinal.pdf

Criteria Selected for Screening	Definition	High	Good	Moderate	Low
Ease of Implementation	The ease with which a delivery solution can be implemented, considering technology readiness,[85] existing and complementary infrastructure, entry barriers, and construction time	Mature technology readiness, existing complementary infrastructure, and limited entry barrier and lowest construction time	Mature technology readiness, existing complementary infrastructure, and limited entry barrier but requires more complex infrastructure	Feasible technology readiness, with some complementary infra., possible entry barriers and longer time for construction	Challenged by technology readiness, technical challenges, or entry barriers
Scalability	The potential for an alternative to support California's need for 1.5 Mtpa and its ability to expand volume or extend footprint	Supports at least 1.5 Mtpa, adaptable to expand volume or extend footprint	Feasible at 1.5 Mtpa, with limited potential to expand volume or extend footprint	Feasible at 1.5 Mtpa but severely challenged by land or other constraints	Challenging or impractical to scale to 1.5 Mtpa due to infrastructure requirements

The Hydrogen Delivery Alternatives were evaluated based on the selected criteria summarized above. State Policy and Range were analyzed for each delivery method; Reliability and

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[85] See Appendix 7.4.1 for Technology Readiness Level definition.

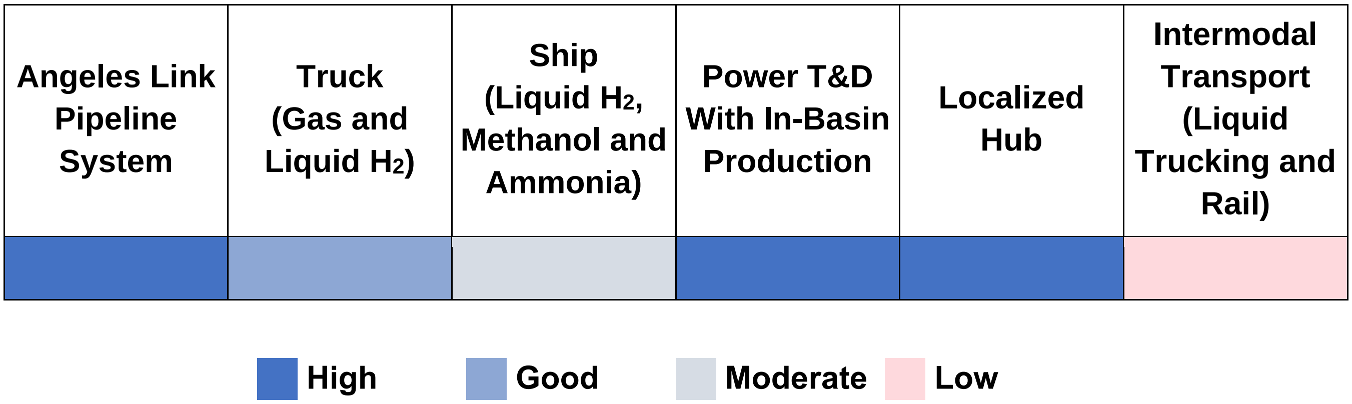
Resiliency and Ease of Implementation were analyzed at the alternative level (specific options within each transportation method); and Scalability was evaluated for a specific scale and scope configuration.

4.3.1.1. Evaluated Delivery Alternatives

4.3.1.1.1.State Policy

The criterion to evaluate alignment with state policy considers the degree to which Angeles Link and each Delivery Alternative supports California's decarbonization and clean energy objectives, is in line with ongoing legislative and regulatory actions, and can be developed within the parameters of existing regulatory frameworks. This criterion is evaluated for each delivery method. Figure 6 below summarizes the degree to which each potential Hydrogen Delivery Alternative aligns with state policy.

Figure 6: Level of Alignment with State Policy Across Hydrogen Delivery Alternatives



Angeles Link Pipeline System	Truck (Gas and Liquid H_2)	Ship (Liquid H_2, Methanol and Ammonia)	Power T&D With In-Basin Production	Localized Hub	Intermodal Transport (Liquid Trucking and Rail)
🟦	▦	⬜	🟦	🟦	🟥

🟦 **High** ▦ **Good** ⬜ **Moderate** 🟥 **Low**

Pipeline

Assessment: 🟦 Alignment with state policy, including specific incentives or initiatives.

- ✓ Due to their ability to efficiently transport large volumes of hydrogen over long distances, pipelines have relatively low GHG emissions when compared to other alternatives, and thus align well with California's clean energy and environmental policies.
- ✓ Pipeline transport of clean renewable hydrogen can enable the scale of deployment required to support the adoption of clean renewable hydrogen on an economy-wide basis, which supports job creation and other economic benefits, as well as the integration and growth of the ARCHES hydrogen hub (which has been selected for

federal funding by the DOE pursuant to the Infrastructure Investment and Jobs Act (IIJA) funding program).[86]

- × As a linear project, pipelines can face extensive permitting processes, requiring a longer development timeline which would potentially delay the realization of decarbonization objectives.

Truck (Gas and Liquid Hydrogen)

Assessment: 🟦 Alignment with state policy but potential conflicts with decarbonization goals.

- ✓ The emissions intensity of hydrogen trucking is expected to decline as technologies advance; for example, as vehicle emissions standards become more stringent, vehicle stocks turn over and trucks transition from diesel internal combustion engines to fuel cell drive trains, and as efficiency improvements are achieved in fuel cell drive trains.
- ✓ Regulatory processes for truck deployment and liquefaction/compression terminal development may have a more favorable timeline than other larger-scale alternatives.
- ✓ A trucking alternative is in line with state policy until a pipeline system is developed.
- × Liquefaction and compression terminals for trucks are highly energy intensive and may face challenges related to emissions intensity based on their source of power.[87]
- × Diesel trucks, which currently dominate the truck fleet for hydrogen transport, may face challenges in earlier years related to emissions before fleets are converted to zero emission vehicles, based on the distance travelled, quantity of diesel trucks, and number of trips.[88]
- × Trucking at the scale required to meet projected demand would result in a very large number of trucks on the road, leading to an increase in road congestion.

Ship (Liquid Hydrogen, Methanol and Ammonia)

Assessment: ⬜ No alignment with state policy and potential conflicts with decarbonization goals.

- × No existing policy nor economic incentives exist to support the development of transporting clean renewable hydrogen (using ships) as derivative carriers (such as ammonia or methanol) within California.

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[86] ARCHES hydrogen hub was awarded up to $1.2 billion from the U.S. DOE to accelerate the development and deployment of clean renewable hydrogen in California, see https://www.gov.ca.gov/2023/10/13/california-selected-as-a-national-hydrogen-hub/

[87] https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/ca-greet/lut-doc.pdf?_ga=2.201451796.486364569.1720469315-728837761.1706478186, pg. 37.

[88] Ibid.

- × Large scale facilities for hydrogen conversion/reconversion at the port of departure and receipt are highly energy intensive and may face challenges related to emissions intensity based on their source of power.

Power T&D with In-Basin Production

Assessment: 🟦 Alignment with state policy, including specific incentives or initiatives.

- ✓ The addition of renewable power transmission and distribution to support load in the L.A. Basin supports California's commitment to decarbonize power generation.[89]
- ✓ California's Independent System Operator (CAISO) has put into place plans and a more proactive approach to support investments in power transmission.[90]
- × Power transmission and distribution infrastructure faces extensive permitting processes, requiring a longer development timeline. [91]

Localized Hub

Assessment: 🟦 Alignment with state policy, including specific incentives or initiatives.

- ✓ Pipelines can transport hydrogen with low GHG emissions when compared to other alternatives.
- ✓ A localized hub with production near end users aligns with the State's decarbonization goals for end users to use more hydrogen.
- ✓ The development of additional in-basin distributed solar capacity aligns with California's clean energy goals.[92]
- × Permitting and regulatory processes for power generation, hydrogen production, and delivery infrastructure may be more challenging in a population dense area.

Intermodal Transport (Liquid Trucking and Liquid Rail)

Assessment: 🟥 Low alignment with state policy and conflicts with decarbonization goals.

- × Diesel engines and locomotives transporting hydrogen may encounter challenges related to emissions and transportation and safety regulations (e.g., hydrogen transportation safety regulations for rail movement across bridges, tunnels, etc.).
- × Intermodal transfer of liquid hydrogen between different modes at transfer stations can pose safety challenges and boil-off losses.

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[89] https://ww2.arb.ca.gov/our-work/programs/ab-32-climate-change-scoping-plan/2022-scoping-plan-documents

[90] https://www.nrdc.org/bio/kelsie-gomanie/california-iso-approves-73-billion-investment-transmission

[91] https://www.publicadvocates.cpuc.ca.gov/-/media/cal-advocates-website/files/press-room/reports-and-analyses/230612-caladvocates-transmission-development-timeline.pdf

[92] D.22-12-055.

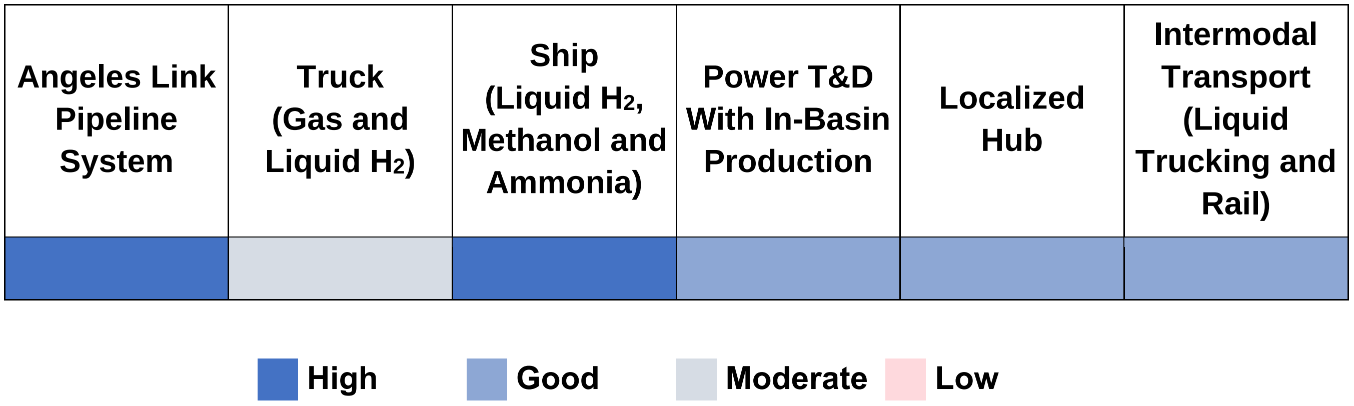
4.3.1.1.2.Range

The distance traveled, associated volumes of transport, and end-use requirements all influence the selection of a certain transportation option/pathway. Transportation options that can cover longer distances provide options for sourcing the highest quality renewable resources for hydrogen production. Infrastructure requirements, general range capabilities, and suitability for specific transport distances (based on the volume of hydrogen transported and distances traveled) were considered when evaluating the range for each transportation mode. Range is defined as the capability to efficiently cover delivery distances and follows the 4-point scale ranking defined in

Table 9. This criterion is evaluated for each delivery method.

Figure 7 below summarizes the extent to which each delivery alternative can serve hydrogen for the range envisioned between major production and demand hubs, followed by a summary of the advantages and challenges for each delivery alternative associated with range.

Figure 7: Level of Alignment with Range Across Hydrogen Delivery Alternatives



Angeles Link Pipeline System	Truck (Gas and Liquid H_2)	Ship (Liquid H_2, Methanol and Ammonia)	Power T&D With In-Basin Production	Localized Hub	Intermodal Transport (Liquid Trucking and Rail)
🟦	░	🟦	▨	▨	▨

🟦 High ▨ Good ░ Moderate 🟥 Low

Pipeline

Assessment: 🟦 Capable of efficiently transporting hydrogen at least the length of California.

✓ Pipelines have high range capabilities, making them efficient for transporting hydrogen over long distances, as demonstrated by the extensive network established in the U.S. Gulf Coast.[93]

Truck (Gas and Liquid Hydrogen)

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[93] The U.S. has ~1,600 miles of dedicated hydrogen pipelines network (with varying pipeline mileage), connecting multiple production and demand centers. See https://harnessinghydrogen.npc.org/files/H2-Appendix_J-2024-04-23.pdf Appendix J, Table 3-6.

Assessment: ⬜ Moderate range with the ability to efficiently cover fewer than 450 miles in a day.

- ✓ Compressed gaseous hydrogen (GH$_2$) and liquefied hydrogen (LH$_2$) trucking are an effective solution for supplying hydrogen to dispersed consumers at shorter distances in local and urban areas.[94]
- × Trucking larger volumes of hydrogen over longer distances can be economically challenging due to boil-off losses, labor, and fuel costs.
- × Liquid or gaseous hydrogen trucks may need more frequent refueling or replenishment relative to other transportation modes.

Ship (Liquid Hydrogen, Methanol and Ammonia)

Assessment: 🟦 Capable of efficiently transporting hydrogen at least the length of California.

- ✓ Ships can cover long distances.
- × Ships require complex multi-modal and large-scale conversion/liquefaction infrastructure for conversion before shipping and for large scale reconversion/regasification at the point of delivery. The complex infrastructure value chain has the potential for conversion/boil-off losses.

Power T&D with In-Basin Production

Assessment: 🟦 Capable of covering at least 450 miles, or is optimal given supply and demand locations, but might face inefficiencies (losses).

- ✓ Bulk power transmission systems enable the transmission of electrons from high quality renewable resources over longer distances to hydrogen production near demand locations.
- × Significant transmission losses coupled with potential grid congestion impacts, or operational challenges from utilization and solar variability, could lead to lower transmission throughput.[95]

Localized Hub

Assessment: 🟦 Capable of supporting the development of a dedicated clean renewable hydrogen pipeline system located within the L.A. Basin with production and end use in proximity (range).

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[94] In the U.S., GH$_2$ and LH$_2$ are the most common forms of hydrogen transported by truck. See https://harnessinghydrogen.npc.org/files/H2-Appendix_J-2024-04-23.pdf Chapter 3: LCI Hydrogen—Connecting Infrastructure, pg. 24.

[95] U.S. Energy Information Administration, HARNESSING HYDROGEN - A Key Element of the U.S. Energy Future (npc.org), see: https://www.eia.gov/tools/faqs/faq.php?id=105

- ✓ Localized hub could connect local (distributed) clean renewable hydrogen producers to multiple end users in the hard-to-electrify sectors via open access, common carrier pipeline infrastructure.
- × The ability to extend service to demand outside of the localized hub would be limited due to limited renewable and hydrogen production capacity in-basin.

Intermodal Transport (Liquid Trucking and Liquid Rail)

Assessment: ▨ Capable of covering the transport distances as envisioned for the Angeles Link - but might face inefficiencies (losses).

- ✓ Transportation by truck is suitable for short- or mid-distance transport. Rail systems can support longer distances.
- × There are challenges associated with rail transport safety regulations over longer distances (e.g., hydrogen transportation safety regulations for rail movement across bridges, tunnels, etc.).

4.3.1.1.3. Reliability and Resiliency

Reliability and Resiliency evaluates an alternative's ability to provide uninterrupted and/or consistent hydrogen supply and to reduce the duration/magnitude of disruptive events. The assessment follows the 4-point scale ranking as defined in

Table 9. This criterion is evaluated for each delivery alternative (e.g., shipping as liquid hydrogen vs. ammonia) whereas the previous criteria have been evaluated for each delivery method (e.g., shipping). Figure 8 below summarizes the degree to which each potential alternative achieves reliability and resiliency, followed by a summary of the advantages and challenges for each alternative associated with reliability and resiliency.

Figure 8: Level of Alignment with Reliability and Resiliency Across Hydrogen Delivery Alternatives

Angeles Link Pipeline System	Gaseous Hydrogen Trucking	Liquid Hydrogen Trucking	Liquid Hydrogen Shipping	Methanol Shipping	Ammonia Shipping	Power T&D With In-Basin Production	Localized Hub	Intermodal Transport (Liquid Trucking and Rail)
▨	⬜	▨	⬜	⬜	🟥	▨	▨	🟥

🟦 **High** ▨ **Good** ⬜ **Moderate** 🟥 **Low**

Angeles Link

Assessment: 🟦 Infrequent hydrogen supply disruptions due to the adaptability to mitigate the duration/ magnitude of disruptive events.

- ✓ Hydrogen pipelines are well suited to integrate supply and demand, with the ability to connect production and storage (e.g., third-party storage resources) across strategic locations along their routes and the ability to provide storage in the pipeline system (for example, by linepacking). This integration provides operational flexibility, system scalability, and robust reliability and resiliency as the demand for hydrogen scales over time.
- ✓ Pipelines can be built underground and are therefore typically more resilient to extreme weather and other external factors.
- ✓ Pipeline systems at scale have the potential to provide energy system reliability and resiliency and help advance California’s emissions reduction goals in tandem, by providing an alternative pathway for the delivery of renewable energy as clean renewable hydrogen.
- × Pipelines require significant lead time to provide access to new/distant service areas and storage locations beyond those accounted for in the pipeline system’s initial design.

Trucking (General)

- ✓ Hydrogen trucking offers flexibility to adapt to potential disruptions, as the fleet can be rerouted or rescheduled as needed.
- × Truck load cycles are slower than pipelines accessing hydrogen storage locations, which results in slower dispatchability.
- × Trucks are more likely to face supply disruptions due to traffic, road closures, or accidents, especially when transporting over long distances, which could affect system reliability.

Gaseous Hydrogen Trucking

Assessment: ⬜ Unforeseen hydrogen supply disruptions and limited adaptability to manage disruptive events.

- × Gaseous hydrogen trucking serving long distance hydrogen transport necessitates a large compression terminal and gaseous hydrogen trucking fleet covering long distances to transport hydrogen, which can potentially lead to supply disruptions impacting reliability. In the mobility sector, California has previously experienced hydrogen supply disruptions (e.g., lack of availability of gaseous hydrogen) to serve the existing hydrogen refueling stations for the light duty FCEV sector.[96]

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[96] https://h2fcp.org/sites/default/files/Hydrogen-Distribution-and-Supply.pdf

Liquid Hydrogen Trucking

Assessment: 🟦 Hydrogen supply disruptions can be lessened (albeit not eliminated) due to adaptability to mitigate the duration/magnitude of disruptive events.

- ✓ Hydrogen in its liquid form has a much higher energy density compared to its gaseous form, meaning fewer LH_2 trucks and deliveries are needed for the same energy content, which reduces exposure to potential disruptions.
- × Even with the benefit of a smaller fleet and fewer deliveries, LH_2 trucks still face higher potential for supply disruptions when transporting over long distances than pipelines.

Shipping (General)

- ✓ Hydrogen demand located near delivery hubs and ports would benefit from close proximity to supply produced at the port or delivered via ships.
- × Shipped hydrogen may offer limited access to certain demand centers and/or may require additional infrastructure to reach demand centers not located near ports.
- × Delivery via ship exposes hydrogen supply to port congestion, weather disruptions, and supply chain constraints as seen during events like the COVID-19 pandemic, Russia's war in Ukraine,[97] and the Suez Canal blockage,[98] potentially diminishing reliability.

Liquid Hydrogen Shipping

Assessment: ⬜ Expected and unavoidable hydrogen supply disruptions and limited adaptability to manage disruptive events.

- ✓ Liquid hydrogen can be re-gasified and consumed as a gaseous fuel, which is a relatively less complex, costly, and energy intensive process than reconverting ammonia or methanol to hydrogen.
- × With current liquified hydrogen shipping technology, more ships and deliveries are required for the same energy content as ammonia and methanol, creating more opportunity for disruption.

Methanol Shipping

Assessment: ⬜ Expected and unavoidable hydrogen supply disruptions and limited adaptability to manage disruptive events.

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[97] https://jag.journalagent.com/jems/pdfs/JEMS_12_1_106_114.pdf, Journal of ETA Maritime Science 2024.

[98] https://porteconomicsmanagement.org/pemp/contents/part10/port-resilience/suez-canal-blockage-2021/

- ✓ Methanol can be more easily stored than hydrogen and used directly as a fuel or converted back to hydrogen if necessary, providing flexibility via multiple pathways to energy utilization.
- × The extra steps in the value chain process to transform hydrogen into methanol and reconvert methanol to hydrogen would create more opportunities for disruption.

Ammonia Shipping

Assessment: 🟥 Constant hydrogen supply disruptions and limited adaptability to manage disruptive events.

- ✓ Ammonia can be easily stored and used directly as a fuel or converted back to hydrogen if necessary, providing flexibility via multiple pathways to energy utilization.
- × The process for ammonia production (i.e. Haber-Bosch) requires a 24/7 stream of electricity, hydrogen, and nitrogen as feedstocks.[99] Clean renewable electricity and hydrogen produced via solar generation face challenges in this process due to the intra-day production profile of solar. This incompatibility could create reliability challenges for ammonia as a hydrogen transportation pathway.

In-Basin Production with Power T&D

Assessment: 🟦 Infrequent hydrogen supply disruptions due to adaptability to mitigate the duration/ magnitude of disruptive events.

- ✓ In-basin production is closer to demand, supporting market access and reducing risk of disruption to delivery infrastructure.
- ✓ Additional transmission lines contribute to the system’s reliability.
- × In-basin above-ground storage capacity may not be sufficient to provide hydrogen supply reliability for the scale of hydrogen demand projected long-term.

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[99] Refer to Appendix 7.3.1, the process of converting hydrogen to ammonia (known as Haber Bosch ammonia synthesis) requires constant input of hydrogen and power, which is not conducive with non-grid interconnected clean renewable hydrogen production from solar facilities.

- × Due to the significant transmission mileage required to support in-basin hydrogen production[100], this alternative is at higher risk of interruption for Power Safety Public Shut-off (PSPS)[101] events, which could result in system reliability impacts.
- × Development timelines for new transmission and distribution infrastructure may create limitations to respond to growing hydrogen demand and to deliver on production resiliency needs.[102]

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[100] The scope configuration for In-Basin Hydrogen Production with T&D requires 400 miles of electricity transmission corridor to connect solar generation capacity locations in San Joaquin Valley, Lancaster, and Blythe to hydrogen production in the L.A. Basin. Refer to Table 3, Appendix 7.2.2.2, and Appendix 7.3.1.2.4 in the Cost Effectiveness Study.

[101] The In-Basin Production with Transmission and Distribution alternative requires over 400 miles of transmission line corridor, making it more likely to face Public Safety Power Shut-Offs than other alternatives. See https://www.cpuc.ca.gov/psps/

[102] https://www.publicadvocates.cpuc.ca.gov/-/media/cal-advocates-website/files/press-room/reports-and-analyses/230612-caladvocates-transmission-development-timeline.pdf

Localized Hub

Assessment: 🟦 Infrequent hydrogen supply disruptions due to the adaptability to mitigate the duration/ magnitude of disruptive events.

- ✓ Avoiding the need to transport hydrogen from external sites to demand centers minimizes the risks of transport disruptions.
- × In-basin above-ground storage capacity may not be sufficient to provide hydrogen supply reliability for the scale of hydrogen demand projected long-term.
- × The ability to flexibly serve demand outside of the localized hub would be limited due to limited renewable and hydrogen production capacity in-basin.
- × Limited in-basin electricity and hydrogen production capacity could impact reliability for power needs and, in the long-term, the mobility sector.

Intermodal Transport (Liquid Trucking and Rail)

Assessment: 🟥 Constant hydrogen supply disruptions and limited adaptability to manage disruptive events.

- × Integration of truck and train transport, each with its own infrastructure needs, shipping sizes, schedules, and regulatory requirements, adds complexity that can lead to challenges and disruptions.
- × Reliability is limited by the challenges associated with all the individual delivery methods outlined previously for trucking and shipping.

4.3.1.1.4.Ease of Implementation

Ease of implementation evaluates how readily each Hydrogen Delivery Alternative can be implemented, considering technical and commercial maturity, the availability of existing and complementary infrastructure, construction time, and regulatory frameworks in place to support the implementation of each delivery alternative. The assessment follows the 4-point scale to categorize the ease of implementation for each alternative as defined in
Table 9. To assess technical and commercial maturity, Technology Readiness Levels (TRL) were evaluated to further assess the ease of implementation of each Hydrogen Delivery Alternative. TRLs measure the operational readiness of a technology, providing insights into its commercial viability, and are defined in the International Energy Agency's (IEA) Clean Tech Guide. A detailed description of each TRL score can be found in Appendix 7.4.1.[103] Technologies rated with a TRL of 9 or above are considered technically and commercially mature technologies that are operational at-scale in the U.S. or in other markets globally.

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[103] Appendix 7.4.1 Technology Readiness Levels for Hydrogen Delivery Alternatives and Non-Hydrogen Alternatives

Gaseous and liquid hydrogen trucking, along with ammonia shipping, are assessed at a TRL of 11, indicating technical and commercial maturity has been demonstrated in multiple market environments. Hydrogen pipelines, such as Angeles Link, are the primary method used to transport hydrogen over short and long distance to large scale consumers.[104] Hydrogen pipelines are assessed at a TRL of 9, with demonstrated technical and commercial maturity in relevant environments. In the U.S. the largest pipeline systems are in the Gulf Coast region, where 1,500 miles of pipeline have been developed to serve large consumers such as refineries, ammonia and methanol production facilities.[105] Liquid hydrogen shipping is assessed at a TRL of 7 and is currently in the pre-commercial demonstration phase. Methanol and ammonia shipping is assessed at a TRL of 11, with traditional methanol and ammonia shipped commercially as a global commodity.[106]

Figure 9 below summarizes the degree to which each potential delivery alternative may have ease of implementation, followed by a summary of the advantages and challenges for each alternative associated with ease of implementation.

Figure 9: Ease of Implementation Across H_2 Delivery Alternatives

Angeles Link Pipeline System	Gaseous Hydrogen Trucking	Liquid Hydrogen Trucking	Liquid Hydrogen Shipping	Methanol Shipping	Ammonia Shipping	Power T&D With In-Basin Production	Localized Hub	Intermodal Transport (Liquid Trucking and Rail)
⬜	🟦	▦	⬜	⬜	🟥	⬜	⬜	⬜

🟦 **High** ▦ **Good** ⬜ **Moderate** 🟥 **Low**

Angeles Link

Assessment: ⬜ Feasible technology readiness with some complementary infrastructure, however, implementation faces possible entry barriers and longer time for construction.

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[104] The U.S. has ~1,600 miles of dedicated hydrogen pipelines network (with varying pipeline mileage), connecting multiple production and demand centers. See https://harnessinghydrogen.npc.org/files/H2-Appendix_J-2024-04-23.pdf Appendix J, Table 3-6.

[105] Department of Energy Hydrogen Fuel Cell and Technology Office, https://www.energy.gov/eere/fuelcells/hydrogen-pipelines

[106] The TRL for cracking of methanol of Ammonia (at-scale) back to hydrogen or regasification of liquid hydrogen (at scale) may be at the pre-commercial phase.

- ✓ Gaseous pipeline implementation is understood and mature at scale throughout the U.S. and globally, which can support hydrogen pipeline development.
- ✓ Angeles Link will seek to leverage existing land rights for pipeline infrastructure throughout Central and Southern California to the extent this is feasible, potentially reducing development timelines.
- × New pipeline construction requires planning and coordination with hydrogen production and demand components of the developing hydrogen value chain, which may require a longer development timeline.
- × Long-haul pipelines require an extensive development lifecycle.[107]

Trucking (General)

- ✓ California has an existing supply chain for hydrogen compression and liquefaction technology and delivery trucks which currently serve refueling stations and the growing FCEV fleet.
- ✓ Existing highway infrastructure minimizes the need for new construction.
- ✓ Truck fleet additions, and development of new liquefaction/compression and loading terminals can be phased to match demand growth.

Gaseous Hydrogen Trucking

Assessment: 🟦 Mature technology readiness, existing complementary infrastructure, and limited entry barrier and lowest construction time.

- ✓ Gaseous hydrogen compression and trucks are relatively straightforward to implement in comparison to the liquid value chain.
- × There are limits to the implementation of gaseous hydrogen trucking to serve demand once it grows past consumption of approximately 500-600 kg/d due to the capacity limit of current truck and tank technology.[108]

Liquid Hydrogen Trucking

Assessment: ▨ Mature technology readiness, existing complementary infrastructure, and limited entry barrier but requires more complex infrastructure.

- × Liquid hydrogen trucking requires more specialized infrastructure compared to gaseous transportation, to handle the conversion between gaseous and liquid states.

Shipping (General)

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[107] https://www.phmsa.dot.gov/technical-resources/pipeline/pipeline-construction/phases-pipeline-construction-overview

[108] https://www.energy.gov/eere/fuelcells/articles/hydrogen-delivery-roadmap

- ✓ Hydrogen and its carriers have the potential to leverage existing port locations and infrastructure currently in use for traditional ammonia, methanol, or liquefied natural gas (LNG).
- × New facilities required to handle hydrogen or its carriers inside ports with geospatial limitations may complicate the implementation of hydrogen or carrier shipping in some locations.

Liquid Hydrogen Shipping

Assessment: ⬜ Feasible technology readiness, with some complementary infrastructure, possible entry barriers, and longer time for construction.

- ✓ Liquid hydrogen transportation does not require an additional feedstock (i.e., nitrogen for ammonia or anthropogenic CO_2 for low-carbon methanol) or additional chemical processing facilities for conversion into a hydrogen carrier.
- ✓ Shipping of liquified gases has developed into a commercially viable global market for commodities such as Liquified Natural Gas (LNG).
- × Liquid hydrogen shipping is in the very early stages, with only one prototype ship that has completed a successful voyage in the market and faces technical challenges to reduce boil off and losses.[109]
- × Liquid hydrogen import and export terminals will require retrofits to existing pipeline and storage, liquefaction/regasification infrastructure or new infrastructure that can handle the unique characteristics of hydrogen.

Methanol Shipping

Assessment: ⬜ Feasible technology readiness with some complementary infrastructure; however, implementation faces possible entry barriers and longer time for construction.

- ✓ Methanol has the potential to leverage existing port infrastructure for traditional methanol, without reconversion to hydrogen, in limited applications such as for use as a shipping fuel.
- × Implementing reconversion infrastructure required to “crack” methanol back to its chemical components as a method for hydrogen production is highly energy intensive, releases CO_2, and is not yet demonstrated at scale, limiting methanol’s potential use as a hydrogen carrier for other demand applications.

Ammonia Shipping

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[109] https://maritime-executive.com/article/video-world-s-first-hydrogen-carrier-departs-japan-on-maiden-voyage, The Maritime Executive.

Assessment: 🟥 Challenged by technology readiness, operational challenges, or entry barriers.

- ✓ Ammonia has the potential to leverage existing port infrastructure for traditional ammonia, without reconversion to hydrogen, in limited applications such as for green fertilizer production, and blending with coal, to reduce the carbon intensity of dispatchable power generation. [110]
- × Implementing reconversion infrastructure required to crack ammonia back to its chemical components as a method for hydrogen production is highly energy intensive and is not yet demonstrated at scale, limiting ammonia's potential use as a hydrogen carrier for other demand applications.
- × The operational requirements of ammonia production through the Haber-Bosch process mean a reliable and continuous supply of hydrogen, nitrogen, and low-carbon electricity are critical for continuous operation. Continuous access to electricity and hydrogen may be challenging if solar generation is the main source of power.

In-Basin Production with Power T&D

Assessment: ⬜ Feasible technology readiness with some complementary infrastructure; however, implementation faces possible entry barriers, and longer time for construction.

- ✓ Power transmission buildout is understood and mature at scale throughout the U.S.
- × Existing rights of way likely could not be fully leveraged for new power transmission lines as a reliable system would likely require the development of multiple parallel lines.
- × Power transmission development has an extensive development lifecycle.[111]
- × Construction involves building new transmission lines with multiple substations.[112]

Localized Hub

Assessment: ⬜ Feasible technology readiness for a limited scale of supply, with some complementary infrastructure; however, implementation faces possible entry barriers and longer time for construction.

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[110] National Petroleum Council. Harnessing Hydrogen: A Key Element of the U.S. Energy Future, see: https://harnessinghydrogen.npc.org/downloads.php

[111] https://www.publicadvocates.cpuc.ca.gov/-/media/cal-advocates-website/files/press-room/reports-and-analyses/230612-caladvocates-transmission-development-timeline.pdf

[112] The In-Basin Hydrogen Production with Power T&D alternative requires the development of four substations and 308 transformers (Refer to Appendix 7.3.1.2.4 in the Cost Effectiveness Study). In comparison, the Angeles Link scope configuration for Scenario 7 requires the development of two compressor stations (Refer to Appendix 7.3.1.2.1 in the Cost Effectiveness Study).

- ✓ The development of major transmission infrastructure is not required, as production is near end users. Infrastructure development is limited to in-basin delivery infrastructure.
- × Solar generation capacity is constrained by land availability, which in turn limits the scale of hydrogen production that can be developed to meet demand. The supply-demand gap is likely to be substantial in the longer term.
- × Land availability for solar generation in L.A. Basin is not contiguous, likely requiring complex integration of electricity production from numerous scattered sites.

Intermodal Transport (Liquid Trucking and Rail)

Assessment: ⬜ Feasible technology readiness, with some complementary infrastructure; however, implementation faces possible entry barriers and longer time for construction.

- ✓ Trucking and train can both leverage existing infrastructure for more straightforward implementation.
- × Intermodal transport requires many liquefaction/compression terminals to handle the conversion between gaseous and liquid states, to load trains in a timely manner, and to avoid logistical challenges with loading times.
- × More storage infrastructure is required to support intermodal transport to offset the lack of flexibility in train shipment capacity.

4.3.1.1.5.Scalability

Scalability is assessed on each alternative’s potential to support increasing throughput volumes along a conceptual route serving 1.5 Mtpa into L.A. Basin and Central California through third-party production sites such as via SJV, Lancaster, and Blythe. The scale of 1.5 Mtpa and associated delivery routes are defined by Scenario 7 in the Preliminary Routing/Configuration Analysis and the Design Study. Scalability is assessed on a 4-point scale, following the ranking defined in

Table 9. This criterion is evaluated for each delivery alternative.

Figure 10 below summarizes each alternative’s scalability, followed by a summary of the advantages and challenges for each delivery alternative associated with scalability.

Figure 10: Scalability Assessment Across H_2 Delivery Alternatives

Angeles Link Pipeline System	Gaseous Hydrogen Trucking	Liquid Hydrogen Trucking	Liquid Hydrogen Shipping	Methanol Shipping	Ammonia Shipping	Power T&D With In-Basin Production	Localized Hub	Intermodal Transport (Liquid Trucking and Rail)
🟦	🟥	⬜	⬜	⬜	🟥	🟥	🟥	🟥

🟦 **High** ▦ **Good** ⬜ **Moderate** 🟥 **Low**

Angeles Link

Assessment: 🟦 Supports at least 1.5 Mtpa, adaptable to expand volume or extend footprint.

- ✓ Pipelines are highly scalable as they can serve different volumes, with economies of scale, using relatively the same infrastructure. As noted in the Cost Effectiveness Study (Section 1.3 Key Findings), pipelines are the most scalable because they are the lowest cost alternative for the end users which will drive adoption at scale.[113]
- ✓ Pipeline delivery fully supports the specified scale of 1.5 Mtpa and is adaptable for expansions or extensions, as hydrogen can be further compressed to increase throughput or transported through a pipeline with a larger diameter.
- × Hydrogen pipelines require large-scale construction from the onset compared to more modular solutions.

Infrastructure key metrics: Refer to the project description in Section 3.1.

Trucking (General)

- × Achieving scale requires significant infrastructure development, including the development of liquefaction/compression terminals, and truck manufacturing capacity.
- × To meet peak power demand, the truck fleet and associated liquefaction/compression infrastructure will need to be oversized, resulting in underutilized infrastructure and many vehicles being parked and idle for much of the year to ensure availability during those peak periods.

Gaseous Hydrogen Trucking

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[113] Cost Effectiveness Study, Section 1.3 Key Findings shows that hydrogen is most cost effective and therefore scale when delivery through a pipeline. This was added in response to a stakeholder comment on pipeline scalability was overstated in the study.

Assessment: 🟥 Challenging or impractical to scale to 1.5 Mtpa due to infrastructure requirements.

- × Gaseous hydrogen trucking may be a solution for smaller volumes. However, as throughput increases to 1.5 Mtpa, infrastructure and implementation challenges increase due to the number of trucks and the associated compression/loading infrastructure required.

Infrastructure key metrics: To meet maximum daily production, storage and demand requirements for the delivery of 1.5 Mtpa of clean renewable hydrogen, there is a requirement for approximately 12,700 trucks and 3,400 compression and loading terminals across transportation corridors connecting various parts of the value chain: (1) hydrogen production sites; (2) underground storages sites; and (3) demand sites in L.A. Basin and Central California.[114] For reference, 12,700 trucks on the road translates to a chain of trucks that extends 127 miles.[115] As demand scales, the need for more trucks and associated infrastructure escalates, impacting traffic routes and making this alternative challenging to scale.

Liquid Hydrogen Trucking

Assessment: ⬜ Feasible at 1.5 Mtpa but severely challenged by land or other constraints.

- ✓ Liquid hydrogen trucking has a higher capacity to scale than gaseous hydrogen trucking as liquified gas is more energy-dense, requiring a smaller fleet of trucks and loading terminals.
- × Liquid trucking still encounters traffic and infrastructure constraints at higher volumes due to the number of trucks on the road and associated liquefaction infrastructure required.

Infrastructure key metrics: To meet maximum daily production, storage, and demand requirements for the delivery of 1.5 Mtpa of clean renewable hydrogen, there is a requirement for 3,200 trucks and 700 liquefaction and loading terminals[116] across

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[114] A portion of the clean renewable hydrogen is envisioned to support demand in other parts of Central and Southern California.

[115] The number of loading terminals and trucks required were estimated to meet the maximum daily requirement of hydrogen over a one-year period considering truck capacity, loading bay capacity, loading time, and truck mileage (refer to Appendix 7.3.1.2.2 in the Cost Effectiveness Study for technoeconomic assumptions and Appendix 7.3.1.6 for details on the rationale for above ground storage).

[116] The number of loading terminals and trucks required were estimated to meet the maximum daily requirement of hydrogen over a one-year period considering truck capacity, loading bay

transportation corridors connecting various parts of the value chain: (1) hydrogen productions sites; (2) underground storage sites; and (3) demand sites in L.A. Basin and Central California. For reference, 3,200 trucks on the road translates to a chain of trucks that extends 32 miles.[117] As demand scales, the need for more trucks and associated infrastructure escalates, impacting traffic routes and making this alternative challenging to scale.

Shipping (General)

- ✓ Can be a good large-scale solution for long distance hydrogen delivery.
- × Shipping alternatives face land constraints near associated port/terminal locations due to the need for specialized handling facilities and as above-ground storage needs increase in tandem with project scale.

Liquid Hydrogen Shipping

Assessment: ⬜ Feasible at 1.5 Mtpa but severely challenged by land or other constraints.

- ✓ Liquid hydrogen production can be scaled to the assumed throughput levels to meet projected demand.
- × Liquid hydrogen shipping requires more trips than methanol or ammonia due to lower energy density, making scalability more logistically complex.
- × The development of specialized handling facilities and storage infrastructure is likely to face constraints due to land availability near ports as scale approaches 1.5 Mtpa of throughput.

Infrastructure key metrics: To ship 1.5 Mtpa of liquid hydrogen from Northern California to LA ports, approximately 27 ships making 2,100 round trips a year and more than 600 liquid hydrogen storage vessels (700 tH_2) would be required.[118] Additionally, specialized handling infrastructure such as liquefaction and regasification facilities would be needed for this option.

Methanol Shipping

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capacity, loading time, and truck mileage (refer to Appendix 7.3.1.2.2 in the Cost Effectiveness Study for technoeconomic assumptions and Appendix 7.3.1.6 for details on the rationale for above ground storage).

[117] Ibid

[118] The number of ships required were estimated to meet the maximum daily requirement of hydrogen over a one-year period considering vessel capacity and distance traveled (refer to Appendix 7.3.1.2.3 in the Cost Effectiveness Study and Appendix 7.3.1.6 for details on the rationale for above ground storage).

Assessment: ⬜ Feasible at 1.5 Mtpa but severely challenged by land or other constraints.

- ✓ Shipping hydrogen as methanol is more efficient than liquid hydrogen, given methanol's higher energy density, in terms of the number of trips and ships required to transport the same quantity of liquid hydrogen.
- × This delivery alternative requires additional infrastructure to convert hydrogen into methanol and revert it back to hydrogen upon delivery.
- × The development of specialized handling facilities and storage infrastructure is likely to face constraints due to land availability near ports as scale approaches 1.5 Mtpa of throughput.

Infrastructure key metrics: To ship 1.5 Mtpa of hydrogen in the form of methanol requires two tanker ships making 60 round trips a year and more than 600 liquid hydrogen storage facilities (700 tH_2) at the destination terminal.[119] Specialized handling infrastructure like methanol conversion and re-conversion facilities would also be required for this option. Additionally, the need to develop specialized handling infrastructure needed for methanol conversion and reconversion (reforming or cracking) back to hydrogen could complicate the scalability of this alternative.

Ammonia Shipping

Assessment: 🟥 Challenging or impractical to scale to 1.5 Mtpa due to infrastructure requirements.

- ✓ Similar to the methanol shipping delivery alternative, ammonia benefits from a higher energy density than liquid hydrogen and offers more efficiency in terms of trips, requiring around 100 trips annually[120].
- × This delivery alternative requires additional infrastructure to convert hydrogen into ammonia and revert it back to hydrogen upon delivery.
- × Facilities to synthesize ammonia (as a hydrogen carrier) require continuous operations, which may become challenging as demand scales and because of the constraints of solar power generation as the key resource for power and hydrogen supply for synthesizing ammonia.

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[119] The number of trips and ships required were estimated to meet the maximum daily requirement of hydrogen over a one-year period considering vessel capacity and distance traveled (refer to Appendix 7.3.1.2.3 in the Cost Effectiveness Study and Appendix 7.3.1.6 for details on the rationale for above ground storage).

[120] The number of trips required were estimated to meet the average requirement of hydrogen over a one-year period considering vessel capacity and distance traveled (refer to Appendix 7.3.1.2.3 in the Cost Effectiveness Study).

- × The development of specialized handling facilities and storage infrastructure is likely to face constraints due to land availability near ports as scale approaches 1.5 Mtpa of throughput.

Infrastructure key metrics: To ship 1.5 Mtpa of hydrogen as ammonia would require three ships making 150 round trips a year and more than 600 liquid hydrogen storage vessels (700 tH_2). [121], [122] Additionally, the need to develop specialized handling infrastructure like ammonia conversion and re-conversion (reforming or cracking) back to hydrogen could complicate the scalability of this alternative.

In-Basin Production with Power T&D

Assessment: 🟥 Challenging or impractical to scale to 1.5 Mtpa due to infrastructure requirements.

- × The lead-time for developing electric system infrastructure could limit the ability to develop infrastructure at the pace required to keep up with demand growth.[123]
- × When scaling to 1.5 Mtpa, significant new electric system infrastructure and land access (18-20 ft width per line)[124] is required to meet power demand.

Infrastructure key metrics: A 500kV AC transmission system was selected in order to meet the capacity requirements for the Delivery Alternative. The 500kV system is largely compatible with the CAISO grid, which is mostly AC. As discussed in the Cost Effectiveness Study (Appendix 7.3.1.2.4), the effective load carrying capacity for a typical 500kV AC transmission system does not exceed 3GW, rapidly declining with the transmitting distance. Hence, supporting 26.6 GW of electricity load requirement (in addition to the 1.8 GW of transmission load losses) for hydrogen production would require multiple transmission lines consisting of 10 double circuit and 1 single circuit transmission system (for a total of 21 circuits) across a 400-mile transmission corridor (accounting for a total of 2,500 miles of transmission). Refer to Appendix 7.2.2 and 7.3.1 (Cost Effectiveness Study) for additional details. In-basin production

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[121] The number of ships required were estimated to meet the maximum daily requirement of hydrogen over a one-year period considering vessel capacity and distance traveled (refer to Appendix 7.3.1.2.3 in the Cost Effectiveness Study and Appendix 7.3.1.6 for details on the rationale for above ground storage).

[122] See the Cost Effectiveness Study for more details on the Methanol Shipping infrastructure requirements.

[123] https://www.publicadvocates.cpuc.ca.gov/-/media/cal-advocates-website/files/press-room/reports-and-analyses/230612-caladvocates-transmission-development-timeline.pdf

[124] Assumes 60 meters (~18 ft) is required for double circuit 500 kV lines and 65 meters (~20 ft) for single circuit 500 kV lines. See https://39713956.fs1.hubspotusercontent-na1.net/hubfs/39713956/220211%20APGA%20Submission%20-%20AEMO%202022%20Draft%20ISP%20Consultation.pdf , Figure 10.

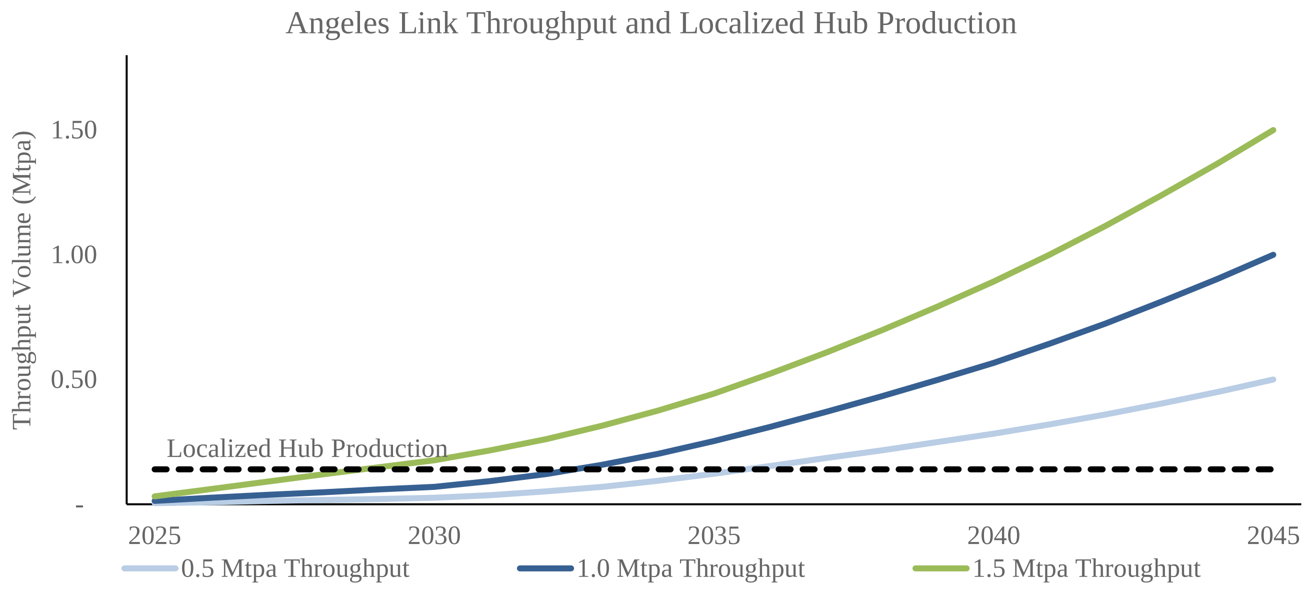
with power T&D would also require more than 600 liquid hydrogen storage vessels (700 tH_2) for above-ground storage.

Localized Hub

Assessment: 🟥 Challenging or impractical to scale to 1.5 Mtpa due to infrastructure requirements.

- × The utility-scale solar potential in the area is 4.4 GW,[125] equating to 0.14 Mtpa of hydrogen production (as shown on Figure 11 below), which is insufficient compared to the throughput range of 0.5-1.5 Mtpa to serve California's decarbonization needs.

Figure 11: Angeles Link Throughput and Localized Hub Production[126]



Infrastructure key metrics: To develop the potential 4.4 GW of solar capacity in L.A. Basin, an estimated 26,400 acres of land is required, which equates to 8% of the LA area.[127] In a case where this land could be acquired and the 4.4 GW of solar generation could be developed, the hydrogen production potential is sub-optimal, reaching just 0.14 Mtpa of

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[125] Los Angeles Department of Water & Power, Los Angeles 100% Renewable Energy Study (LA100), see: https://www.ladwp.com/strategic-initiatives/clean-energy-future/la100-equity-strategies/100-renewable-energy-study P.26 "A site development cost ranking analysis of this potential indicates that about 4,400 MW or about 80% of the non-rooftop local solar potential can be built at or below $100/megawatt-hour (MWh) based on 2019 capital costs"

[126] For additional context, please refer to Figure 28: Localized Hub Area Map in Appendix 7.1.1.

[127] Considering 6 acres per MW, see: https://www.nrel.gov/docs/fy13osti/56290.pdf

hydrogen. Additionally, in-basin hydrogen production also requires 60 liquid hydrogen storage vessels for the production of 0.14 Mtpa[128] due to the lack of underground storage available in the L.A. Basin.

Intermodal Transport (Liquid Trucking and Rail)

Assessment: 🟥 Challenging or impractical to scale to 1.5 Mtpa due to infrastructure requirements.

× As volumes approach 0.5 Mtpa, delivery by train encounters logistical impasses, as hydrogen rail cars would occupy 66%-95%[129] of the on-dock rail available space in the Port of L.A., deeming the port unusable for other commercial activities.
× This setup demands substantial time to load each tank car. As volumes increase, the necessity for more tank cars grows, making the option impractical at larger volume sizes.

Infrastructure key metrics: The delivery of 1.5 Mtpa of hydrogen by rail would require 900 tank cars daily. [130] Additionally, specialized infrastructure would be required to fill multiple sequentially placed railroad cars with hydrogen at each production location.

4.3.1.2. Dismissed Hydrogen Delivery Alternatives

Ammonia shipping and intermodal transport (liquid trucking and rail) ranked the lowest in the evaluation of alternatives based on the criteria analyzed above, and therefore they were not carried forward for further analysis.

4.3.1.2.1.Ammonia Shipping

Ammonia shipping was initially evaluated but not carried forward for analysis in the Cost Effectiveness Study or Environmental Analysis due to incompatibility with the criteria discussed above. The Haber-Bosch process requires a reliable and continuous supply of electricity and power which is incompatible with the intra-day profile for solar availability as elaborated below:

- **Hydrogen-to-ammonia process requirements:** The process of converting hydrogen to ammonia (known as Haber Bosch ammonia synthesis) requires constant input of hydrogen and power. Ammonia units require several days to start up to reach 250-350 bar of pressure and 450-600°C of temperature. Once the units are turned on, they have a limited operating utilization range between 60-80%. Large fluctuations in temperatures impact performance and damage the integrity of the catalyst.

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[128] Please refer to the Angeles Link High-Level Economic Analysis & Cost Effectiveness Report for more details on the Localized Hub infrastructure requirements.
[129] See 4.3.1.2.2 for additional context.
[130] High-level analysis considering an average day using train cars of 4.5 tons of liquified hydrogen.

- **Project technical parameters:** The Production Study identified solar generation as the most likely power source to meet the CPUC's definition for clean renewable hydrogen production and to serve demand in California.
- **Challenges for solar-to-ammonia production:** Solar power generation is especially incompatible with the ammonia production process due to the intra-day intermittency of its availability (even for solar plus battery energy storage system (BESS) facilities). To meet the constant power input needs of the Haber-Bosch process, it is likely that higher carbon intensity power grid access would be required during the hours when solar or BESS resources are not available. This system configuration is inconsistent with non-grid interconnected renewable power that would be aligned with the CPUC's definition of clean renewable hydrogen.

The incompatibility between the operational requirements of the Haber-Bosch process and the assumption that solar generation would serve as the primary electricity input for clean renewable hydrogen production[131], meant the ammonia shipping alternative was not well suited to meet the criteria for state policy, reliability and resilience, ease of implementation, and scalability. Therefore, this alternative was excluded from further analysis in the Cost Effectiveness Study and the Environmental Analysis.[132]

4.3.1.2.2.Intermodal Transport (Liquid Trucking and Rail)

Rail as a delivery alternative has unique logistical challenges as described below, which deem it incompatible with the criteria applied in this study for the evaluation of delivery alternatives.

- **Loading infrastructure requirements:** The system would need between 200-300 loading terminals running 24/7 to fill the rail cars required to deliver 1.5 Mtpa of clean renewable hydrogen.[133]
- **Infrastructure challenges:** On an average day, the system would need to transport approximately 900 rail cars per day, and on a peak production day approximately 1,300, which is equivalent to 7.5 to 10.5 miles of rail cars on the tracks daily.

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[131] The Production Study found that solar capacity was the best resource for renewable electricity generation within the state of California for the production of clean renewable hydrogen. The intra-day availability of solar poses a challenge for the ammonia production process.

[132] Additional considerations regarding ammonia as an alternative can be found in Appendix 7.3.

[133] Average and peak day rail car requirements are 900-1300 rail cars. Each bay can load 20 tonnes per day, and a rail car can transport 4.5 tonnes. Accordingly, the loading bays required would be 200 on an average and 300 on a peak day (calculation: 900*4.5/20 to 1,300*4.5/20).

- **Unloading constraints:** The Port of L.A. consists of approximately 65 miles of on-dock track and has an average dwell time for on-dock rail containers of 5.8 days.[134] This means hydrogen containers would occupy 43-62 miles of the 65 miles available for on-dock rail containers. Hydrogen rail cars would occupy 66%-95% of the on-dock rail available space in the Port of L.A., deeming the port unusable for other commercial activities.

As a result of rail infrastructure constraints described above, and the high emissions associated with the fuels currently used to power trains and trucks, the intermodal transport alternative was not well suited to meet the criteria as defined for state policy, reliability and resilience, ease of implementation, and scalability and was therefore excluded from further analysis in the Cost Effectiveness Study and the Environmental Analysis.

4.3.1.3. Hydrogen Delivery Alternatives Advanced

The Hydrogen Delivery Alternatives noted below were advanced for evaluation in the Cost Effectiveness Study and the Environmental Analysis, as they were determined to meet at least a minimum level of the evaluation criteria.

- Angeles Link Pipeline System
- Liquid Hydrogen Trucking
- Gaseous Hydrogen Trucking
- Liquid Hydrogen Shipping
- Methanol Shipping
- In-Basin Production with Power T&D
- Localized Hub

4.3.2. Evaluation of Non-Hydrogen Alternatives

Five assessment criteria were applied to evaluate the Non-Hydrogen Alternatives relative to Angeles Link for their suitability to serve as decarbonization pathways for each use case in California and to determine their advancement to the next steps in the analysis: (i) state policy; (ii) reliability and resiliency; (iii) technical maturity; (iv) scalability; and (v) end user requirements, summarized in Table 10 below. A 4-point assessment rubric (high, good, moderate, low) was used to evaluate the extent to which each Non-Hydrogen Alternative may achieve or be consistent with each criterion.

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[134] https://kentico.portoflosangeles.org/getmedia/a9af147a-ace7-4f27-9b2f-b25ecb73dc30/import-container-dwell-report

Table 10: Non-Hydrogen Alternatives Assessment Criteria

Criteria Selected for Screening	Definition	High	Good	Moderate	Low
State Policy	Level of alignment with California's clean energy and environmental policies	Alignment with state policy, including specific mandates or incentives	Alignment with state policy but potential conflicts with decarbonization goals	No alignment with state policy and potential conflicts with decarbonization goals	Explicit misalignment with state policy and conflicts with decarbonization goals
Reliability & Resiliency	Contribution to both use case-level and energy system-level reliability and resiliency	Notable improvement of user and/or system reliability and resiliency.	No/minimal benefits/risks relative to business as usual (BAU) user and/or system reliability and resiliency	Unclear or moderate risk of disruption to user and/or system reliability and resiliency	Likely disruption to user and/or system reliability and resiliency
Technical Maturity	Likelihood of achieving widespread commercial availability by 2030[135]	Commercially available and widespread	Commercially available but limited in deployment	Pilot stage	Lab stage

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[135] 2030 is used as technology development beyond this date is difficult to predict. This is partly informed by the https://www.iea.org/data-and-statistics/data-tools/etp-clean-energy-technology-guide published by the International Energy Agency. See Appendix 7.4.1 for additional detail on the TRL scores.

Criteria Selected for Screening	Definition	High	Good	Moderate	Low
Scalability	Likelihood of full value chain ability to support large-scale deployment by 2030 (up/mid/downstream)	Robust current value chain; minimal risks to scalability	Minimal potential risks to scalability in the value chain	Multiple potential risks to scalability in the value chain (but addressable)	High risk somewhere in the value chain to prevent scalability
End-User Requirements	Ability to support the full set of end-user requirements in a way that supports decarbonization with minimal impact on operations and business models	Strong ability to serve end-user requirements; clear path to implement	Minimal disruption to operations and/or business models	Material disruption to operations and/or business models (but addressable)	High risk in serving a key end-user requirement

Because the use cases relevant to electrification and CCS differ, each alternative is evaluated below in comparison to Angeles Link across relevant sectors and use cases.

4.3.2.1. Electrification

For the electrification use cases, analysis was conducted to understand where it may be possible for end users to electrify in lieu of using clean renewable hydrogen or traditional fuels and what changes end users might have to implement to make that change. The assessment of electrification was conducted primarily on a use case level (e.g., FCEV vs. BEV for heavy-duty vehicles (HDVs)), and certain system-level considerations and assumptions, such as the T&D infrastructure required to deliver the electricity for consumption by the end user, are incorporated into the use case level assessments where relevant. A broader analysis of system-level electrification considerations was also conducted based on a high-level review of existing research, third-party studies, and California policy. These system-level electrification considerations are summarized below, with additional details in Appendix 7.3.3.

4.3.2.1.1.System-Level Electrification Considerations

System-level electrification considerations include impacts across the electricity system value chain, such as electricity demand, generation supply to meet the demand, and supporting electric transmission and distribution infrastructure. Appendix 7.3.3 provides an in-depth exploration of system electrification, presenting literature reviews, examining critical implications throughout the electrification value chain, and discussing key findings. Key findings from the high-level review of these considerations include the following:

- **Demand considerations**: Electrification is widely recognized as a primary decarbonization pathway for many sectors, including light-duty vehicles and residential and commercial heating, but it is also known to be less technically feasible in hard-to-electrify sectors like heavy-duty transportation and high-heat industrial processes.[136]
- **Supply considerations**: Wind, solar, and battery storage are being deployed at scale, but there remains a need for clean firm generation and long duration storage in the power system to ensure reliability.[137] The industry-accepted approach to determine how supply portfolios meet demand and ensure power system reliability is power flow modelling analysis to determine the necessary infrastructure capacity expansion, system interconnections, and system operational requirements.
- **Electric T&D infrastructure considerations**: The electricity system requires substantial investment in new T&D infrastructure to accommodate planned increases in electric generation and load growth. The additional infrastructure needed to support a higher level of electrification of the use cases supported by Angeles Link would be incremental and would increase the burden on already ambitious power T&D

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[136] Discussed in the demand section of Appendix 7.3.3.

[137] EDF, https://www.edf.org/sites/default/files/documents/SB100%20clean%20firm%20power%20report%20plus%20SI.pdf

investment plans as detailed by the CPUC Integrated Resource Plan (IRP)[138] and CAISO.[139]

4.3.2.1.2. Use Case Level Electrification Evaluation

Angeles Link is assessed relative to electrification in specific use cases across the priority sectors identified in the Demand Study. Details of the four use case assessments are below, comparing Angeles Link to electrification across the following applications:

- **Mobility**: FCEV as compared to BEV for long-haul, heavy-duty applications
- **Power**: Hydrogen-fueled combustion plant as compared to battery energy storage facility for peaking and reliability needs
- **Food & Beverage**: Hydrogen-fueled ovens/fryers as compared to electric ovens/fryers
- **Cement**: Hydrogen-fueled kilns as compared to electric kilns

4.3.2.1.2.1. Mobility

In the mobility sector, FCEVs were identified as the end use application for hydrogen supplied by Angeles Link, while BEVs were identified as the end use application for electrification. Specifically, both FCEVs and BEVs were evaluated for the four primary long-haul, heavy-duty applications described in the Demand Study as having the greatest hydrogen adoption potential due to their operational requirements: transit buses, sleeper cabs, day cabs and drayage trucks. Figure 12 shows an assessment of FCEVs and BEVs in the mobility sector.

Figure 12: Evaluation: Mobility (FCEV and BEV)

Alternative	Technology Application	Mobility Use Case	State Policy	Reliability & Resiliency	Maturity	Scalability	End-User Requirements
Angeles Link	Fuel Cell Electric Vehicle	• Transit Bus • Drayage • Sleeper Cab • Day Cab	■	■	▨	□	▨
Electrification	Battery Electric Vehicle		■	▨	▨	□	□

■ **High** ▨ **Good** □ **Moderate** ▫ **Low**

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[138] https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/electric-power-procurement/long-term-procurement-planning

[139] http://www.caiso.com/InitiativeDocuments/ISO-Board-Approved-2022-2023-Transmission-Plan.pdf

- **State Policy. Both clean renewable hydrogen and electrification are strongly aligned with state policy supporting mobility decarbonization.**
  Adoption of FCEVs and BEVs is strongly aligned with California regulations and incentives targeting the decarbonization of HDVs and fleets by 2045. The primary state policy drivers for HDV decarbonization are the Advanced Clean Fleet and the Advanced Clean Trucks regulations, which mandate transitioning to zero emission vehicles (ZEVs), for which both FCEVs and BEVs qualify.[140]
- **Reliability & Resiliency. Clean renewable hydrogen is advantaged due to long-duration molecule storage.**
  FCEVs offer a reliability and resiliency advantage compared to BEVs due to the advantage molecules have over electrons to meet long-term storage requirements.[141] Fleet-based BEVs face a disadvantage in siting charging stations due to the importance of locating stations in areas that have enough electrical distribution capacity. BEVs may also face demand response actions (such as those under the CPUC's Emergency Load Reduction Program for EVs) that restrict charging during peak demand periods, unlike FCEVs which are exempt from such constraints.
- **Technical Maturity. Though not yet widespread currently, both clean renewable hydrogen and electrification technologies are ready to serve the heavy-duty transport sector.**
  On the IEA's technology readiness scale,[142] FCEVs and BEVs score nine, indicating both technologies are in commercial deployment in select markets. However, FCEVs and BEVs have not yet achieved widespread adoption to serve the heavy-duty vehicle segment, with BEV adoption outpacing FCEVs due to the more prevalent charging infrastructure available today. According to the California Energy Commission (CEC), there are over 100 FCEV buses and Class 8 trucks on the road as of 2023, while the number of BEV buses and Class 8 trucks operating on California roads exceeds 1,200.[143]

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[140] California Air Resources Board Advanced Clean Fleet and Advanced Clean Truck regulations.
[141] Typically 2-4 days of hydrogen is stored onsite at refueling stations (according to a https://eec.ky.gov/Energy/Documents/Hydrogen-Powered%20Truck%20Operations%20in%20KY%20-%20Feasibility%20Study.pdf), while typical battery durations last between 4-8 hours.
[142] IEA's https://www.iea.org/reports/innovation-gaps identifies the solutions that exist today and rank their readiness along an extended "Technology Readiness Level" (TRL) scale covering concept stage to scaling up the technology solution.
[143] California Energy Commission – https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics-collection

- **Scalability. Although clean renewable hydrogen and electrification are scalable solutions in the mobility sector, both face important challenges across the value chain which must be addressed to achieve scale.**
  While there is interest among original equipment manufacturers (OEMs) to scale FCEV and BEV manufacturing, scalability challenges for these solutions are primarily due to the availability of supporting infrastructure. Hydrogen requires key elements across the value chain to scale, including water availability, electrolyzer supply, and new delivery and storage infrastructure. BEV requirements to scale include strengthening transmission and distribution infrastructure, supply chain risks around vehicle battery raw materials, transformers and other charging infrastructure equipment, and land availability for siting of new electrical capacity.
- **End-User Requirements. Clean renewable hydrogen is advantaged due to the operational requirements met by FCEV technology for heavy-duty, long-range, fast-refueling applications.**
  FCEVs offer a natural advantage to fleet operators as drivers spend comparable times to refuel relative to current technology.[144] For BEVs, fleet operators may need to accommodate new business models, new charging/refueling patterns, longer charging/refuelling times, and potentially increased investment in additional vehicles due to decreased payload.[145] These issues are discussed in greater detail in the Demand Study.

4.3.2.1.2.2. Power

Both clean renewable hydrogen and electrification are potential alternatives to support power generation. Hydrogen can be used in fuel cells or combusted using a turbine. For the purpose of this study, hydrogen-fueled combustion plants were identified as the end use application for hydrogen supplied by Angeles Link. Batteries are typically used to store electricity for discharge at a later time of need. For the purpose of this study, lithium-ion battery energy storage facilities were identified as the end use application for electrification.

With an increasing share of renewables displacing gas generation in California, clean firm generation and LDES resources are needed to balance the shortfall in renewables output. As a result, this study considered a 12-hour Lithium-ion battery storage “stack” as the most reasonable comparison to a hydrogen-fueled power plant.[146] Other LDES technologies, like compressed air energy storage (CAES) and vanadium redox flow batteries (VRFB), are

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[144] UC Davis, ITS Hydrogen Study: https://escholarship.org/uc/item/97s439v1

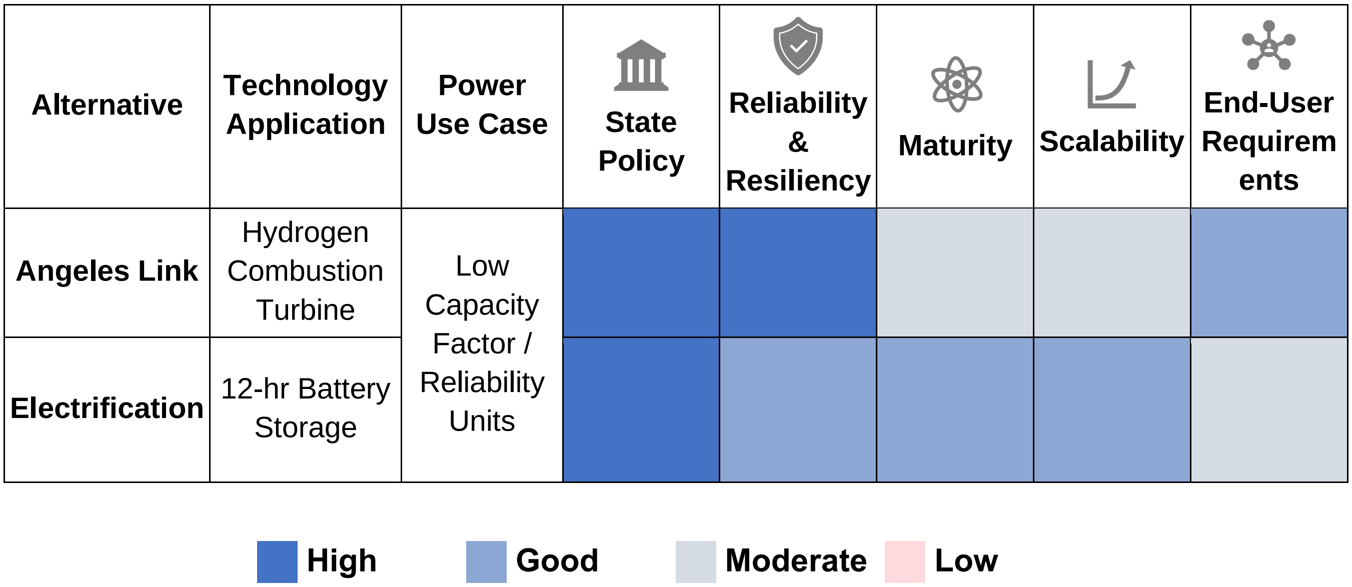
[145] Payload refers to the maximum amount of weight that can be safely added to a truck's cargo area in addition to its own weight with no cargo.

[146] See Appendix 7.3.4 for the rationale for selection of 12-hour Lithium-ion battery storage as a reasonable comparison.

emerging and may serve as better candidates for LDES than lithium-ion in the long run, but they were not deemed mature enough for further discussion in this study.

There are few decarbonization options that can play the diversity of roles that hydrogen can in the power system. This is discussed further in Appendix 7.3.3 and 7.3.4 on system-level electrification and the selection of 12-hour lithium-ion battery storage for the power use case. Figure 13 shows an assessment of hydrogen power plants and battery energy storage facilities in the power sector.

Figure 13: Evaluation: Power (Hydrogen Combustion Plants and Battery Storage)



Alternative	Technology Application	Power Use Case	State Policy	Reliability & Resiliency	Maturity	Scalability	End-User Requirements
Angeles Link	Hydrogen Combustion Turbine	Low Capacity Factor / Reliability Units	■	■	□	□	▨
Electrification	12-hr Battery Storage		■	▨	▨	▨	□

■ **High** ▨ **Good** □ **Moderate** 🟥 **Low**

- **State Policy. Clean renewable hydrogen and electrification are strongly aligned with state and local policies driving decarbonization of the power sector.** Both clean renewable hydrogen to support power generation and battery storage resources help advance California's key policy goals, including SB 100, California's landmark policy requiring renewable energy and zero-carbon resources supply 100 percent of electric retail sales to end-use customers by 2045, and LA100, L.A.'s plan to transition to 100% clean energy by 2035.[147] Standalone battery storage does not qualify for the State's renewables portfolio standard (RPS) targets due to the inability to

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[147] Although renewable hydrogen and battery storage do not qualify under the list of "eligible fuels" under SB 100, the policy leaves a provision for 40% of CA's generation to come from other "zero-carbon polluting resources."

determine the power stored and dispatched is renewable unless directly connected to an otherwise qualifying renewable facility.[148]

- **Reliability & Resiliency. Hydrogen turbines supplied by Angeles Link are advantaged due to their ability to address seasonal and multi-day power system needs.**
  Hydrogen has a natural advantage over battery storage due to its ability to store energy and use it to generate firm dispatchable electricity, including seasonal balancing and multi-day dispatch (e.g., during extreme weather).[149] Current battery technologies have a storage duration of 2-4 hours or up to 8 hours when stacked. While battery storage has a role to play in power system reliability and can address shorter duration events, to meet needs of long duration storage, lithium-ion facilities would have to be significantly oversized. Hydrogen and battery storage can play important but likely distinct roles to provide grid services and support reliability of the California power system.
- **Technical Maturity. Clean renewable hydrogen is less technically mature compared to electrification as lithium-ion battery technology is currently more mature than 100% hydrogen-capable turbines.**
  Lithium-ion technology scores 10 on the IEA technology readiness scale, representing commercial deployment at scale. Lithium-ion battery storage offers a commercially available and mature solution that can be stacked, however uneconomically, to achieve longer durations of storage (e.g., up to 12 hours).[150] Turbines that run on unblended hydrogen score seven, indicating pre-commercial demonstration.[151] 100% hydrogen-capable turbines are under development globally with Tier 1 OEMs and are expected to be commercially available by 2030.[152]
- **Scalability. Clean renewable hydrogen is less scalable versus electrification since battery energy storage is a modular technology, meaning there are fewer challenges to scale across the value chain.**
  From an end-use case perspective, hydrogen combustion plants require key elements across the value chain to scale, including water availability, electrolyzer supply, and new

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[148] https://www.energy.ca.gov/programs-and-topics/programs/renewables-portfolio-standard/renewables-portfolio-standard-0

[149] EDF, https://www.edf.org/sites/default/files/documents/SB100%20clean%20firm%20power%20report%20plus%20SI.pdf

[150] California Energy Commission. Retrieved from https://www.energy.ca.gov/sites/default/files/2024-01/CEC-500-2024-003.pdf

[151] This is partly informed by the https://www.iea.org/data-and-statistics/data-tools/etp-clean-energy-technology-guide published by the International Energy Agency. See Appendix 7.4.1 for additional detail on the TRL scores.

[152] Angeles Link Demand Study.

transport and storage infrastructure. Battery storage could offer a modular solution to meet specific power system requirements, but it faces raw material supply chain constraints, siting and interconnection delays, and would require significant deployment to reach the scale possible with seasonal storage of hydrogen.

- **End-User Requirements. Clean renewable hydrogen is advantaged due to the unique set of roles it can play in the power system and the ability to retrofit existing gas plants.**
  Hydrogen turbines can play a strategic role in the power system as both clean firm generation and as a longer-duration reliability resource and can be dispatched like a baseload unit[153] or a peaker power plant[154] catering to peak loads. Hydrogen turbines can also be introduced as a retrofit to current natural gas power plants, like Los Angeles Department of Water and Power's (LADWP) Scattergood plant,[155] some of which are strategically located for local reliability. Battery storage can also play a diverse but different role (primarily grid services, shaping of renewables, and shorter-duration reliability needs), and would require new-build facilities.

4.3.2.1.2.3. Industrial – Food & Beverage

In the food & beverage (F&B) sector, clean renewable hydrogen-fueled or electrically powered ovens and fryers could be used to decarbonize operations. Both hydrogen delivered via Angeles Link, and electrification may be able to serve additional needs of the diverse food & beverage sector, however this direct technology comparison was deemed most insightful for purposes of this Phase 1 study. Figure 14 compares hydrogen and electric ovens and fryers in the F&B sector.

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[153] The term "baseload power" refers to the minimum quantity of electricity required to supply the electrical grid at any given time, see: https://energyeducation.ca/encyclopedia/Baseload_power

[154] Supplement other types of power plants and operate during peak power demand periods, such as hot summer afternoons, see: https://www.gao.gov/products/gao-24-106145

[155] https://www.ladwp.com/community/construction-projects/west-la/scattergood-generating-station-units-1-and-2-green-hydrogen-ready-modernization-project

Figure 14: Evaluation: Food & Beverage (Hydrogen-Fueled and Electric Ovens and Fryers)

Alternative	Technology Application	Food and Beverage Use Case	State Policy	Reliability & Resiliency	Maturity	Scalability	End-User Requirements
Angeles Link	Hydrogen Ovens/Fryers	Low Process Heating Application	▨	🟦	▨	⬜	⬜ .
Electrification	Electric Ovens/Fryers		🟦	▨	🟦	▨	⬜

🟦 **High** ▨ **Good** ⬜ **Moderate** 🟥 **Low**

- **State Policy. Clean renewable hydrogen must be able to address the regulation of NOx emissions in the F&B sector.**
  While there are few major state policies targeting decarbonization in the F&B sector, a rule by the South Coast Air Quality Management District (AQMD) subjects commercial food ovens to a future zero-emission standard, specifically targeting NOx.[156] Hydrogen combustion bears a greater compliance risk due to potential for NOx emissions. Additional details on NOx emissions can be found in the Angeles Link NOx Study.
- **Reliability & Resiliency. Clean renewable hydrogen is advantaged due to long-duration molecule storage.**
  From a use case level perspective, Angeles Link offers a reliability and resiliency advantage compared to electrification due to the advantage molecules have over electrons to meet long-term storage requirements. Electrification also faces a slight disadvantage of adding load to an already strained grid, although incremental electrification in the F&B sector is expected to be relatively small compared to other industrial loads.
- **Technical Maturity. Clean renewable hydrogen is less technically mature than electrification given the more widespread commercial availability of electric equipment in the F&B sector.**
  For low temperature heating applications that would be applicable in food and beverage equipment such as ovens and fryers, hydrogen and electrification have a TRL score of

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[156] Rule-1153.1. South Coast Air Quality Management District NOx emissions regulation.

nine, representing different stages of market uptake in select environments.[157] For the food and beverage industry particularly, a wide range of electric equipment, including fryers and ovens, are commercially available in the market today. However, hydrogen fueled equipment, while commercially available for certain applications such as baking ovens, is not widespread enough to cover the diverse set of equipment needed to fully decarbonize the sector.

- **Scalability. Clean renewable hydrogen is disadvantaged as electrification can leverage existing electric grid infrastructure.**
  Scaling hydrogen equipment in the F&B sector would require a robust hydrogen delivery infrastructure that sustains reliable hydrogen supply to food and beverage facilities. Obstacles to scale for electrification in the F&B sector could be influenced by the need to strengthen transmission and distribution infrastructure to accommodate any increased electricity demand.
- **End-User Requirements. Both clean renewable hydrogen and electrification require new equipment but can meet end-users' needs.**
  Hydrogen and electrification require new equipment investment from facility owners to upgrade their ovens and fryers, potentially resulting in temporary business disruptions. However, these challenges are considered minor.

4.3.2.1.2.4. Industrial – Cement

Clean renewable hydrogen and electrification can support decarbonization of high process heating associated with cement kilns, which are typically the second-largest source of cement facility emissions following clinker production. Clinker production emissions are intrinsic to the chemical calcination process and are not addressable by hydrogen or electricity. For the purpose of this study, hydrogen-fueled kilns were identified as the use case application for Angeles Link, while electric kilns were identified as the use case application for electrification. Figure 15 compares hydrogen and electric kilns in the cement sector.

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[157] This is partly informed by the https://www.iea.org/data-and-statistics/data-tools/etp-clean-energy-technology-guide published by the International Energy Agency. See Appendix 7.4.1 for additional detail on the TRL scores.

Figure 15: Evaluation: Cement (Hydrogen-Fueled and Electric Kilns)

Alternative	Technology Application	Cement Use Case	State Policy	Reliability & Resiliency	Maturity	Scalability	End-User Requirements
Angeles Link	Hydrogen Kiln	High Process Heating Application	🟦	🟦	⬜	⬜	⬜
Electrification	Electric Kiln		🟦	▨	⬜	⬜	⬜

🟦 **High** ▨ **Good** ⬜ **Moderate** 🟥 **Low**

- **State Policy. Both clean renewable hydrogen and electrification are strongly aligned with state policy driving decarbonization of the cement industry.** Hydrogen-fueled and electric kilns can support the cement industry's decarbonization in line with SB 596, which requires cement producers to reduce their GHG emissions by 40% below 1990 levels by 2030, achieving net-zero by 2045.[158]
- **Reliability & Resiliency. Clean renewable hydrogen is advantaged due to long-duration molecule storage.** Clean renewable hydrogen offers a reliability and resiliency advantage compared to electrification due to the advantage molecules have over electrons to meet long-term storage requirements. Electrification also adds load to an already strained grid, and this could be a concern for large loads running at high load factors like electric kilns.
- **Technical Maturity. Both clean renewable hydrogen and electric kilns are in the large-scale pilot stage.** Hydrogen-fueled and electric kilns have achieved a rating of five on the IEA's TRL scale, signifying that both options are presently undergoing pilot testing.[159] Four hydrogen kiln projects were recently announced by Cemex in Mexico.[160] Several kiln

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[158] https://ww2.arb.ca.gov/our-work/programs/net-zero-emissions-strategy-cement-sector

[159] This is partly informed by the https://www.iea.org/data-and-statistics/data-tools/etp-clean-energy-technology-guide published by the International Energy Agency. See Appendix 7.4.1 for additional detail on the TRL scores.

[160] https://www.cemex.com/w/cemex-to-introduce-hydrogen-technology-to-reduce-co2-emissions-in-four-cement-plants-in-mexico

manufacturers are also exploring electrification, with Coolbrook's RotoDynamic Reactor technology being used in several large-scale pilot projects.[161]

- **Scalability. Clean renewable hydrogen and electric kilns are scalable solutions for the cement sector, but both also face challenges to achieve that scale.**
  Scaling hydrogen equipment in the cement sector will require a robust hydrogen infrastructure that maintains reliable hydrogen supply to cement facilities. Requirements for scale for electrification in the cement sector include the need to strengthen power distribution infrastructure to accommodate any increased electricity demand, which could be significant for large loads running at high load factors like electric kilns.
- **End-User Requirements. Cement kilns driven by clean renewable hydrogen and electrification both require new equipment but can meet end-users' needs.**
  Both hydrogen kilns and electric kilns require investment in new equipment from facility owners to transition to zero-carbon cement processing, which could result in business disruptions.

4.3.2.2. CCS

CCS is an alternative decarbonization pathway across several sectors and can be applied where natural gas is used today. Assessment of CCS was conducted on a use case level (e.g., hydrogen combustion turbines vs. gas combustion turbines with CCS for the power generation sector), and certain system-level considerations and assumptions, such as the CO_2 transport and sequestration infrastructure required to enable carbon management for end users, are incorporated into the use case level assessments.

4.3.2.2.1. Use Case Level CCS Evaluation

Angeles Link is assessed relative to CCS based on specific use cases across the priority sectors identified in the Demand Study. A comparison of Angeles Link and CCS across the four use case assessments is provided below.

- **Power**: Hydrogen-fueled combustion plant vs. natural gas-fueled combustion plant with CCS
- **Cogeneration**: Hydrogen-fueled cogeneration facility vs. natural gas-fueled cogeneration facility with CCS
- **Cement**: Hydrogen-fueled kilns vs. natural gas-fueled kilns with CCS
- **Refineries**: Angeles Link-delivered clean renewable hydrogen for refinery process needs vs. conversion of current unabated hydrogen (derived from fossil fuels), supply to abated hydrogen (low-carbon) via addition of CCS to existing natural gas-fueled steam methane reformers (SMRs)

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[161] https://coolbrook.com/electrification-solutions/rdr-electric-cracking/

4.3.2.2.1.1. Power and Cogeneration

Given similarities in applications and considerations, the power and cogeneration sectors are presented together. The existing natural gas power and cogeneration fleet presents an opportunity for decarbonization through either hydrogen turbine retrofits or carbon capture retrofits. In both sectors, a hydrogen-fueled combustion facility is assumed to utilize the hydrogen delivered from Angeles Link, and CCS is assessed based on a natural gas-fueled combustion facility retrofitted with CCS. Figure 16 compares Angeles Link with CCS in the power and cogeneration sectors.

Figure 16: Evaluation: Power and Cogeneration (Hydrogen Combustion Plants and Natural Gas Plants with CCS)

Alternative	Technology Application	Power Use Case	State Policy	Reliability & Resiliency	Maturity	Scalability	End-User Requirements
Angeles Link	Hydrogen Combustion Turbine	High Capacity Factor / Baseload Units	■	■	░	░	▨
CCS	Gas Turbine with CCS		▨	▨	░	░	░

■ **High** ▨ **Good** ░ **Moderate** □ **Low**

Alternative	Technology Application	Cogeneration Use Case	State Policy	Reliability & Resiliency	Maturity	Scalability	End-User Requirements
Angeles Link	Hydrogen Combustion Turbine	Cogen Units (Typically Dispatched as Baseload)	■	■	░	░	▨
CCS	Gas Turbine with CCS		▨	▨	░	▨	▨

🟦 **High** 🟦 **Good** ⬜ **Moderate** 🟥 **Low**

- **State Policy. Hydrogen turbines are advantaged due to more specific incentives.** Both Angeles Link and CCS meet key California and local policy goals. Although neither hydrogen nor CCS are considered under the list of eligible fuels for SB 100, the policy leaves a provision for 40% of California's generation to come from "zero-carbon polluting resources," where hydrogen and CCS can play a role.[162] CCS facilities do not qualify for the State's RPS targets as they are not considered renewable.
- **Reliability & Resiliency. Hydrogen turbines are advantaged due to having a single energy ecosystem (hydrogen) vs. two (gas and CO_2) plus the complexity of multiple system integrations.**
  Angeles Link can enable the development of a long-duration storage capability to support reliability and resiliency of the power and cogeneration sectors. When compared to clean renewable hydrogen, CCS could potentially introduce additional infrastructure development and operational challenges when tasked with capturing and aggregating point source CO_2 emissions from power generation facilities dispersed throughout Central and Southern California.
- **Technical Maturity. Both hydrogen turbines and CCS solutions are in similar stages of technology readiness.**
  On the IEA's TRL scale, hydrogen turbines score seven, while CCS scores eight, which signifies that both technologies are close to commercial operations.[163] 100% hydrogen-capable turbines are under development with Tier 1 OEMs and are expected to be commercially available by 2030.[164] CCS solutions are in various stages of demonstration globally and are expected to be commercially available in a similar time frame as hydrogen turbines.
- **Scalability. Both hydrogen turbines and CCS face similar scaling challenges in the power sector, while proximity to industrial clusters offers CCS an advantage in cogeneration applications.**
  From an end-use case perspective, hydrogen combustion plants require key elements across the value chain in order to scale, including water availability, electrolyzer supply, and permitting of new transport and storage infrastructure. Requirements to scale for CCS solutions include the integration of multiple point sources for large scale CO_2 transport and sequestration infrastructure buildout particularly in the power sector (as

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[162] https://www.energy.ca.gov/sb100

[163] This is partly informed by the https://www.iea.org/data-and-statistics/data-tools/etp-clean-energy-technology-guide published by the International Energy Agency. See Appendix 7.4.1 for additional detail on the TRL scores.

[164] Angeles Link Demand Study.

gas power plant capacity factors are expected to decline over time, this reduces the scale benefits of CO_2 infrastructure). Cogeneration facilities operate at high capacity factors and are typically co-located with industrial clusters where they can benefit from the scale of CCS opportunities at these clusters.

- **End-User Requirements. Hydrogen turbines are advantaged in the power sector due to the relative ease of turbine retrofits vs. CCS retrofits, while proximity to industrial clusters brings CCS back to parity in cogeneration applications.**
  In the power sector, existing gas plants can be retrofitted with either new hydrogen turbines or carbon capture equipment, although the impact on operations and business disruption risk is significant for the balance of plant and operational changes required for carbon capture and integration with CO_2 transport infrastructure. In the cogeneration sector, the operational and business disruption risk is mitigated by the proximity of most cogeneration units in the region to refineries, where the cogeneration units can benefit from the larger scale and diversity of opportunities for CCS in the refinery sector.

4.3.2.2.1.2. Industrial – Cement

Cement facilities can be decarbonized through (among other solutions) hydrogen kiln retrofits or carbon capture retrofits. For the purpose of this study, a hydrogen-fueled kiln is assumed to utilize clean renewable hydrogen delivered from Angeles Link, and CCS is assessed based on a natural gas-fueled kiln retrofitted with CCS. This assessment is primarily focused on decarbonization of the kiln, which is the portion of the cement process for which hydrogen is best suited and is typically the second-largest source of emissions in a cement facility. CCS has the potential to address a range of emissions sources within a cement facility, including clinker production, which is the largest contributor to cement emissions. Figure 17 compares Angeles Link with CCS in the cement sector.

Figure 17: Evaluation: Cement (Hydrogen-Fueled Kilns and Gas Kilns with CCS)

Alternative	Technology Application	Cement Use Case	State Policy	Reliability & Resiliency	Maturity	Scalability	End-User Requirements
Angeles Link	Hydrogen Kiln	High Process Heating Application	🟦	🟦	⬜	⬜	⬜
CCS	Gas Kiln with CCS		🟦	▦	⬜	▦	▦

🟦 **High** ▦ **Good** ⬜ **Moderate** 🟥 **Low**

- **State Policy. Hydrogen kilns and gas kilns with CCS are both well-equipped to support decarbonization of the cement sector.**
  Both Angeles Link and CCS can support cement producers in meeting SB 596 targets, which require cement producers to reduce GHG emissions by 40% below 1990 levels by 2030, achieving net-zero by 2045. However, there is ongoing work at the federal and state level[165] to develop safety regulations regarding the transport and sequestration of CO_2, which presents temporary policy uncertainty for the development of a broader CO_2 infrastructure in California. CCS retrofits have the potential to address a larger share of facility emissions beyond the kiln.
- **Reliability & Resiliency. Hydrogen kilns are advantaged due to having a single system (hydrogen) vs. two (gas and CO_2) with the complexity of multiple system integrations.**

  Angeles Link can enable the development of a long-duration storage capability to support reliability and resiliency of supply to the cement sector. CCS could introduce infrastructure development and operational challenges associated with the integration of both gas and CO_2 transportation and storage networks.

- **Technical Maturity. Hydrogen kilns and gas kilns with CCS are in the same stage of technology readiness.**
  According to the IEA's TRL scale, hydrogen kilns achieve a score of five, while various capture technologies in the cement industry range between five and seven, indicating their respective stages of demonstration projects.[166] Hydrogen combustion kilns are currently in pilot stage as of the date of this study, with four projects recently announced by Cemex in Mexico. A CCS project is also in pilot stage in Canada demonstrating the first full-scale application of CCS for the cement sector, a joint venture between Heidelberg and Mitsubishi.[167]
- **Scalability. Hydrogen kilns face greater scaling challenges in the cement sector.**
  From an end-use case perspective, hydrogen kilns require key elements across the value chain in order to scale, including water availability, electrolyzer supply, and permitting of new transport and storage infrastructure. Requirements to scale for CCS

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[165] See SB 905, which directs CARB to establish a regulatory framework for the deployment of CCS in California, and new CO_2 pipeline safety measures under development by the Pipeline and Hazardous Materials Safety Administration (PHMSA). More information available at https://www.phmsa.dot.gov/news/phmsa-announces-new-safety-measures-protect-americans-carbon-dioxide-pipeline-failures

[166] This is partly informed by the https://www.iea.org/data-and-statistics/data-tools/etp-clean-energy-technology-guide published by the International Energy Agency. See Appendix 7.4.1 for additional detail on the TRL scores.

[167] https://www.mhi.com/news/24041103.html

solutions include similar considerations for transport and sequestration infrastructure; however, the proximity of many cement facilities in Kern County to the refinery ecosystem and potential CO_2 storage sites that have been announced may mitigate integration concerns as the connective carbon management infrastructure is developed.

- **End-User Requirements. CCS offers the potential to address a larger share of cement facility emissions.**
  Both hydrogen and CCS retrofits require investment in new equipment, which comes with some operational and business disruption risk. CCS retrofits have the potential to address a larger share of facility emissions beyond the kiln.

4.3.2.2.1.3. Industrial – Refineries

The refineries operating in Central and Southern California are concentrated near the Port of Los Angeles and in the SJV. These refineries currently use unabated hydrogen for operations like hydrocracking and sulphur removal. The advancement of the energy transition and demand for fossil fuels and clean alternatives like renewable diesel will determine the future utilization rates of refineries and their decarbonization efforts. In the refinery sector, clean renewable hydrogen is assumed to be delivered by Angeles Link for the refinery process needs mentioned above, and CCS is evaluated based on the conversion of current unabated hydrogen supply[168] to abated hydrogen (decarbonized hydrogen) via the addition of CCS to existing natural gas-fueled SMRs. The Alternatives Study does not address other refinery emission sources. Figure 18 compares Angeles Link with CCS in refineries.

Figure 18: Evaluation: Refineries (Clean Renewable Hydrogen and Low-Carbon Hydrogen with CCS)

Alternative	Technology Application	Refinery Use Case	State Policy	Reliability & Resiliency	Maturity	Scalability	End-User Requirements
Angeles Link	Clean Renewable Hydrogen	Fuel Switching	▨	🟦	⬜	⬜	⬜
CCS	Low-Carbon Hydrogen		▨	▨	⬜	▨	▨

🟦 **High** ▨ **Good** ⬜ **Moderate** 🟥 **Low**

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[168] Unabated hydrogen supply refers to hydrogen produced using natural gas-fueled steam methane reformers, which produce CO_2 emissions.

- **State Policy. Both clean renewable hydrogen and CCS score the same due to the absence of refinery-specific decarbonization policies.**
  While there are no refinery-specific decarbonization targets in California policy, both Angeles Link and CCS can support refinery participation in other incentives like the Low-Carbon Fuel Standard. There is ongoing work at the federal and state level to develop safety regulations regarding the transport and sequestration of CO_2,[169] which presents temporary policy uncertainty for the development of a broader CO_2 infrastructure in California.
- **Reliability & Resiliency. Clean renewable hydrogen benefits due to the advantage of having a single system (hydrogen) vs. two (gas and CO_2) with the complexity of multiple system integrations.**
  Angeles Link is intended as an integrated, open access system, providing an inherent long-duration storage capability to support reliability and resiliency of supply to the refinery sector. CCS could introduce infrastructure development and operational challenges associated with the integration of both natural gas and CO_2 transportation and storage networks.
- **Technical Maturity. Clean renewable hydrogen and CCS in refineries are in the same stage of technology readiness.**
  Both hydrogen and CCS in the refinery sector are in small-scale pilot/demonstration stage (CCS scores four on the IEA TRL scale).[170] Clean renewable hydrogen projects are in pilot/demonstration stages at refineries in China, and CCS solutions are being demonstrated at refineries in Sweden and Norway.[171]
- **Scalability. Clean renewable hydrogen is at a slight disadvantage due to the role of the refinery ecosystem in driving scale needed for higher utilization of CO_2 transport and sequestration infrastructure.**
  Hydrogen requires key elements across the value chain to scale, including water availability, electrolyzer supply, and permitting of new transport and storage infrastructure. Requirements to scale for CCS solutions include similar considerations for transport and sequestration infrastructure, but refineries can serve as anchor

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[169] See SB 905, which directs CARB to establish a regulatory framework for the deployment of CCS in California, and new CO_2 pipeline safety measures under development by the Pipeline and Hazardous Materials Safety Administration (PHMSA). More information available at https://www.phmsa.dot.gov/news/phmsa-announces-new-safety-measures-protect-americans-carbon-dioxide-pipeline-failures

[170] This is partly informed by the https://www.iea.org/data-and-statistics/data-tools/etp-clean-energy-technology-guide published by the International Energy Agency. See Appendix 7.4.1 for additional detail on the TRL scores.

[171] Ibid.

customers to provide scale needed to drive utilization of CO_2 transport and sequestration infrastructure.

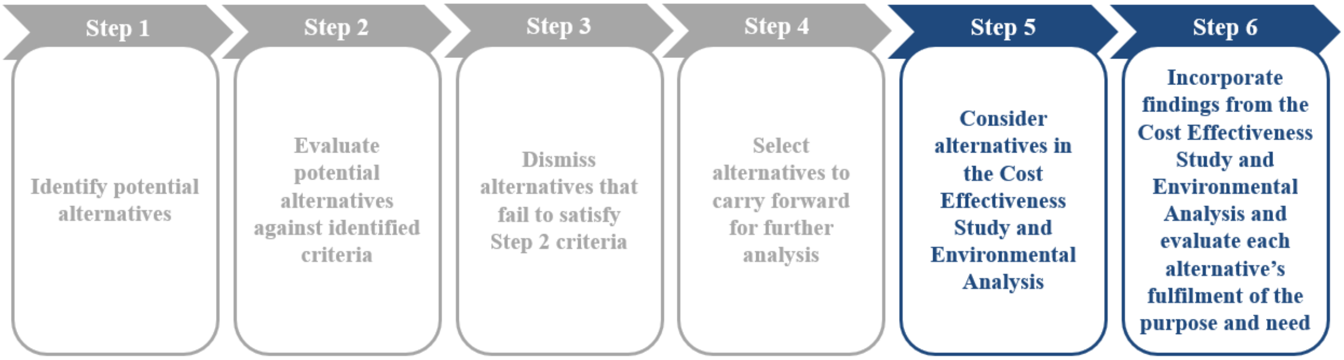
- **End-User Requirements. Clean renewable hydrogen faces challenges due to the ability of CCS to integrate with existing unabated hydrogen supply.**
  CCS retrofits require investment in new equipment for unabated hydrogen suppliers, which comes with some operational and business disruption risk. Angeles Link could displace existing onsite and/or near site grey hydrogen supply, but adoption may be limited by the ability to replace existing long-term supply contracts in place with refineries.

4.3.2.3. Non-Hydrogen Alternatives Advanced

After applying the evaluation criteria described above, both electrification and CCS were deemed appropriate to move forward to the Cost Effectiveness Study and the Environmental Analysis.

4.4. Cost Effectiveness, Environmental Analysis, and Purpose and Need Assessment

Figure 19: Six-Step Evaluation Process: Cost-Effectiveness and Environmental Analysis Findings and Purpose and Need Assessment



This section summarizes the incorporation of findings from the Cost Effectiveness Study and Environmental Analysis and evaluates the alternatives' fulfillment of Angeles Link's purpose and need as part of the six-step process.

4.4.1. Potential Environmental Impacts

A high-level analysis of the potential environmental impacts of the alternatives selected for further analysis is included in the Environmental Analysis being prepared as a separate Phase 1 Angeles Link feasibility study. This desktop analysis was prepared to identify and evaluate potential environmental impacts that could result from construction and operation and maintenance (O&M) of Angeles Link and from the alternatives to Angeles Link. The Environmental Analysis relies on the potential pipeline routes identified in the Preliminary Routing/Configurations Analysis and relies on assumptions related to conventional pipeline construction and O&M for the desktop analysis. Results and impact analysis are based upon publicly available datasets and information.

Table 24 in Appendix 7.4.3 provides a high-level summary of the assessment completed in the Environmental Analysis.[172]

4.4.2. Cost Effectiveness Findings

Considering the criteria and cost methodology are distinct to each category of alternatives, the findings from the Cost Effectiveness Study are categorized into two sections—Hydrogen Delivery Alternatives and Non-Hydrogen Alternatives.

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[172] Refer to the Environmental Analysis for more detailed information.

4.4.2.1. Hydrogen Delivery Alternatives

Findings from the Cost Effectiveness Study were incorporated into this study to compare the cost-effectiveness of the Hydrogen Delivery Alternatives in relation to Angeles Link. Like the Step 2 criteria, cost effectiveness for each alternative was evaluated based on a 4-point scale ranked from high to low using the rubric detailed in Table 11.

Table 11: Cost Effectiveness Assessment Rubric (Hydrogen Delivery Alternatives)

Criteria Selected for Screening	Definition	High	Good	Moderate	Low
Cost Effectiveness	The degree to which the costs[173] associated with the delivery method are competitive relative to alternatives	Below or at $6/kgH_2$	More than $6 and below or at $8/kgH_2$	More than $8 and below or at $10/kgH_2$	More than $10/kgH_2$

Cost-effectiveness assesses the total cost of delivered hydrogen ($/kg), including production, transportation, storage, and delivery to end users. This analysis compares the alternatives using the Levelized Cost of Delivered Hydrogen (LCOH) as the unifying metric. LCOH has the advantage of being an objective and comparable metric across different technologies delivering the same product. The costs are estimated in the Cost Effectiveness Study, where the methodology is explained in detail, along with additional cost-related results.

Cost-effectiveness analysis examines the economic feasibility of each option and follows the 4-point scale ranking defined in Table 9. Table 12 summarizes the results for each delivery mode.

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[173] Real 2024 Levelized Cost of Delivered Hydrogen.

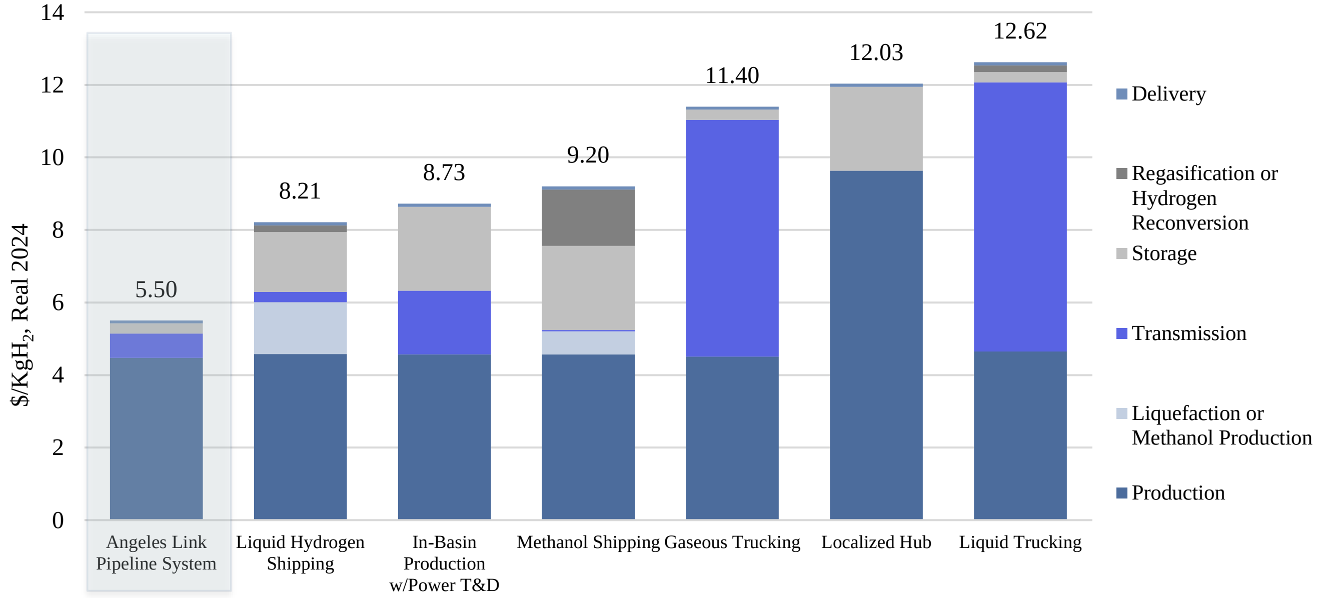
Table 12: Cost Effectiveness

Angeles Link	Gaseous Hydrogen Trucking	Liquid Hydrogen Trucking	Liquid Hydrogen Shipping	Methanol Shipping	In-Basin Production with Power T&D	Localized Hub
🟦	🟥	🟥	⬜	⬜	⬜	🟥

🟦 **High** ▨ **Good** ⬜ **Moderate** 🟥 **Low**

The results shown in Figure 20 correspond to Angeles Link transporting 1.5 Mtpa to connect to third-party production sites such as SJV and Lancaster areas to end users. The component values are included in Appendix 7.2.1.

Figure 20: Cost Effectiveness of Angeles Link vs. Hydrogen Delivery Alternatives[174]



Notes: Reflects costs from Scenario 7 (corresponding to Design Study, Configuration A, single run scenario) for 1.5 Mtpa. Production is assumed to begin in 2030 to take advantage of tax incentives, including Production Tax Credits (PTC) for hydrogen (45V)[175] and power (45Y)[176], which provide $3 per kgH$_2$ and $0.028 per kWh for ten years. Storage assumptions were based on proximity to production sites, and the geographic footprint under consideration for storage in the Production Study.[177] For Angeles Link and the trucking alternatives (gaseous and liquid), identified routes allowed for access to underground storage sites, therefore, underground storage costs were assumed. Delivery alternatives with production sites that did not overlap with the identified geological storage sites, were assumed to rely on above ground storage. These alternatives include shipping, in-basin production with T&D, and localized hub. The shipping solutions include the costs of specialized handling required to deliver methanol and liquid hydrogen. The cost for liquefaction in the liquid hydrogen trucking alternative is included as a part of transmission costs.

Results from the cost effectiveness assessment indicate the following:

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[174] See Cost Effectiveness Study 6.3.1 Delivery Alternatives Assumption Tables Delivery Alternatives Assumption Tables and 6.2.2 Delivery Alternatives Descriptions for additional details.

[175] 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

[176] https://www.federalregister.gov/documents/2024/06/03/2024-11719/section-45y-clean-electricity-production-credit-and-section-48e-clean-electricity-investment-credit

1. **Angeles Link Pipeline System** was found to be the most cost-effective method when comparing Angeles Link to the identified Hydrogen Delivery Alternatives for delivering hydrogen at scale across Central and Southern California, at a cost of $5.50/kgH$_2$. As with almost every delivery alternative, third-party production cost of the clean renewable hydrogen is the single greatest contributor to total LCOH. The pipeline transmission system represents only 12% of the total LCOH, contributing to its lower costs when compared to other delivery alternatives for the assessed supply locations and volume requirements by 2045.
2. **Liquid hydrogen and methanol shipping alternatives,** though efficient for long-distance transport, are not cost-effective for intrastate needs, with a cost of $8.21 and $9.20/kgH$_2$, respectively. These solutions are expensive overall due to the specialized handling required to convert, reconvert, and store the hydrogen,[178] which incurs higher costs.
3. **In-basin production with power T&D**, while feasible, has a cost of $8.73/kgH$_2$, as it would require extensive and costly infrastructure compared to pipelines, as multiple long-distance electric transmission lines are needed to bring the power to production centers and requires in-basin above-ground storage. Costs associated with long distance transmission complemented by above-ground storage can have a significant impact on the cost of delivered hydrogen, especially at scale.[179]
4. **Gaseous and liquid hydrogen trucking** alternatives could serve as interim solutions; however, with a cost of $11.40 and $12.62/kgH$_2$ respectively, they lack the scalability and cost-effectiveness of a pipeline system to support at-scale demand transported over longer distances in a cost-effective manner. Higher transportation costs are driven by the volumetric constraints of trucks, the long distances, and transport time required to connect hydrogen produced via high-quality renewable resources to demand, and additional expenses associated with liquefaction/compression, as well as loading and unloading at production and storage locations.
5. **Localized hub** was found to have the highest production costs, with over $9.6 /kgH$_2$. Higher costs are driven by its in-basin location which limits scale and requires the aggregation of electricity from multiple scattered solar generation sites. It is also impacted

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[177] For additional details on the rationale for Storage assumptions for each alternative please refer to Cost Effectiveness Study Appendix 7.5.1. The storage solution selected reflects the best available for a like for like comparison.

[178] Storage can occur as methanol as well, but it is assumed to be hydrogen to facilitate comparison between storage on the delivery alternatives. Additionally, it will ultimately be consumed as hydrogen.

[179] More details on storage assumptions can be found at Appendix 7.5.1 in the Cost Effectiveness Study.

by the need for above-ground storage costs, as underground storage options have not yet been identified in the localized hub area.

4.4.2.2. Non-Hydrogen Alternatives

Findings from the Cost Effectiveness Study were incorporated into this study to compare the cost-effectiveness of the Non-Hydrogen Alternatives in relation to Angeles Link. Like the Step 2 criteria, cost effectiveness for each alternative was evaluated based on a 4-point scale ranked from high to low using the rubric in Table 13.

Table 13: Cost Effectiveness Assessment Rubric (Non-Hydrogen Alternatives)

Criteria Selected for Screening	Definition	High	Good	Moderate	Low
Cost Effectiveness	Economics relative to Angeles Link based on a common metric	Materially more economic compared to Angeles Link	At or near the cost of Angeles Link	Materially less economic than Angeles Link	Significantly less economic than Angeles Link

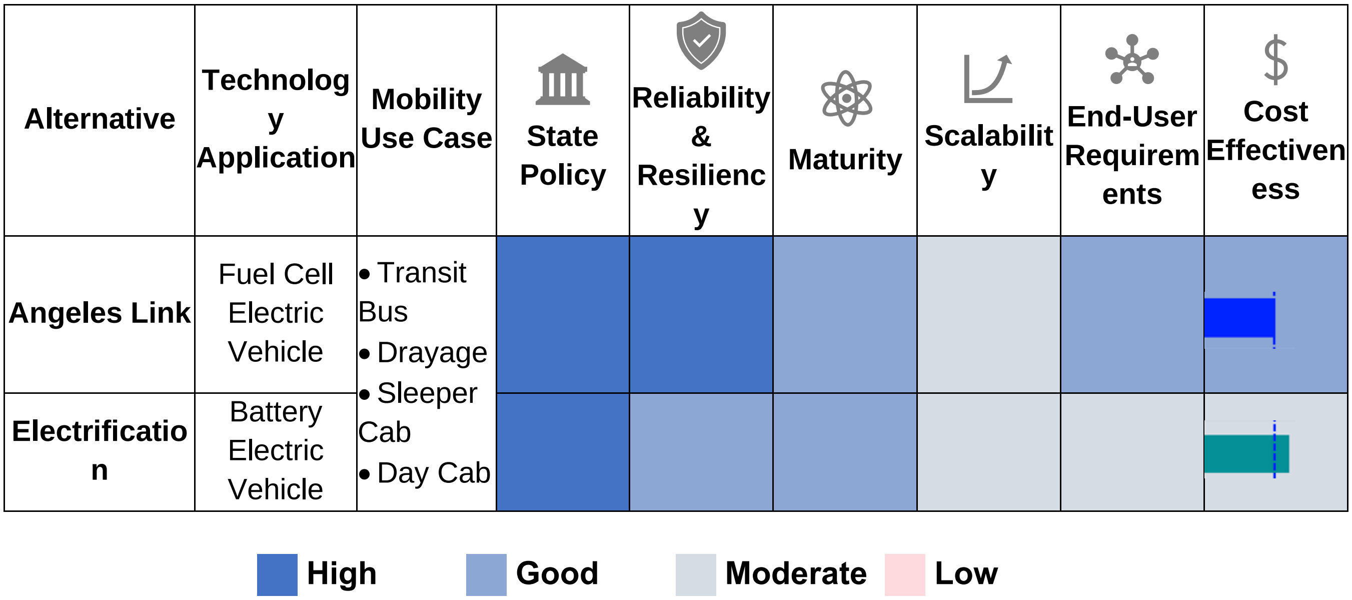
For the cost effectiveness criterion, the results of the Cost Effectiveness Study are summarized in a comparison chart for each use case to illustrate the cost effectiveness of the alternative relative to Angeles Link. See the Cost Effectiveness Study for additional details identifying the use case specific metrics and detailed breakdowns of cost analysis results for Non-Hydrogen Alternatives. This relative cost effectiveness measure was then translated into the 4-point scale for purposes of scoring the cost effectiveness criterion, as discussed in the sub-sections below. Because the use cases and considerations relevant to electrification and CCS differ, each alternative is presented below in direct comparison to end uses consuming hydrogen delivered by Angeles Link across the relevant sectors.

4.4.2.2.1.Electrification Cost Effectiveness Analysis

4.4.2.2.1.1. Mobility

As part of the cost effectiveness analysis for the mobility sector, the Cost Effectiveness Study evaluated FCEVs against BEVs across transit buses, sleeper cabs, day cabs and drayage trucks. Results of the analysis are illustrated in Figure 21, and the main cost are drivers discussed below.

Figure 21: Comparison of FCEVs and BEVs in the Mobility Sector



Alternative	Technology Application	Mobility Use Case	State Policy	Reliability & Resiliency	Maturity	Scalability	End-User Requirements	Cost Effectiveness
Angeles Link	Fuel Cell Electric Vehicle	• Transit Bus • Drayage • Sleeper Cab • Day Cab	🟦	🟦	▨	⬜	▨	▨
Electrification	Battery Electric Vehicle		🟦	▨	▨	⬜	⬜	⬜

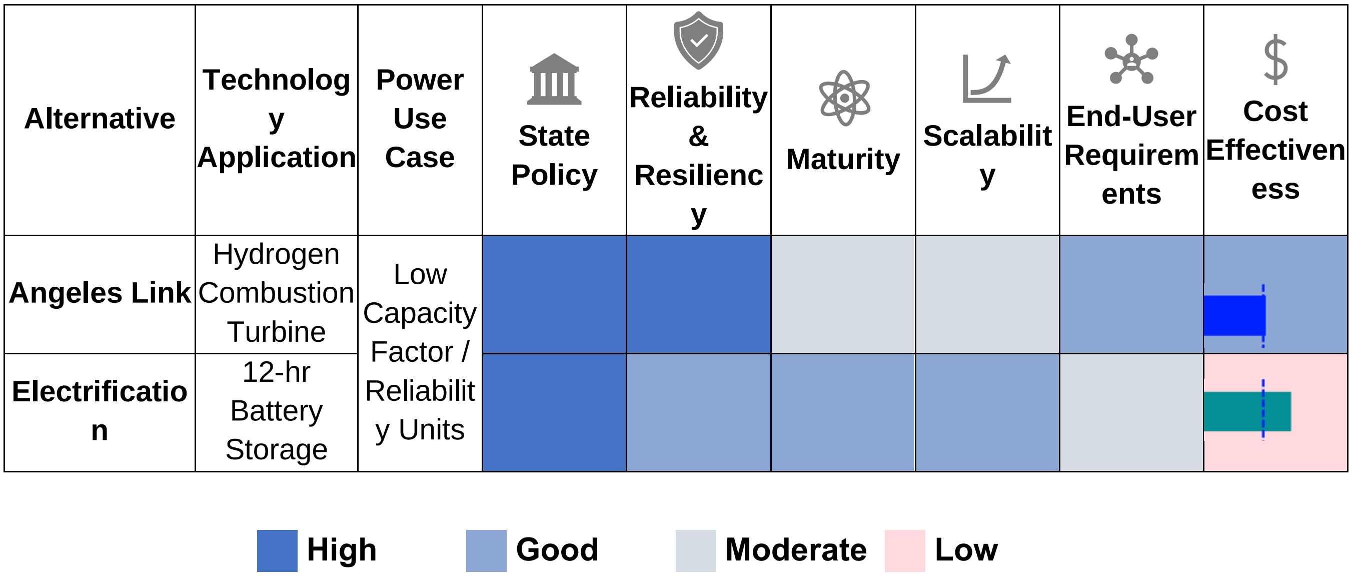
🟦 **High** ▨ **Good** ⬜ **Moderate** 🟥 **Low**

- **Cost Effectiveness. FCEVs are advantaged because of their reduced operational expenses and the comparative disadvantages of BEVs, such as longer charging durations and increased vehicle weight.**
  FCEVs have the potential to be more cost effective than BEVs, particularly in situations where HDVs have a higher payload and more frequent refueling stops. Detailed analysis and discussions of key drivers are provided in the Cost Effectiveness Study.

4.4.2.2.1.2. Power

As part of the cost effectiveness analysis for the power sector, the Cost Effectiveness Study evaluated hydrogen combustion turbines against a 12-hr battery storage unit that has a peaker/reliability dispatch profile. Results of the analysis are illustrated in Figure 22, with the main cost drivers discussed below.

Figure 22: Comparison of Hydrogen Combustion Plants and Battery Storage in the Power Sector



Alternative	Technology Application	Power Use Case	State Policy	Reliability & Resiliency	Maturity	Scalability	End-User Requirements	Cost Effectiveness
Angeles Link	Hydrogen Combustion Turbine	Low Capacity Factor / Reliability Units	🟦	🟦	⬜	⬜	▨	▨
Electrification	12-hr Battery Storage		🟦	▨	▨	▨	⬜	🟥

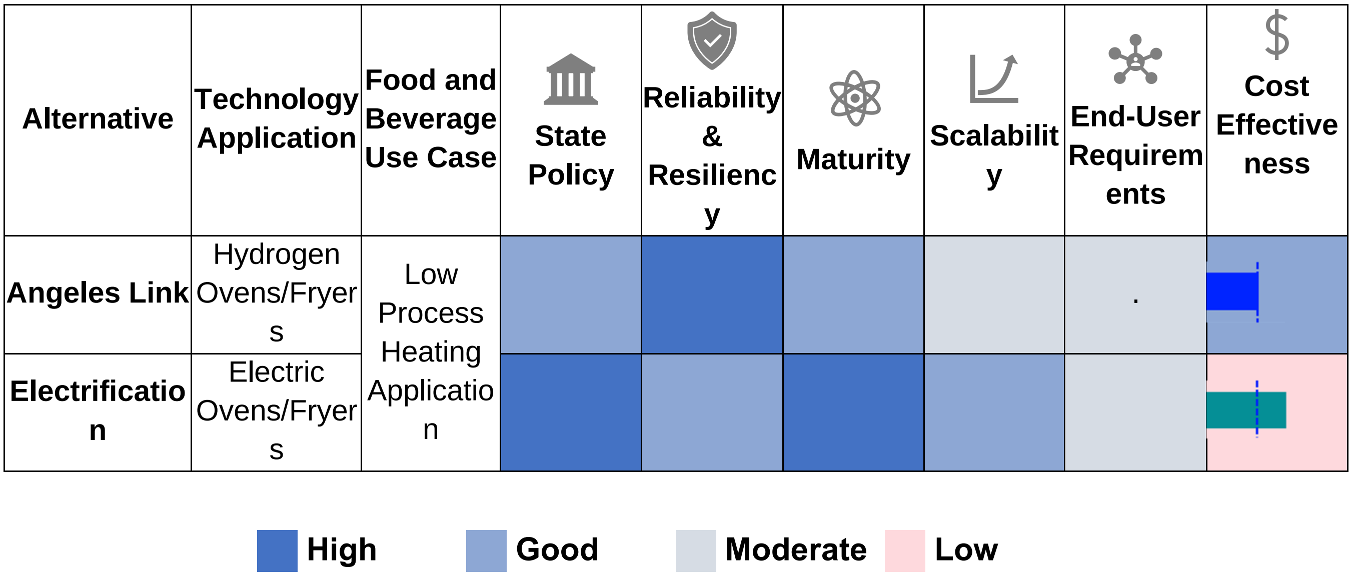
🟦 **High** ▨ **Good** ⬜ **Moderate** 🟥 **Low**

- **Cost Effectiveness. Hydrogen turbines are cost-advantaged due to the high cost of building battery energy storage in configurations sufficient to deliver longer duration capabilities.**
  A gas facility retrofitted with a hydrogen turbine operating as a peaker unit is more cost effective than a lithium-ion battery storage facility built with sufficient redundancy to achieve longer duration capability. The higher hydrogen fuel cost is outweighed by the high capital cost of oversized battery storage. Detailed analysis and discussions of key drivers are provided in the Cost Effectiveness study.

4.4.2.2.1.3. Industrial – Food & Beverage

As part of the cost effectiveness analysis for the F&B sector, the Cost Effectiveness Study evaluated hydrogen ovens and fryers against electric ovens and fryers for low process heating applications. Results of the analysis are illustrated in Figure 23, with the main cost drivers discussed below.

Figure 23: Comparison of Hydrogen and Electric Kilns in the Food & Beverage Sector



Alternative	Technology Application	Food and Beverage Use Case	State Policy	Reliability & Resiliency	Maturity	Scalability	End-User Requirements	Cost Effectiveness
Angeles Link	Hydrogen Ovens/Fryers	Low Process Heating Application	▨	■	▨	□	□ .	▨
Electrification	Electric Ovens/Fryers		■	▨	■	▨	□	🟥

■ **High** ▨ **Good** □ **Moderate** 🟥 **Low**

- **Cost Effectiveness. Hydrogen kilns are advantaged due to the relatively high electricity rates in California.**
  While electrification of low to medium process heating applications is technically feasible, hydrogen ovens and fryers are more cost effective (on a fuel cost basis only) due to relatively high industrial electricity tariffs in California. For example, the weighted average retail rate for industrial customers in Pacific Gas & Electric's (PG&E) service territory is 21 cents per kWh or about $62 per MMBtu, which is about 53% higher than the delivered cost of hydrogen on a $/MMBtu basis.[180] Additional details are provided in the Cost Effectiveness Study.

4.4.2.2.1.4. Industrial – Cement

As part of the cost effectiveness analysis for the cement sector, the Cost Effectiveness Study evaluated hydrogen and electric cement kilns for high process heating applications. Results of the analysis are illustrated in Figure 24, with the main cost drivers discussed below.

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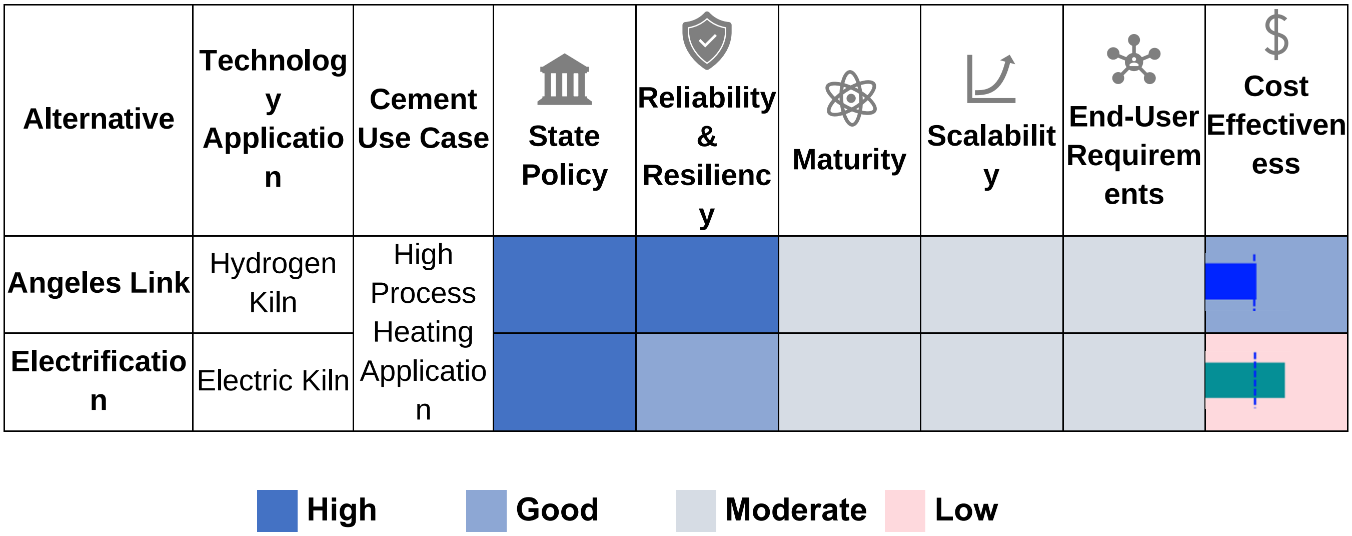
[180] PG&E Industrial Tariffs – Industrial Service (B-20)

Figure 24: Comparison of Angeles Link and Electrification in the Cement Sector



Alternative	Technology Application	Cement Use Case	State Policy	Reliability & Resiliency	Maturity	Scalability	End-User Requirements	Cost Effectiveness
Angeles Link	Hydrogen Kiln	High Process Heating Application	🟦	🟦	⬜	⬜	⬜	▦
Electrification	Electric Kiln		🟦	▦	⬜	⬜	⬜	🟥

🟦 **High** ▦ **Good** ⬜ **Moderate** 🟥 **Low**

- **Cost Effectiveness. Hydrogen kilns are advantaged due to high electricity rates in California.**
  While electrification of high process heating applications is becoming more technically feasible, Angeles Link is more cost effective (on a fuel cost basis only) due to relatively high industrial electricity tariffs in California. For example, the weighted average retail rate for industrial customers in PG&E service territory is 21 cents per kWh or about $62 per MMBtu, which is about 53% higher than the delivered cost of hydrogen on a $/MMBtu basis. Additional details are provided in the Cost Effectiveness study.

4.4.2.2.2.CCS Cost Effectiveness Analysis

4.4.2.2.2.1. Power and Cogeneration

Across the power and cogeneration use cases, the cost effectiveness analysis evaluated hydrogen turbines and natural gas turbines retrofitted with CCS equipment for a baseload dispatch profile. Results of the analysis are illustrated in Figure 25, with the main cost drivers discussed below.[181]

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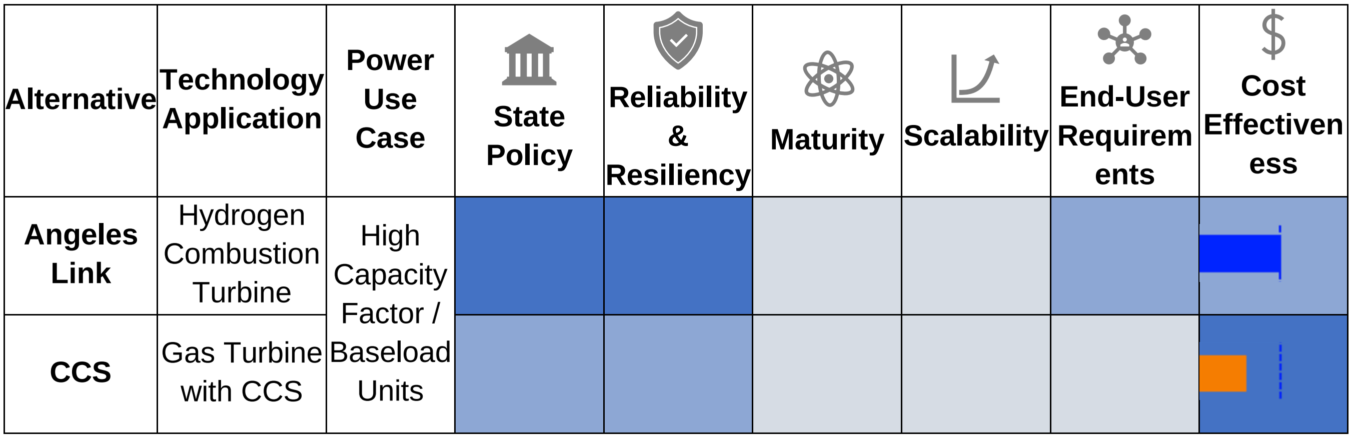
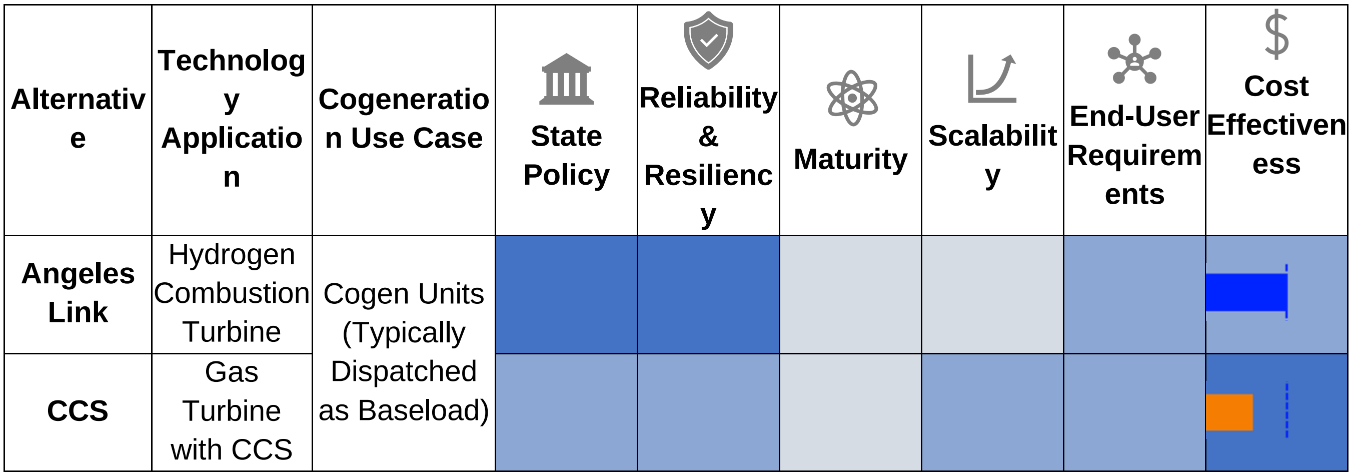
[181] The CCS cost analysis reflects several important assumptions, including sufficient space for capture equipment within the plant boundary, access to transport and sequestration infrastructure, transport and sequestration tariffs based on a commercially reasonable level of utilization, and no new carbon taxes. Refer to the Cost Effectiveness Study for additional details of assumptions, key drivers, and results of cost analysis. See Appendix 7.3.2 for additional CCS considerations.

Figure 25: Comparison of Hydrogen Turbines and Gas Turbines with CCS in the Power and Cogeneration Sectors



Alternative	Technology Application	Power Use Case	State Policy	Reliability & Resiliency	Maturity	Scalability	End-User Requirements	Cost Effectiveness
Angeles Link	Hydrogen Combustion Turbine	High Capacity Factor / Baseload Units	■	■	░	░	▨	▨
CCS	Gas Turbine with CCS		▨	▨	░	░	░	■

■ **High** ▨ **Good** ░ **Moderate** □ **Low**



Alternative	Technology Application	Cogeneration Use Case	State Policy	Reliability & Resiliency	Maturity	Scalability	End-User Requirements	Cost Effectiveness
Angeles Link	Hydrogen Combustion Turbine	Cogen Units (Typically Dispatched as Baseload)	■	■	░	░	▨	▨
CCS	Gas Turbine with CCS		▨	▨	░	▨	▨	■

■ **High** ▨ **Good** ░ **Moderate** □ **Low**

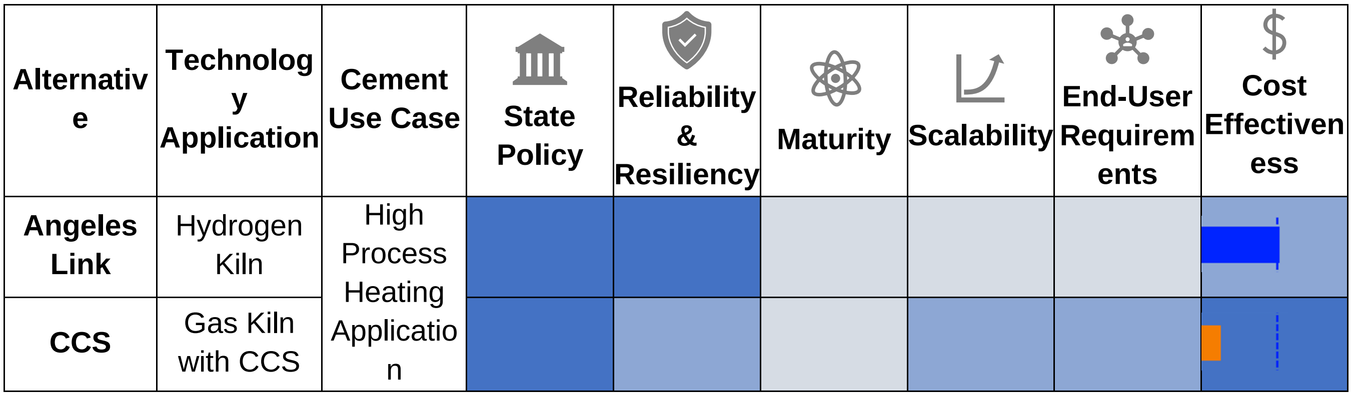
- **Cost Effectiveness. Hydrogen turbines are not at cost parity due to the lower cost of natural gas relative to hydrogen.**
  Under the assumptions considered for the purpose of this study, gas facilities retrofitted with carbon capture equipment are currently a more cost effective decarbonization solution than gas facilities retrofitted with a hydrogen turbine. The higher hydrogen fuel cost outweighs the higher capital expenditure of the carbon capture equipment, although the gap can narrow significantly depending on the CO_2 transport and

sequestration cost, which is dictated by the integration of distributed point source CO_2 emitters for the development of large-scale CO_2 transport pipeline infrastructure. The integration of CO_2 point source emitters would increase if various sectors within California's economy were to implement CCS technology concurrently, which could drive costs down. In contrast, the emissions output from single industrial point sources might not be adequate to warrant the economic outlay for a CO_2 pipeline. The gap in cost parity between hydrogen turbines and gas turbines with CCS may decline over time as the cost of delivered hydrogen is expected to decline. For an in-depth analysis and exploration of the cost factors, refer to the Cost Effectiveness Study.

4.4.2.2.2.2. Industrial – Cement

As part of the cost effectiveness analysis for the cement sector, the Cost Effectiveness Study evaluated hydrogen kilns and kilns retrofitted with CCS for high process heating applications. Results of the analysis are illustrated in Figure 26, with the main cost drivers discussed below.

Figure 26: Comparison of Hydrogen Kilns and Gas Kilns with CCS in the Cement Sector



Alternative	Technology Application	Cement Use Case	State Policy	Reliability & Resiliency	Maturity	Scalability	End-User Requirements	Cost Effectiveness
Angeles Link	Hydrogen Kiln	High Process Heating Application	■	■	░	░	░	▨
CCS	Gas Kiln with CCS		■	▨	░	▨	▨	■

■ **High** ▨ **Good** ░ **Moderate** □ **Low**

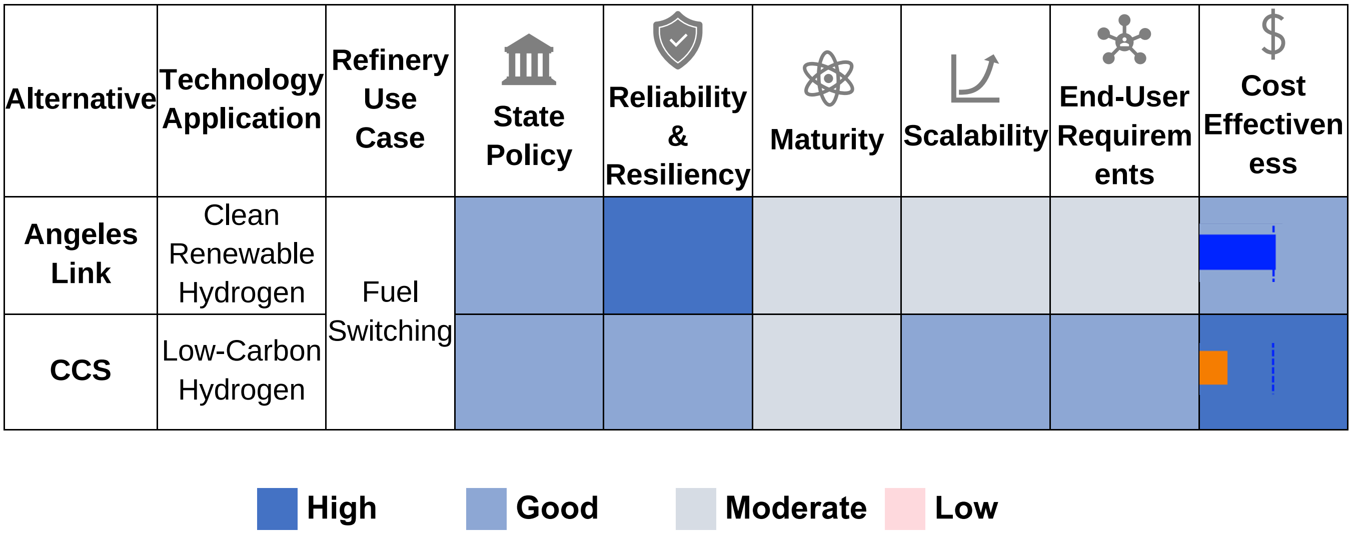
- **Cost Effectiveness. Hydrogen kilns are currently not at cost parity due to the lower cost of natural gas relative to hydrogen.**
  Cost effectiveness in the cement sector was analyzed based on fuel cost and the cost of CO_2 transport and sequestration. For the cement sector analysis, the capital costs associated with hydrogen kiln retrofits and CO_2 capture equipment were not considered, nor were the costs of incremental energy to power the capture equipment. Hydrogen's current higher fuel cost vs. natural gas generally outweighs the anticipated cost of CO_2

transport and sequestration, making CCS the more cost-effective solution.[182] However, this gap could significantly narrow depending on the CO_2 transport and sequestration cost, which is dictated by the integration of distributed point source CO_2 emitters to the broader CO_2 transport infrastructure. The gap in cost parity between hydrogen kilns and gas kilns with CCS may decline over time as the cost of delivered hydrogen is expected to decline. For an in-depth analysis and exploration of the cost factors, refer to the Cost Effectiveness Study.

4.4.2.2.2.3. Industrial – Refineries

In the refinery use case, the cost effectiveness analysis evaluated clean renewable hydrogen provided by Angeles Link and low-carbon hydrogen provided by existing unabated hydrogen supply with CCS for refinery process needs. Results of the analysis are illustrated in Figure 27, with the main cost drivers discussed below.

Figure 27: Comparison of Clean Renewable Hydrogen and Low-Carbon Hydrogen in the Refinery Sector



Alternative	Technology Application	Refinery Use Case	State Policy	Reliability & Resiliency	Maturity	Scalability	End-User Requirements	Cost Effectiveness
Angeles Link	Clean Renewable Hydrogen	Fuel Switching	▦	■	░	░	░	▦
CCS	Low-Carbon Hydrogen		▦	▦	░	▦	▦	■

■ **High** ▦ **Good** ░ **Moderate** ▢ **Low**

- **Cost Effectiveness. Clean renewable hydrogen is currently not at cost parity due to the relatively lower cost of natural gas for unabated hydrogen with CCS.**

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[182] The CCS cost analysis reflects several important assumptions, including sufficient space for capture equipment within the plant boundary, access to transport and sequestration infrastructure, transport and sequestration tariffs based on a commercially reasonable level of utilization, and no new carbon taxes. Refer to the Cost Effectiveness Study for additional details of assumptions, key drivers, and results of cost analysis. See Appendix 7.3.2 for additional CCS considerations.

Cost effectiveness in the refinery sector was analysed based on LCOH for hydrogen delivered via Angeles Link vs. near-site hydrogen retrofitted with CCS from SMRs, including the anticipated cost of CO_2 transport and sequestration. Near site hydrogen using CCS is currently expected to be more cost effective for refineries than clean renewable hydrogen.[183] However, this gap could narrow depending on the CO_2 transport and sequestration, which is dictated by the integration of distributed CO_2 point source emitters to the broader CO_2 transport infrastructure. The gap in cost parity between clean renewable hydrogen and abated hydrogen with CCS may decline over time as the cost of clean renewable hydrogen is expected to decline. For an in-depth analysis and exploration of the cost factors, refer to the Cost Effectiveness Study.

4.4.3. Purpose and Need Assessment

As a final step in the evaluation of Angeles Link relative to Hydrogen Delivery Alternatives and Non-Hydrogen Alternatives, this study performed a summary assessment based on the purpose and need for Angeles Link. This final step examines the criteria and analyses conducted in this study to allow for a comprehensive consideration of Angeles Link's purpose and need.

The nine elements of purpose and need are presented below.

1. **California-wide decarbonization.** 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 hydrogen for the hard-to-electrify sectors as playing a key role in the State achieving carbon neutrality by 2045 or earlier.[184]
2. **Mobility decarbonization.** To support the State of California's decarbonization goals in the mobility sector, including the Governor's Executive Order N-79-20, which seeks to accelerate the deployment of zero-emission vehicles;[185] CARB's implementation of the Advanced Clean Fleets regulation, which is a strategy to deploy medium- and heavy-duty zero-emission vehicles;[186] as well as the implementation of the March 15, 2021

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[183] The CCS cost analysis reflects several important assumptions, including sufficient space for capture equipment within the facility boundary, access to transport and sequestration infrastructure, transport and sequestration tariffs based on a commercially reasonable level of utilization, and no new carbon taxes. Refer to the Cost Effectiveness Study for additional details of assumptions, key drivers, and results of cost analysis. See Appendix 7.3.2 for additional CCS considerations.

[184] https://ww2.arb.ca.gov/sites/default/files/2022-12/2022-sp.pdf at pp. 9-10.

[185] https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf and Advanced Clean Fleets | California Air Resources Board.

[186] Advanced Clean Fleets | California Air Resources Board.

Advanced Clean Truck regulation, which aims to accelerate a large-scale transition of zero-emission medium- and heavy-duty vehicles.[187]

3. **Open access.** To optimize service to all potential end-users in the project area by operating an open access, common carrier clean renewable hydrogen transportation system dedicated to public use.
4. **Air quality.** To support improving California's air quality by displacing fossil fuels for certain hard-to-electrify uses, including the mobility sector.
5. **Reliability.** To enhance energy system reliability, resiliency, and flexibility as California industries transition fuel usage to achieve the State's decarbonization goals.
6. **Long-duration storage.** To enable long-duration clean energy storage that can further accelerate renewable development, minimize renewable curtailments, and provide seasonal storage when renewable output is diminished.
7. **Cost.** To provide a cost effective and affordable open access clean renewable hydrogen transportation system at just and reasonable rates.
8. **Safety.** To provide efficient and safe clean renewable energy transportation in support of the State's decarbonization goals.[188]
9. **Reduce reliance on Aliso Canyon.** Over time and combined with other current and future clean energy projects and reliability efforts, to help support decreased reliance on Aliso Canyon natural gas storage facility, while continuing to provide reliable and affordable energy service to the region.

Each alternative's level of alignment with the applicable purpose and need elements was evaluated based on the findings of this study and other considerations where direct evidence from this study was not available. Table 14 summarizes the purpose and need evaluation, with additional context for the scoring provided below.

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[187] Advanced Clean Fleets | California Air Resources Board.

[188] https://ww2.arb.ca.gov/sites/default/files/2022-12/2022-sp.pdf , at pp. 9-10.

Table 14: High-Level Assessment of Alternatives' Alignment with Purpose & Need for Angeles Link

	Angeles Link	Trucking	Shipping	In-Basin Production with Power T&D	Localized Hub	Electrification	CCS
California-wide decarbonization	🟩	🟩	🟩	🟩	🟧 Sub-scale	🟧 Cannot serve all sectors	🟧 Cannot serve all sectors
Mobility decarbonization	🟩	🟩	🟩	🟩	🟧 Sub-scale	🟩	🟥 Cannot serve mobility[189]
Open access	🟩	⬜ N/A	⬜ N/A	🟩 If distribution is open access	🟩	🟩	🟩 If CO_2 pipeline is open access
Air quality	🟩	🟥	🟥	🟩	🟥	🟩	🟧
Reliability	🟩	🟧 Lower dispatchability	🟧 Lower dispatchability	🟩	🟧 Sub-scale	🟧 Need clean firm	🟧 Secondary system alongside gas
Long-duration storage	🟩	🟩	🟩	🟩	🟩	🟧 LDES still emerging	🟩 Existing gas storage
Cost	🟩	🟧 Higher LCOH	🟧 Higher LCOH	🟧 Higher LCOH	🟧 Higher LCOH	🟧 High electricity tariffs	🟩
Safety	🟩	🟧	🟧	🟧	🟧	🟩	🟧
Reduce reliance on Aliso Canyon	🟩	🟩	🟩	🟩	🟧 Sub-scale	🟩	🟥 No reduction in gas

🟩 High alignment

🟧 Some alignment

🟥 Low or no alignment

⬜ Not applicable (N/A)

Trucking inherently has lower dispatchability than a pipeline system and is therefore less reliable. Trucking has low alignment with the air quality objective, given tailpipe emissions from trucks in the short to near term horizon. It requires extensive loading/offloading infrastructure, where safety incidents are more likely to occur[190]. Trucking also comes at a higher cost than a pipeline system based on the results of the Cost Effectiveness Study.

Shipping inherently has lower dispatchability than a pipeline system and is therefore less reliable. Shipping has low alignment with the air quality objective, given emissions from ocean vessels in the short to near term horizon and supporting facilities. While shipping is generally considered a safe method of transporting oil and gas, shipping alternatives would require extensive loading/offloading infrastructure, where safety incidents are more likely to occur. [191] While the shipping alternative has been assumed to be able to access storage sized to meet long-duration requirements, this storage is assumed to be solely above-ground, which comes with cost and feasibility challenges at the scale required.[192] Shipping also comes at a higher cost than a pipeline system based on the results of the Cost Effectiveness Study.

In-basin production with power T&D can be used as an open access solution dedicated to public use for the hydrogen produced and transported in-basin. This alternative has high alignment with the air quality objective because it can deliver the same volume of hydrogen for end users without increasing emissions from the mode of delivery. In-basin production with power T&D has potentially greater safety considerations than Angeles Link, as production would be in more urbanized areas compared to Angeles Link. While this alternative has been assumed to access hydrogen storage sized to meet long-duration requirements, storage is assumed to be solely above-ground, which comes with cost and feasibility challenges at the scale required.[193] This alternative also comes at a higher cost than a pipeline system based on the results of the Cost Effectiveness Study.

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[189] While direct air capture (DAC) is a form of carbon dioxide capture that could help address mobility emissions, this study was focused on point source carbon dioxide capture and its implications for end use emitters.

[190] Fraser Institute, Fraser Research Bulletin: https://www.fraserinstitute.org/sites/default/files/safety-in-the-transportation-of-oil-and-gas-pipelines-or-rail-rev2.pdf (August 2015), at p. 3.

[191] Fraser Institute, Fraser Research Bulletin: https://www.fraserinstitute.org/sites/default/files/safety-in-the-transportation-of-oil-and-gas-pipelines-or-rail-rev2.pdf (August 2015), at p. 3.

[192] More details on storage assumptions can be found in the Cost Effectiveness Study Appendix 7.5.1.

[193] Ibid.

Localized hub, due to its inherent limitation to scale to meet the expected hydrogen demand by end users in Central and Southern California, offers a partial solution to meet a fraction of the in-basin decarbonization needs, including the mobility sector. This alternative has low alignment with the air quality objective due to its limited scalability. Localized hub has potentially greater safety considerations than Angeles Link, as hydrogen production would occur in more urbanized areas compared to Angeles Link. This sub-scale nature also impacts the localized hub's ability to meet the system's reliability and resiliency needs and support the scale of reduction in natural gas usage.

Electrification will be one of the most important decarbonization pathways, in addition to hydrogen and CCS, and can provide both decarbonization and air quality benefits. However, it offers limited potential across hard-to-electrify sectors. This non-hydrogen alternative could also result in safety concerns if the energy system is less reliable and resilient (e.g., safety issues during extended outages). As discussed in the system electrification appendix, it is challenging for renewables and battery storage alone to provide the clean firm generation essential to support energy system reliability. Finally, high electricity tariffs in California impact the cost effectiveness of electrification across multiple sectors.[194]

CCS offers a potential pathway to support decarbonization of the cement industry in California (SB 596).[195] CCS has some alignment with the air quality objective given the potential for concurrent air emission reductions along with greenhouse gas emission reductions. CCS could introduce infrastructure development and operational challenges associated with the integration of both gas and CO_2 transportation and storage networks. The adoption of CCS solutions will most likely be driven by region-specific considerations (such as proximity of multiple point sources at scale and accessibility of sequestration sites) as well as federal, state, and local decarbonization policies.

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[194] PG&E Industrial Tariffs – Industrial Service (B-20).

[195] https://ww2.arb.ca.gov/our-work/programs/net-zero-emissions-strategy-cement-sector

5. Key Findings

This section summarizes the overall findings of the study across all criteria analyzed for Hydrogen Delivery Alternatives and Non-Hydrogen Alternatives.

5.1. Hydrogen Delivery Alternatives

The evaluation of Angeles Link and Hydrogen Delivery Alternatives found that Angeles Link is the best suited option to meet the evaluation criteria for the delivery of clean renewable hydrogen at scale across Central and Southern California, including the L.A. Basin. A key advantage of Angeles Link is that it supports the delivery of clean hydrogen at the scale required to serve the heavy-duty transportation, clean dispatchable power generation, and hard-to-electrify industrial sectors in support of California’s decarbonization objectives.Table 15 compares alternatives based on the 4-point scale

Table 9 developed across all identified criteria.

Table 15: Hydrogen Delivery Alternatives Comparison

Project and Alternatives	State Policy	Range	Reliability & Resiliency	Ease of Imp.	Scalability	Cost Eff. ($/KgH$_2$)	Key Findings
Angeles Link Pipeline System	🟦	🟦	🟦	⬜	🟦	🟦	Appropriate for distance/scale. Potential to continually access storage, increasing delivered hydrogen reliability/resiliency
Liquid Hydrogen Shipping	⬜	▨	⬜	⬜	⬜	▨	Efficient long-distance transportation of H_2 requires specialized handling and above-ground storage facilities

Project and Alternatives	**State Policy**	**Range**	**Reliability & Resiliency**	**Ease of Imp.**	**Scalability**	**Cost Eff. ($/KgH$_2$)**	**Key Findings**
In-Basin Production w/ Power T&D	🟦	▨	▨	⬜	🟥	▨	In-basin hydrogen production incurs additional electric T&D costs, and is also limited by hard to resolve transmission constraints. Scalability limited by above-ground storage need
Methanol Shipping	⬜	🟦	⬜	⬜	⬜	▨	Requires additional processing steps, specialized handling and storage facilities. Suitable for relatively long-distances
Gaseous Trucking	▨	⬜	⬜	🟦	🟥	⬜	Quickly deployable. Scalability of on-road transportation is limited
Liquid Trucking	▨	⬜	▨	▨	⬜	⬜	Quickly deployable. Scalability of on-road transportation is limited. Higher costs due to storage and loading costs
Localized Hub	🟦	🟥	▨	⬜	🟥	⬜	Production costs alone for the localized hub exceed the cost of other alternatives; this option cannot be scaled to meet projected demand

Project and Alternatives	State Policy	Range	Reliability & Resiliency	Ease of Imp.	Scalability	Cost Eff. ($/KgH$_2$)	Key Findings
Ammonia Shipping	⬜	🟦	⬜	🟥	🟥	Screened Out	
Intermodal Transport (Liq. Truck+ Train)	🟥	▦	🟥	⬜	🟥		

🟦 **High** ▦ **Good** ⬜ **Moderate** 🟥 **Low**

The **Angeles Link Pipeline System** provides the best scalability to serve the 1.5 Mtpa of clean renewable hydrogen throughput as defined in the Demand Study. It is also the most reliable and resilient alternative due to its potential to integrate storage access via multiple routes.[196] The Cost Effectiveness Study also found Angeles Link to be the most cost-effective hydrogen delivery solution for the distance/scale evaluated. Other delivery alternatives like trucking, shipping, and in-basin production with power T&D are less scalable, reliable, resilient, and cost effective than Angeles Link. These alternatives face a higher risk of supply disruption, suboptimal economics, and higher-cost storage access.

The shipping solutions are efficient for the long-distance transportation of hydrogen. These delivery alternatives may also become relevant for potential hydrogen exports as an option to manage costs for local end users by sharing the infrastructure costs as domestic demand ramps up. However, shipping is not the most suitable option for transporting intrastate hydrogen production throughout Central and Southern California, as envisioned for Angeles Link.

In-basin production with power T&D is also an efficient long-distance land transportation alternative. However, for the volumes analyzed, the system would need multiple parallel transmission lines, which would impact its delivery costs and impact the feasibility of

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[196] More details on storage assumptions can be found in the Cost Effectiveness Study Appendix 7.5.1.

implementation. As a result, this delivery alternative ranks comparatively below a pipeline like Angeles Link to meet the 1.5 Mtpa demand as defined in Scenario 7.[197]

Gaseous and liquid hydrogen trucking solutions provide the most favorable ease of implementation but lack the cost and scalability of a pipeline solution for the volumes and distances envisioned. However, trucking solutions may be a bridge option to Angeles Link for hydrogen distribution as demand reaches critical mass for transmission and distribution pipelines.

Finally, the feasibility of a **localized hub** option is constrained by scale-driven capacity limitations to build dedicated renewable electricity resources within L.A. Basin. As a result of land availability constraints in the L.A. Basin area, a localized hub can only provide 9.3% of the 1.5 Mtpa hydrogen throughput expected in 2045. This alternative also faces significantly higher development costs, which results in a higher LCOH in-basin.[198]

The **ammonia shipping** and **intermodal** (liquid hydrogen trucking and liquid rail) options were excluded from further analysis because these options were incompatible with the evaluation criteria.

5.2. Non-Hydrogen Alternatives

This study's findings indicate that clean renewable hydrogen delivered via Angeles Link is well suited to serve hard-to-electrify industries, including electric generation, heavy-duty transportation, and certain industrial sectors. These findings are aligned with the Demand Study, which projected meaningful hydrogen adoption rates in these and other sectors, indicating total hydrogen demand in the region of 1.9 to 5.9 million tons per year by 2045, 0.5-1.5 Mtpa of which is proposed to be served by Angeles Link.

Table 16 below summarizes the use case-level scores and key findings for Angeles Link, electrification, and CCS based on the 4-point scale Table 10 across all of the identified criteria and use cases. Taken together, these scores provide an indication of the strengths and weaknesses of each alternative and their ability to serve the use cases targeted by Angeles Link. Following the table, cross-sector findings are discussed for electrification and CCS as overall decarbonization pathways relative to Angeles Link.

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[197] More details on the new transmission infrastructure requirements and costs can be found in the Cost Effectiveness Study Appendix 7.3.1.2.4.

[198] As seen in the Cost Effectiveness Study.

Table 16: Non-Hydrogen Alternatives Comparison

Use Case[199]	Project & Alternatives	State Policy	Reliability & Resiliency	Maturity	Scalability	End-User Req.	Cost Eff.	Key Findings
Mobility ○ *1.0 Mtpa*	**AL**	🟦	🟦	▨	⬜	▨	▨	FCEVs utilizing hydrogen are better suited to serve the operational requirements of long-haul, high payload, high duty-cycle vehicles than BEVs.
	Elec.	🟦	▨	▨	⬜	⬜	⬜	
Power ○ *1.7 Mtpa*	**AL**	🟦	🟦	⬜	⬜	▨	▨	While battery storage is mature and modular, it is cost-prohibitive to build at the scale required for long-duration system reliability needs without advances in other LDES technologies.
	Elec.	🟦	▨	▨	▨	⬜	🟥	

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[199] Circles reflect 2045 projected hydrogen demand (in Mtpa) in the Demand Study "Moderate Case", with the exception of refineries, for which demand was only projected in the "Ambitious Case". See Demand Study for additional information.

Use Case[199]	Project & Alternatives	State Policy	Reliability & Resiliency	Maturity	Scalability	End-User Req.	Cost Eff.	Key Findings
	AL	■	■	□	□	▨	▨	Hydrogen and CCS are well-positioned in the power sector. Adoption may be determined on an asset specific level depending on proximity to potential transportation and storage infrastructure.
	CCS	▨	▨	□	□	□	■	
Cogeneration ○ *0.4 Mtpa*	**AL**	■	■	□	□	▨	▨	Cogeneration units are well suited for both hydrogen and CCS. Adoption may be determined on an asset specific level depending on proximity to potential transportation

Use Case[199]	Project & Alternatives	State Policy	Reliability & Resiliency	Maturity	Scalability	End-User Req.	Cost Eff.	Key Findings
	CCS	▨	▨	□	▨	▨	■	and storage infrastructure. Those units that are co-located with refineries may be best suited for CCS; others may be better suited for hydrogen due to cost of supporting infrastructure.
Food & Beverage ○ *0.03 Mtpa*	**AL**	▨	■	□	□	□	▨	Both Angeles Link and electrification are good solutions for certain applications. Specifically, electrification is a more mature, scalable solution

Use Case[199]	Project & Alternatives	State Policy	Reliability & Resiliency	Maturity	Scalability	End-User Req.	Cost Eff.	Key Findings
	Elec.	🟦	▦	🟦	▦	⬜	🟥	for low-to-medium heat applications. Generally, hydrogen delivered via Angeles Link may be more cost-effective based on current industrial electricity tariffs.
Cement ◦ *0.02 Mtpa*	**AL**	🟦	🟦	⬜	⬜	⬜	▦	CCS has the potential to be more cost-effective; however, this assumes access to CO_2 transport and sequestration infrastructure. CCUS also has the potential to address cement emissions beyond the kiln, supporting SB596 targets.
	CCS	🟦	▦	⬜	▦	▦	🟦	
	Elec.	🟦	▦	⬜	⬜	⬜	🟥	

Use Case[199]	**Project & Alternatives**	**State Policy**	**Reliability & Resiliency**	**Maturity**	**Scalability**	**End-User Req.**	**Cost Eff.**	**Key Findings**
Refineries ○ *0.7 Mtpa*	**AL**	▨	🟦	⬜	⬜	⬜	▨	CCS may be a decarbonization tool for refineries due to current cost differences between clean renewable hydrogen and unabated hydrogen and existing contracts with unabated hydrogen suppliers. However, Angeles Link has the potential to play a role where site constraints or lack of existing near site unabated hydrogen supply or CO_2 transport or storage infrastructure create opportunity
	CCS	▨	▨	⬜	▨	▨	🟦	

🟦 **High** ▨ **Good** ⬜ **Moderate** 🟥 **Low**

Angeles Link can play a key role supporting California's decarbonization objectives as identified in the CARB's 2022 Scoping Plan. Angeles Link is intended to support the CARB's Scoping Plan and California's decarbonization goals through the delivery of clean renewable hydrogen to serve customers in hard-to-electrify sectors. Angeles Link performed well with respect to the criteria defined for the evaluation of Non-Hydrogen Alternatives and is well positioned to serve hard-to-electrify industrial consumers, dispatchable electric generation, and heavy-duty transportation in Central and Southern California.

Electrification is and will continue to be a major driver of the energy transition in California; however, a 100% clean, reliable energy system is not likely to be solely served by renewables and battery storage and meet all expected energy demand.[200,201] CARB and several other industry sources model the need for clean firm dispatchable power resources in addition to a renewables and battery portfolio in order to support system reliability and meet the State's policy targets.[202] In the mobility sector, Angeles Link is well-suited to serve the operational requirements of heavy-duty, long-range trucks and buses. In the power sector, renewables and battery energy storage can be paired with clean firm generation and LDES, which is facilitated by Angeles Link. Finally, in several industrial subsectors, high electricity tariffs in California make the cost of hydrogen supplied by Angeles Link competitive with electrification, especially for higher heat applications like cement. While this analysis was required by the CPUC to compare electrification as an "alternative" to Angeles Link, the CARB Scoping Plan supports the finding that a portfolio of pathways, including electrification and clean renewable hydrogen, will be needed to drive the State's decarbonization goals.

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[200] The CEC's 2023 Integrated Energy Policy Report (IEPR) also identifies clean renewable hydrogen's potential to support electric generation, transportation electrification, and industrial decarbonization. (CEC, 2023 Integrated Energy Policy Report, Chapter 2: Potential Growth of Clean and Renewable Hydrogen, available at: https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report/2023-integrated-energy-policy-report. The IEPR reports: "California is electrifying much of the transportation and building sectors while rapidly scaling up deployment of low-carbon, renewable generation like solar and wind that are increasingly paired with lithium-ion battery storage. Yet these resources alone may not be sufficient to reach economy-wide decarbonization."

[201] Governor Gavin Newsom, Building the Electricity Grid of the Future: California's Clean Energy Transition (May 2023), available at: https://www.gov.ca.gov/wp-content/uploads/2023/05/CAEnergyTransitionPlan.pdf ("[C]lean sources of electricity like solar and wind energy are more variable and more intermittent. We will not be able to build a reliable, clean electric grid using solar and wind energy alone. California needs more diverse clean energy resources – including batteries, clean hydrogen, and long duration storage - and a wide range of technologies and resources to meet the unprecedented growth in demand for electricity at all hours of the day and different times of year.").

[202] Described in greater detail in Appendix 7.3.3.

CCS provides a potential pathway to achieve the State's carbon neutrality targets by 2045, particularly for certain industrial sectors like refineries and cement. Refinery hydrogen is one of the most viable use cases for CCS solutions due to the ability for CCS to be integrated with existing hydrogen supply agreements. Additionally, the scale and location of refinery hydrogen emissions could support the integration of smaller nearby CO_2 point sources with CO_2 transport and sequestration infrastructure. Cement is also a viable use case for CCS due to the ability of CCS solutions to support SB 596 targets. However, CCS may face challenges in terms of maturity and scalability in power and other industrial sectors. The adoption of CCS for capturing CO_2 is highly sector and location specific, and will require the consideration of site, sector, and regional factors, that may require further evaluation beyond the scope of this study. For example, access to CO_2 transport and sequestration infrastructure near point sources is crucial to the development of capture projects, particularly for point sources that do not have the scale to support integrated infrastructure development on their own. Additional considerations include site-level decarbonization strategies, geospatial constraints, or remaining facility life. Regional dynamics such as natural gas prices, or new federal or state level carbon reduction mechanisms may also impact the commercial viability of CCS implementation.

6. Stakeholder Feedback

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

Table 17: Key Milestone Dates

Milestone	Date Provided to PAG/CBOSG	Comment Due Date	Responses to Comments in Quarterly Report
1. Draft Scope of Work	July 6, 2023	July 31, 2023	Q3 2023
2. Draft Technical Approach	September 7, 2023	November 2, 2023	Q3 2023/Q4 2023
3. Preliminary Findings and Data	May 21, 2024	June 4, 2024	Q2 2024
4. Draft Report	July 26, 2024	September 6, 2024	Q3 2024

Feedback provided at the PAG/CBOSG meetings is memorialized in the transcripts of the meeting. Written feedback received is included in the quarterly reports, along with responses. Meeting transcripts are also included in the quarterly reports. The quarterly reports are submitted to the CPUC and are published on SoCalGas's website.[203]

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

Key feedback that was incorporated through the development of the Alternatives Study is summarized in the table below.

Table 18: Summary of Incorporation of Stakeholder Feedback

Stakeholder Feedback

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

Thematic Comments from PAG/CBOSG Members	Incorporation of and Response to Feedback
Electrification Stakeholders requested that the Alternatives Study include evaluation of electrification and a localized hub as alternatives.	Consistent with this stakeholder feedback, electrification and a localized hub were included as alternatives in the Alternatives Study. In the six-step evaluation process described in this study (Section 4), both electrification and the localized hub were identified as alternatives that should be evaluated further in the separate Cost Effectiveness Study and Environmental Analysis. Both alternatives were evaluated in those separate studies and through the full six-step process in this Alternatives Study. Key findings from this study related to the localized hub can be found in Section 5.1 (Hydrogen Delivery Alternatives) and key findings related to electrification can be found in Section 5.2 (Non-Hydrogen Delivery Alternatives).
Criteria Clarifications Stakeholders commented that the criteria for selecting and assessing alternatives are not clearly defined.	In response to this stakeholder feedback, as the draft report was being prepared, the Alternatives Study has expanded the discussion around the selection and assessment criteria in this report in Section 4 (Framework for Evaluation of Project Alternatives).
Scalability Stakeholders commented that trucking is more scalable than pipelines.	The design for the Angeles Link pipeline system is preliminary at this feasibility stage in its development. Angeles Link is intended to be scalable and serve both lower, near-term demand in the 2030's and higher, long-term demand post 2045. In terms of its scalability, the preliminary design is based on the 2045 projected throughput of 1.5 MMTPY, with approximately 0.5-0.75 MMTPY being transported from regional third-party production locations. Through this preliminary design, the Angeles Link system would be capable of meeting the near-term anticipated 0.5 MMTPY throughput by operating compressor stations and the pipeline system at a lower capacity. (See the

	separate Pipeline Sizing & Design Criteria Study for additional information on Angeles Link's preliminary design). As noted in (Section 1.3 Key Findings) the Cost Effectiveness Study, pipelines are the most scalable because they are the lowest cost alternative for the end users which will drive adoption at scale and achieve the scale needed to serve projected demand at the lowest level of logistical complexity. Trucking may be used to for certain last mile delivery solutions (requiring shorter distances and smaller transport volumes, however, pipelines allow for higher throughput volumes over longer distances offering an economic advantage, which brings down costs and adds to the likelihood for additional adoption.

7. Appendix

7.1. Alternatives Descriptions

7.1.1. Localized Hub Definition[204]

A dedicated clean renewable hydrogen pipeline system located within the L.A. Basin with production and end use in close proximity that could support connections between the state's decarbonization projects within the ARCHES portfolio. This Localized Hub connects clean renewable hydrogen producers to multiple end users in the hard-to-electrify sectors via open access, common carrier pipeline infrastructure. The Localized Hub within the L.A. Basin is fed only by in-basin renewable generation and hydrogen production and/or production in close proximity to multiple in-basin end users and storage. The considerations for the Localized Hub are split into two areas: A) Geography and B) Value Chain Evaluation.

A. **Geography** The L.A. Basin is a geographically defined area in Southern California; a coastal plain bounded by the Pacific Ocean to the west and surrounded by mountains and hills, including the Santa Monica Mountains to the north, the San Gabriel mountains to the northeast, and the Santa Ana Mountains to the southeast. The L.A. Basin encompasses the central part of Los Angeles County, including portions of the San Fernando Valley, and extends into parts of Orange, Riverside and San Bernardino counties.

B. **Value Chain Evaluation** The Localized Hub is characterized and analyzed to account for the hydrogen value chain to support local production, transport, storage, and delivery systems and the associate feasibility considerations.

    a. **Production**: The Localized Hub considers hydrogen production within and in close proximity to multiple in-basin end users and storage and will assess production prospects within a 40-mile radius expanding outward from the area of concentrated demand near the Ports of Los Angeles and Long Beach. This approach is designed to encompass the L.A. Basin and those outskirt areas close to multiple in-basin end users and storage. See Figure 28 for a map depicting the L.A. Basin and close proximity boundary.
    Hydrogen production will include two primary feedstocks: solar energy and biomass. Regarding solar energy, the assessment will include the feasibility of constructing independent solar power sites. Biomass will focus on the utilization of woody biomass and the conversion of municipal waste.

    b. **Target Demand Sectors**: The Hub aims to address the dedicated demand from multiple sectors within the L.A. Basin contributing to a reduction in GHG

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[204] D.22-12-055, p. 75 ("SoCalGas shall study a localized hydrogen hub solution, under the specifications required to be eligible for federal funding provided through the Infrastructure Investment and Jobs Act, as part of Phase One.").

emissions and will seek to meet the diverse capacity and unique consumption patterns of the different end use applications. These sectors include the following:

    i. Power Generation: Supporting the transition to cleaner energy solutions for public and private power generation facilities.
    ii. Industrial & Commercial Manufacturing: Catering to the energy and feedstock demands of factories, processing plants, and other industrial and manufacturing end users.
    iii. Mobility: Especially focusing on heavy-duty trucking operations emerging from ports, which require substantial low-carbon and zero-carbon energy solutions. The Localized Hub's close proximity to ports provides efficient fueling solutions for these heavy-duty transport systems.

c. **Pipeline Transmission**: Within the Hub, hydrogen would be transported through a series of high-pressure trunk transmission pipelines to connect production and offtake and facilitate potential connections to third-party storage facilities. The pipeline system would be designed for safe, efficient, and rapid transport of hydrogen from production sources located within or close to multiple delivery points within the L.A. Basin. For purposes of the feasibility stage, the Hub is assumed to include approximately 80 miles of transmission pipeline within the 40-mile radius for production and storage assessed for the Hub. This mileage corresponds to the miles of transmission pipeline that would be located within the L.A. Basin for the Angeles Link preferred routes, as this provides a baseline for potential transmission needs for the Hub to connect well-known demand centers near the Ports of Los Angeles and Long Beach. The total mileage of pipelines for the Hub may be greater, as land constraints may result in more distributed production facilities and additional pipeline mileage needed for transmission and distribution to meet the production, demand, and storage needs.

d. **Storage**: In the intermittence of synchronized production and demand, reserve hydrogen would be stored above-ground. Storage solutions within a 40-mile radius expanding from the area of concentrated demand near the Ports of Los Angeles and Long Beach are considered with regard to their high-level suitability and technology readiness level.

Figure 28: Localized Hub Area Map

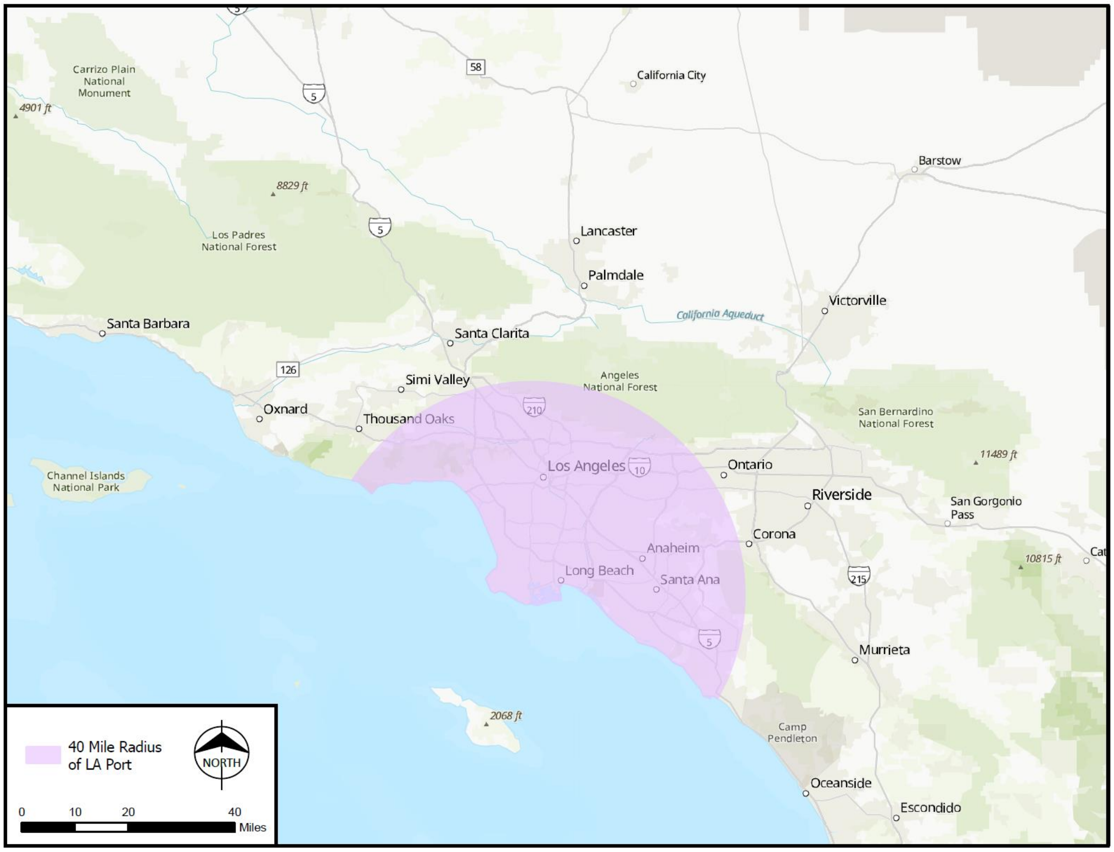
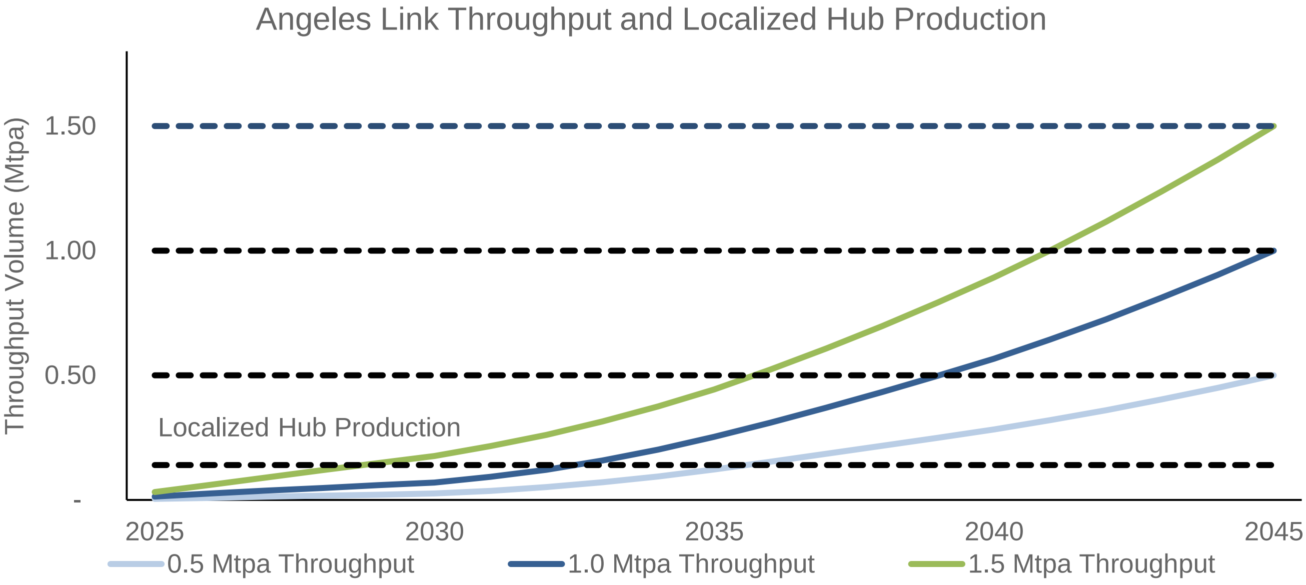


Figure 29: Angeles Link Throughput and Localized Hub Production



7.2. Results Tables

7.2.1. Levelized Cost of Delivered Hydrogen (see Cost Effectiveness Study)

Table 19: Levelized Cost of Delivered Hydrogen by Alternative and Value Chain Segment

Cost Component ($/KgH₂)	Angeles Link Pipeline System	Liquid Hydrogen Shipping	In-Basin Production w/Power T&D	Methanol Shipping	Gaseous Trucking	Localized Hub	Liquid Trucking
Delivery[205]	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08
Regasification or Hydrogen Reconversion[206]	N/A	$0.18	N/A	$1.56	N/A	N/A	$0.18
Storage[207]	$0.28	$1.65	$2.31	$2.31	$0.28	$2.31	$0.29
Transmission	$0.67	$0.29	$1.76	$0.04	$6.53	N/A	$7.41
Liquefaction or Methanol Production	N/A	$1.42	N/A	$0.64	N/A	N/A	Inc. in Transmission
Production[208]	$4.47	$4.59	$4.58	$4.57	$4.51	$9.64	$4.66
Total LCOH	**$5.50**	**$8.21**	**$8.73**	**$9.20**	**$11.40**	**$12.03**	**$12.62**

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[205] Assumes a delivery line of approximately 80-miles.

[206] Regasification or hydrogen reconversion is part of the transportation process for liquid hydrogen shipping, methanol shipping, and liquid hydrogen trucking. These processes are not used for the other Hydrogen Delivery Alternatives.

[207] Underground storage was assumed for Angeles Link and the trucking options. All other Hydrogen Delivery Alternatives were assumed to have above-ground storage due to a lack of nearby underground storage options.

[208] Assumes production tax credits (PTC) in place

Notes: Reflects costs from Scenario 7 (corresponding to Design Study, Configuration A, single run scenario) for 1.5 Mtpa. Production is assumed to begin in 2030 to take advantage of tax incentives, including Production Tax Credits (PTC) for hydrogen (45V)[209] and power (45Y)[210], which provide \$3 per kgH_2 and \$0.028 per kWh for ten years. Storage assumptions were based on proximity to production sites, and the geographic footprint under consideration for storage in the Production Study.[211] For Angeles Link and the trucking alternatives (gaseous and liquid), identified routes allowed for access to underground storage sites, therefore, underground storage costs were assumed. Delivery alternatives with production sites that did not overlap with the identified geological storage sites, were assumed to rely on above ground storage. These alternatives include shipping, in-basin production with T&D, and localized hub. The shipping solutions include the costs of specialized handling required to deliver methanol and liquid hydrogen. The cost for liquefaction in the liquid hydrogen trucking alternative is included as a part of transmission costs.

LCOH Calculation

To compare \$/kg cost across the different Delivery Alternatives, all capital expenditures (CapEx) and operating expenditures (OpEx) over the lifetime of the system should be considered. The pipeline LCOH considers the lifetime costs from production, transmission, storage, and distribution. For Delivery Alternatives, the costs may also include loading, trucking, shipping, liquefaction, compression, power transmission, and other specialized handling like methanol conversion and reconversion (reforming).

LCOH Formula

$$LCOH_{\substack{Post-Tax, \\ Levered}} = \frac{\sum_{i=1}^{T} \frac{(Opex^i + Capex_L^i + Interest^i + Principal^i)}{(1+r)^i}}{\sum_{i=1}^{T} v^i \left(\frac{1+\inf}{1+r}\right)^i}$$ [212]

Parameter	**Description**
OpEx	Operating Expenses
CapEx	Capital Expenses
DTS	Depreciation Tax Shield

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[209] 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

[210] https://www.federalregister.gov/documents/2024/06/03/2024-11719/section-45y-clean-electricity-production-credit-and-section-48e-clean-electricity-investment-credit

[211] For additional details on the rationale for Storage assumptions for each alternative please refer to Cost Effectiveness Study Appendix 7.5.1. The storage solution selected reflects the best available for a like for like comparison.

[212] Wood Mackenzie Lens Hydrogen.

L	Levered
T	Total years of Project Lifetime
Inf	Rate of Inflation (%)
r	Discount Rate (%)
v	Volume of Hydrogen / Ammonia
$Interest$	Interest Loan Payments
$Principal$	Principal Loan Payment
i	Time, assumes each year of the operational or economic life of the relevant hydrogen infrastructure
$\sum$	Mathematical shorthand notation to indicate the sum of a number of similar terms, in this case the sum of all years of the operational or economic life of the relevant hydrogen infrastructure

7.3. Key Considerations

7.3.1. Ammonia Considerations

Ammonia shipping, with ammonia production in Central and Northern California with access to ports, was evaluated as a potential alternative for hydrogen delivery. To compare ammonia shipping to the other alternatives on a like for like basis, the options and alternatives evaluation assumed hydrogen and ammonia production for this alternative is powered from non-grid interconnected solar generation facilities. As discussed in Section 4.3.1.2, there are many reasons why non-grid interconnected solar power generation is incompatible with the technical requirements of ammonia production. The incompatibility is largely driven by the requirement of the Haber-Bosch process to receive a steady 24/7 power and hydrogen supply.

However, there are several supply chain configurations that may or may not be applicable or available in California that are in development across projects globally to support a more consistent supply of low-carbon hydrogen and attempt to bypass the inherent technical constraints present for a project aiming to produce 100% renewable ammonia via solar power. These configurations often come with significant added costs and are typically focused on: (1) increasing the availability of renewable power generation, and (2) increasing the availability of renewable hydrogen.

Renewable Power Availability

- Combining wind with solar (in certain advantaged regions with high-quality and complimentary wind and solar availability)
- Combining batteries with solar
- Oversizing solar and/or wind power generation
- Procuring renewable power purchase agreements (PPAs) (although the availability of renewable PPAs at the scale required for operating a world-scale ammonia production facility may be costly and challenging)

Renewable Hydrogen Availability

- Oversizing electrolyzer capacity (would also require commensurate renewable power generation to be developed)
- Developing high-capacity hydrogen storage solutions (requires access to geological hydrogen storage with a high level of deliverability at a high quality)

7.3.2. CCS Considerations

D.22-12-055, OP 5(e), requires SoCalGas to demonstrate how the activities of Phase 1 "consider and evaluate Project alternatives, including … other decarbonization options..."[213] While electrification is the primary non-hydrogen decarbonization option mentioned in the Decision, CCS was also determined to be a non-hydrogen decarbonization option for evaluation in this study.[214] CCS could play an important role in supporting California's decarbonization targets in several sectors, as the CARB Scoping Plan accounts for CCS to be implemented in the majority of petroleum refining operations by 2030 and 40% of cement operations by 2035.[215]

For the purpose of this study, the assessment of CCS was primarily conducted on a use case level in comparison with hydrogen (e.g., cement kilns run on clean renewable hydrogen vs. natural gas with CCS), with certain system-level assumptions made where relevant (e.g., scalability considerations related to the need to aggregate point source emissions from large facilities or large clusters of smaller facilities). For CCS to be successfully implemented at scale and considered as an alternative to Angeles Link, there are multiple important economic and non-economic considerations at the individual site, the sector, and the regional level (see a non-comprehensive list of examples in Table 20 below). While many of these considerations were incorporated into the analysis in this study, it was outside the scope of this study to conduct a comprehensive analysis of the prospects for CCS in California.

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[213] As described in D.22-12-055, p. 75.

[214] As set out in the glossary of terms in Section 0.2, for purposes of this study, CCS refers to the capture of CO_2 from point sources (not direct air capture), with sequestration in geologic formations (such as depleted oil and gas reservoirs and saline formations).

[215] California Air Resources Board. Retrieved from https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf, p. 74, 77.

Table 20: CCS Considerations

Level of Value Chain	Considerations
Site level	• Plants require physical space within the plant boundary to add capture equipment, which is often a challenge for CCS retrofits • The ability to support the capital investment and operating costs of CCS depends on the utilization and remaining operational life of the site • In the absence of access to CO_2 infrastructure, the scale of CO_2 captured at an individual site may not support the costs of infrastructure development for transport and sequestration • Additional energy is required to operate capture equipment, increasing the overall energy intensity of operations
Sector level	• Certain sectors have specific factors that make CCS an attractive pathway. The cement sector has a specific state policy target for decarbonization (SB 596) but few other decarbonization pathways that can address the full scope of a facility’s emissions to the degree CCS can • Certain sectors face challenges for CCS implementation; for example, CCS is not technically viable as a solution to address tailpipe emissions in the mobility sector
Regional level	• The ability to access to open access regional CO_2 pipeline and storage infrastructure is required in many cases to make CCS viable • The aggregation of either large point sources or large clusters of smaller point sources is required in many cases to make CCS viable • The cost considerations for CCS on a use case level are highly sensitive to the cost of fuel, should a carbon price or tax mechanism (or other market factors) increase the regional price of natural gas, the commercial viability of CCS may be greatly reduced

Ultimately, CCS provides a potential pathway among a portfolio of solutions, including clean renewable hydrogen, to help contribute to the state’s carbon neutrality targets by 2045. If CO_2 transport and sequestration infrastructure is developed at scale, and in the absence of new carbon taxes or other policy mechanisms to penalize residual emissions, CCS could be cost-effective relative to alternatives like clean renewable hydrogen for certain end users. However, CCS is only technically and commercially feasible under certain site-level and regional considerations, including the availability of space for additional equipment within the plant boundary, access to transport and sequestration infrastructure, and regional concentration of point source emissions at scale. The CARB Scoping Plan forecasts a role for CCS in specific sectors (including refineries and cement), but clean renewable hydrogen may be a better pathway for other sectors (including mobility and power generation), and for specific refineries and cement facilities where conditions are less favorable to CCS implementation.

7.3.3. System-Level Electrification Considerations

D.22-12-055, OP 5(e), requires SoCalGas to demonstrate how the activities of Phase 1 "consider and evaluate Project alternatives, including … other decarbonization options such as electrification."[216] For the purpose of this study, an electrification alternative refers to a combination of system level transformation and use case level technology changes, including the grid infrastructure required to support growing electric load.

To assess system-level electrification as an alternative to Angeles Link, the Alternatives Study first investigated whether electrification was a viable decarbonization alternative for the end-use sectors targeted by Angeles Link. Electrification is a decarbonization option if the electricity delivered is clean and reliable; however, the current carbon intensity[217] of California's average grid electricity is estimated to be 80.55 gCO_2e/MJ[218] and primarily driven by remaining fossil fuel-based generation mix. The CARB Scoping Plan commits to "adding four times the solar and wind capacity by 2045 and about 1,700 times the amount of current hydrogen supply", while noting that "electrification is not possible in all situations", and residual emissions will remain from difficult to decarbonize industries such as cement, internal combustion vehicles still on the road, and global warming chemicals used as refrigerants.[219] As the electric grid continues to integrate more renewables at scale and existing fossil fuel based generation

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[216] As described in D.22-12-055, p. 75.

[217] For smart charging or smart electrolysis in California, see California Air Resources Board, https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/comments/tier2/elec_update.pdf.

[218] Annual update to carbon intensity (CI) values for Lookup Table electricity pathways under the Low Carbon Fuel Standard (LCFS). See https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/comments/tier2/elec_update.pdf .

[219] California Air Resources Board. Retrieved from https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf, p.8.

retires, California needs clean firm dispatchable power to meet the increased electric load, ramping, and system reliability needs.[220,221,222]

A detailed assessment of system-level electrification would need to consider all aspects of the electric system value chain, with examples shown in Table 21 below:

Table 21: Examples of Analysis Required for a Full Assessment of System-level Electrification

Electrification Value Chain	Analysis Needed
Demand	• Electrification adoption analysis by sector and hourly load forecast.
Dispatchable Supply	• Resource assessment and incremental deployment forecast for wind, solar, and battery storage. • Power system dispatch modeling to provide hourly supply/demand balancing within system reliability requirements.[223]
Infrastructure	• Power flow modeling to determine ability of current and planned T&D investments to accommodate additional generation and load vs. the need for new T&D investment.

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[220] EDF, https://www.edf.org/sites/default/files/documents/SB100%20clean%20firm%20power%20report%20plus%20SI.pdf

[221] The CEC's 2023 Integrated Energy Policy Report (IEPR) identifies clean renewable hydrogen's potential to support electric generation, transportation electrification, and industrial decarbonization. (CEC, 2023 Integrated Energy Policy Report, Chapter 2: Potential Growth of Clean and Renewable Hydrogen, available at: https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report/2023-integrated-energy-policy-report.

[222] Governor Gavin Newsom, Building the Electricity Grid of the Future: California's Clean Energy Transition (May 2023), at 6, available at: https://www.gov.ca.gov/wp-content/uploads/2023/05/CAEnergyTransitionPlan.pdf ("[C]lean sources of electricity like solar and wind energy are more variable and more intermittent. We will not be able to build a reliable, clean electric grid using solar and wind energy alone. California needs more diverse clean energy resources – including batteries, clean hydrogen, and long duration storage - and a wide range of technologies and resources to meet the unprecedented growth in demand for electricity at all hours of the day and different times of year.").

[223] A detailed power modeling study would need to be conducted to determine the clean electricity portfolios capable of meeting demand while maintaining system reliability. This analysis is typically conducted using specialized software to simulate hourly demand and the specific power plants built each year and dispatched in each hour to minimize system costs while meeting reliability requirements. This level of analysis was not in the scope of this study.

	- Sizing, routing, and cost of incremental T&D infrastructure.

For the purpose of this study, the detailed analyses above were deemed out of scope, and assessment of electrification was primarily conducted on a use case level (e.g., FCEV vs. BEV for heavy-duty vehicles), with certain system-level considerations incorporated into the use case level assessments where relevant (e.g., reliability and resiliency and scalability considerations). A broader discussion of the demand, dispatchable supply, and infrastructure considerations of system-level electrification is included below based on a high-level review of existing research, third-party studies, and California's clean energy and environmental policies.

Electricity Demand Considerations for System Electrification

This study evaluates electrification as an alternative to hydrogen by assuming that projected hydrogen demand in the mobility, power generation, and industrial sectors is served with electricity rather than hydrogen supplied by Angeles Link. Electrification of heavy-duty transport and high-temperature industrial heat applications would impose significant demand for clean electricity on the California power system, challenging its ability to meet reliability and resiliency requirements.

Electrification is widely recognized as a favorable decarbonization pathway for many sectors, but it is also known to be less technically feasible in sectors like long-haul, heavy-duty trucking, and high-heat industrial processes. Delivering clean renewable hydrogen via Angeles Link would offer a feasible technology transition based on existing business models, while electrification could create operational and business model challenges for fleet owners. This is supported by the CARB Scoping Plan, which projects hydrogen to serve 40% of medium- and heavy-duty transportation demand by 2045. Additionally, the relatively high electricity tariffs in California mean hydrogen are projected to be more cost-effective for industrial applications. See Sections 4.3.2.1.2 and 4.4.2.2.1 for additional findings related to the evaluation of electrification for specific end use segments.

Electricity Supply Considerations for System Electrification

Supply refers to the electricity generation and storage portfolio needed to support decarbonization of the power system, including the ability of that portfolio to match demand on an hourly basis, supporting system reliability. Other carbon-free alternatives like nuclear power generation, hydro power generation, geothermal power generation, and biomass power generation are not forecasted to play a large role in the California power system.[224] However, renewables and battery storage alone may not be able to provide the clean firm generation

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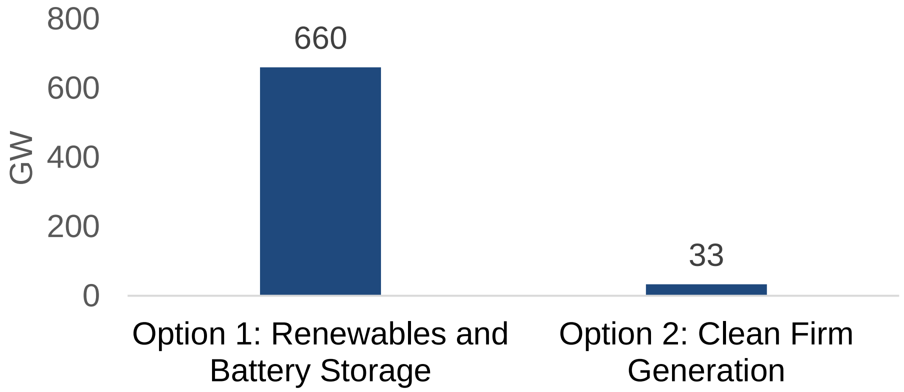
[224] California Air Resources Board. Retrieved from https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf

(available to be dispatched 24/7) and long-duration storage (to compensate for days or weeks of lower renewable output) needed to fully decarbonize the California power system and meet the state's clean energy targets. Additional information on the role of lithium-ion batteries and the need for LDES in California is provided in Appendix 7.3.4.

- **Relying solely on solar, wind, and battery storage in California would require a significant overbuild of California generation capacity.** Sufficient supply of carbon-free generating resources needs to be available to achieve California's decarbonization targets. A recent power modeling study[225] analyzed power system decarbonization pathways for California and determined that the pathway relying only on solar, wind, and battery storage (Option 1 in Figure 30 below) would require a significant overbuild of generation compared to the pathway that included renewables and clean firm generation (Option 2 in Figure 30 below). To meet California's decarbonization targets, the renewables and storage-only portfolio (Option 1) required 660 GW of generation and storage capacity in California, or about half of current U.S. installed renewable capacity, compared to only 33 GW of capacity using clean firm generation in California (Option 2), as seen in Figure 30 below.

Figure 30: New Power Generation Capacity Deployment Required to Meet SB 100 Target[226]



- **Clean firm resources can provide reliability for the California grid**. Clean firm generation plays a critical role in maintaining system reliability while supporting full decarbonization of power supply. Development of roughly 25-40 GW of firm

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[225] EDF, https://www.edf.org/sites/default/files/documents/SB100%20clean%20firm%20power%20report%20plus%20SI.pdf

[226] Ibid

dispatchable power capacity would significantly eliminate the large capacity needs of additional and solar and wind resources. [227]

Wind, solar, and battery storage will be deployed at scale in California, but there remains a need for clean firm generation and long-duration storage in the power system to support reliability. Alongside wide-scale deployment of renewables and battery storage, the power system needs clean firm generation and long-duration storage resources—both of which can be supported by Angeles Link as part of a clean, reliable hydrogen system. Advancing a portfolio of clean firm power generation technologies including hydrogen can play an important role in maintaining system reliability while supporting full decarbonization of the power supply. This is supported by the CARB Scoping Plan, which includes 9 GW of hydrogen turbine capacity by 2045,[228] and the approval of plans to convert the Scattergood Generating Station to run on green hydrogen by LADWP.[229]

Electric T&D Infrastructure Considerations for System Level Electrification

Infrastructure refers to the T&D equipment required to deliver electricity to end users. As of 2023, California had 25,000 miles of electric transmission lines in operation.[230] Adding the roughly 17 to 50 TWh of new electric demand that would have been served by Angeles Link and several hundred GWs of new supply would require significant new electric transmission infrastructure to reliably serve demand.

- **Current electric transmission investment plans are already ambitious without accounting for additional levels of electrification in sector use cases targeted by Angeles Link.** The latest transmission infrastructure plan released by the CAISO includes 45 transmission projects designed to support reliability of the grid, totaling an investment of $7.3 billion by 2033.[231] Reliability planning for incremental electrification would require additional resources and likely significant additional infrastructure given the scale of new generation and new load being discussed.
- **Transmission lines require more land to deliver the same amount of energy compared to hydrogen pipelines.** High-voltage transmission lines carry less energy than hydrogen pipelines. For example, a 500 kV electric transmission line transports approximately 25% of the energy compared to the proposed capacity of

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[227] Ibid.
[228] California Air Resources Board. Retrieved from https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf
[229] https://www.ladwp.com/community/construction-projects/west-la/scattergood-generating-station-units-1-and-2-green-hydrogen-ready-modernization-project
[230] California Public Utilities Commission. (n.d.). https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/infrastructure/electric-reliability/undergrounding-program-description
[231] California ISO. http://www.caiso.com/InitiativeDocuments/ISO-Board-Approved-2022-2023-Transmission-Plan.pdf

the Angeles Link pipeline.[232] To deliver the same amount of energy as Angeles Link into the L.A. Basin, additional circuits, towers, transmission lines, and associated land would be needed. While power system studies would be required to analyze the impact of additional electrification on existing and planned transmission infrastructure, the increased land needed due to lower energy carrying capacity presents scalability challenges for electric transmission lines.

The electricity system needs substantial investment in new T&D infrastructure to accommodate planned increases in electric generation and load growth. The additional infrastructure needed to support a higher level of electrification of the use cases targeted by Angeles Link would increase the burden on already ambitious power T&D investment plans. Angeles Link provides a cost-effective energy transportation method and mitigates the need for additional power infrastructure. Multiple studies based on a variety of high-voltage AC and DC electric transmission systems and hydrogen pipeline comparisons have found that transmission lines are more expensive per unit of energy delivered than hydrogen pipelines due to the lower energy-carrying capacity of transmission lines.[233,234] This conclusion is supported by the Cost Effectiveness Study's finding that the LCOH of Angeles Link[235] is lower than the LCOH of an alternative that would generate renewable electricity outside the basin, transport that electricity into the basin using electric transmission lines, and produce hydrogen in-basin.

7.3.4. Rationale for Selecting 12-Hour Lithium-ion Battery Storage as Electrification Alternative for Power Use Case

In the Non-Hydrogen Alternatives section, Angeles Link is assessed for the power sector based on hydrogen-fueled combustion turbines (hydrogen turbines), and electrification is evaluated based on a 12-hour lithium-ion battery energy storage facility. The 12-hour lithium-ion battery storage was selected as the most appropriate comparison to the hydrogen turbines to serve inter-day loads, and the required ramping needs to support reliability requirements lasting longer than a few hours.

With an increasing share of renewables displacing natural gas generation in California, clean firm generation and LDES resources are needed to balance the shortfall in renewables output due to extreme weather, demand fluctuations, and seasonal patterns in output. Studies assessing the reliability of California's grid have projected that solar and wind resources may

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[232] National Park Service. (n.d.). https://parkplanning.nps.gov/showFile.cfm?projectID=25147&MIMEType=application%252Fpdf&filename=poster_10trans101%20lores.pdf&sfid=76974

[233] https://www.oxfordenergy.org/publications/hydrogen-pipelines-vs-hvdc-lines-should-we-transfer-green-molecules-or-electrons/

[234] https://www.osti.gov/pages/biblio/1832081.

[235] Refer to Cost Effectiveness Study.

experience “resource drought” events.[236] These events, characterized by sustained low output, can last one to two days and occur up to 30 times throughout the year. LDES may be a good solution for these events. Longer duration battery technologies (12-hour discharge duration) offer partial grid support solutions to mitigate such resource-drought events. This is supported by a retrospective analysis of how LDES could have performed during the 2020 California heat wave, which showed that energy storage with 12-plus-hour duration would have effectively managed the lower renewable energy output.[237]

LDES technologies can be characterized by their ability to serve different duration use cases, including inter-day and multi-day durations. Inter-day LDES technologies comprise mechanical storage options, such as pumped hydro, compressed air, liquid air energy storage, and certain types of flow batteries, typically lasting between 10 and 36 hours. Multi-day LDES comprises a variety of thermal and electrochemical technologies and electrolytic fuels with durations ranging from 36 to 160 hours. Many LDES technologies are not yet technologically mature to be deployed at commercial scale and need further advancements to become commercially viable in the future. Furthermore, the discharge capabilities of LDES technologies suggest they are likely to play a different role when compared to shorter duration lithium-ion battery technologies. While lithium-ion is expected to remain a dominant energy storage technology for intra-day requirements and fast-response grid services, LDES technologies will serve the emerging inter-day and multi-day needs of the decarbonizing power system.

Of the handful of emerging LDES technologies, compressed air energy storage (CAES) and vanadium redox flow batteries (VRFB) are the most mature. CAES and VRFB are commercially available at pilot scale, particularly in China. Recently, Hydrostor announced a 500 MW CAES facility in California and has secured an offtake agreement from a community choice aggregator.[238] However, these technologies face certain limitations. They are

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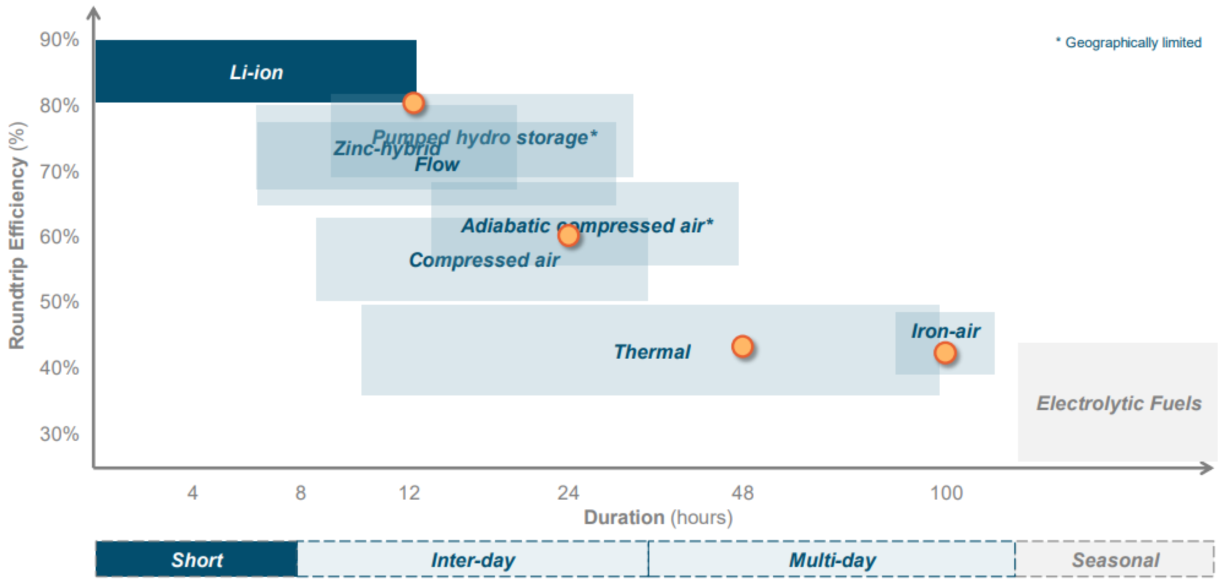
[236] Wind and Solar Resource Droughts in California. Rinaldi, Katherine Z., et al. s.l.: Environmental Science & Technology. https://pubs.acs.org/doi/10.1021/acs.est.0c07848

[237] California Energy Commission. Retrieved from https://www.energy.ca.gov/sites/default/files/2024-01/CEC-500-2024-003.pdf

[238] https://hydrostor.ca/first-offtake-deal-signed-for-500mw-4000mwh-advanced-compressed-air-energy-storage-project-in-california/. California Air Resources Board. (2022). Retrieved from 2022 Scoping Plan for Achieving Carbon Neutrality: https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf

California Energy Commission. (2023). Retrieved from Assessing the Value of Long-Duration Energy Storage in California: https://www.energy.ca.gov/sites/default/files/2024-01/CEC-500-2024-003.pdf geographically constrained and can be subject to price volatility for key raw materials (such as vanadium for VRFB), which restricts their deployment. Figure 31 below illustrates the relative capabilities of a variety of storage technologies.

Figure 31: Round-trip Efficiency of Storage Technologies Categorized by Duration[239]



Driscoll, W. (2023). Retrieved from 500 MW compressed air energy storage project in California secures offtaker: https://pv-magazine-usa.com/2023/01/13/500-mw-compressed-air-energy-storage-project-in-california-secures-offtaker/
Rinaldi, K. Z., Dowling, J. A., Ruggles, T. H., Caldeira, K., & Lewis, N. S. (n.d.). Wind and Solar Resource Droughts in California.
California Air Resources Board. (2022). Retrieved from 2022 Scoping Plan for Achieving Carbon Neutrality: https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf
California Energy Commission. (2023). Retrieved from Assessing the Value of Long-Duration Energy Storage in California: https://www.energy.ca.gov/sites/default/files/2024-01/CEC-500-2024-003.pdf
Driscoll, W. (2023). Retrieved from 500 MW compressed air energy storage project in California secures offtaker: https://pv-magazine-usa.com/2023/01/13/500-mw-compressed-air-energy-storage-project-in-california-secures-offtaker/
Rinaldi, K. Z., Dowling, J. A., Ruggles, T. H., Caldeira, K., & Lewis, N. S. (n.d.). Wind and Solar Resource Droughts in California.

[239] California Energy Commission. Retrieved from https://www.energy.ca.gov/sites/default/files/2024-01/CEC-500-2024-003.pdf

Lithium-ion has and will continue to play a critical role in system reliability for short and inter-day durations offering higher round trip efficiencies. However, as renewable energy penetration increases, other LDES technologies will play an important role beyond what traditional lithium-ion technology can provide. For purposes of Phase 1 feasibility analysis, a 12-hour lithium-ion battery[240] stack (made up of three 4-hour stacks) was used as an electrification end-use alternative for comparison.

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[240] This is in line with a recent study from the CEC, which also used 12-hour lithium-ion as a benchmark against emerging LDES technologies, California Energy Commission. Retrieved from https://www.energy.ca.gov/sites/default/files/2024-01/CEC-500-2024-003.pdf

7.4. References for Alternatives Assessments

7.4.1. Technology Readiness Levels for Hydrogen Delivery Alternatives and Non-Hydrogen Alternatives

Technology readiness level scores discussed throughout this study are adopted from IEA's Clean Tech Guide.

Table 22: IEA's Technology Readiness Levels [241]

TRL Score	Category	Description
1	**Concept**	**Initial idea:** Basic principles have been defined
2		**Application formulated:** Concept and application of solution have been formulated
3		**Concept needs validation:** Solution needs to be prototyped and applied
4	**Small Prototype**	**Early prototype:** Prototype proven in test conditions
5	**Large Prototype**	**Large prototype:** Components proven in conditions to be deployed
6		**Full prototype at scale:** Prototype proven in test conditions
7	**Demonstration**	**Pre-commercial demonstration:** Prototype working in expected conditions
8		**First-of-a-kind commercial:** Commercial demonstration, full-scale deployment in final conditions
9	**Market Uptake**	**Commercial operations:** Solution is commercially available, needs evolutionary improvement to stay competitive
10		**Integration needed at scale:** Solution is commercial and competitive but needs further integration efforts
11	**Mature**	**Proof of stability reached:** Predictable growth

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[241] https://www.iea.org/data-and-statistics/data-tools/etp-clean-energy-technology-guide

7.4.2. Select California State/Local Policies Evaluated

Table 23: Select California State/Local Policies Evaluated for Non-Hydrogen Alternatives

State Policy	Description	Applicable Use Cases
SB 100 [242]	100% renewable or zero-carbon electricity sales in California by 2045	Power and Cogeneration
Renewable Portfolio Standard [243]	California regulations require utilities to procure 60% of retail sales through RPS eligible resources by 2030	
LA100 [244]	L.A.'s goal of reliable, 100% renewable electricity by 2045	
Cap and Trade [245]	Establishes a declining limit on major GHG emissions sources throughout California; provides a statewide system of allowances for emissions	
SB 905 [246]	Creation of a carbon capture regulatory framework to adopt regulations for new technologies	Power, Cogeneration, Refineries, and Cement
Pipeline Moratorium [246]	State law banning flow of carbon dioxide through new pipelines until the finalization of safety regulations by the federal government	
Executive Order N-79-20 [247]	100% of in-state sales of new passenger cars and trucks should be zero-emission by 2035; 100% of medium- and heavy-duty vehicles should be zero-emission by 2045	Mobility
Advanced Clean Fleets and Advanced Clean Trucks [248]	State requirement for fleets and trucks to be zero-emission vehicles by 2036	

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[242] https://legiscan.com/CA/text/SB100/id/1819458

[243] California Public Utilities Commission, https://www.cpuc.ca.gov/rps/

[244] LA100 Equity Strategies, https://www.ladwp.com/strategic-initiatives/clean-energy-future/la100-equity-strategies/100-renewable-energy-study

[245] California Air Resources Board, https://ww2.arb.ca.gov/our-work/programs/cap-and-trade-program

[246] https://legiscan.com/CA/text/SB905/id/2606955

[247] https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf

[248] California Air Resources Board, https://ww2.arb.ca.gov/our-work/programs/advanced-clean-fleets

State Policy	Description	Applicable Use Cases
Innovative Clean Transit [249]	Regulation for all public transit agencies to gradually transition to 100% zero-emission bus fleet	
Low Carbon Fuel Standards [250]	Regulation designed to incentivize and encourage the use of low-carbon transportation fuels in California	Mobility and Refineries
Assembly Bill 32 [251]	Mandates that California reduce its GHG emissions to 1990 levels by 2020	Power, Mobility, Cogeneration, Refineries, Food & Beverage, and Cement
PR-1153.1[252]	L.A. County Air Quality Management District methane and NOx emissions regulation for the Food & Beverage sectors	Food & Beverage
Senate Bill 596 [253]	Requires cement producers in California to reduce their GHG emissions in the production phase by 40% below 1990 levels by 2030, with the goal of achieving zero emissions by 2045	Cement

7.4.3. Environmental Analysis of Alternatives

Alternatives that met the criteria in the Alternatives Study were carried forward to the Environmental Analysis. Results of the Environmental Analysis are noted in Table 24 below.

Table 24: High-Level Environmental Analysis of Alternatives

Assessment Criteria[254]	High-Level Assessment
Air Quality • Conflict with or obstruct implementation of an applicable air	• The project and alternatives are expected to have construction and operational impacts to air quality.

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[249] California Air Resources Board, https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit

[250] California Air Resources Board, https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard

[251] California Air Resources Board, https://ww2.arb.ca.gov/resources/fact-sheets/ab-32-global-warming-solutions-act-2006

[252] South Coast AQMD, http://www.aqmd.gov/home/rules-compliance/rules/scaqmd-rule-book/proposed-rules/rule-1153-1

[254] The high-level environmental assessment uses applicable questions from the CEQA Guidelines Appendix G as a framework to evaluate potential impacts in selected resource

Assessment Criteria[254]	High-Level Assessment
quality plan; result in a cumulatively considerable net increase of criteria pollutants; expose sensitive receptors to pollutant concentrations; result in other emissions adversely affecting a substantial number of people	• For example, for various alternatives, impacts may occur from construction and operation activities, including pipeline and electric transmission line construction, vehicle miles traveled from truck trips, nautical miles traveled from ships, and from construction of liquefaction and regassification facilities.
Biological Resources • Direct or indirect impacts to candidate, sensitive, or special status species or modification of their habitat, impacts to any riparian habitat, wetlands, or other sensitive natural community; interference with movement of native resident or migratory fish or wildlife species or with established wildlife corridors; conflict with local policies protecting biological resources, provisions of an adopted Habitat Conservation Plan, Natural Community Conservation Plan, or other approved habitat conservation plan.	• The project and alternatives are expected to have construction and operational impacts to biological resources. • For example, for various alternatives, impacts may occur, including for pipeline and electric transmission line construction, vehicle miles traveled from truck trips, and nautical miles traveled from ships. • For certain construction activities, potential impacts may occur in previously-disturbed areas. • Potential impacts during operational phases of certain facilities, such as underground pipelines or electric

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areas. Findings are preliminary and high level and therefore 1) do not represent if an impact is significant from the CEQA/NEPA perspective nor address the magnitude of the impact; 2) do not capture all impact areas that will be evaluated in a CEQA/NEPA document; and 3) do not account for the project's or alternatives' benefits, including those benefits from the use of the clean energy delivered by the project or alternative.

[254] The high-level environmental assessment uses applicable questions from the CEQA Guidelines Appendix G as a framework to evaluate potential impacts in selected resource areas. Findings are preliminary and high level and therefore 1) do not represent if an impact is significant from the CEQA/NEPA perspective nor address the magnitude of the impact; 2) do not capture all impact areas that will be evaluated in a CEQA/NEPA document; and 3) do not account for the project's or alternatives' benefits, including those benefits from the use of the clean energy delivered by the project or alternative.

Assessment Criteria[254]	High-Level Assessment
	transmission lines during periodic operations and maintenance activities.
Cultural Resources • Cause substantial adverse change(s) in the significance of historical and/or archaeological resources, or disturbance of human remains.	• The project and alternatives are expected to have construction and operational impacts to cultural resources. • For example, for various alternatives, impacts may occur from pipeline and electric transmission line construction. • For certain construction activities, potential impacts may occur in previously-disturbed areas. • Potential impacts may occur during periodic operational and maintenance phases of certain facilities, such as underground pipelines or electric transmission lines.
Energy • Wasteful, inefficient, or unnecessary consumption of energy resources; conflict with state or local plans for renewable energy or energy efficiency.	• The project and alternatives are not expected to result in the wasteful, inefficient, or unnecessary consumption of energy. • Potential impacts from alternatives, such as trucking and shipping, may require energy consumption through diesel fuel. However, over time trucks and ships may transition to electric, hydrogen fuel-cells, or lower carbon intensive fuels. • For the project and some alternatives, periodic operations and maintenance could result in limited energy consumption. • The project and certain alternatives may temporarily conflict with state or local plans for renewable energy or energy efficiency during construction. For example, potential conflicts could occur

Assessment Criteria[254]	High-Level Assessment
	during construction of pipelines, vehicle miles traveled from trucks, and nautical miles traveled from ships.
Greenhouse Gas Emissions • Generate GHG emissions, either directly or indirectly, including conflicts with applicable plans, policies, or regulations for reducing GHG emissions.	• The project and alternatives are expected to have construction and operational impacts related to GHG emissions. • For example, for various alternatives potential impacts are expected to occur from pipeline and electric transmission line construction, vehicle miles traveled from trucks, nautical miles traveled from ships, and construction of liquefaction and regassification facilities.
Hydrology and Water Quality • Cause water quality degradation; groundwater depletion or recharge; alter existing drainage patterns; location within flood hazard; conflict with Water Quality Control or Ground Water Management plans.	• The project and alternatives are expected to have construction and operational impacts related to hydrology and water quality. • For example, for various alternatives, potential impacts are expected to occur from pipeline construction and construction of liquefaction and regassification facilities. • Construction activities for the project and alternatives could cause short-term water quality impacts, and/or could potentially conflict with water quality control or ground water management plans. • Construction activities for several facilities, such as underground pipelines, could be constructed in floodplains and/or cause erosion.
Land Use	• The project and alternatives could have construction and operational impacts,

Assessment Criteria[254]	High-Level Assessment
- Physically divide a community; conflict with existing plans, policies, or regulations.	and associated impacts to communities, related to land use, such as electric transmission lines for the power transmission & distribution or electrification alternatives. - Depending on location of pipeline routes and other facilities, potential conflict could occur with existing land use plans, policies, or regulations.
Tribal Cultural Resources - Cause a substantial adverse change in the significance of a tribal cultural resource.	- The project and alternatives may have construction and operational impacts to tribal cultural resources. - For example, for various alternatives, potential impacts may occur in previously-disturbed areas, from pipeline and electric transmission line construction, construction of liquefaction and regassification facilities. - Potential impacts during periodic operational and maintenance phases of certain facilities such as underground pipelines or electric transmission lines may occur.