Hydrogen Pipeline Study

Project Report

PREPARED FOR

Southern California Gas Company

Prepared by SPEC Services, Inc.
Fountain Valley, CA
714.963.8077
specservices.com

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Revision Summary

Date	Revision	Approved	Reviewed
11/01/21	0	[redacted]	
02/02/22	1	[redacted]	

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1.0 Introduction

1.1 Purpose

This conceptual, high level prefeasibility study was developed for SoCalGas to explore the potential for development of hydrogen infrastructure at scale and to determine whether there is a feasible business case to pursue such development. This prefeasibility study provides engineering and supporting information to assist SoCalGas in assessing the practical and economic viability of producing green hydrogen in large quantities and transporting it via pipeline to demand centers in the Los Angeles Basin and surrounding areas.

Three possible levels of future demand (Low Demand, Medium Demand, and High Demand) have been considered based on available energy consumption data and guidance from SoCalGas.

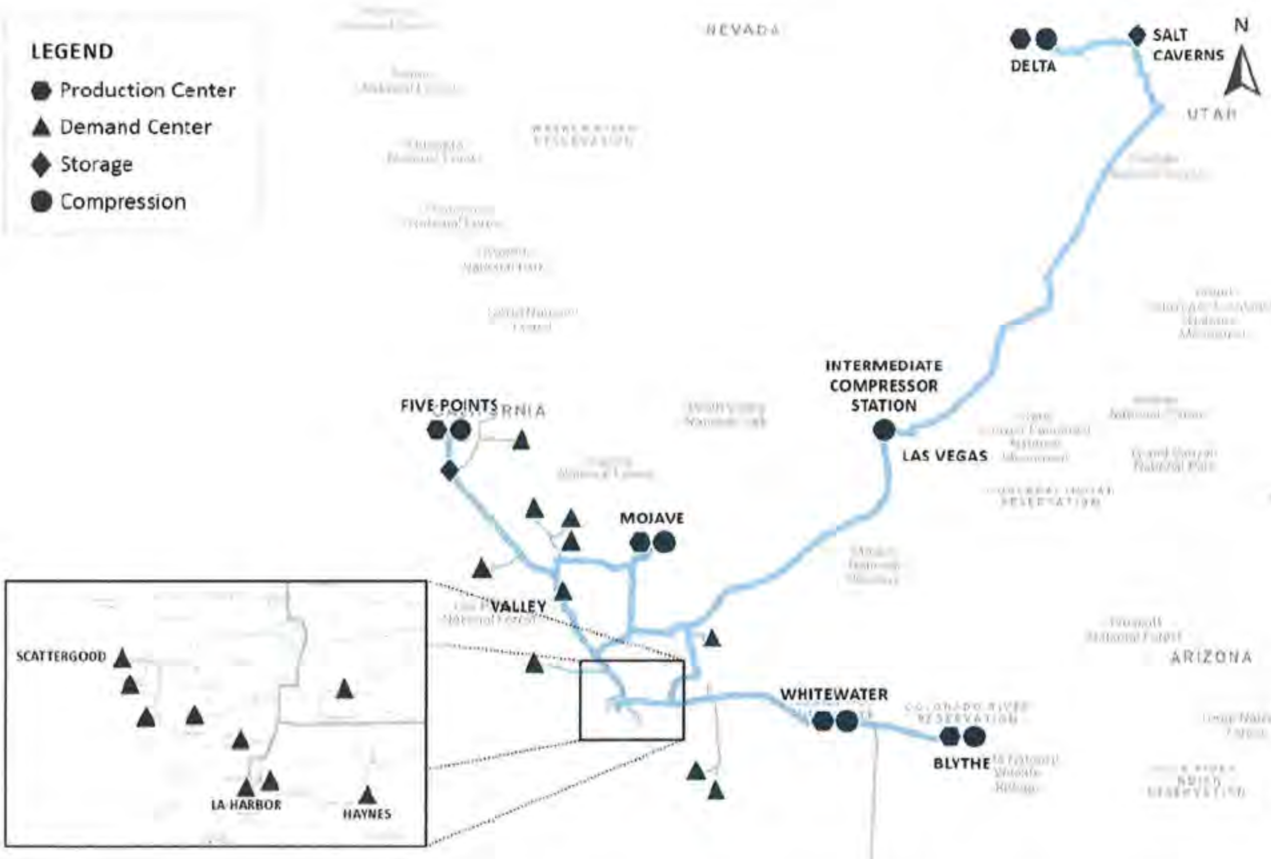
The major components of this prefeasibility study include the following:

- Establishment of Low, Medium, and High Demand scenarios for green hydrogen.
- Assessment of green hydrogen production at 5 potential production centers (4 in California and 1 in Utah).
- Assessment of new hydrogen transmission pipelines from production centers to potential major demand centers.
- Assessment of potential hydrogen storage options for large quantities of green hydrogen.
- Assessment of potential water resources related to the production of green hydrogen.
- Development of cost estimates related to the production, transportation, and storage of hydrogen.

Separate studies and reports have been prepared for the renewable energy/hydrogen production system, the hydraulic analysis and overall system planning, potential geologic storage in an oil/gas reservoir, water source (for hydrogen production), environmental, and right-of-way/land acquisition. The pipeline system (including compression and alternative storage assessment) is presented in this report, as well as an introduction to each of the separate reports.

1.2 Locations and Pipeline Routing

Five production areas identified by SoCalGas have been evaluated: (1) Five Points (southwest of Fresno), (2) Mojave, (3) Blythe, (4) Whitewater in California, and (5) a location near the LADWP Intermountain Power Plant in Utah. For the purposes of providing a workable system upon which to base this study, it has been assumed that sufficient on-site pressurized storage will be installed at each production site (in the form of many miles of high pressure pipeline/piping) to deliver hydrogen to the pipeline system at a relatively uniform rate throughout each day. Conceptual pipeline routes from each production center location to the Los Angeles Basin are shown on the map below, along with two potential storage locations. The storage location options include salt caverns near Delta, Utah and oil/gas reservoir storage development in San Joaquin Valley.



For the Low Demand case, it was assumed that all hydrogen would be generated at a single site. For the Medium and High Demand cases, it was assumed that multiple sites would be needed due to land constraints. Therefore, the analysis of the Medium and High Demand cases included several alternative combinations of the identified production sites, pipeline systems, and storage locations.

This study also assumes construction of all new facilities for a dedicated hydrogen system. Consideration of any existing pipelines or the staged development from a Low Demand case system to a higher demand system and capacity is not included in this study.

1.3 Limitations of Study

The results of this prefeasibility study are considered order of magnitude. The actual production, transportation, and storage of green hydrogen at the scale discussed in this report has not been completed domestically or internationally. This study will discuss the major technical aspects of producing, storing, and transporting such large quantities of green hydrogen.

Costs are considered order of magnitude and the study has largely relied on parametric and factored costs. Material and construction costs are estimated based on representative costs for similar equipment, material and construction. Construction costs are parametric or factored based on costs for similar but smaller scale projects. Demand projections provided in the report are based on available data and guidance from SoCalGas and are used solely for developing basis of design scenarios. Actual projections would involve a detailed study of individual customer demand requirements, detailed long term projections, and assessment of environmental, state and local regulations.

1.4 Appendices

For more detailed information, please refer to the appendices summarized below.

Table 1: Reports Included as Appendices

Study Scope	Revision	Consultant
Hydrogen Demand Assessment Report	8/31/21	Strategen Consulting
Hydrogen Production Assessment Report	Revision B, 9/30/2021	Technip Energies
Hydraulic Analysis, Hydrogen Pipeline Study Transportation System, 8143-M-002 (Low Rate)	Revision 0, 9/30/2021	SPEC Services, Inc.
Hydraulic Analysis, Hydrogen Pipeline Study Transportation System, 8143-M-003 (Medium and High Rates)	Revision 0, 10/25/2021	SPEC Services, Inc.
Assessment of Underground Storage In Oil and/or Gas Reservoirs Report	Revision 1, 10/1/2021	InterAct PMTI
Right-of-way Assessment Report	Revision 1, 9/17/21	Paragon Partners
Conceptual Pipeline Permit Assessment, Mojave	8/27/21	D. Edwards, Inc. and Rincon Consultants, Inc.
Conceptual Pipeline Permit Assessment, Delta	9/2/21	D. Edwards, Inc. and Rincon Consultants, Inc.
Conceptual Pipeline Permit Assessment, Whitewater & Blythe	9/3/21	D. Edwards, Inc. and Rincon Consultants, Inc.
Conceptual Pipeline Permit Assessment, Five Points	9/10/21	D. Edwards, Inc. and Rincon Consultants, Inc.
Water Supply Analysis, Mojave	Revision 1, 9/14/21	D. Edwards, Inc. and Rincon Consultants, Inc.
Water Supply Analysis, Delta	9/21/21	D. Edwards, Inc. and Rincon Consultants, Inc.

Water Supply Analysis, Whitewater & Blythe	9/30/21	D. Edwards, Inc. and Rincon Consultants, Inc.
Water Supply Analysis, Five Points	9/30/21	D. Edwards, Inc. and Rincon Consultants, Inc.
Analysis of Major Pipeline Precedence	8/27/21	D. Edwards, Inc. and Rincon Consultants, Inc.

2.0 Design Basis

2.1 Demand Scenarios

Demand for hydrogen in the Los Angeles Basin will be affected by the course of future developments, including potential implementation of bulk hydrogen supply explored in this study. This study assumes hydrogen delivery to power plants, transportation centers at ports, refineries, sites for blending hydrogen with natural gas, and to additional locations for distribution to supply a substantial share of vehicle fuel. Power plant hydrogen demand is likely to vary by time of day, by season (higher in summer and into fall), and by periods of very hot weather. Power plants need a supply that is uninterruptible or may have to provide their own local storage if available. Refineries use substantial volumes of hydrogen now and could benefit from green hydrogen supply. However, they currently have only grey hydrogen supply and other currently more economical options. Hydrogen is projected to increasingly replace diesel fuel for trucking, as it becomes economical and the reliability of supply improves. Regardless of the final users of the hydrogen, this study illustrates the requirements for a very large-scale hydrogen production and supply system, provides an order-of-magnitude cost estimate, and identifies major considerations.

A detailed market driven prediction of hydrogen demand is outside the scope of this report and would require an in-depth study and survey of potential end users, regulations, and other market factors. However, the study did include an assessment of hydrogen demand developed by Strategen to supplement SoCalGas analysis of demand cases. Considering the available demand information provided as part of this study in conjunction with their own research, SoCalGas edited and issued the demand for the three cases as the basis of design for the project. The Strategen report is available as a separate document. A detailed summary of the demand scenarios is included in Table 2.

Table 2: Scenario 7 - SoCalGas Requested Demand Case

Demand Center Description	Low Case		Medium Case		High Case	
	Volume (Tons H2/Year)	Description	Volume (Tons H2/Year)	Description	Volume (Tons H2/Year)	Description
Power	[redacted]	Valley, Haynes, Scattergood, Harbor Only	[redacted]	Four LADWP Plants + Other Major	[redacted]	All Served Power Generation
Transportation	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Refinery	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Residential Blending	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Commercial	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Industrial			[redacted]	[redacted]	[redacted]	[redacted]
Total Demand, Tons H2/Year	[redacted]		[redacted]		[redacted]	
Requested Range Million Tons per Year	[redacted]		[redacted]		[redacted]	

2.2 Project Team

Due to the many components associated with this study, a team of consultants was assembled to make full use of expertise in specific fields. This approach was considered appropriate considering the wide variety of subject matter expertise required to assess the system, develop costs, conclusions and recommendations. The team and their specific scope are as follows:

Table 3A: SoCalGas Hydrogen Pipeline Project Consultant Team

Scope	Consultant	Lead
Prime Contractor and Project Lead	SPEC Services, Inc.	[redacted]
Green Hydrogen Production Assessment and Development	Technip Energies and Strategen Consulting	[redacted]
Hydrogen Storage – Underground	InterAct	[redacted]
Water Resources	D. Edwards, Inc. and Rincon Consultants, Inc.	[redacted]
Pipeline Transportation System	SPEC Services, Inc.	[redacted] – [redacted]
Pipeline Transportation System – Environmental	D. Edwards, Inc. and Rincon Consultants, Inc.	[redacted]
Pipeline Transportation System – Right-of-Way	Paragon Partners	[redacted]
Pipeline Transportation System – Cost Estimating	Campos EPC and SPEC Services, Inc.	[redacted]

2.3 System Flow Diagrams

The scale of hydrogen production consists of many components. At this prefeasibility level of study, focus was dedicated to sizing and estimating the major components and system as a whole. In reality any of the major components discussed and estimated in this prefeasibility study would typically be considered a major capital project on its own. The following is a brief description of each part of the hydrogen system. Additionally, a simplified flow diagram is provided showing how these major components are connected on a system wide basis.

- Green hydrogen production consisting of photovoltaic cells, electrolysis and battery storage systems located at the conceptual production centers;
- Water source for use in production of hydrogen by electrolysis;
- Hydrogen compression and intermediate compression;
- Transmission and distribution pipelines from the production centers to the demand centers; and
- Hydrogen storage.

Below is a listing of the system numbers and system names referenced in this report:

Table 4: System Numbers and Names	
System 1	Five Points
System 2	Mojave
System 3	Whitewater
System 4	Blythe
System 5	Delta
System 6	Mojave with Delta Pipeline
System 7	Medium – Mojave/Delta
System 8	Medium – Mojave/Five Points
System 9	High – All Cases

In total, nine systems were assessed. For the Low Demand scenario, one system was studied for each of the five specified production centers (Systems 1 through 5) and a sixth system included a hybrid combination of the Mojave production and Delta pipeline and storage system (System 6). The hybrid System 6 was included due to uncertainty regarding potential reservoir storage closer to the LA Basin.

For the Medium Demand Scenario, two system configurations were studied. One Medium Demand case included production at both Mojave and Delta, and the Delta pipeline and cavern storage system (System 7). The other included production at both Mojave and Five Points, and a San Joaquin Valley pipeline and oil/gas reservoir storage system (System 8). For the High Demand Scenario, all production areas were included (Mojave, Five Points, Blythe, Whitewater, and Delta), and storage and connecting pipelines were included for both Delta and San Joaquin Valley storage sites (System 9).

These systems are summarized in the following figures.

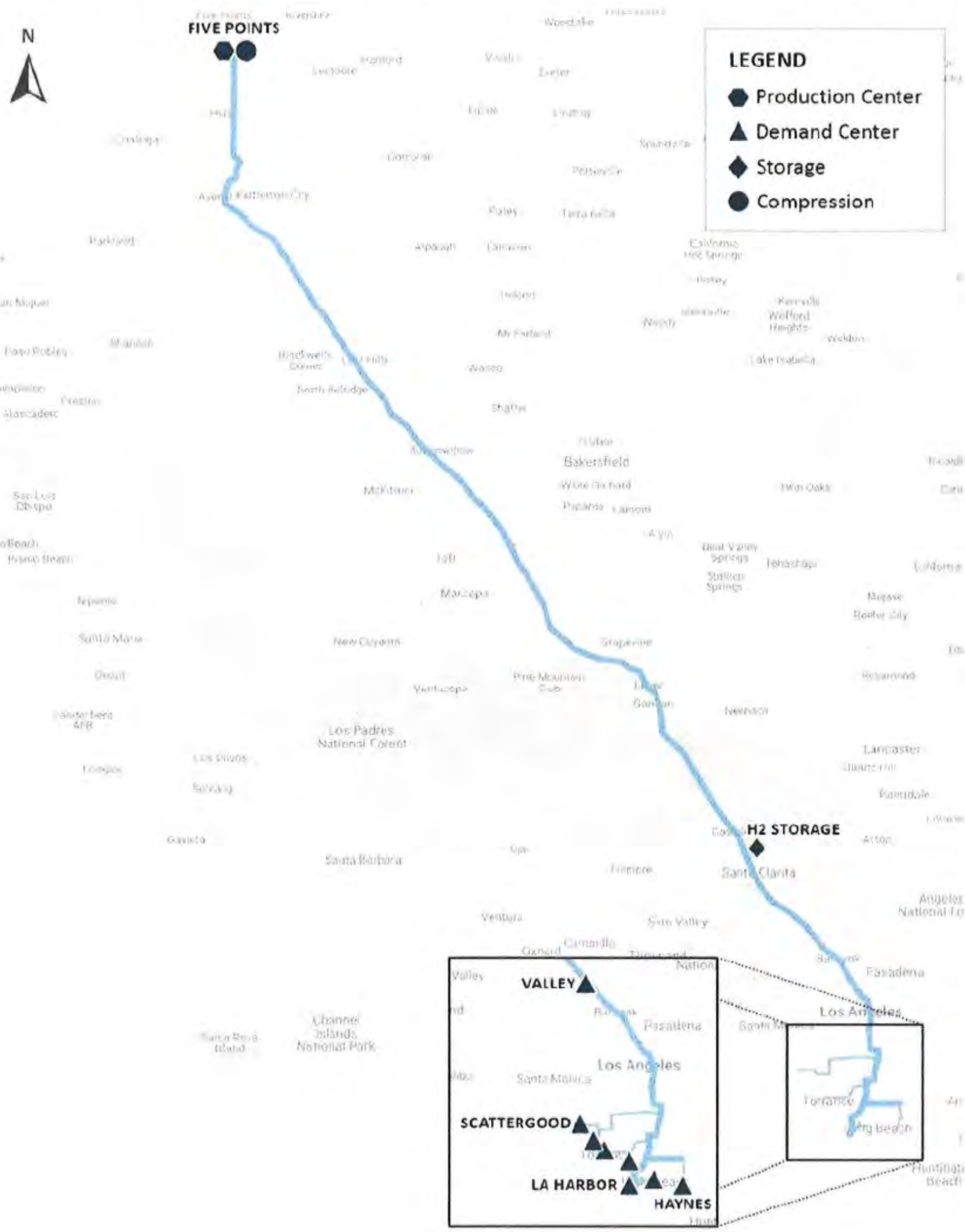
2.3.1 System 1

The Five Points low demand system includes production center at Five Points, [redacted] to a storage area near Castaic Junction, and a [redacted] trunk line and [redacted] lines to the low case demand centers.

FIGURE 1A, SYSTEM 1: FIVE POINTS LOW DEMAND SCENARIO OVERALL FLOW DIAGRAM

FIVE POINTS – LOW DEMAND SYSTEM

FIGURE 1B, SYSTEM 1: FIVE POINTS LOW DEMAND SCENARIO OVERALL SYSTEM MAP



2.3.2 System 2

The Mojave low demand system includes production center at Mojave, a [redacted] to a storage area near Castaic Junction, and a [redacted] trunk line and [redacted] lines to the low case demand centers.

FIGURE 2A, SYSTEM 2: MOJAVE LOW DEMAND SCENARIO OVERALL FLOW DIAGRAM

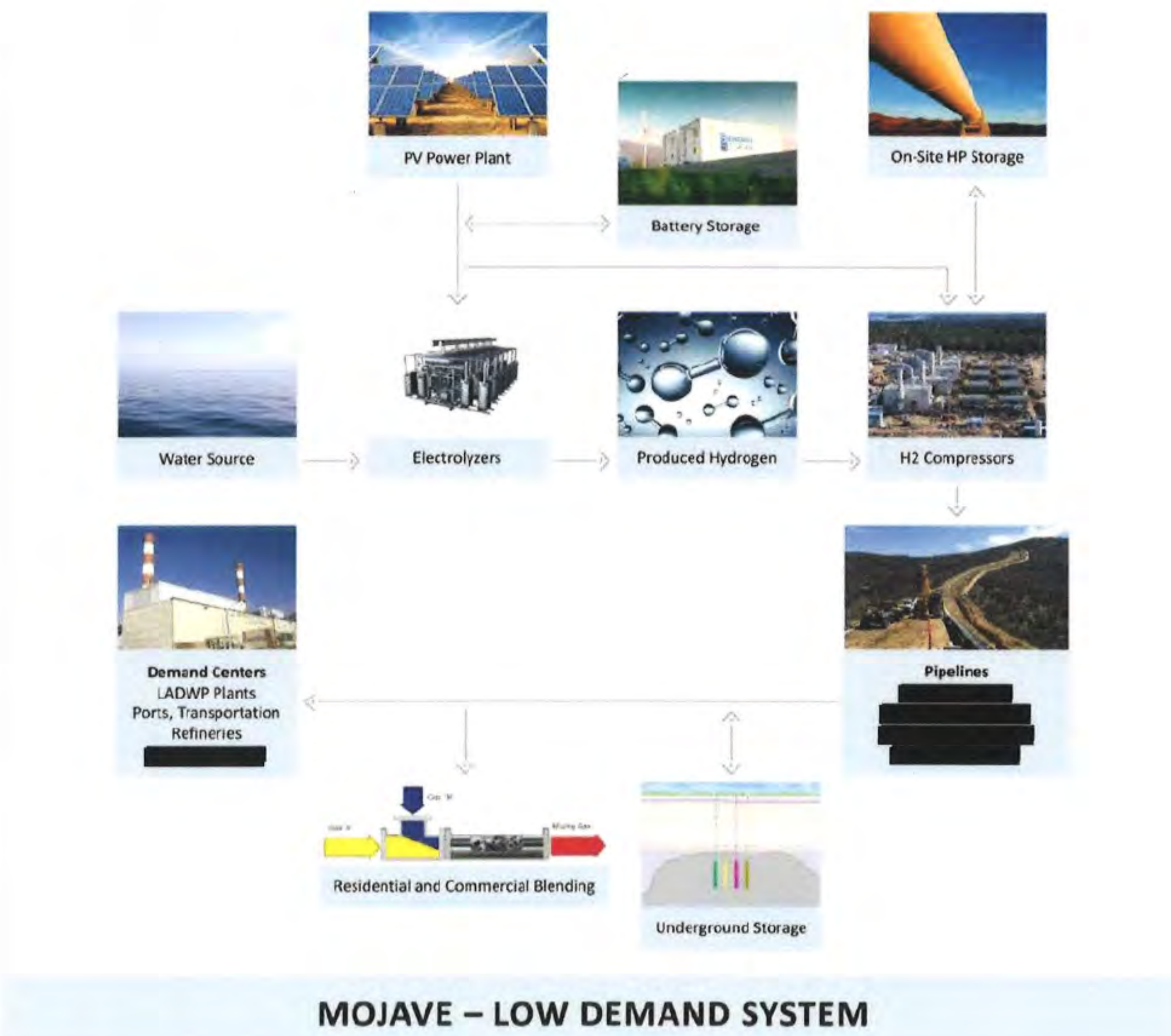
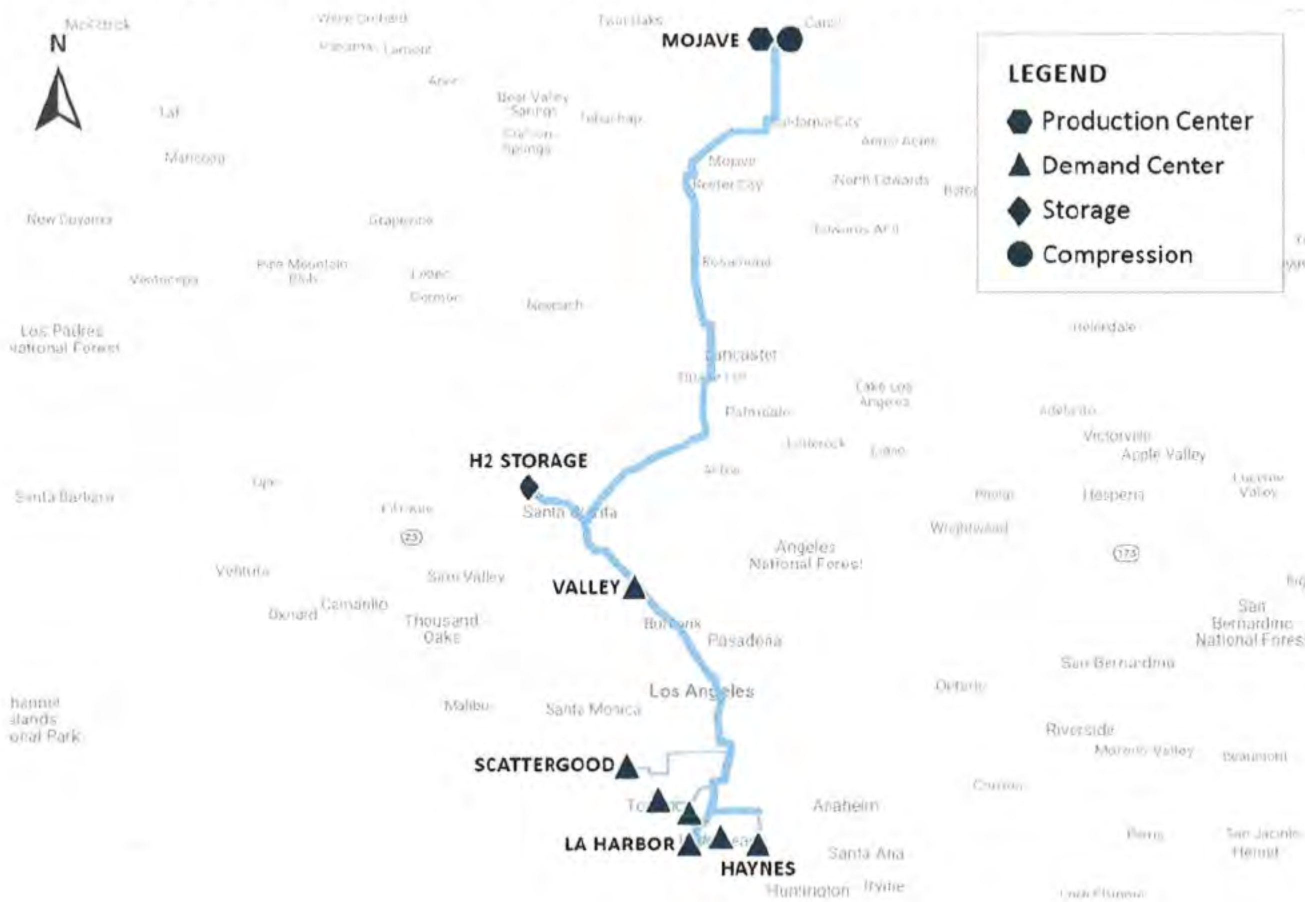


FIGURE 2B, SYSTEM 2: MOJAVE LOW DEMAND SCENARIO OVERALL SYSTEM MAP



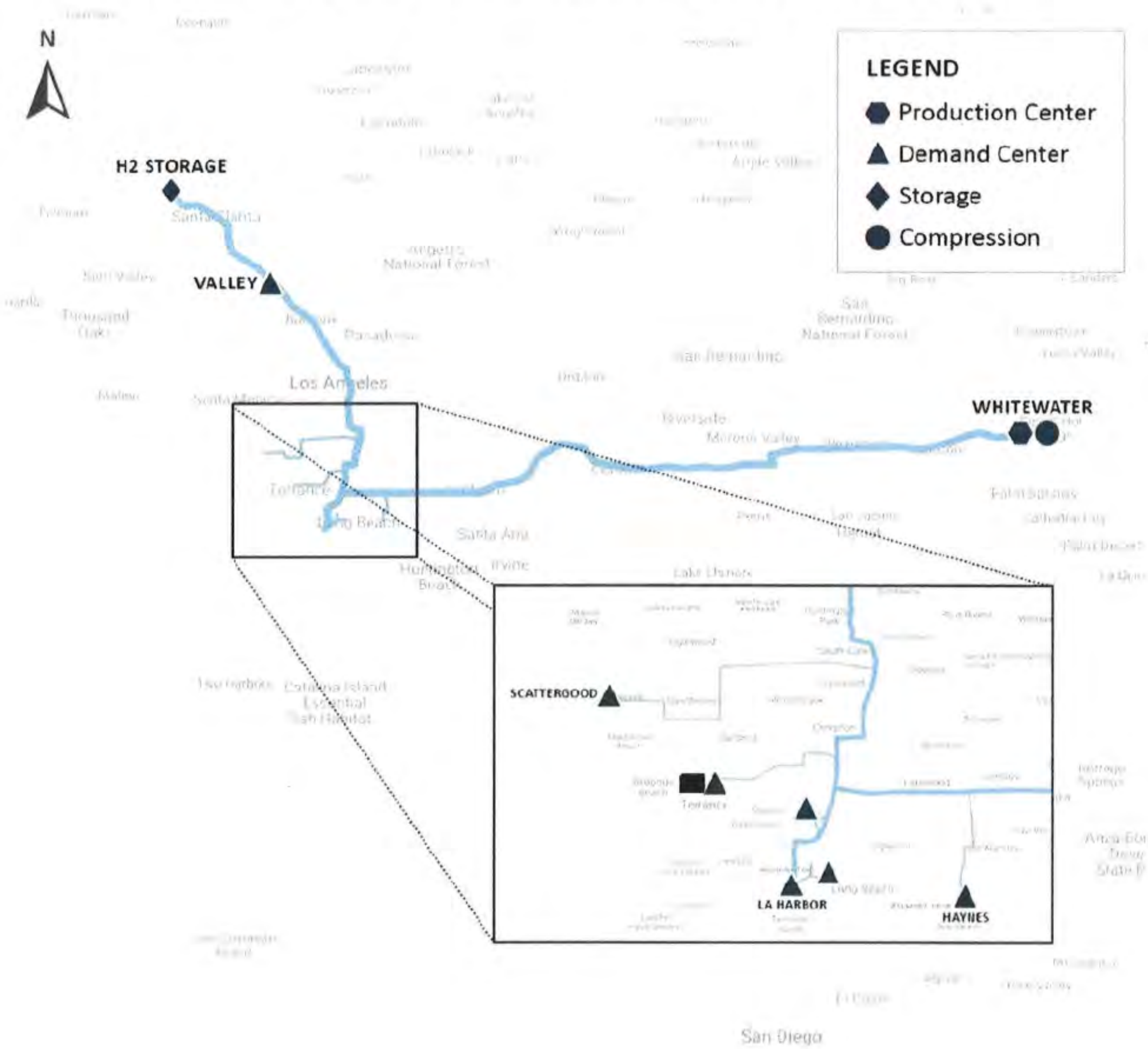
2.3.3 System 3

The Whitewater low demand system includes production center at Whitewater, [redacted] to Long Beach, a [redacted] trunk line to a storage area near Castaic Junction, and a [redacted] trunk line and [redacted] lines to the low case demand centers.

FIGURE 3A, SYSTEM 3: WHITEWATER LOW DEMAND SCENARIO OVERALL FLOW DIAGRAM

WHITEWATER – LOW DEMAND SYSTEM

FIGURE 3B, SYSTEM 3: WHITEWATER LOW DEMAND SCENARIO OVERALL SYSTEM MAP



2.3.4 System 4

The Blythe low demand system includes production center at Blythe, [redacted] to Whitewater, [redacted] from Whitewater to Long Beach, [redacted] a storage area near Castaic Junction, and a [redacted] trunk line and [redacted] lines to the low case demand centers.

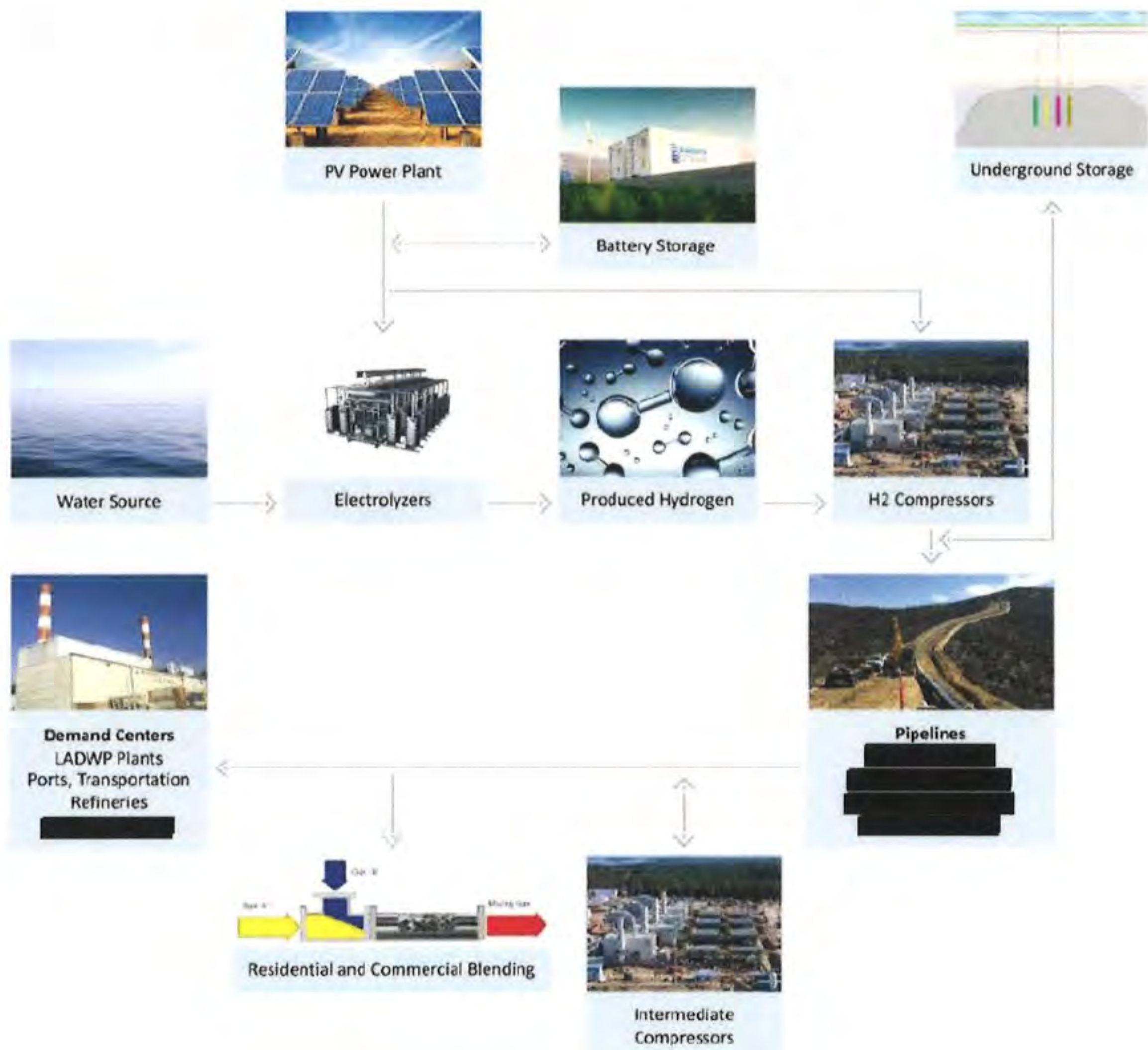
FIGURE 4A, SYSTEM 4: BLYTHE LOW DEMAND SCENARIO OVERALL FLOW DIAGRAM

FIGURE 4B, SYSTEM 4: BLYTHE LOW DEMAND SCENARIO OVERALL SYSTEM MAP

2.3.5 System 5

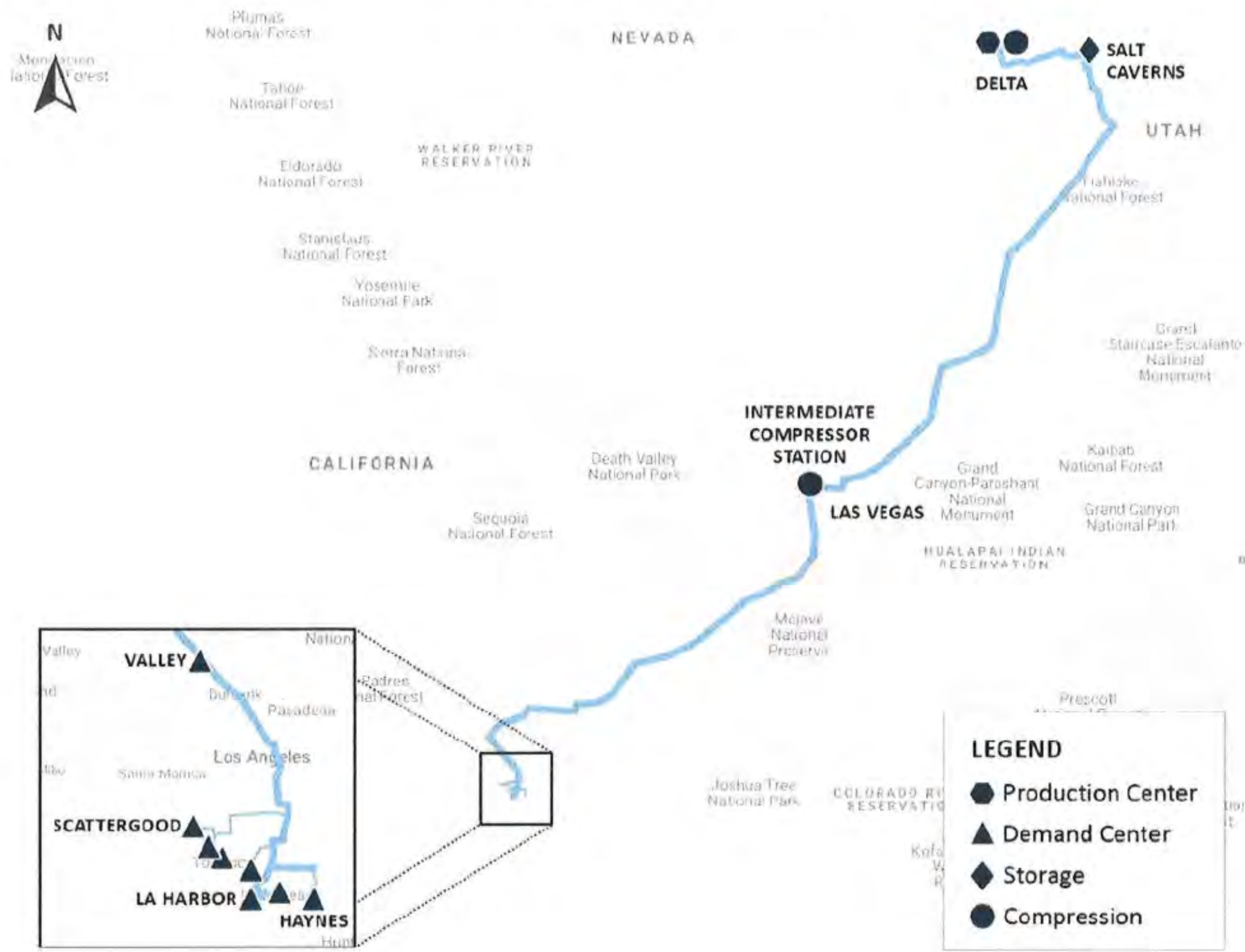
The Delta low demand system includes production center at Delta, Utah, a [redacted] to Long Beach, an intermediate compression station near North Las Vegas, and a [redacted] trunk line and [redacted] lines to the low case demand centers.

FIGURE 5A, SYSTEM 5: DELTA LOW DEMAND SCENARIO OVERALL FLOW DIAGRAM



DELTA – LOW DEMAND SYSTEM

FIGURE 5B, SYSTEM 5: DELTA LOW DEMAND SCENARIO OVERALL SYSTEM MAP



2.3.6 System 6

Mojave with Delta Pipeline low demand system includes production center at Mojave, a [redacted] CA and to Delta, Utah, an intermediate compression station near North Las Vegas, and a [redacted] trunk line and [redacted] lines to the low case demand centers.

FIGURE 6A, SYSTEM 6: MOJAVE WITH DELTA PIPELINE LOW DEMAND SCENARIO OVERALL FLOW DIAGRAM

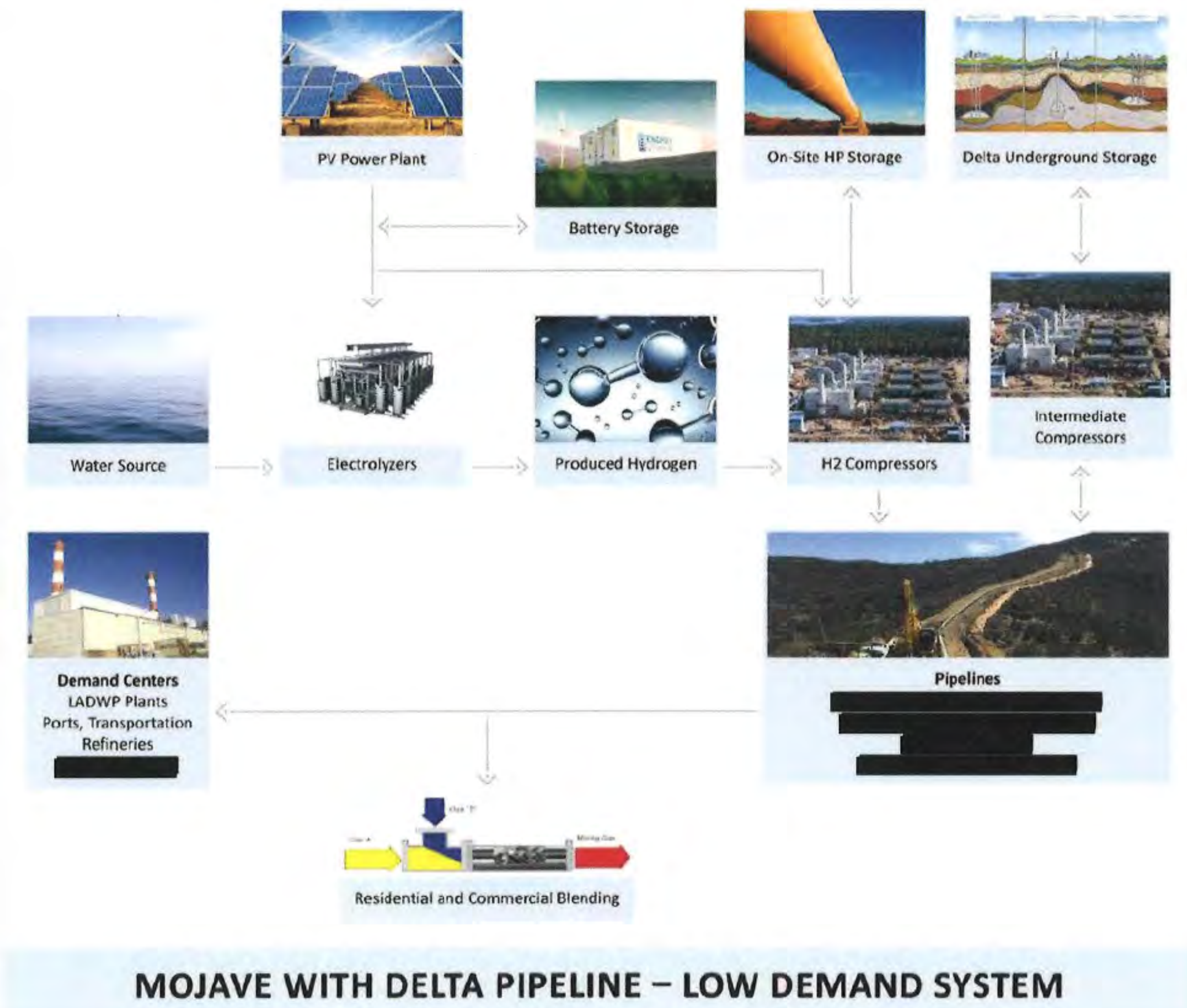
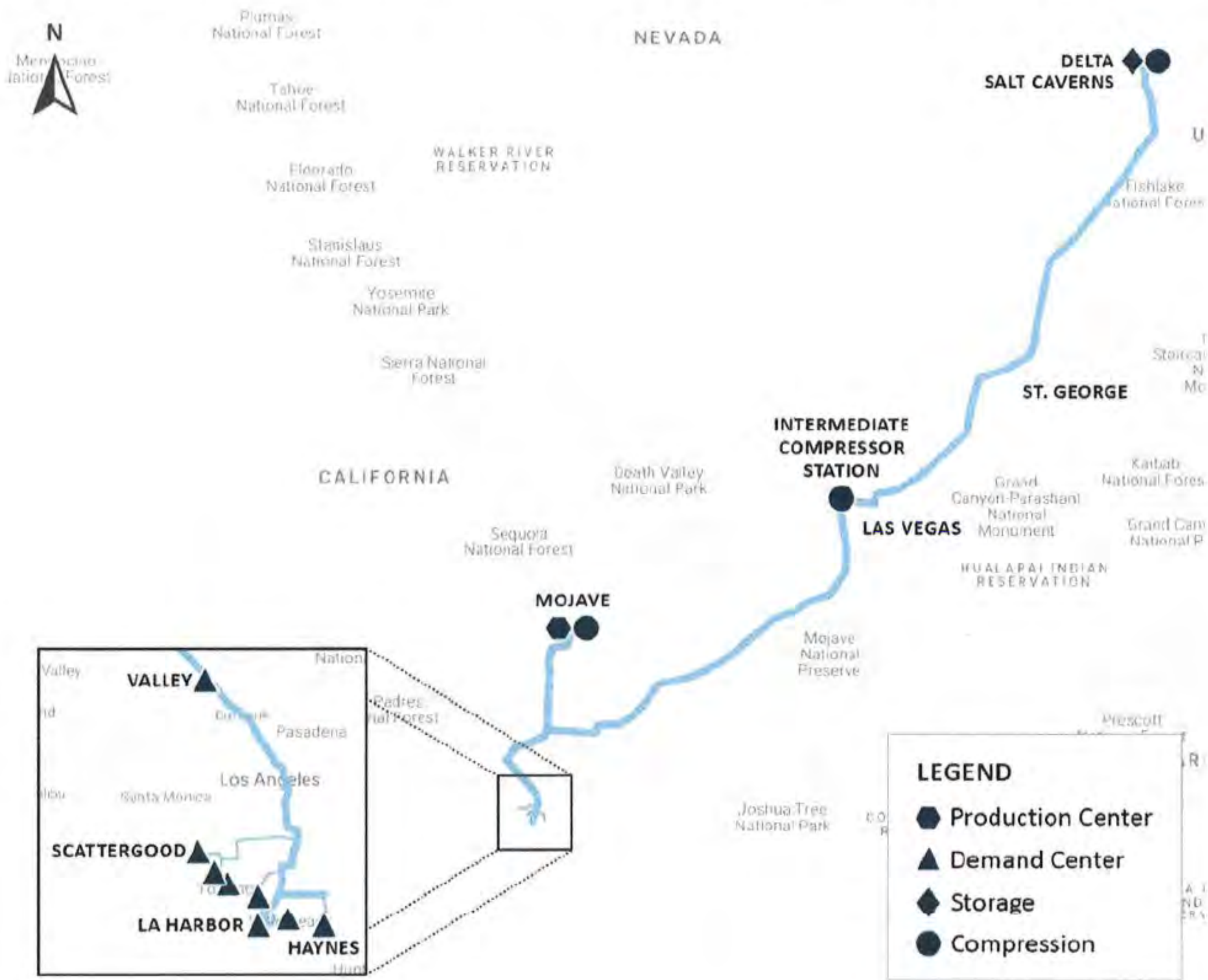


FIGURE 6B, SYSTEM 6: MOJAVE WITH DELTA PIPELINE LOW DEMAND SCENARIO OVERALL SYSTEM MAP



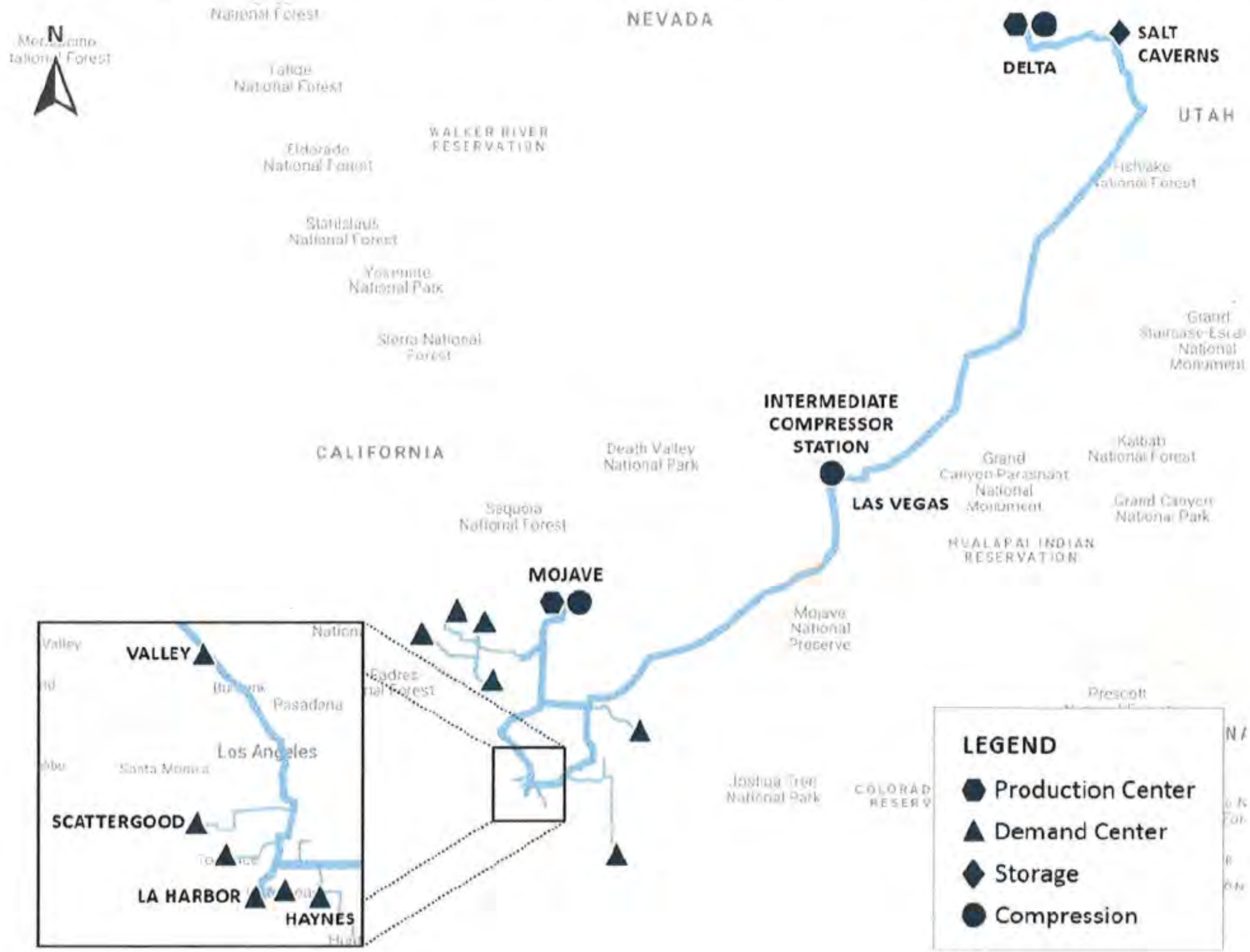
2.3.7 System 7

The Medium – Mojave/Delta demand system includes production centers at Mojave (split into two areas called Mojave North and Mojave South) and Delta, Utah; [redacted] diameter transmission lines from these production centers to the trunk line system; salt cavern storage at Delta; an intermediate compression station near North Las Vegas; and [redacted] lines to a number of other demand centers.

FIGURE 7A, SYSTEM 7: MEDIUM – MOJAVE/DELTA PRODUCTION SCENARIO OVERALL FLOW DIAGRAM

[redacted]

FIGURE 7B, SYSTEM 7: MEDIUM – MOJAVE/DELTA PRODUCTION SCENARIO OVERALL SYSTEM MAP



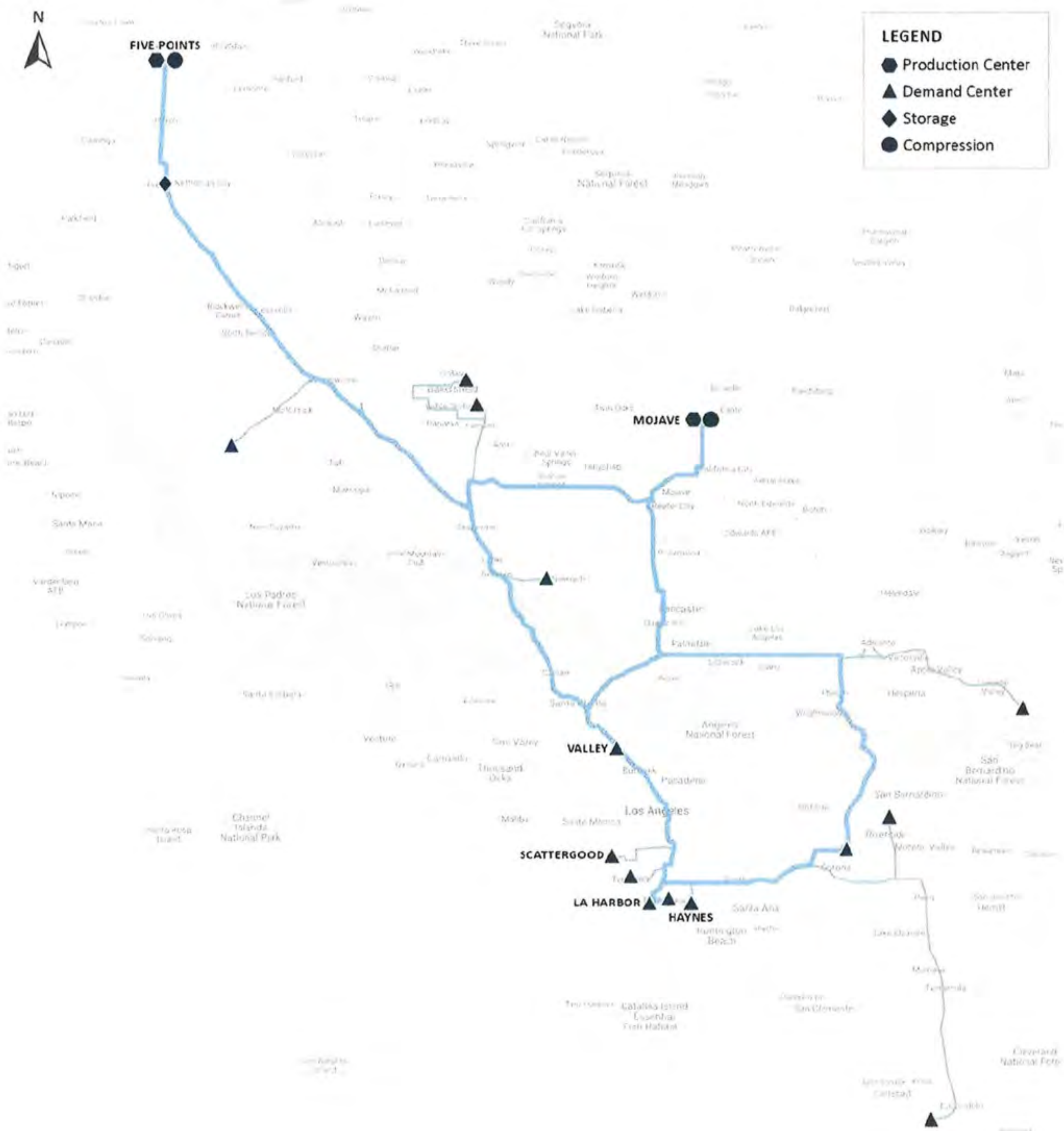
2.3.8 System 8

The Medium – Mojave/Five Points demand system includes production centers at Mojave (split into two areas called Mojave North and Mojave South) and Five Points; [redacted] diameter transmission lines from these production centers to the trunk line system; underground reservoir storage in San Joaquin Valley; and [redacted] lines to a number of other demand centers.

FIGURE 8A, SYSTEM 8: MEDIUM – MOJAVE/FIVE POINTS PRODUCTION SCENARIO OVERALL FLOW DIAGRAM

[redacted]

FIGURE 8B, SYSTEM 8: MEDIUM – MOJAVE/FIVE POINTS PRODUCTION SCENARIO OVERALL SYSTEM MAP



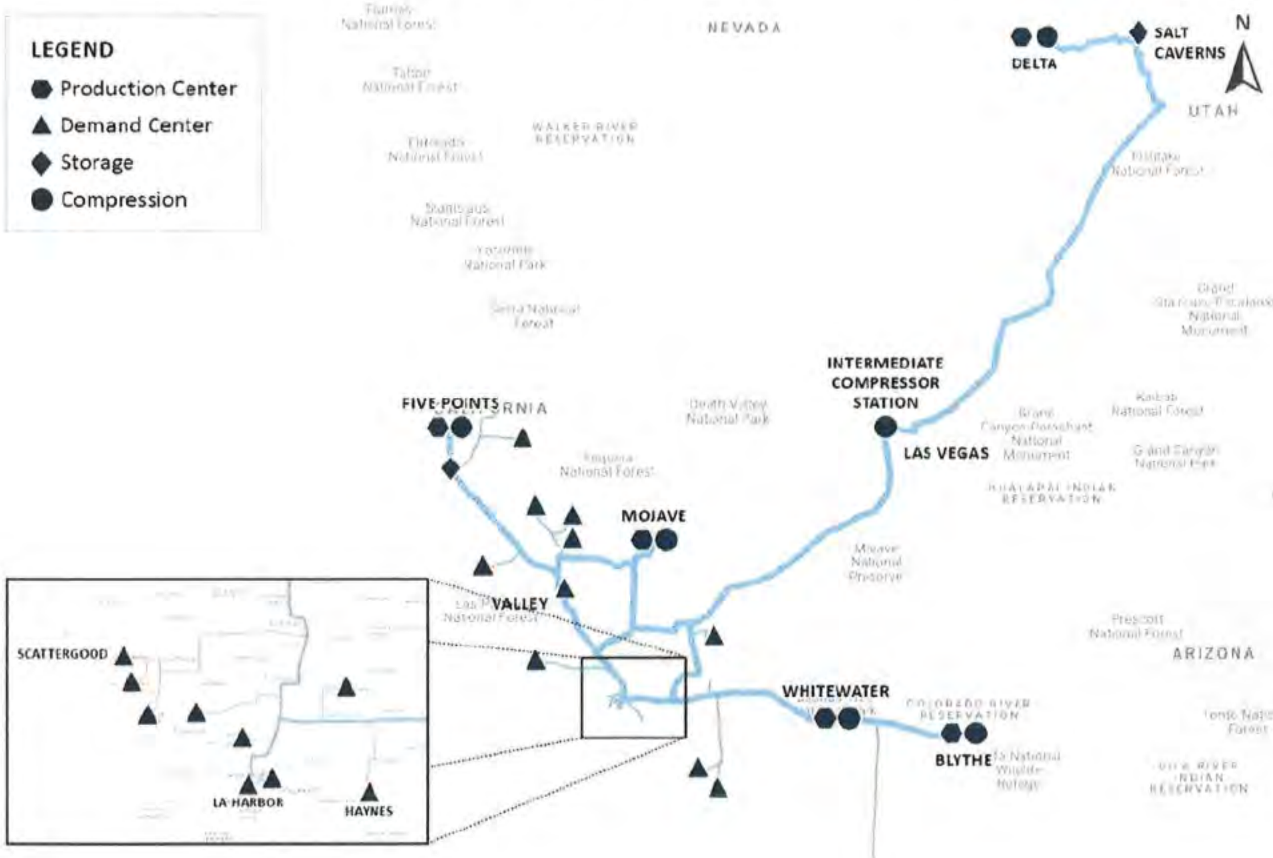
2.3.9 System 9

High – All demand systems assumed production at all five of the production areas considered, and storage at both storage options considered: salt caverns in Delta, Utah and an oil/gas reservoir in San Joaquin Valley. This High Demand case includes production centers at Mojave (split into two areas called Mojave North and Mojave South), Five Points, Blythe, Whitewater, and Delta; [redacted] diameter transmission lines from these production centers to the trunk line system; salt cavern storage in Delta, Utah, and reservoir storage in San Joaquin Valley; an intermediate compression station near North Las Vegas; and [redacted]r distribution lines to a number of other demand centers lines to a number of other demand centers.

FIGURE 9A, SYSTEM 9: HIGH – ALL CASES PRODUCTION SCENARIO OVERALL FLOW DIAGRAM

[redacted]

FIGURE 9B, SYSTEM 9: HIGH – ALL CASES PRODUCTION SCENARIO OVERALL SYSTEM MAP



3.0 Conceptual Hydrogen Production System

3.1 Green Hydrogen Production

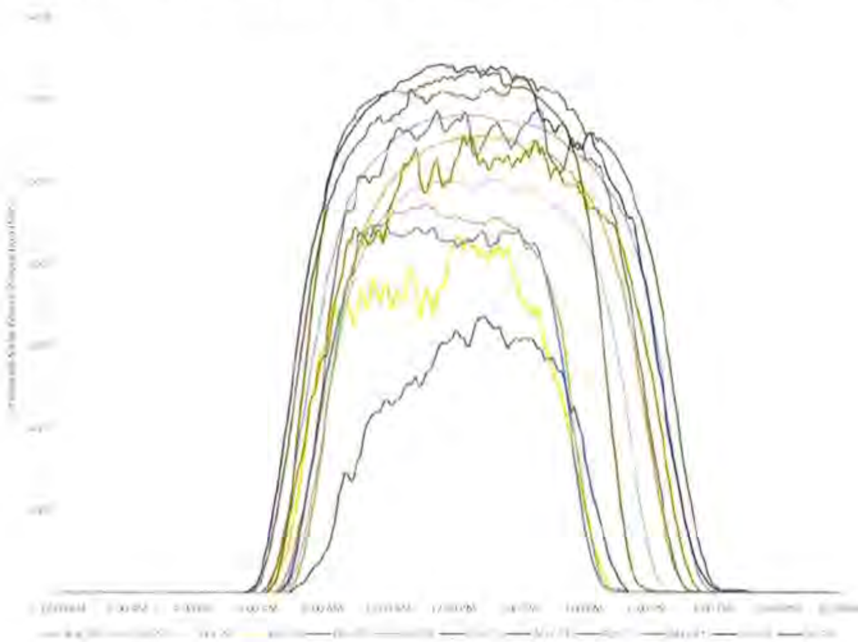
Technip Energies developed the renewable power and hydrogen production system analysis and estimates. A separate report summarizes their work and findings.

The scope of the study included assessing power generation with both photovoltaic (PV) solar panels and wind turbines, which would be constructed solely to power electrolyzers for the production of hydrogen from water. When power is available, each electrolyzer unit operates at its design capacity to separate water into hydrogen and oxygen, with the hydrogen being captured and compressed and the oxygen released to the atmosphere. If more power is generated than the total capacity of the facility electrolyzers, the excess power cannot be used and must be curtailed.

Wind turbines can generate more power as wind speed increases, potentially in excess of the capacity of the electrolyzers to use the power. Wind turbines also require substantially more land area than solar panels generating the same amount of power due to the distances required between turbines (approximately 200 acres per 5.8 MW turbine). An optimization analysis was performed for a combination of wind and solar at each of the four sites in California, with the goal of maintaining the rate of hydrogen generation within [redacted]% of the average annual production rate. The power generated from wind varied substantially by site, required more land than was likely to be available and suitable for this purpose, and did not result in substantial cost reduction. Although actual development may be able to implement a combination solar and wind system economically, this study continued on the basis of producing all of the renewable power using solar (PV panels).

Desert environments provide some of the most optimal conditions for solar power generation; however, the generation rate still varies widely between seasons. The following chart illustrates the relative power generation in California by solar from the past year.

FIGURE 10: CALIFORNIA SOLAR POWER GENERATION FOR 2020 (SOURCE: CALIFORNIA INDEPENDENT SYSTEM OPERATOR)



The capacity factor for solar power also varies somewhat between the sites. In Southern California, a solar panel can generate approximately 218% more watt-hours in a typical summer day than a winter day, due to the longer daylight hours and higher intensity of the sunlight. The average peak generation rate in summer is approximately 47% higher than the average peak generation rate in winter. The hydrogen production rate generally follows the same daily cycles as the power generation rate, and electrolyzers are either oversized and not using all of their capacity in the winter, or undersized relative to being able to use all of the summer power available at peak generation rates. These factors and equipment and operating costs are considered in the optimization analysis.

The PEM electrolyzers selected as the basis of the study can ramp up and down in capacity very quickly. The base study followed the specifications of some manufacturers that the PEM electrolyzers must be powered at all times at a minimum 5% power level. Other manufacturers have indicated that powering down the electrolyzers fully for up to several days is acceptable, which greatly reduces the power required during the non-productive hours of the day, and is used as the basis for the estimates in this report.

The base system includes batteries charged during the daytime to provide minimum power to the site while there is no solar power production. It may be possible to connect to an external power transmission system and purchase power for this purpose, but for the purposes of this pre-feasibility study batteries were assumed to be necessary for this self-contained system to operate. The projected cost and scale of the batteries to supply the electrolyzers with a 5% minimum power is very high, so it has been assumed that electrolyzers will be available that have a 0% minimum power level.

To make up for the lack of hydrogen production at night, the daytime hydrogen production rate must typically be more than twice the average annual production rate. Without massive low pressure on-site storage, which is not feasible due to the increased volume and compression requirements, the hydrogen must be compressed at the rate that it is produced. Some of the hydrogen will satisfy demand as it is produced. The balance of the production, which could be over 60% of the actual daytime production rate, must be sent to storage of some type. Optimizations were performed by Technip for Systems 1-4 above using a combination of solar and wind to power the electrolyzers. For these optimizations, Technip included consideration of low pressure storage volumes, compression, and pipeline transmission system volumes in producing the optimizations. This data was used in the hydraulic modeling of the pipeline and storage system by SPEC for Systems 1-4. Subsequently an optimization of Whitewater was performed based on using solar only for renewable power generation, with no constraints imposed by low pressure storage, compression, and high pressure storage. This data was factored and used by SPEC in the hydraulic analysis for System 6. For this case, the hydrogen was assumed to be produced at a pressure of [redacted] psig and made available for shipping and/or storage as it was produced.

Analysis was performed for each production site based on the upper range of the Low Demand case, [redacted] of hydrogen production. The results of this analysis are representative and directly proportional to the three demand cases included in this study: Low Demand of [redacted], Medium Demand of [redacted], and High Demand of [redacted]. The discussion in this section on conceptual hydrogen production system applies to all demand cases, and the data from the [redacted] production rate analysis is directly proportional and was factored accordingly to provide data for the low, medium, and high demand cases. Production volumes and rates for Systems 7, 8, and 9 are based on factoring the analysis of the PV only data relative to the (solar) capacity factor for each site and the assumed amount of hydrogen production to be provided by each site.

The Technip Green Hydrogen report on renewable power generation and hydrogen production provides details on these optimizations and on the program used to perform the optimizations, the basis for cost, the total costs and cost breakdown for each site (including water and land), and other details and graphics. Tables of estimated hydrogen production costs (CAPEX and OPEX) are presented in the Technip report and included in section 11.6 of this report. The optimization program uses the following methodology to determine the production solution.

The Technip "Hydrogen Production Assessment Report" is based on using the Typical Meteorological Year (TMY) time series for potential renewable power production at each site from the National Renewable Energies Laboratory (NREL) System Advisor Model (SAM). The TMY is an hourly potential energy profile created from a database of the hourly solar irradiance as measured at a given location over multiple years. It includes "typical" yearly weather phenomena, such as days with little or no potential solar production. The TMY time series, initially given every hour, is then interpolated linearly to have a time step of 5 minutes. This was done initially to adequately model the LP storage volume effect, but retained on subsequent simulations after the LP storage constraint was removed.

The technical and economic characteristics of each component were input to the program. Specific details of each item are included in the hydrogen production report, but for reference below are the PV modules, batteries, and electrolyzer data:

Table 5: PV Modules Inputs	
Parameter	**Value**
Number of Modules	Optimization parameter
Footprint per module	[redacted]
Power production	[redacted]
Annual Production Decrease Rate	[redacted]
Total Investment Cost	[redacted]
Annual O&M Cost	[redacted]

Table 6: Battery Inputs	
Parameter	**Value**
Number of batteries	Optimization parameter
Storage Capacity	[redacted]
Minimum state of charge	[redacted]
Initial state of charge	[redacted]
Maximum charge/discharge rate	[redacted]
Efficiency in charge/discharge REDACTED	[redacted]
Self-discharge	[redacted]
Calendar degradation of storage capacity	[redacted]

Table 6: Battery Inputs	
Parameter	**Value**
Investment Cost	[redacted]
Replacement Frequency	[redacted]
Replacement Cost	[redacted]
Annual O&M Cost	[redacted]

Table 7: Electrolyzer Inputs	
Parameter	**Value**
Number of stacks	Optimization parameter
Stack Maximum Power	[redacted]
Stack Minimum Power	[redacted]
Efficiency	[redacted]
Maximum ramp-up & ramp-down rate	[redacted]
Efficiency Decrease	[redacted]
Investment Cost	[redacted]
Replacement Frequency	[redacted]
Replacement Cost	[redacted]
Replacement Cost Annual Decrease Rate	[redacted]
Annual O&M Cost	[redacted]

For each time step, the program evaluates the energy production potential against the battery storage state of charge and the entire power demand for the hydrogen production. The full year is simulated and the result is considered satisfactory if the energy balance is satisfied for every time step and the minimum hydrogen production value is met. For this report, no imported energy is considered and therefore all of the power must come from the PV array or battery storage. Battery storage power is used for operating the electrolyzers at a minimum 5% power level, for running a compressor during that minimum power/production case, and for other incidental loads when PV power is unavailable.

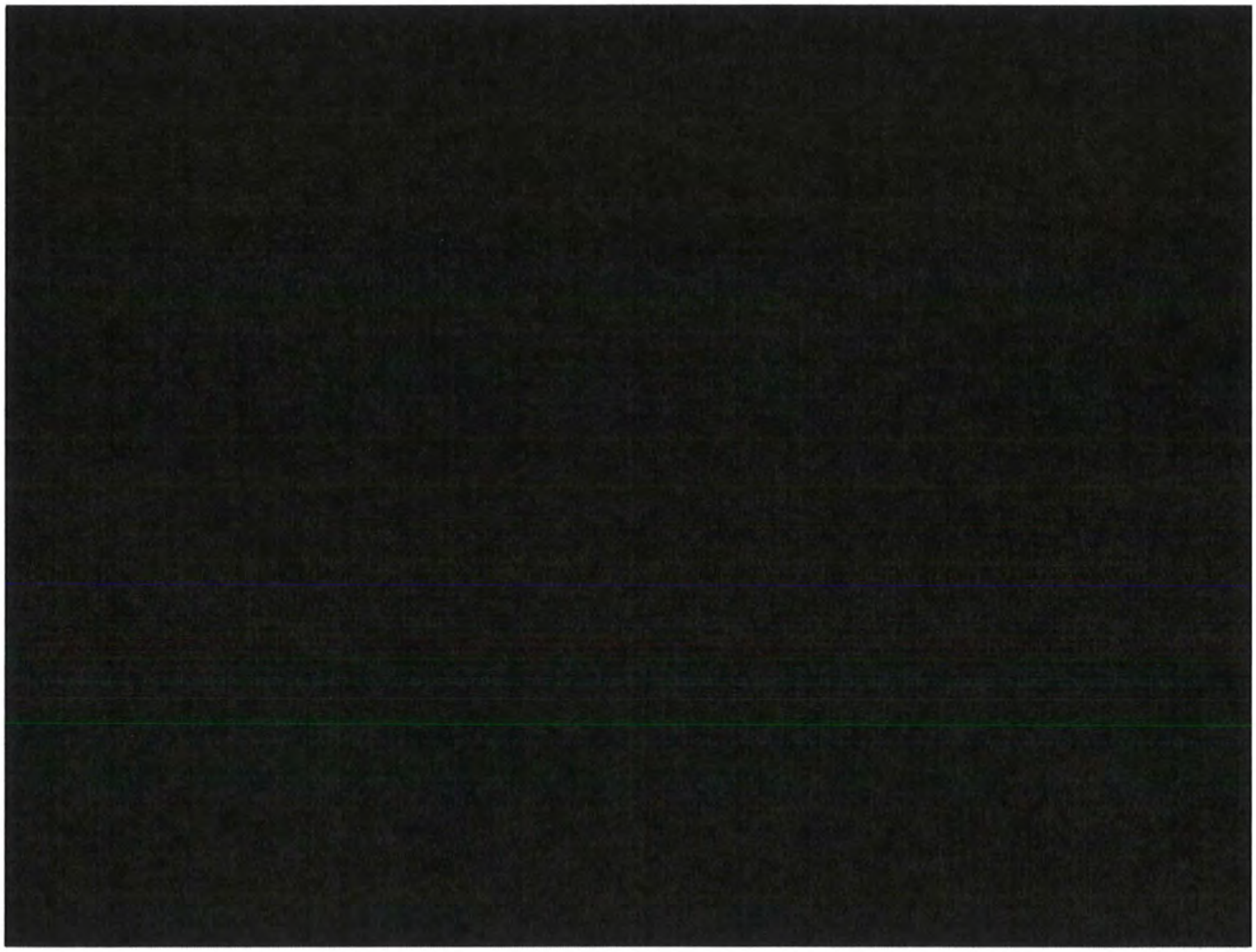
The program uses an algorithm to minimize the Levelized Cost of Hydrogen (LCOH) by investigating multiple values for each input parameter, such as the quantity of PV modules, batteries, and electrolyzer installed power. For each satisfactory simulation the economic data and input values are tabulated. After multiple simulations, an optimum value for each parameter is determined and this represents the basis of design for the hydrogen production at the given location. The final economic data is calculated based on the selected input values.

The following parameters are optimized:

- Quantity of [redacted] PV modules. [redacted]
- Quantity of [redacted] wind turbines.
- Quantity of [redacted] batteries [redacted]
- Installed power of electrolyzers.
- Minimum electrolyzer operating power when no renewable source is available.
- Electrolyzer maximum flowrate.

After the optimization is complete, full technical data time series as well as economic data are available for all of the production parameters. The following figure is a series of charts depicting a typical week of power production and hydrogen output for the Whitewater [redacted] production case, the upper limit of the Low Demand scenario range. Although the quantities would scale up or down proportionately based on the required demand case, these graphs are representative of results and variation during this sample week at this site for all studied demand cases. The top graph depicts the power output from the solar electrical generation plant which varies each day based on weather patterns. Summer days result in curtailed power as part of the optimization to make-up for lower winter output. The middle graph depicts the battery storage status with 100% charge during the day and nominal consumption at night. This energy storage is based on the assumptions that no external power is available to power the electrolyzers during hours of no solar power output and that the selected electrolyzers may require minimum 5% operating level. The bottom graph depicts the resulting hydrogen production during this period of time for this optimized plant configuration.

FIGURE 11: WEEKLY POWER PRODUCTION AND HYDROGEN OUTPUT



[redacted]

A hydrogen production rate of [redacted] of hydrogen, the upper limit of the Low Demand range, was assessed relative to power generation and hydrogen production. The results of the power generation and hydrogen production analysis were then factored to correspond with the hydrogen production rates for each of the demand cases: Low Demand Rate of [redacted], Medium Demand Rate of [redacted], and High Demand Rate of [redacted]. Pipeline system analysis and pipeline system sizes were based on these factored values for each of the demand rates.

The following table illustrates the scale of the facilities needed to produce the Low/Medium/High Demand hydrogen cases based on power generated by solar/PV only:

Table 8: Summary of Production Values

	Low	**Medium – Mojave/Delta**	**Medium – Mojave/Five Points**	**High – All Cases**
Land Area Needed for Solar Panels:				
Five Points	[redacted]		[redacted]	[redacted]
Mojave	[redacted]	[redacted]	[redacted]	[redacted]
Whitewater	[redacted]			[redacted]

Table 8: Summary of Production Values				
	Low	Medium – Mojave/Delta	Medium – Mojave/Five Points	High – All Cases
Blythe				[redacted]
Delta		[redacted]		[redacted]
H2 Production Volumes and Potable Water (million gallon/day) Needed by Electrolyzers for Hydrogen Generation:				
Five Points			[redacted]	[redacted]
Mojave		[redacted]	[redacted]	[redacted]
Whitewater	[redacted]			[redacted]
Blythe				[redacted]
Delta		[redacted]		[redacted]
Land Area for Electrolyzers:				
Five Points			[redacted]	[redacted]
Mojave		[redacted]	[redacted]	[redacted]
Whitewater	[redacted]			[redacted]
Blythe				[redacted]
Delta		[redacted]		[redacted]
Installed Compression Needed to Accommodate Peak Production Rate at the Origin:				
Five Points	[redacted]		[redacted]	[redacted]

Table 8: Summary of Production Values

	Low	Medium – Mojave/Delta	Medium – Mojave/Five Points	High – All Cases
Mojave	[redacted]	[redacted]	[redacted]	[redacted]
Whitewater				[redacted]
Blythe				[redacted]
Delta		[redacted]		[redacted]
Total Capex Generation/Production Cost Alone, Excluding Land and Compression:				
Five Points			[redacted]	[redacted]
Mojave	Between [redacted] depending on location	[redacted]	[redacted]	[redacted]
Whitewater				[redacted]
Blythe				[redacted]
Delta		[redacted]		[redacted]

Note that production center compressor figures do not include intermediate pipeline or underground storage compression needs, which vary depending on the selected configuration.

3.2 Blue Hydrogen as a Supplement to Green Hydrogen

Assessment of blue hydrogen is being provided as information only and is also conceptual in nature. Blue hydrogen production involves production of hydrogen from hydrocarbon and water, and capture and permanent sequestration of the carbon dioxide produced in the process. Technip Energies conducted a high-level assessment of complementing conceptual green hydrogen production with blue hydrogen for the low demand case [redacted] scenario. This assessment is included in the "Hydrogen Production Assessment

Report." This assessment was not performed for the Medium and High Demand cases due to the large scale of carbon sequestration that would be required, the potential lack of suitable sequestration near a given production site, and because blue hydrogen has generally been considered an interim or backup solution to green hydrogen production.

Capital costs for blue hydrogen production and sequestration are typically much lower than for green hydrogen production. Blue hydrogen also offers some benefits in being able to provide the cushion gas for underground storage more quickly and economically, and could provide backup supply long term in the event of weather-related or other impacts on green hydrogen production.

As outlined by Technip, the production of green hydrogen by electrolysis produces oxygen as a by-product, and at such high volumes that there is no market for it. Blue hydrogen technologies entail either the use of Steam Methane Reforming (SMR) with carbon capture or Auto Thermal Reforming (ATR) based technology with carbon capture. The SMR technology reacts the feed and steam in the presence of a catalyst to make syngas. This reaction is endothermic and is supported by burning natural gas and off gases. The ATR based technology uses oxygen to combust the feed in a pressurized vessel and then reforms the resulting product gases to generate Syngas. The endotherm for this reaction is supplied by the combustion of feed itself.

The ATR process is more efficient and effective in capturing carbon dioxide for sequestration. For every ton of green hydrogen produced by electrolyzers, the ATR process can produce up to 2.2 tons using the oxygen produced by the electrolyzers. Storage of oxygen is required to balance the uneven daily production, in the same way that daily hydrogen storage it required.

If blue hydrogen is to be considered, further assessment is needed, particularly in conjunction with the development of hydrogen storage in oil/gas reservoirs and potential for nearby carbon sequestration. A blue hydrogen production plant would preferably be located near the sequestration location to minimize CO2 transport in pipelines. Oxygen may be able to be transported by pipeline from the electrolyzer site to the blue hydrogen plant, dependent upon project economics.

4.0 Conceptual Pipeline System Analysis

Hydraulic analysis was performed for delivery of hydrogen to the Los Angeles Basin from each of the 9 systems considered. This included 6 cases at the Low Demand rate of [redacted] of hydrogen, 2 cases at the Medium Demand rate of [redacted], and 1 case at the High Demand rate of [redacted]. These cases are illustrated and briefly described in Section 2. A separate Hydraulic Analysis Report provides details of the analysis and is available for review.

The feasibility and operability of the conceptual hydrogen pipeline system depends heavily on the ability to meet the storage needed to accommodate the daily and seasonal changes in solar power and hydrogen production rates. Surplus backup storage would be in addition to seasonal storage and would be required, but has not been considered in this study. Hydrogen storage could include a combination of a) excess pipeline capacity allowing storage by packing/unpacking, b) remote underground storage delivered by pipeline, and/or c) "onsite" pressurized gas storage ([redacted] diameter pipe). These and other conceptual storage options are described in Section 8.

With most hydrogen being produced in the daytime due to solar availability, the rate that the compressors and pipeline system must handle during the peak production hours of the day can be 250-260% of the average flow rate (based on the all-solar, no-wind case). In other words, limiting hydrogen production to only daylight hours requires that compression capacity be [redacted] over a case where production could be spread throughout all hours of the day. Large volume, high pressure storage at the production area was assessed to accommodate the daily variation in production rate, as was installation of additional batteries to allow compressors to operate longer hours. [redacted]

For the Delta Low Demand case, System 5, all hydrogen production is specified to be relatively close to Delta, and to the salt cavern storage in Delta that is included in this case. For this case, it is assumed that cavern storage will have sufficient capacity to accommodate both daily and seasonal storage needs without exceeding operating parameters. For most other cases, large volume high pressure storage is included at the production area, but for this System 5 Delta Low Demand case it is assumed that it would not be needed. [redacted] The Mojave with Delta storage Low Demand case, System 6, also is assumed not to need storage at the production site. [redacted] For the Mojave/Delta Medium Demand case, System 7, it was conservatively assumed that there would not be cavern capacity to accommodate the daily storage needs, and local storage was provided at both Mojave and Delta production sites.

For cases involving oil/gas reservoirs for storage, as included in Systems 1-4, 8, and 9, the assumed injection rate was limited to satisfying seasonal storage needs. Daily storage would require more than double the reservoir injection rates, which would require more wells, more injection compressors, and more pipelines to transport hydrogen from production to the reservoir storage location at the higher rates. As such, for the purposes of this conceptual study, "onsite" pressurized gas storage (or near-site) has been added to all systems except System 5 to store daily excess production and allow relatively steady flow of produced hydrogen to the pipeline system.

4.1 Initial Low Demand Cases for Five Production Sites (Systems 1-5)

The hydrogen production rate varies daily from peak daytime production to minimum night time production, and seasonally with much higher production rates in summer than in winter. The pipeline system and hydraulic analysis considered both daily storage requirements and seasonal storage requirements. [redacted]. For each of the five California production sites, geologic storage in a reservoir was modeled with the ability to go into and out of the reservoir at the full rates required for daily and seasonal storage, and assumed confirmation of a suitable storage reservoir in the Castaic Junction or the San Joaquin Valley areas for this purpose. However, that storage of hydrogen in existing gas and oil reservoirs in Southern California has not been fully studied; accordingly, additional analysis of storage options and feasibility is recommended.

For initial hydraulic analysis and pipeline estimating purposes, local storage was assumed to be feasible and located near the Castaic Junction area [redacted] As described previously, production site pressurized storage has been added to cost estimates for Systems 1-4 to provide daily storage capability. (An option for using California production with Utah storage is discussed in Section 4.2, [redacted]

For the case of production in the Delta, Utah area, storage in multiple local salt caverns was assumed, with delivery to the Los Angeles Basin from either production or storage. The cost of such storage was not included in the scope of this study, and since it is a proven technology and the salt cavern feasibility is reported to have been studied relative to hydrogen storage, it was assumed that sufficient capacity could be provided. For this Utah production low demand case, [redacted] with an intermediate compressor station near Las Vegas was found to be sufficient.

For the purposes of this conceptual study, a working storage volume of [redacted] hydrogen production rate was assumed as the minimum to accommodate the production rate variation between summer and winter. Future study of demand variation between seasons may result in reduced seasonal storage requirements, as it is possible that summer demand will be higher than winter demand, which would correspond somewhat with the higher summer PV output and hydrogen production rates. Additional working storage should be considered for backup supply and resiliency. Note that working storage does not include the initial gas charge required to prime the volume with hydrogen nor losses inherent to the characteristics of the specific formation.

Demand/delivery rate was assumed to be uniform throughout the year except for power plant demand. A demand profile was developed that provided daily variation in delivery rates based on typical power plant demand cycle. [redacted]

[redacted]his variation will require additional pressure controls to ensure that the line has sufficient downstream pressure to handle the higher flow rates for certain portions of the day.

Hydraulic analysis included both the great variation in daily production rate and the variation in power plant demand rate. Each production site/case was analyzed to determine the number and sizes of pipelines required to accommodate the high daytime peak production rates. Initial hydraulic analysis did not include storage at the production sites, and with daily peak production rate approximately [redacted] the average production rate, pipeline transportation capacity had to be increased accordingly. As an example, production at Blythe required [redacted] to Whitewater and [redacted] from there to the LA Basin to accommodate the high peak production rate and work with the potential storage in the Castaic Junction are[redacted]

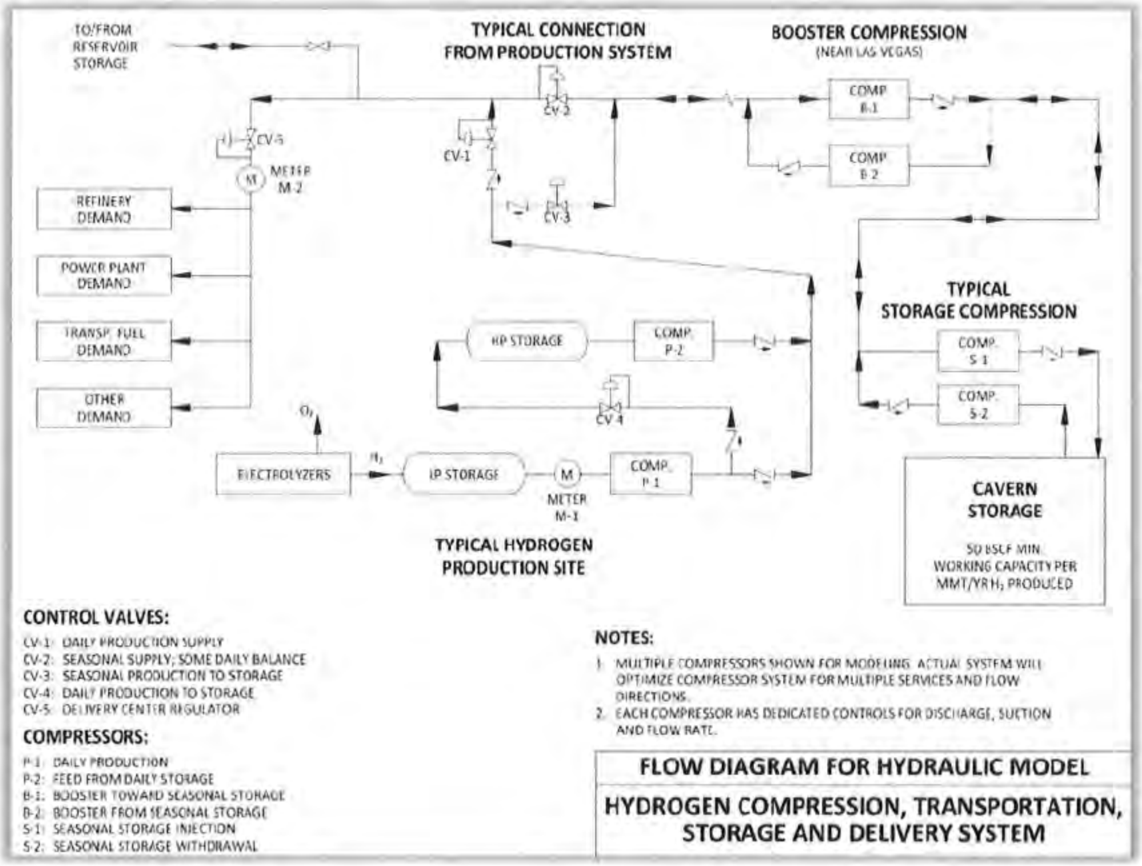
As mentioned in Section 3 Hydrogen Production Summary, further consideration was given to pressurized storage at the production site, in the form of buried [redacted] diameter pipe. Although this requires many miles of [redacted]-diameter high pressure "pipeline" and substantial cost, it reduces the number and size of pipelines from what would otherwise be required without it, reduces the pressure cycling in the primary transmission pipelines, and, with appropriate compression, establishes a potentially feasible option for handling the daily production cycles. (This concept may also be advantageous for the staged development of the system, in which the pipeline packing/unpacking contributes more storage volume in early stage development, but onsite storage must be added at each production site as total production volume increases.) The use of this form of high pressure storage was not included in the initial pipeline system plan, hydraulic analysis, and cost estimating for these low demand cases in this report, but has now been added to the cost estimates (See System 6).

4.2 Additional Low Demand Case, Mojave Production with Delta Pipeline (System 6)

Sites in California such as Mojave have a substantially higher capacity factor relative to solar power generation and subsequent hydrogen production than Delta, Utah. For this reason, and because salt cavern storage is a proven storage method for hydrogen, a separate low demand case was assessed based on hydrogen production in the Mojave area with a pipeline to/from salt cavern storage near Delta, Utah. This case included pressurized storage at the production site (modeled as [redacted] pipeline) in order to accommodate daily production cycling, reduce the transmission pipeline pressure cycling, and eliminate daily flow oscillations in and out of underground storage.

As mentioned above, the pipeline to Delta salt cavern storage was included to complement in-state storage options and handle the seasonal storage requirements. These features were compiled as System 6. The following diagram shows the component and controls for the hydraulic modelling of this scheme.

FIGURE 13: SYSTEM FLOW DIAGRAM



Additional analysis was performed relative to this System 6, production at Mojave and using storage in Utah. Mojave was selected as the logical site for this system as it lies geographically between Utah and the Los Angeles Basin and has favorable solar performance. The system was simulated with the controls shown in the figure above. During the peak production times, hydrogen charges the high-pressure (HP) storage, feeds the Los Angeles demand points, and flows toward the storage area in Utah. Intermediate compression in the Las Vegas area would be reversible and was used to manage the pipeline inventory. The daily variation in production rate was accommodated by the variation of HP storage at Mojave and in pipeline pressure, with cavern storage being used primarily for variation in production rate between summer and winter. Cavern storage was also used to supply demand when production was interrupted or reduced for several days by weather/solar interference.

The scenario described above, with production in the Mojave area and storage in the Utah salt caverns, currently seems to be a favorable configuration for the large-scale development of this low demand case. This same concept is expected to be able to accommodate other potential production areas that would tie into the Utah/LA pipeline, such as Whitewater; however, it would require modifications to the current "Low Demand Scenario" pipeline routing to allow direct, high-pressure access to the Utah pipeline from the production site.

These options will be illustrated further in the cases selected for inclusion in the Medium and High demand scenarios, as production will most likely be distributed across multiple sites.

4.3 Medium Demand Case, Mojave and Delta Production with Utah Storage (System 7)

The medium demand cases consider potential production in multiple locations with seasonal storage at a single location. Medium Demand Case System 7 is based on an expansion of System 6 hydrogen production rates and locations, and expansion of pipeline and Utah storage capacities.

Mojave area production was increased to [redacted], an additional [redacted] production was added near Adelanto (referred to herein as Mojave South), and [redacted] production was added in Utah approximately [redacted] miles from the Delta cavern storage site. System operation, controls, and facilities were assumed to be similar to System 6, with high pressure gas storage at each production site and seasonal storage at Delta, Utah salt caverns.

This System 7 case is illustrated in Figures 7A and 7B in Section 2. Figure 7B shows the numbers and sizes of pipelines included in the conceptual development and assessment of this demand case. [redacted] were added to the System 6 case between Delta storage and Adelanto ([redacted]) to provide sufficient capacity to meet the full average system demand from underground storage. Additionally, a pipeline route/segment was created from Adelanto south to Chino Hills to allow delivery to the LA Basin from the north (Santa Clarita) and east (Chino Hills) using the sizes and numbers of pipelines shown on Figure 7B. The intermediate compression facility in the Las Vegas area was expanded for the higher capacity.

Smaller distribution lines were included in the project cost to provide additional connections and supply throughout the Southern California region. Delivery locations and volumes for the Medium Cases are based on conceptual totals only, and the medium case system development is based on the ability to deliver the medium case volumes to the Los Angeles Basin. Hydraulics were performed and pipelines were sized with sufficient capacity to deliver the full [redacted] to the LA Basin. This approach provides a reasonable estimate of capacities required by the pipeline system to produce in the Mojave area, store in Delta, and deliver to potential demand centers.

4.4 Medium Demand Case, Mojave and Five Points Production with San Joaquin Valley Storage (System 8)

Oil reservoirs in the San Joaquin Valley were identified as a potential hydrogen storage solution and alternative or supplement to Utah salt cavern storage. In-state storage could have advantages over storage in Utah due to closer proximity to southern California demand centers and resulting lower pipeline costs and potentially enhanced ability to respond to demand fluctuations. This Medium Demand Case System 8 provides conceptual analysis of use of a San Joaquin Valley storage facility rather than the Utah storage included in System 7.

For this case, production in the Mojave area remains the same as in System 7, producing the bulk of the hydrogen ([redacted] across Mojave North and Mojave South). The balance of the required [redacted] production is assumed to be from the Five Points area, potentially [redacted] miles from the San Joaquin Valley storage site.

This System 8 case is illustrated in Figures 8A and 8B in Section 2. Figure 8B shows the numbers and sizes of pipelines included in the conceptual development and assessment of this demand case. From the San Joaquin Valley storage facility to Kern Junction, [redacted] are included for this case. [redacted] pipeline connects Mojave Junction to Kern Junction to provide a more direct route for Mojave production (North and South) to be transported to the San Joaquin Valley storage facility. The system installation and operation is similar to System 7, with storage and pipelines in Utah being replaced by storage and pipelines in the San Joaquin Valley and southern California.

As with System 7, smaller distribution lines were included in the project cost to provide additional connections and supply throughout the Southern California region. The arrangement of pipelines through the California central valley reduces the length of distribution lines in this area that were included in this conceptual study, and the cost for same included in the cost estimate for this case. Delivery locations and volumes for the Medium Cases are based on conceptual totals only, and the medium case system development is based on the ability to deliver the medium case volumes to the Los Angeles Basin. Hydraulics were performed and pipelines were sized with sufficient capacity to deliver the full [redacted] to the LA Basin. This approach provides a reasonable estimate of capacities required by the pipeline system to produce in the Mojave area, store in the San Joaquin Valley, and deliver to potential demand centers.

4.5 High – All Cases Demand Case, California Production with San Joaquin Valley and Utah Storage (System 9)

For conceptual analysis of the High Demand Case of [redacted] of hydrogen production, some amount of hydrogen production was assumed to be required at all of the conceptual areas considered in this study. High pressure gas storage was included at each production location for daily storage volumes, and both of the seasonal storage facilities considered in Systems 7 and 8 , San Joaquin Valley and Delta, were included with this High Demand system plan (System 9). System 9 is essentially a combination of Medium Case Systems 7 and 8, with the addition of a total of [redacted] total production from Blythe and Whitewater areas, and pipelines transporting the additional production.

This High Demand Case System 9 is illustrated in Figures 9A and 9B in Section 2. Figure 9B shows the numbers and sizes of pipelines included in the conceptual development and assessment of this demand case. In addition to the combined pipelines from Systems 7 and 8, System 9 also includes [redacted] from Blythe to Whitewater and [redacted] from Whitewater to Chino Hills Junction. [redacted] are included between Santa Clarita Junction and the LA Basin, and between Chino Hills Junction and the LA Basin. Together these pipelines can feed the total [redacted] of average demand flow. The pipelines to/from both Delta and San Joaquin Valley storage facilities remain unchanged from their respective system configurations in Systems 7 and 8, since storage for this System 9 is split between the two seasonal storage sites.

Additional distribution lines were included in the project cost for this High Demand case based on conceptual distribution to supply points throughout Southern California, approximately doubling the mileage of the distribution lines included in Medium Demand Case System 8. As was done for the Medium Demand cases, hydraulics were performed and pipelines were sized to provide sufficient capacity to deliver the ful [redacted] High Demand Case rate to the Los Angeles Basin. This approach provides a reasonable approximation of a pipeline system that could transport the high demand case hydrogen from the production sites, to and from storage, and to potential demand centers in southern California.

5.0 Water Resources

Potential water sources were researched relative to each of the production sites. The following section provides a summary of water demand and viability with more detailed information available in the "Water Resources Reports."

5.1 Demand Scenario

The water resources assessment was based on preliminary demand cases production rates and corresponding water requirements. The assessment and data in the water resources report has been adjusted in this report to correlate to the final demand rates in this study.

The electrolyzers use demineralized water for the production of hydrogen. The actual amount of water required to produce the needed demineralized water will depend on the quality of water available and the treatment process required. [redacted]

[redacted]

Table 9: Potable Water Demand for Production Scenarios

Production Scenario*	Daily Demand (acre-feet/day)[1]	Daily Demand (million gallons/day [MGD])	Annual Demand (AFY)[2]
Low ([redacted])	[redacted]	[redacted]	[redacted]
Med. [redacted])	[redacted]	[redacted]	[redacted]
High ([redacted])	[redacted]	[redacted]	[redacted]

[redacted]

[2] Annual demand assumes the daily demand is constant each day over 365 days of the year. For comparison to the proposed project demands shown here, total SWP water deliveries to the High Desert Region were recently 66,200 AFY (SWC 2021), although the actual demand quantity varies each year. In 2021, SWP deliveries will be reduced to five percent of allocations (DWR 2021a).

5.2 Current Availability

Water availability by production site varies, [redacted] The water resource study indicated that water resources are over allocated in California. The following table summarizes current, existing major water supply by site.

Table 10: Preliminary Water Viability by Site

[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Several types of water sources were explored including groundwater, water projects, recycled water, and desalination. Groundwater basins exist at all sites (Blythe groundwater is part of the Colorado River), [redacted]. Water projects import water, such as California Aqueduct (Northern California), Los Angeles Aqueduct (Owen's Valley) and Colorado River Aqueduct (Colorado River). These are considered more reliable but can be seasonal and have generally all been oversubscribed. Recycled water is considered a potentially reliable long term source, [redacted]s. Desalination would be a potential means of replacing water from another source.

Utah currently does not use its full allocation of Colorado River water (approximately 22% is unused), and has not developed its allocation of Colorado River water, but is in process of expanding its share as projected water demand increases in the state. The water volume required to produce the hydrogen for the Delta High Demand case, System 5, would be equivalent to approximately [redacted] of total current water usage in Utah.

5.3 Recycled Water

[redacted]

Table 11: Preliminary Assessment of Recycled Water Viability by Site

Production Scenario	[redacted]	[redacted]
Five Points	[redacted]	[redacted]
Mojave	[redacted]	[redacted]
Whitewater	[redacted]	[redacted]
Blythe	[redacted]	[redacted]
Delta	[redacted]	[redacted]

[redacted] For comparison, the existing Lancaster and Palmdale water recycling plants currently have a combined permitted treatment capacity of 33,500 AFY, but in 2015 only 500 AFY of recycled water was provided to recycled water customers. The bulk of recycled water produced was disposed of on agricultural fields, as irrigation water. [redacted].

[redacted].

The amount of recycled water able to be produced is a direct function of the amount of wastewater entering the treatment system. For purposes of this study, recycled water is assumed to be reliable since it consists of treated waste water generated by an area's population. As long as the population for the service area remains stable or grows, the volume of recycled water available is not expected to vary significantly for average, single-dry, or multi-dry year water conditions. [redacted].

[redacted].

5.4 Existing Water Allocation

Generally, existing surface water and groundwater resources in California are over-allocated, meaning there is greater demand than what is available. [redacted]. However, the amount of SWP water that is actually delivered in the production area is highly variable and subject to fluctuations within the state-wide system; for example, in 2021, SWP contractors will only receive 5% of their allocated supply. The following table summarizes major water import projects to the Southern California area.

Table 12: Overview of Major Water Supply Projects (Source: Mojave Water Resources Report by D. Edwards/Rincon Consultants)

Water Supply Project	Infrastructure Nearest to Mojave	Management	Source Water	Key Summary Data
State Water Project	California Aqueduct	State – DWR	Sacramento-San Joaquin Delta (surface runoff)	131,678 AFY = 2021 SWP allocations to be conveyed in the California Aqueduct to Southern California SWP contractors
Central Valley Project	San Luis Unit (San Luis Dam, Reservoir, and Canal)	Federal – USBR	Sacramento-San Joaquin Delta (surface runoff)	75,972 AFY = 2021 CVP allocations for Municipal & Industrial in Southern California
Owens Basin and Mono Lake Projects	Los Angeles Aqueduct	Local – LADWP	Eastern Sierra Nevada Mtns. (snowpack / surface runoff)	190,400 AFY = total 2025 diversions to LADWP via Los Angeles Aqueducts for municipal demands
Colorado River Project	Colorado River Aqueduct	Federal – USBR; State – Multiple; Local – Metropolitan	Colorado River Lower Basin (surface runoff & conjunctive use management)	550,000 AFY = total authorized diversions from Colorado River Lower Basin to Metropolitan via Colorado Aqueduct for municipal demands

Notes:
AFY = acre-feet per year; CVP = Central Valley Project; DWR = Department of Water Resources; LADWP = Los Angeles Department of Water Resources; Metropolitan = Metropolitan Water District of Southern California; SWP = State Water Project; USBR = U.S. Bureau of Reclamation

[redacted].

In contrast, Utah has not developed its full allotment of Colorado River water though it is expanding its system in anticipation of future water demands.

5.5 Expansion of Existing Water Supply

[redacted].

[redacted]. [redacted], [redacted] in general recycled water supply is developed in response to demand. For comparison, the existing Lancaster water recycling plant currently has a permitted treatment capacity of 18 million gallons per day (MGD), [redacted]. [redacted]

[redacted].

5.6 Desalination

[redacted].

[redacted]. The Poseidon Carlsbad desalination plant and the proposed Huntington Beach desalination plant each are sized to produce 50 MGD, [redacted] [redacted]. Based on news articles only, the Carlsbad plant apparently provides water at $2250 per acre-foot, or $.0069 per gallon of water. [redacted] of hydrogen produced. (Note that amount of raw water to process water may be higher than 2:1, depending on the water quality.) Water from the California Aqueduct and the Los Angeles Aqueduct flow relatively close to the Mojave area, and the Colorado River Aqueduct brings additional water to the southern California coastal region, passing through potential green hydrogen production areas.

[redacted].

[redacted] this and other approaches to increasing the water supply should be considered in future feasibility studies.

6.0 Conceptual Pipeline Infrastructure

6.1 Permitting

A high-level, preliminary permit assessment was completed for each conceptual pipeline system and should be referenced for details specific to environmental permitting for each conceptual pipeline system. Blythe and Whitewater were combined into one individual report due to their overlap. The assessments include a high-level review of each conceptual route, expected major permits, potential lead agencies and permitting issues and schedule. These individual assessments have been provided as attachments and a summary is provided below.

Pipeline routes are high-level and are subject to further refinement, including re-routing to avoid sensitive areas.

6.2 High-Level Permitting Considerations

For components in California, the project would require completion of environmental review, such as an Environmental Impact Report (EIR), under the California Environmental Quality Act (CEQA). Similarly, approvals by any federal agency would require environmental review, such as an Environmental Assessment (EA) or Environmental Impact Statement (EIS), under the National Environmental Policy Act (NEPA).

A pipeline system will necessarily require a variety of state, local, and potentially federal permits typical of any other large-scale natural gas pipeline, with which the Company is familiar, and are therefore not repeated herein.

Special considerations for each of the geographic areas are discussed below.

6.2.1 Five Points

[redacted].

6.2.2 Mojave

[redacted].

6.2.3 Whitewater and Blythe

[redacted]..

6.2.4 Delta

It is anticipated that neither Utah nor Nevada would require a state review. However, as discussed above, components in California would require CEQA review. Further, like California, Nevada would require obtaining a Certificate of Public Convenience and Necessity (CPCN).

[redacted]

[redacted]).

6.3 Additional Permitting Considerations and Schedule

Permitting considerations include potential environmental constraints that would complicate the permitting process. Those constraints could increase lead times and permitting requirements associated with the alignments. See Table 24 below for representative permitting durations.

Individual reports prepared for each of the pipeline systems summarizes the major permits that may be required and the involved agencies. A separate table is provided summarizing potential permit considerations and options for each route. As potential routes are assessed in future studies, particular areas should be reviewed to determine if re-route of the pipeline is preferable. In addition, the reports include estimated times for obtaining permit approval. Most major permits are expected to take a minimum of one to three years to obtain.

At the Federal level, NEPA lead and/or cooperating agencies could include the Department of Transportation (DOT), the Federal Energy Regulatory Commission (FERC) or the Bureau of Land Management (BLM) for the Delta and Blythe options.

6.4 Conceptual Pipeline Routes

Conceptual pipeline routes were developed to allow the pipeline systems to be estimated. This allowed the estimates to account for construction type, mileage and other factors at a conceptual level. For purposes of the study, all class 2, 3, and 4 pipe was specified as a class 3 pipe specification and all class 1 was specified as class 1. This adds some conservatism on the material specification of the pipeline.

Tables 13A, 13B and 34 (in appendix) summarize information for the proposed conceptual pipeline systems.

TABLE 13A: TOTAL MILEAGE AND CURRENT CLASS LOCATION OF LOW DEMAND CONCEPTUAL PIPELINES

[redacted]

Table 13B: Total Mileage and Current Class Location for Medium and High Demand Pipelines

	Class 1	Class 2	Class 3	Class 4	Total
			System 7, Medium - Mojave/Delta		
Trunks	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Distribution	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 13B: Total Mileage and Current Class Location for Medium and High Demand Pipelines

	Class 1	Class 2	Class 3	Class 4	Total
Service	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Total	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
		System 8, Medium - Mojave/Five Points			
Trunks	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Distribution	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Service	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Total	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
		System 9, High - All Cases			
Trunks	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Distribution	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Service	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Total	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

6.4.1 Conceptual Route Considerations

Pipelines routed from the production centers to the main demand centers are all [redacted] diameter [redacted] pipes and may require [redacted] to feed the system. The routes selected are considered conceptual and high level at this stage of study and did not take into account all of the issues associated with routing [redacted] diameter pipelines. No substructure research was completed, and the routes largely follow existing established pipeline corridors.

Pipeline routing did take into account constructability and SoCalGas standard practices for locating pipelines. Through urban areas, the pipelines are routed largely on city streets and in agricultural areas the pipelines are routed following local roads rather than across open farm fields. Thus, the overall mileages are considered representative of actual SoCalGas requirements for pipelines. An allowance for Caltrans (auger bore installations) and major water crossings (Horizontal Directional Drills) has also been included, but is considered preliminary and subject to change.

For this study, new pipeline routes reflect areas that have been highly developed over time. Other factors that influence pipeline routes are assumptions based on user demands and maximum usage of the Federal Energy Corridor. Users considered are power plants, transportation, refineries, residential, industrial and commercial, and are categorized by demand assumptions of High, Medium, and Low volume usages. The pipelines will route through and in between cross-country areas, rural and high urban, and production plant boundaries within the wider Central California down to Southern California. Pipeline routes will generally avoid areas that are highly challenging areas for environmental reasons such as national parks, wildlife habitats, and wetlands. When possible, pipelines will route in public land or city right-of-way (ROW), and private ROW.

To capture pipeline routing and destination points, the conceptual pipelines were assumed to route to major demand centers including demands centers outside of Los Angeles County. Centers include the following:

- LA Basin Demand Centers Listed in RFI
    - LADWP Power Plants
        - Valley
        - Scattergood
        - Harbor
        - Haynes
    - Ports of Los Angeles and Long Beach
    - LA Refineries
- Other Demand Centers
    - Other Demand Centers
        - Other Refineries and Chemical Plants
        - SoCal Edison and third-party Power Plants
        - San Bernardino
        - Ventura County
        - Cement Plants

6.4.2 Co-location within Existing SoCalGas ROW

This assumes the width of the existing easement could accommodate an additional pipeline(s) [redacted] in diameter. Regardless of co-location, additional workspace out of the existing right-of-way for construction would be necessary.

6.4.3 Pipe Corridors

Federal government agencies have established Federal Energy Corridors that would typically reduce the time to plan, permit and construct energy infrastructure projects. The pipeline routes in this study have utilized designated federal utility corridors where they exist. The following designated corridors are used in this study:

Table 14: Designed Federal Energy Corridors	
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

6.4.4 Constructability

6.4.4.1 Existing Pipelines

Steel pipeline service conversions were outside of the scope of this study.

6.4.4.2 Type of Construction

- Type 1A - Cross Country: Pipeline installation within rural setting assumes no paving, minimum 36" cover, native backfill, minimum 70 ft. wide workspace, limited existing substructures along alignment, no traffic control, minimal environmental restrictions, and unrestricted work hours.
- Type 1B - Cross Country with Environmental Restrictions: The same parameters as Type 1A with the addition of environmental restrictions in place.
- Type 1C - Cross Country with Hilly Terrain/Rocky Soils: The same parameters as Type 1A with the exception that hilly terrain and/or rocky soil conditions are assumed to be present.
- Type 2 - Rural Roadway: Pipeline installation assumes shoulder installation with minimal asphalt paving, minimum 48" cover, native backfill, minimum 2-lane workspace, low density substructures, limited traffic control, minimal environmental restrictions, and normal working hours.
- Type 3 - Secondary Roadway: Pipeline installation assumes asphalt paving, minimum 48" cover, native backfill, minimum 2-lane workspace, medium density substructures, limited traffic control, minimal environmental restrictions, and normal working hours.

- Type 4 - Primary Roadway: Pipeline installation assumes asphalt/concrete paving, minimum 48" cover, slurry backfill, minimum 2-lane workspace, high density substructures, heavy traffic control, minimal environmental restrictions, and restricted working hours (9 am- 3:30 pm).
- Type 5 - Auger Bore: Auger Bore: Assumes cost of bore/receiving pit excavation; auger bore equipment rental and stringing/welding. Assume typical bore length of 200'.
- Type 6 - HDD: Assumes cost for equipment rental, 1500' typical length, and pipe stringing/welding.
- Type 7 - Night Work on Primary Roadway (30% more than Type 3): Pipeline installation assumes asphalt/concrete paving, minimum 48" cover, slurry backfill, minimum 2-lane workspace, high density substructures, heavy traffic control, minimal environmental restrictions, and restricted working hours (10pm - 5am).

6.4.4.3 Auger Bores

Auger bores are assumed for all pipelines crossing Caltrans and RR lines with a typical length of 200'. The total crossings for each system and demand case are as follows:

Table 15: Auger Bores in Estimate

System	Total Crossings
System 1, Five Points	[redacted]
System 2, Mojave	
System 3, Whitewater	
System 4, Blythe	
System 5, Delta	
System 6, Mojave– with Delta Pipeline	
Distribution - Low	
System 7, Medium – Mojave/Delta	
Distribution, Medium – Mojave/Delta	
Medium – Mojave/Five Points	
Distribution, Medium – Mojave/Five Points	

Table 15: Auger Bores in Estimate	
High – All Cases	[redacted]
Distribution – High, All Cases	[redacted]

6.4.4.4 Horizontal Direction Drills (HDDs)

HDDs are assumed for major waterbody crossings with a typical length of 2,000 feet. The total crossings for each system and demand case are as follows:

Table 16: HDDs in Estimate	
System	**Total Crossings**
System 1, Five Points	[redacted]
System 2, Mojave	
System 3, Whitewater	
System 4, Blythe	
System 5, Delta	
System 6, Mojave– with Delta Pipeline	
Distribution - Low	
System 7, Medium – Mojave/Delta	
Distribution, Medium – Mojave/Delta	
Medium – Mojave/Five Points	
Distribution, Medium – Mojave/Five Points	
High – All Cases	
Distribution – High, All Cases	

6.4.4.5 Motor Operated Valve Sites (MOV)

MOV sites are assumed to be installed every 16 miles in cross country and rural areas, and every 8 miles in urban areas.

6.4.5 Public Right-of-Way (ROW)

[redacted].

6.4.6 Established Right-of-Way (ROW)

For purposes of this study, the use of established ROW was not considered. [redacted].

6.5 Design and Pressure Class

6.5.1 Code Requirements

To meet the future build-out of hydrogen pipeline systems, ASME developed and issued ASME B31.12, Hydrogen Piping and Pipelines, with the first edition published in 2008. This code addresses the unique requirements of transporting hydrogen in both facility piping and pipeline systems. ASME B31.12 is formatted similarly to ASME B31.8, Gas Transmission and Distribution Piping Systems. Both provide detailed methods for specifying material, welding requirements, operations and maintenance.

For purposes of this study, this code was referenced for the specification of line pipe. ASME B31.12 adds a significant de-rating factor for higher grade carbon steel pipe as shown in the figure below from ASME B31.12.

FIGURE 14: X-GRADE PIPE DE-RATING FACTORS FOR HYDROGEN PIPELINES FROM B31.12

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

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

GENERAL NOTES:

(a) Tables IX-5A, IX-5B, and IX-5C are for use in designing carbon steel, low, and intermediate alloy piping and pipeline systems that will have a design temperature within the hydrogen embrittlement range of the selected material [recommended lowest service temperature up to 150°C (300°F)]. If the system design temperature is out of this range, use the design allowable stresses from Table IX-1A for piping or the specified minimum yield strength for pipelines from Table IX-1B.

(b) Table IX-5A was developed for pipeline systems and as such the design factors are based on the specified minimum yield strength of the material ranges shown.

(c) Design factors may be calculated by interpolation between pressures shown in the tables.

(d) For materials not covered by Tables IX-5A, IX-5B, and IX-5C, use the allowable stresses in Table IX-1A.

For higher grade pipe, a greater wall thickness is required when compared to a natural gas pipeline of the same grade, pressure, and class location. Increases in grade do not result in the same corresponding decreases in wall thickness as for a natural gas pipeline.

Hydraulic analysis showed that the pipeline system should be specified as an [redacted] Pipe materials used in the estimates are as follows:

Table 17: Pipe Selection

Pipe Wall Thickness Selection Table for [redacted] PSI MAOP, [redacted] Pipe

[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

6.5.2 Recommendations

The pipeline system should be optimized beginning with a reassessment of system capacities. The pipelines have been optimized based on demand scenarios and operating requirements [redacted]

6.6 Pressure Cycling

The compressibility of hydrogen gas under pressure allows for significant mass storage in a pipeline. Due to the disparity between variable hydrogen production and relatively constant hydrogen use at the demand centers, the pipeline system will be subject to pressure cycling. During the day, production will exceed demand and pipeline pressure will be allowed to increase up to the design rating. At night, production will wain and demand will be fed by residual pressure from the pipeline for several hours. This will result in a daily pressure cycling of the pipeline system with the respective production site discharge undergoing a pressure swing of approximately [redacted], and the demand centers in the LA Basin maintaining a more uniform and lower operating pressure.

For the potential production centers and demand capacities, hydrogen gas packing in the pipeline is insufficient to maintain supply until the following day's production, so storage is required on a daily basis. Additionally, seasonal fluctuations require additional gas storage at a dedicated bulk hydrogen storage facility.

7.0 Pipeline Compression

7.1 Production Center Pipeline Compressors

Hydraulic analysis was completed for each demand scenario to develop the conceptual compression facilities. Costs developed are parametric with the exception that ROM costs for the compressor package were obtained from a compressor vendor to validate existing database costs. Analysis indicated that only the Delta option and the hybrid Mojave with Delta Pipeline option, Systems 5 and 6 respectively, needed intermediate compression.

The table below summarizes the inputs used for costing the compression facilities. The optimal configurations of the production sites will determine the actual number of compressors required for each site, with costs for those configurations factored based on this large system.

Table 18: Basis of Estimate Production Compressors – Low Demand Scenario

Component	Quantity and Size
Location	Production center origination
Compressor type (Production site)	Reciprocating
Quantity and size	[redacted]

Table 18: Basis of Estimate Production Compressors – Low Demand Scenario	
Compressor rating	[redacted]
System maximum capacity	[redacted]
Assumed Inlet pressure	[redacted]
Assumed outlet pressure	[redacted]
ANSI class	900
Motor type	16KV, synchronous motors (dual windings)
Electrical Substation	With estimate
Other components	Back-up diesel generator Water treatment system Aftercoolers, Lube oil Inlet scrubbers Firewater Inbound meter skids (4-16" meters) Blowdown system and flare 2,500 SF office building 5,000 SF warehouse building

7.2 Intermediate Pipeline Compressors – Delta Scenario

The table below summarizes the inputs used for costing the intermediate compression facilities for delivering hydrogen from storage in Utah to the LA Basin. For cases involving production in California and storage in Utah, these compressors will also operate in the reverse direction, packing the line from California to Utah during daily production cycles and to storage in Utah as needed. The optimum configuration of the California production sites may require additional compressors at this intermediate location, and if so, costs can be factored from this base estimate.

Table 19: Basis of Estimate Delta Intermediate Compressors – Low Demand Scenario

Component	**Quantity and Size**
Location	Near North Las Vegas
Compressor type (Production site)	Reciprocating

Table 19: Basis of Estimate Delta Intermediate Compressors – Low Demand Scenario	
Quantity and size	[redacted]
Compressor rating	[redacted]
System maximum capacity	[redacted]
Assumed Inlet pressure	[redacted]
Assumed outlet pressure	[redacted]
ANSI class	900
Motor type	4KV, Variable frequency drives
Electrical Substation	With estimate, assume power is within 3 miles
Other components	Back-up diesel generator Water treatment system Aftercoolers, Lube oil Inlet scrubbers Firewater Inbound meter skids (4-16" meters Blowdown system and flare 2,500 SF office building 5,000 SF warehouse building

7.3 Underground Storage Compressors

Salt cavern design and costing was not in the scope of this study. Compression requirements for salt cavern storage depend on maximum and minimum operating pressures of the cavern, and have not been estimated. For the purposes of this study, the cost of intermediate compression facilities has been used as an approximation of the compression and facilities at the salt caverns, not including the costs for actual cavern storage.

Compression requirements for potential oil/gas reservoir storage facilities are a component of the estimates in Section 8.4.

8.0 Conceptual Hydrogen Storage

8.1 Overall Summary of Storage Options

Hydrogen storage is used:

- To manage the variation in daily hydrogen production rate.
- To account for seasonal variation in production rates and demand rates.
- To provide backup supply in the event of system disruption (100% backup rate if possible) or lower production rates.

The pipeline systems developed in this study do not provide sufficient storage capacity (through pressure cycling) to accommodate the variation in daily hydrogen production rate. As such, hydrogen storage is required for daily and seasonal variations in production rate and for overall system backup. Options for hydrogen storage and the purposes that they may achieve are summarized as follows:

Table 20: Conceptual Storage Option Preliminary Summary

Storage Type	Daily Variation in Production Rate	Seasonal Storage at Make-up Rates	Backup Supply at Full Rate
Salt Cavern	Yes	Yes	Yes, but possible limitations on demand rate variation
Oil/Gas Reservoir Conversion	Maybe, [redacted]	Yes	Maybe, [redacted]
Onsite Pressure Storage	Yes	No	No
H2 Liquid or Pressure Storage in Los Angeles Basin	No	No	No
Ammonia Liquid Storage near production site	No	Yes	Maybe

The use of salt cavern storage currently appears to be feasible for daily (Delta production primarily) and seasonal storage and general backup supply. Geologic storage in a converted oil/gas reservoir, if proven to be feasible in storing hydrogen, will require high pressure compression to inject the hydrogen and process facilities, including dehydration and hydrogen separation/purification, for gas withdrawal. Well capacities and numbers may limit both injection and withdrawal rates. Onsite pressure storage is still limited to providing only daily storage capacity. Liquid or pressure storage in Los Angeles Basin may be of value to a particular user of hydrogen but further evaluation is needed on a case by case basis.

8.2 Salt Cavern Storage

Salt caverns are currently the best method to store large quantities of hydrogen gas underground. Hydrogen has been stored successfully in a salt cavern by Chevron in Texas since the 1980's. This type of storage requires a very large salt dome, which are more common in the US Gulf Coast area, but not common in the Western US. A salt dome in the Delta, Utah area is being developed for hydrogen storage to support the LADWP Intermountain Power Plant. At present, this is the closest salt dome to Los Angeles that has been characterized as capable of large volume hydrogen storage. A possible Nevada salt dome was identified by HyDeal LA, which would be closer to LA and should be tracked as more information becomes available.

This study has assumed that hydrogen storage in salt caverns is a proven technology and operation, and that salt cavern storage in Utah would be available if needed. The cost of this storage is not included in this study, as it requires investigation and/or negotiation by SoCalGas. Salt caverns are privately owned and development information relative to storage capacities, flow rates, cost factors, etc. must be obtained in discussion with the owner. Since storage is necessary to meet all the operational needs for the system, it is recommended that some level of analysis be included. Included in the cost of the storage should be consideration of the minimum amount of hydrogen necessary to pressurize and maintain the minimum working pressure in the cavern. For example, it may be required that 30% of the hydrogen that it takes to fill the cavern to maximum pressure may need to remain in storage as cushion gas, maintaining a certain minimum operating pressure.

Based on an article published on salt cavern development, which referred to the Utah site "The formation has the potential to create up to 100 caverns, each one capable of holding 150,000 MWh of energy" (Reference: CNBC online article, *An $11 trillion global hydrogen energy boom is coming. Here's what could trigger it*, published November 1, 2020). This calculates to a potential hydrogen storage capacity of 440,000 to 700,000 metric tons, although, it is not clear if this value represents working capacity or total capacity. At the [redacted] Low Demand hydrogen production rate, these reported total capacities would accommodate approximately [redacted] of production [redacted] for the [redacted] Medium Demand case; and [redacted] for the [redacted] High Demand case). [redacted] the storage amount required to match seasonal difference between winter and summer, assuming that demand is flat through the year (which it probably will not be). As another reference point, the Chevron hydrogen salt cavern storage that has operated many years has a working capacity of approximately 2500 metric tons, which at the average [redacted] production rate would fill in approximately [redacted]. At the [redacted] High Demand rate, this total possible capacity represents [redacted] of hydrogen production at the average production rate. This analysis indicates the need to assess the capacity of caverns in this salt dome and how this storage fits with large scale hydrogen system development, as seasonal storage alone (with no provision for surplus storage) for the [redacted] Low Demand case could require [redacted] caverns [redacted] for the [redacted] Medium Demand case and [redacted] for the [redacted] High Demand case).

Caverns typically have limits regarding the number of pressure cycles per year and the rate of change in pressure. Injection and withdrawal rates are typically limited to avoid damage to the structure from rapid pressure change, so multiple caverns would probably operate together to reduce the rate of change in pressure.

This study has not included assessing the capacity and cost of the salt cavern storage, or the analysis and cost of compression and the multiple cavern connections and controls that would be required at the salt cavern storage area.

8.3. Geologic Screening for Potential Oil/Gas Reservoir Storage

The potential storage of hydrogen in existing oil/gas reservoirs is being widely studied and may or may not become viable for incorporation into this project. Storage in existing gas and oil fields in Southern California has not been well studied. Despite the uncertainty of using this type of storage, long term seasonal storage is required, and reservoir storage would offer large capacity storage in Southern California. An initial assessment of oil and gas fields in the SoCalGas service territory was performed with the goal of identifying potential viable storage fields for further study.

Storage site candidates were identified from [redacted] onshore oil and gas fields listed in the California Oil and Gas Fields, Volume 1 (Central California, 1998) and Volume II (Southern California, 1992) publications from CalGEM. [redacted]. This left [redacted] potential sites. [redacted] The remaining [redacted] potential storage candidates were then subject to the three filter categories which can be classified as follows:

- Location
- Geological Criteria
- Commerciality

Some manual adjustments were made where unique factors not captured in prior screening, or the filters called for the inclusion or rejection of a site. [redacted] Applying the filter categories, [redacted] potential sites were identified for hydrogen storage and [redacted] for carbon dioxide sequestration.

The process is summarized in the following figure with filters (in grey) set for hydrogen storage criteria.

FIGURE 15: SUMMARY OF SCREENING PROCESS

[redacted]

8.3.1 Pre-Screening

[redacted]:

- [redacted]

[redacted]

[redacted].

FIGURE 16: ACTIVE SEISMICITY IN SOUTHERN AND CENTRAL CALIFORNIA AND SHORT-LISTED CANDIDATES
(SOURCE: INTERACT STUDY, ASSESSMENT OF UNDERGROUND STORAGE IN OIL AND/OR GAS RESERVOIRS, 8/27/2021)

[redacted]

In the figure above, red lines represent recent fault traces identified by the California Geological Survey.

8.3.2 Location Filter

[redacted]

- [redacted]
- [redacted]

8.3.3 Geologic Filter

A [redacted]

- [redacted]
- [redacted]
- [redacted]. In the case of carbon dioxide, the IPCC recommends it to be ideally sequestered at depths greater than 800m (~2600ft) where the gas will be supercritical, in a dense liquid-like form.

8.3.4 Commerciality Filter

[redacted]

- [redacted]
- [redacted]
- [redacted]

8.4 Geologic Storage in Oil/Gas Reservoir

[redacted]. A separate report regarding assessment of existing reservoirs for hydrogen storage, the "Assessment of Underground Storage in Oil and/or Gas Reservoirs Report", has additionally been prepared.

Multiple studies are being performed globally regarding the issues and challenges of geologic storage of hydrogen which includes existing oil/gas reservoirs, so the "Assessment of Underground Storage in Oil and/or Gas Reservoirs Report" is not intended to assess the feasibility of such storage. Due to the desirability of a storage facility closer to Los Angeles than the salt caverns in Utah, existing southern California oil and gas fields were assessed relative to their potential to store hydrogen, should such storage be proven to be workable. Consistent with that overview, the report has also included a high level assessment of the cost to develop a hydrogen storage reservoir and associated facilities, should it prove to be feasible.

[redacted]

[redacted]

The following table summarizes the key design assumptions used for estimating the topside facilities at a conceptual field in Castaic Junction area. In the studied case, peak production rate in the summer is approximately [redacted] of average annual production rate. This Peak Injection Rate to storage is therefore based on injecting the incremental [redacted] excess production during this time. This rate is sufficient for seasonal storage but not to fully manage daily production variation. The lowest daily production rate of the year in the studied case is approximately [redacted] of the average annual production rate. The Peak Withdrawal Rate from storage is therefore based on withdrawing the additional 66% of annual production rate required for full backup of the average rate. These rates are for estimating topside facilities. Until better information is developed, injection and withdrawal rates of wells are based on the reported volumetric capacity of similar natural gas storage field wel[redacted]

Multiple parallel trains for pressure swing adsorption (PSA) are included for separating the hydrogen from methane and other hydrocarbons and gases that may be produced with the hydrogen. Assessment of topside facilities is limited and intended primarily for establishing order-of-magnitude cost estimate.

Table 21: Basis of Estimate for Conceptual Underground Storage Site			
Component	**Quantity and Size**		
	Low Demand	**Medium Demand**	**High Demand (1)**
[redacted] REDACTED	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]		
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]		
[redacted]	[redacted]		
[redacted]	[redacted]		
[redacted]	[redacted]		

Table 21: Basis of Estimate for Conceptual Underground Storage Site			
[redacted]	[redacted]		
[redacted]	[redacted]		
[redacted]			
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]			
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]		

Notes:

1. The High Demand Case described in this report utilizes the development of two, independent underground storage sites, each equivalent to the Medium Demand Case capacities. One of these storage sites is based on developing an oil/gas reservoir for storage, and the other is using salt caverns. Relative to the oil/gas reservoir storage in this Table 21, the High Demand Case is the same as the Medium Demand Case, with the additional storage being provided as salt caverns.

8.5 Onsite Pressure Storage

As mentioned in Sections 3 and 4, further consideration has been given to pressurized storage at the production site which includes a long pipeline looping back multiple times in a large area. [redacted] Such storage at production sites would allow the site to deliver hydrogen to the pipeline at a steadier rate throughout the day, would reduce the number and size of pipelines from what would otherwise be required, and would reduce the pressure cycling of the transmission pipelines. This concept may also be advantageous for the staged development of the system. Transmission line pressure cycling would have a greater effect on required storage volume for lower production rate early-stage development. Onsite storage would be added at each production site as total production volume increases and the pipeline operates closer to full capacity most of the time. This type of storage will help with the daily production rate variation but will not affect seasonal or backup storage.

8.6. Above-ground Storage in/near Los Angeles Basin

Above-ground storage options are too small to have any impact on the overall operation of this system, even for the Low Demand scenario. Above-ground storage may have some value to individual customers, but this is not economic to enhance the operation of this hydrogen pipeline system.

The largest liquid hydrogen storage sphere in the world is 5,000 cubic meters (m^3), which has the capacity of approximately to 2 hours of average production at a [redacted] rate. Other liquid storage spheres have been designed, but not constructed at up to 8 times this volume (40,000 m^3). The cost for the storage sphere alone is approximately [redacted]. The energy required to liquefy hydrogen for storage is approximately 1/3 of the energy value of the hydrogen stored, and the cost of liquefaction facilities typically exceeds the cost of the spheres. Liquid hydrogen storage is practical for applications where the hydrogen will be used or stored on-board as a liquid.

Budget costs (rough order of magnitude) were provided by CB&I Storage Solutions/McDermott, which recently constructed the 5,000 m^3 liquid hydrogen storage sphere at the space center in Florida. The following current day cost estimates took into consideration installation in California (for seismic conditions) and the use of union labor.

8.6.1 Liquid Hydrogen Storage Spheres

- 5,000 m^3 Storage Sphere (working capacity of approx. 320 MT liquid H2): [redacted] for foundation, storage along with typical accessories, plus [redacted] for deluge system and fireproofing of the columns.
- 2,250 m^3 Storage Sphere (working capacity of approx. 160 MT liquid H2): [redacted] for foundation, storage along with typical accessories, plus [redacted] for deluge system and fireproofing of the columns.
- Boil-off percentage per day <0.1% (recovered/re-liquefied by liquefaction system).

8.6.2 Hydrogen Liquefaction Systems

- Filling 5,000 m³ sphere in 4 days with a liquefaction rate of 200 gpm (54 kg/min): [redacted]
- Filling 5,000 m³ sphere in 12 days with liquefaction rate of 70 gpm (19 kg/min): [redacted]

Overall, liquefaction has high capital and energy cost and is a relatively slow process.

8.6.3 Hydrogen Vaporization System (approximately [redacted] psig gas pressure)

- Vaporization rate of 1,000 gpm (268 kg/min): [redacted]
- Vaporization rate of 300 gpm (80 kg/min): [redacted]

8.6.4 Pressurized Gaseous Hydrogen Storage Sphere

- 5,000 m³ GH2 Storage Sphere at a 30 bar [redacted] psig) design pressure: [redacted]
- Budget costs were provided for a 5000 m³ pressurized gas storage sphere at 30 bar pressure. [redacted] This working volume is based on the difference in pressure between the maximum and minimum storage pressures. A 5000 m³ sphere operating between 6 bar and 30 bar pressures would have a working volume of 10 metric tons of hydrogen, about 3% of the working capacity of the same size liquid sphere. For comparison, a 42" pipeline 3.75 miles in length would provide the same physical volume and could store more due to higher allowable pressure. At the [redacted] estimated cost of the sphere, the equivalent 42" pipeline cost per volume would be [redacted] per mile. [redacted].

8.7. Ammonia/Chemical Storage

Chemical storage of hydrogen in the form of anhydrous ammonia was not included in this assessment due to the additional energy required by the hydrogen/ammonia/hydrogen conversion process and expected challenges in permitting storage near demand centers. [redacted]. Ammonia production is not expected to have a substantial impact on daily storage requirements, but could be effective for seasonal storage and backup supply. A single tank could potentially hold 50,000 MT of ammonia, or about 8800 MT of hydrogen. Approximately [redacted] of these tanks would be required for the minimum seasonal storage for the Low Demand case of [redacted], [redacted] tanks for the Medium Demand case of [redacted] and [redacted] tanks for the High Demand case of [redacted].

9.0 Project Considerations

Considerations associated with the potential projects has been categorized into the following groups and summarized in the tables below:

- Cost actions that could result in a significant impact to the project cost estimate.
- Design actions that could result in a significant impact on the pipeline or facility or design.
- Schedule actions that could result in significant impact on the project execution schedule.
- Operation actions that are unique to pipeline operation, safety and maintenance.

Table 22A: Preliminary Estimate Considerations

Description	Explanation of Impact	Potential Impact	Mitigation	Stakeholder
[redacted]	[redacted]	[redacted]	[redacted]	Estimating
[redacted]	[redacted]	[redacted]	[redacted]	Procurement
[redacted]	[redacted]	[redacted]	[redacted]	Estimating ROW
[redacted]	[redacted]	[redacted]	[redacted]	Estimating
[redacted]	[redacted]	[redacted]	[redacted]	Estimating

Table 22A: Preliminary Estimate Considerations					
Description	Explanation of Impact	Potential	Impact	Mitigation	Stakeholder
	[redacted]	[redacted]			
[redacted]	[redacted]			[redacted]	Estimating
[redacted]	[redacted]			[redacted]	Estimating
[redacted]	[redacted]			[redacted]	Estimating

Table 22B: Preliminary Design Considerations					
Description	Explanation of Impact	Potential	Impact	Mitigation	Stakeholder
[redacted]	[redacted]	[redacted]		[redacted]	Storage/ Design
[redacted]	[redacted]			[redacted]	Environ.

Table 22B: Preliminary Design Considerations

Description	Explanation of Impact	Potential Impact	Mitigation	Stakeholder
[redacted]	[redacted]	[redacted]	[redacted]	Design
[redacted]	[redacted]		[redacted]	ROW
[redacted]	[redacted]		[redacted]	Design
[redacted]	[redacted]		[redacted]	Design
[redacted]	[redacted]		[redacted]	Design
[redacted]	[redacted]		[redacted]	Design

Table 22C: Preliminary Schedule Considerations

Description	Explanation of Impact	Potential Impact	Mitigation	Stakeholder
[redacted]	[redacted]	[redacted]	[redacted]	Environ.

Table 22C: Preliminary Schedule Considerations

Description	Explanation of Impact	Potential Impact	Mitigation	Stakeholder
[redacted]		[redacted]	[redacted]	
[redacted]	[redacted]		[redacted]	ROW
[redacted]	[redacted]		[redacted]	Contracts
[redacted]	[redacted]		[redacted]	Procurement
[redacted]	[redacted]		[redacted]	Procurement
[redacted]	[redacted]		[redacted]	Project Management

Table 22D: Preliminary Operation Considerations

Description	Explanation of Impact	Potential Impact	Mitigation	Stakeholder
[redacted]	[redacted]	[redacted]	[redacted]	Engineering

[redacted]	[redacted]	[redacted]	[redacted].	Business Development
[redacted]	[redacted]	[redacted]	[redacted]	Operations and Safety
[redacted]	[redacted]	[redacted]	[redacted]	Operations and Safety
[redacted]	[redacted]	[redacted]	[redacted]	Operations and Safety

10.0 Schedule

10.1 Precedence

Due to the scale of the potential project, an overall project schedule would require more thorough development after selection of a build option and demand scenario. Production of hydrogen at this scale would require significant permitting, vendor, and construction resources. Other [redacted] projects in California, such as High Speed Rail and Delta Conveyance Projects, have, or are expected to take several years (over a decade) to permit, design and construct.

As part of this study, a report has been completed discussing pipeline project experience within the United States. Several of the "mega" pipeline projects cited in the report, including Keystone XL, Atlantic Coast, and SCG's North-South Pipeline faced opposition from various agencies or groups during the permitting stage and were ultimately cancelled. In some cases, some construction was started at the operator's risk resulting in lost capital.

The pipelines that were ultimately not built or completed for a variety of reasons. The following table provides a summary of issues that have resulted in major pipeline project cancellations.

Table 23: Representative environmental issues for major pipeline project

Issue Area	Number of Projects Affected	Percentage of Projects Affected	Projects Affected	Resolved/ Unresolved
Ecosystem Threats	6	50%	Keystone KL Atlantic Coast	Resolved: 33% Unresolved: 67%

Table 23: Representative environmental issues for major pipeline project				
Issue Area	**Number of Projects Affected**	**Percentage of Projects Affected**	**Projects Affected**	**Resolved/ Unresolved**
			New York Constitution Trans-Pecos Las Vegas Groundwater Ruby	
Climate Change	5	42%	PSRP Keystone XL Dakota Access New York Constitution Trans-Pecos	Resolved: 20% Unresolved: 80%
Water Quality Concerns	4	33%	Keystone XL Dakota Access New York Constitution Las Vegas Groundwater	Resolved: 0% Unresolved: 100%
Inadequacy of Environmental Review	4	33%	Cadiz Water Las Vegas Groundwater Dakota Access Keystone XL	Resolved: 0% Unresolved: 100%
Tribal Concerns	3	25%	Dakota Access Trans-Pecos Las Vegas Groundwater	Resolved: 33% Unresolved: 66%
Failure to Demonstrate Need	2	17%	PSRP (L1600) North-South	Resolved: 0% Unresolved: 100%

10.2 Permitting

A multi-year permitting process under CEQA and/or NEPA is expected for a project of this scale. The social, economic and environmental impact of any conceptual project would draw a large number of stakeholders including municipal and government agencies, community groups, businesses groups and other special interests.

The following table from the "Mojave Conceptual Pipeline Permit Assessment" report provides representative permit times for major permitting agencies for major industrial type projects. The durations are based on the general experience of the environmental consultant team.

Table 24: Representative durations for pipeline project permits		
Agency or Entity	**Authorization**	**Anticipated Lead Time (months)**[1]
	Federal	
NEPA	EIS	6-24
BLM	ROW Grant	12-18
National Park Service (NPS)	ROW Permit	variable
NPS	Consultation	variable
U.S. Forest Service (USFS)	New Special Use SUP	18-24
U.S. Fish & Wildlife Service (USFWS)	Section 7 Consultation Biological Opinion	6-9
USFWS	Section 10 Habitat Conservation Plan	18-24
Federal Department of Defense	Military Base Approval	6-18
U.S. Army Corps of Engineers (USACE)	404 Certification	6-12
	State	
CEQA	EIR	12-24
California Department of Parks and Recreation (State Parks)	SUP	12-24
California Department of Transportation (Caltrans)	ROW Encroachment / Transportation Permit	6-12
California Energy Commission (CEC)	TBD	n/a
California Department of Fish and Wildlife (CDFW)	CESA ITP	12-36
CDFW	§1600 Programmatic Short-term LSAA	12-18

Table 24: Representative durations for pipeline project permits		
Agency or Entity	**Authorization**	**Anticipated Lead Time (months)**[1]
RWQCB	Individual 401 Certification and Waste Discharge Re-equipment (WDR)	12-24
	Regional: County/City/Community Plan/Special District	
Special Districts		6-12
Local Air District	Clean Air Act	1-3
Railroad (RR) Crossings	ROW, Encroachment potentially a SUP	4 36
	County	
Kern/San Bernardino County	Director Determination	1-3
Los Angeles	CUP Protected Tree Permit Significant Ecological Areas (SEAs)	6-24
	Cities	
City Governments	CUP Anticipated	6-12
All cities	Protected Tree Permit	1-3

10.3 Materials

Purchase of materials, particularly those related to the production of hydrogen at the scale considered in this report has not yet been done and more than likely would require build-out over several years. To determine an accurate schedule for production, a detailed review of build out scenarios is recommended for discussion with material vendors (particularly for electrolyzers, PV panels, line pipe and compressors).

Materials for pipeline, facilities and storage would also be considered long lead but are primarily supplied by well-established industries. Therefore, material deliveries are more predictable but will vary based on overall market demand at the time of purchase.

10.4 Construction

Construction of the hydrogen facilities would likely involve a multi-year process and would be difficult to predict without further analysis of build-out scenarios. The construction of pipelines and pipeline facilities is well understood, so construction of these facility types would be more predictable, although these pipeline systems would be considered multi-year build-outs due to their scale.

Construction for this size project would involve multiple construction spreads, out-of-state and international contractors and significant logistical planning in preparation for construction. To determine an accurate schedule for construction, a detailed review of build out scenarios is recommended for discussion with construction firms (particularly for production, pipeline and compression facilities).

11.0 Estimates

11.1 Accuracy

The estimates completed for this study are considered rough order of magnitude and were developed with limited engineering and design work. Estimate factors used were developed in discussion with Campos Engineering and referred to AACE International Recommended Practice No. 97R-18, Cost Estimate Classification, as the basis for developing contingency and accuracy range factors.

With the level of engineering and design completed at this stage of study, the estimate was classified as a class 5 estimate defined as 1% to 15% engineering, this pre-feasibility study would fall on the lower end of this range. The accuracy ranges vary from (-15% to -50%) on the low end and from (+20% to 100%) on the high end, depending on the technical complexity of the project. Given the scale and engineering complexity of this highly technical type of project, the largest ranges of accuracy were selected.

Estimate factors are summarized below:

Table 25: Project Estimate Factors	
Estimate Classification	Level 5
Engineering Level	1% to 15%
Contingency Factor	50%
Estimate Accuracy Low Range	-50%
Estimate Accuracy High Range	+100%

11.2 Methodology

The study estimate uses gross unit costs/ratios and parametric estimating methods. Campos Engineering provided factored rates for use in estimating pipeline costs and facilities. These rates are based on current SoCalGas data from existing similar, but much smaller scale projects. Therefore, cost estimate factors do not reflect economies of scale and cost optimization that would potentially be experienced by such a large project.

For the hydrogen production and energy generation parametric cost estimates were also utilized, primarily consisting of data available from the National Renewable Energies Laboratory (NREL) Annual Technology Baseline (ATB) costs. The cost basis data from NREL is developed using a number of financial models with multiple assumptions and inputs to produce the CAPEX and OPEX costs utilized in this report. The parametric pricing therefore includes consideration for the following inputs:

- [redacted]

Since the majority of the cost of production is from the renewable energy production, the NREL model inputs are also provided for reference (see hydrogen production report). Similarly, the NREL estimates are based on existing similar, but much smaller scale projects and therefore the cost estimate does not reflect economies of scale and cost optimization.

11.3 Uncertainty and Cost Optimization

With the factored estimate methodology, the cost estimate uncertainty though high would typically be offset by the high contingency and range factors discussed in the section above. Subsequent studies would presumably select a preferred option and complete some preliminary engineering to reduce the uncertainty associated with a class 5 estimate. Also, cost optimization could be accomplished in discussion with outside experts, such as pipeline construction contractors, to increase the accuracy, reduce uncertainty and reduce contingency and accuracy range factors.

11.4 Major Cost Items Not Included in Estimates

Due to the high-level nature of the study some cost items were not included in the estimate. These factors would have significantly increased the costs and conservatism and was deemed unnecessary given the high-level nature of the study, unknown execution strategy and very long time of the project. These factors included the following:

- Demolition is excluded. All project sites are assumed to be green field sites with no existing facilities, soil or ground water contamination.
- Escalation is excluded given the uncertain timeline of the conceptual buildout.
- Storage costs do not include purchase of a potential storage field for Five Points, Mojave, Whitewater or Blythe options.
- Storage costs for Delta do not include development of salt caverns. To the project understanding, salt cavern storage is being developed by third party companies.
- SoCalGas Loaders such AFUDC, depreciation, corporate taxes, etc. are excluded.

11.5 Medium and High Case Cost Estimates

At this level of study, cost estimates for the medium and high cases were factored from the low demand base cases. The following table summarizes the factors for each major estimate component:

Table 26: Medium and High Estimate Factors

Estimate Component	Factor
Production	Factored from low demand case based on total production ratio.
Pipeline	Re-estimated based on new mileage with reduced factors for third party costs based on economies of scale.
Pipeline Compression	Factored from low demand case based on horsepower ratio.
ROW – Production and Pipelines	Factored from low demand case based on total acreage ratio.
Underground Seasonal Storage	Factored from low demand case based on outgoing flow rate ratio.
Underground Daily Storage	Factored from low demand case based on mileage of buried pipe.

11.6 Total Project Cost

TABLE 27A: PROJECT CAPEX COST SUMMARY

[redacted]

- [redacted]
- [redacted]
- [redacted]

TABLE 27B: PROJECT OPEX COST SUMMARY

[redacted]

Notes:

- [redacted]
- [redacted]
- [redacted]
- [redacted]

TABLE 27C: MEDIUM AND HIGH DEMAND PROJECT CAPEX COST SUMMARY

[redacted]

Notes:

[redacted]

[redacted]

TABLE 27D: MEDIUM AND HIGH DEMAND PROJECT OPEX COST SUMMARY

[redacted]

Notes:

[redacted]

11.7 Cost Optimization

Pipeline and facility cost estimates use data provided by Campos Engineering. The data provided is based on SoCalGas rates and costs for pipelines and facilities and are, therefore, a relatively accurate reflection of SoCalGas costs for project execution. [redacted]

Potential cost savings options are discussed in the table below and is based on the project team's experience with other pipeline companies and projects.

Table 28: Potential Cost Saving Opportunities

[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

Table 28: Potential Cost Saving Opportunities

[redacted]	[redacted]	[redacted]
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[redacted]	[redacted]	[redacted]
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[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

Table 28: Potential Cost Saving Opportunities

[redacted] [redacted] [redacted]

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Appendices

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