HYDRAULIC ANALYSIS
REPORT 8143A-M-001

HYDROGEN PIPELINE STUDY
PROPOSED TRANSPORTATION SYSTEM

Prepared For:

SOUTHERN CALIFORNIA GAS COMPANY

Prepared By:

SPEC SERVICES

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1. Executive Summary

1.1 Background

In support of the Southern California Gas Company's (SCG) pre-feasibility study of introducing a large-scale, green hydrogen pipeline system to supply the Los Angeles basin and Southern California energy needs, SPEC Services has been commissioned to develop a preliminary, high-level system concept that can produce, transport, and deliver hydrogen gas at-scale to the LA Basin.

Four hypothetical production regions were selected by SCG for conceptual modeling in pursuance of green-field development of hydrogen production facilities: Five Points (Fresno County, California), Mojave (Kern County, California), Blythe (San Bernardino County, California), and Delta (Utah), which would be developed by third parties (other than SCG). Hydrogen would be delivered to select power plants, transportation fueling centers, and industrial end users. Three potential seasonal storage facilities were selected for underground bulk storage of hydrogen gas: Castaic (just north of Los Angeles), Delta (Utah), and Phoenix (Arizona). The following combinations of production and seasonal storage sites were selected for system analysis:

- Five Points Production with Storage at Castaic
- Mojave Production with Storage at Castaic
- Blythe Production with Storage at Castaic
- Delta Production with Storage at Delta
- Mojave Production with Storage at Delta
- Blythe Production with Storage at Phoenix

Each of these systems were analyzed with a total annual throughput of [redacted]. This report details the conceptual hydraulic basis of design for the hypothetical gas pipeline systems that would receive hydrogen production, flow at transmission pressure, deliver to demand centers, and balance daily and seasonal production cycles with a potential storage facility.

Preliminary hydraulic modeling methodology and conclusions are documented in this report, including pipeline sizing, annual storage requirements, and expected process conditions during operation. Modeled hydrogen production rates, storage viability, and demand rates were critical inputs to this study but are beyond the scope of this report.

1.2 Summary of System Results

Delivery of [redacted] results in an average flow of approximately [redacted] million standard cubic feet per hour (MMscfh). A solar-only system was considered with a peak production rate of [redacted]. The hydrogen production rate was calculated for every hour by Technip and that data used in this initial low case analysis. These values scale proportionately for the [redacted] and [redacted] rate cases. See Section 3 of this report for details on each conceptual production site.

Estimated downstream demand varied from [redacted] MMscfh based on power plant output for the [redacted] rate case. The entirety of this power plant variability was applicable for the [redacted] rate cases, so the demand variability increased with each lower rate case. See Section 4 for details on each demand site.

The pipeline transmission system from the production site would need to accommodate the highest hydrogen production rates, which is [redacted] the average production rate. The pipeline transmission system from storage to the LA Basin demand centers would be closer to the average production rate, depending on the demand profiles of the users. The conceptual Delta Production with Storage at Delta system assumes direct access to the Delta storage cavern from the production discharge and therefore provides continuous flow regardless of production rates. The other five conceptual system configurations accommodate the high hydrogen production rate using local high-pressure storage to absorb the daily production cycle. See Section 5 for details on each proposed system configuration.

This conceptual hydraulic analysis includes California-based geological storage at Castaic, Utah-based geological storage (salt caverns) at Delta, and Arizona-based geological storage at Phoenix. Geologic storage in oil/gas reservoirs is included for the first three systems as an alternative to the Delta salt caverns. Large-scale hydrogen storage was a critical component to system functionality for seasonal changes to hydrogen production and demand. Minimum calculated hydrogen working storage requirements were approximately [redacted] of the annual throughput of the system and required design rates similar to the average throughput of each rate case. Continuous monitoring and controls were modeled to allow the seasonal storage facility to both maintain demand pressures and relieve excess seasonal production as needed.

A significant volume of local high-pressure pipe storage was required at each production site to prevent daily movements in and out of storage. Degradation of gas quantity and quality were not considered for these hydraulics, nor was injecting and withdrawing from underground formations as part of the daily production cycle. Local high-pressure storage was modeled as [redacted] pipeline. For conceptual modeling purposes, it was assumed to be more manageable and economical to construct and cycle pressure on pipe within the production facility than using oversized pipe along the pipeline route.

1.3 Conversion Factors

1 kilogram of hydrogen	=	423.3 standard cubic feet of gas

[redacted]

2. System Description and Approach

2.1 Overall System Aspects for Analysis

Six potential conceptual hydrogen pipeline systems were considered for creating green hydrogen to feed the LA Basin via pipeline. In order to balance the difference between daily and seasonal production against daily and seasonal demand changes, each system would require unique features to function within the parameters documented in this report.

Solar energy was used as the basis of feeding electrolyzer for the production of green hydrogen. The hydrogen production facility was modeled by Technip Energies to develop hourly production data for a representative year. Each site will have slightly different solar exposure due to latitude and local weather patterns. These variances will affect the total area required for photovoltaic solar panels, but will minimally affect the resulting hydrogen output trend. Land usage, water sources, and production process details upstream of the hydrogen gas output stream is beyond the scope of these hydraulics.

The resulting hydrogen output rate varies significantly throughout the day as dictated by solar power supply. High-pressure local storage was considered to absorb the daily production cycle in order to feed the pipeline downstream a more constant stream.

Conceptual hydrogen production was optimized to match the total annual throughput demand provided by SCG. This necessarily results in more hydrogen production during the summer months when solar power is more available than winter months. Underground cavern storage (Castaic, Delta, or Phoenix) was considered to absorb the seasonal production cycle in order to divert the excess summer production for winter use. Seasonal storage also provides make-up gas supply during subsequent days of low solar output.

Each pipeline system configuration is unique in the geographic distance between the production site and the LA Basin, the relative position of production from seasonal storage, and the control method required for supplying the LA Basin. The following figure summarize these relationships for each system:

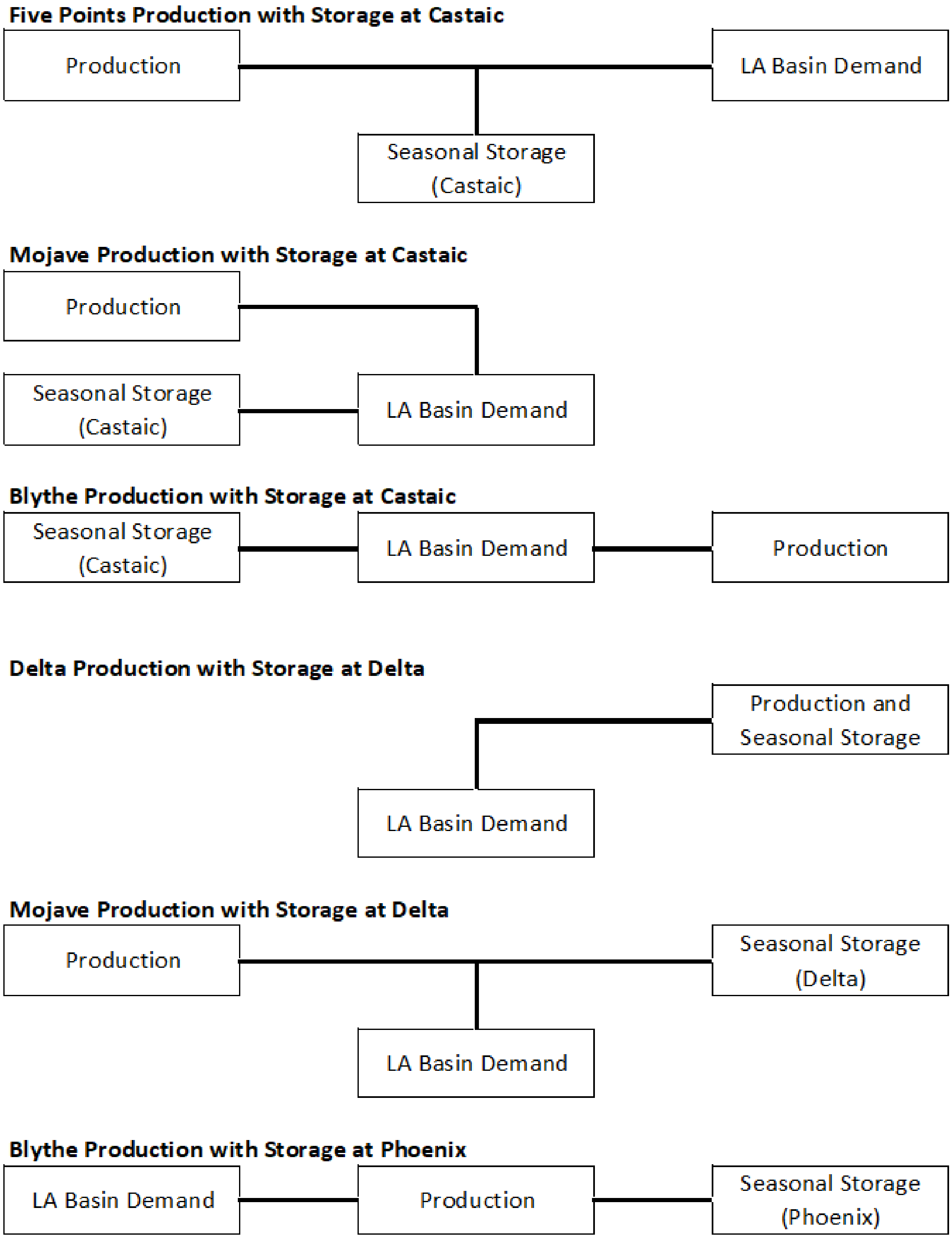

Figure 2.1 – Relative Position for Each System Configuration

2.2 Conceptual Pipeline Routing and Lengths

Pipelines were routed using desktop Geographic Information System (GIS) data to develop a conceptual path from each production location to the selected demand center locations within the LA Basin. Each route consists of a trunk line to the Port of LA / Port of Long Beach area with laterals to pick-up demand locations along the way. Methods for determining individual pipeline routes are beyond the scope of this report.

Distances from this database were used in the hydraulic model of each system route. The following figure shows the pipeline distances between each [redacted]

2.3 Conceptual Design Pressures and Temperatures

[redacted]

2.4 Conceptual Pipeline Hydraulic Properties

The Colebrook equation was used to calculate friction loss for each pipeline segment using an absolute roughness value of 0.0018" for steel pipe. The following table lists the nominal pipe sizes, wall thickness, and inner diameters used in the model. Power plant and refinery laterals were modeled as [redacted] while major branches were modeled as [redacted] Diameters and number of parallel "looped" pipes for the trunk lines from each production site and core lines within the LA Basin were selected to keep the simulation running within the design pressures discussed in Section 2.3.

Table 2.4 – Modeled Pipeline Sizes and Inner Diameters

Nominal Pipe Size	Wall Thickness	Inner Diameter
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

The system was modeled to transition from Class 2 to Class 3 upon entering the greater urban area surrounding the LA Basin. Actual pipeline wall may be thinner depending the selected steel grade in the final design.

2.5 Conceptual Gas Compression Modeling

Idealized compressors were modeled using fixed pressure or fixed flow inputs to move hydrogen gas from production to pipeline or from pipeline to underground storage. These components were set to accommodate flow from the applicable production site or to sustain pressure at the demand locations. Outputs from the model could be used to size an appropriate compression equipment solution based on the performance needs of each simulation case. Modeling of specific compression equipment is beyond the scope of this hydraulic analysis.

2.6 Conceptual Hydrogen Storage Solutions

Hydrogen gas storage would be required for each system based on daily fluctuations of solar-based production, hourly changes to demand from power plants, and seasonal cycles of increased summer production and reduced winter production. Two methods were modeled for the storage of hydrogen gas: [redacted] and [redacted].

Conceptual underground cavern storage locations were modeled at Castaic, Delta and Phoenix. Castaic Storage was modeled to maintain pressure in the LA Basin. Delta Storage was modeled to maintain pressure toward Palmdale Junction. Phoenix Storage was modeled to maintain pressure at the Blythe Production facility. Each of these locations have unique dynamics and interaction with the production sites, but all work under similar principles:

- Excess production during the summer results in an increase to the average system pressure. This pressure is pulled into underground storage to prevent production pressure from exceeding the control limit.
- Reduced production during the winter results in a decrease to the average system pressure. This pressure is made up from underground storage to ensure demand centers maintain their control limits.
- Intermittent lack of solar production due to weather events require supplemental gas from underground storage to maintain supply.

With the exception of Delta Production, aboveground high-pressure plant storage is applicable to each production site. [redacted] pipe was modeled to act as a pressurized volume downstream of the production compressors but upstream of the transmission pipeline. It is assumed that each production site would have sufficient land area to accommodate several hundred miles of looped pipe. This volume acts to normalize the high daytime hydrogen production to maintain supply during low nighttime production. Sizing of high-pressure plant storage was done to prevent daily cycling of the underground seasonal storage. Storage in pipe was modeled over underground storage to prevent additional gas processing. Looping this pipe volume in-plant is also assumed to be more economical than oversized pipe in pipeline right-of-way.

For the Delta Production and Storage case, all excess production is assumed to directly feed the Delta underground cavern while providing a constant supply of hydrogen gas to the LA Basin. Therefore, no high-pressure storage was modeled for this scenario.

Underground reservoir, cavern, and high-pressure pipeline storage were all assumed to have a 100% recovery factor for hydrogen. Initial charge volumes and geological formation losses are beyond the scope of this report.

2.7 Conceptual Transient Gas Pipeline Modeling

DNV GL Synergi Pipeline Simulator version 10.7 was used to model and simulate each pipeline network. A complete model was built of the LA Basin demand centers and interconnections from the various trunk lines upstream (see Attachment 1). This software simulates the transient effects of the pipeline, including changes to line pack as gas pressure fluctuates and the resulting changes to flow in the overall system.

Valves were inserted for modeling purposes to segregate the proposed systems for each production / storage configuration.

The BWRS equation of state was selected to model pure hydrogen with a base viscosity of 0.0084 centipoise.

3. Conceptual Hydrogen Production Locations

SCG has requested four potential production locations to be modeled for five conceptual pipeline systems. The following figure shows the locations of these production sites and the main trunk lines routed to the LA Basin.

Figure 3 – Conceptual Hydrogen Production Sites and Trunk Line Routes

3.1 Basis and Approach

Development, research, and modeling of conceptual large-scale hydrogen production facilities was performed by Technip Energies. Their model considered solar (photovoltaic) renewable energy generation at each of the four production sites and optimized a theoretical hydrogen generation output trend for a 365-day period. A total production of approximately [redacted] was calculated for each site. The production rate data was fed directly in to the transient hydraulic model (at one-hour intervals) to select and validate the functionality of the pipeline system and determine the gas storage parameters for each system configuration. [redacted] and [redacted] rate cases were scaled from the [redacted] case provided by Technip.

The following sections provide details for each production site as relevant to the hydraulic model. The basis of this data is by Technip and is beyond the scope of this report.

3.2 Peak Rates and Performance for California Production Sites

Based on the data provided by Technip, the following table and charts compare the maximum rates scaled for the various rate cases. Production varies daily and seasonally. During the winter months, available green power is less consistent than the summer. This results in a higher average rate during the summer time. This excess production is diverted to underground storage during the summer and withdrawn during the winter. Technip performed an optimization study of the capital costs of installed equipment (PV panels and electrolysis systems) to determine the peak production rate.

Minimum production did not fall below 5% of the maximum value for each rate case due to electrolyzer turndown. The following table and charts illustrate the data used for this system.

[redacted]

[redacted]

Figure 3.2.1 – Modeled Hydrogen Production Rate (raw hourly data)

The optimized solar-only system achieved the same peak production rate nearly every day with only the duration of production changing seasonally. Excess electrical capacity was included to maintain battery charge to meet the 5% electrolyzer turndown requirements. Summer solar capacity was curtailed based on optimization of battery and electrolyzer quantities. The following figure shows a sample of production to compare typical days for the [redacted] rate case.

[redacted]

Figure 3.2.2 – Comparison of Daily Production Curves by Season

The maximum hydrogen output was limited by the modeled electrolyzer capacity. Typical summer days exceed ten hours of production while winter days were less than eight and had more frequent weather-related reductions. During peak solar performance, excess capacity is used to charge batteries which provide for the continuous minimum 5% output.

[redacted]

Figure 3.2.3 – Annual Production Trends per Day ([redacted] Rate Case)

Seasonal changes of daily hydrogen production followed an overall consistent curve with some intermediate drops due to projected weather events.

3.3 Modeled Performance of Delta, Utah Production Site

Large-scale cavernous hydrogen gas storage is available at the conceptual production site in Utah. Because the production site is assumed to be near or co-located with this storage, the performance of the Delta location was modeled as a fixed discharge pressure of [redacted] psig. An intermediate compressor station was modeled near Las Vegas, Nevada to boost the pressure to [redacted] psig toward the LA Basin. These pressures were used to calculate the required flow from the Delta location and the differential pressure required by the intermediate compressor station.

4. Conceptual Hydrogen Demand Locations

SCG requested modeling accounting for four Los Angeles Department of Water and Power (LADWP) power generation plants be fed by the proposed hydrogen systems. Development and research of other large-scale hydrogen consumers was performed by Strategen, including vehicle fueling in the ports, and use by industrial customers. The following figure shows the locations of these potential demand centers and the pipeline laterals routed from the main trunk lines.

[redacted]

Figure 4A – Conceptual Hydrogen Demand Locations

Annual demand totals for each market sector were originally provided by SCG for the [redacted] rate case. Reduced rate cases were proposed [redacted] by prioritizing power plant and refinery demands. The following table lists the breakdown of demand for each market sector for each rate case.

Table 4 – Conceptual Demand Rate Cases by Market Sector

Rate Case	[redacted]
Power Plants (metric tons)	[redacted]
Valley	[redacted]
Scattergood	[redacted]
Harbor	[redacted]
Haynes	[redacted]
Transportation (metric tons)	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
Industrial (metric tons)	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
Total (metric tons)	[redacted]

[redacted]

Figure 4B – Ratio of Demand Types by Rate Case

The following sections provide details for each demand type. Transportation, and industrial uses were modeled as continuous feeds to meet the annual throughput rate. Power plants were variable based on 2019 data provided by Strategen. Therefore, the lower rate cases [redacted] with the power plants has the most variable demand rate when compared to average throughput.

4.1 Power Generation Plants

Four LADWP plants were modeled as representative demand centers for hydrogen. Hourly power output for these facilities were provided by Strategen for 2019 from publicly available information. This data was scaled proportionately to match the annual hydrogen demand data provided in Scenario 7, which is applicable to all rate cases. The following table lists the conversion factors used to determine hourly hydrogen demand.

[redacted]

Plant	Valley	Scattergood	Harbor	Haynes
[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]

Note that this factor does not represent an energy value for hydrogen, but just a proportion from the 2019 publicly available power output data. This method keeps the modeled annual demand consistent with the design values while incorporating the variability of power generation plant demand. The following table summarizes the modeled conditions for each power plant.

[redacted]

Plant	Valley	Scattergood	Harbor	Haynes
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

[redacted]

[redacted] Combined with the demand rates at other locations (see the following sections), the following table lists the maximum system demand rate for each of the rate cases.

[redacted]

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

[redacted]

The following figures show the modeled demand rates for each power plant throughout the year. A [redacted] pipeline lateral was modeled for the connection to each power plant.

[redacted]

[redacted]

4.2 Transportation Fueling Centers

Two vehicular loading centers were modeled for fueling trucks in the Port of Los Angeles (POLA) and Port of Long Beach (POLB). Conceptual annual demand for this operation was provided by SCG for the [redacted] case and factored down for the lower rate cases. This demand was assumed to be split evenly between POLA and POLB and flow continuously to these sites. The following table lists the factors used to determine hourly hydrogen demand for each rate case.

[redacted]

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

[redacted] This factor was used to result in the total demand to be nearly [redacted] with both Power Plant and Refinery demand centers satisfied.

4.3 Refineries and Other Industrial Demand

Refineries are major consumers of hydrogen with natural gas steam reformation being the primary process source. Therefore, they are used as a proxy for industrial demands for this study. Four major refineries in the LA Basin were modeled to represent hydrogen demand of industrial users: [redacted] Conceptual annual demand for these locations was provided in aggregate by SCG as [redacted] metric tons per year. This value was divided between the refineries in proportion to their reported capacity to the California Energy Commission. The following table lists the factors used to determine hourly hydrogen demand assuming continuous hydrogen flow to refineries with a [redacted] pipeline lateral modeled for each refinery connection.

[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]	[redacted]

*Reported Capacity per California Energy Commission (energy.ca.gov)

[redacted]

4.4 Combined Daily Demand Trends

The proposed systems are required to supply the total demand all year. The following figure shows the daily demand volumes.

[redacted]

Figure 4.4 – Annual Demand Trends per Day for Each Rate Case

Since the Power Plants were the only conceptual demand centers that varied, each rate case was shifted from the other by the continuous rate of the other demand centers. Therefore, the [redacted] rate case had the most variability.

Table 4.4 – Average Daily Demand per Rate Case

Rate Case	[redacted]
Total Average Rate (MMscfd)	
Daily Minimum Rate (MMscfd)	
Daily Peak Rate (MMscfd)	
Variability	

5. Results

Synergi Pipeline Simulator (SPS) models were developed to represent each conceptual system combination and perform the transient calculations. Each model utilized the same core configuration within the LA Basin.

[redacted]

Figure 5A – Model Screenshot: Common Pipeline System within LA Basin

The LA Basin "core" system could be fed from the north through Santa Clara Junction by the Five Points, Mojave, or Delta production sites or from the east by the Blythe production site. The modeled Castaic and Delta seasonal storage facilities would also connect from the north while Phoenix seasonal storage would connect east of Blythe. The following figure shows the northern portions of the model.

[redacted]

Figure 5B – Model Screenshot: Northern Production and Storage Segments

The figure above shows hydrogen generation at Five Points (G_FIVE_POINTS), Mojave (G_MOJAVE), and Delta (G_DELTA). Flow from these components is dictated by the production output shown in Figure 3.2.1. Five Points and Mojave also have high pressure facility storage (SH_FIVE_POINTS and SH_MOJAVE) to dampen daily production while Delta production directly feeds Delta storage. Castaic seasonal storage is also shown with the modeled compression to supply or draw from the LA Basin based on pressure. Delta seasonal storage was modeled to supply continuous pressure to the pipeline.

The following systems are represented by this model with logic to enable the applicable features for each production / storage combination:

- Five Points Production with Storage at Castaic
- Mojave Production with Storage at Castaic
- Delta Production with Storage at Delta

The combination of Mojave production with storage at Delta required significant changes to the modeled controls and interconnections to allow Delta seasonal storage to supply or draw from the LA Basin in conjunction with Mojave production. The following figure shows those modifications to the model.

[redacted]

Figure 5C – Model Screenshot: Mojave Production and Delta Storage

The trunk line from Mojave to Santa Clara was modified to intercept the trunk line from Delta. Like Castaic, bi-directional compression was modeled at Delta to draw or supply the trunk line based on pressure. Pressure control was also added to facilitate buffering of pressure to provide continuous feed to the LA Basin.

The LA Basin "core" system could be also fed from the east by the Blythe production site. The Phoenix seasonal storage facilities would also connect from the east. The following figure shows those portions of the model.

[redacted]

Figure 5D – Model Screenshot: Blythe Production and Phoenix Storage

Each conceptual system was modeled and simulated to operate with the year of production and demand scenarios provided by SCG, Technip, and Strategen. The trunk line from each production center, the high-pressure production storage volume, and the core line within the LA Basin were iterated until the respective pipeline systems were able to meet the design requirements. The following sections list the results of those iterations.

5.1 Common LA Basin Core Pipelines

Laterals for power plants and refineries were assumed to be [redacted] pipelines for simplicity (See Sections 4.1 and 4.3). Branch lines where two laterals connect were modeled with [redacted] pipeline. The main core line through the LA Basin was allowed to vary to economize system requirements for the different rate cases. The following table lists the resulting sizes for the LA Basin Core Pipelines.

Table 5.1 – Resulting Common System Requirements

Segment Description	Length (miles)	Proposed Pipeline Requirements		
		[redacted] Rate Case	[redacted] Rate Case	[redacted] Rate Case
Core Trunk Line	[redacted]			
Branches				
Power Plant Laterals				
Refinery Laterals				
Vehicle Fueling Laterals				
Castaic Storage Lateral*				

*Castaic Storage Lateral was not applicable to Delta and Phoenix Storage

A [redacted] core pipeline was required to maintain stable pressure supply with the [redacted] rate case as a [redacted] line was insufficient to buffer the variable power plant demand. The core pipeline increased to [redacted] with the [redacted] rate case to accommodate the higher throughput to the port area as well as transferring seasonal storage from Blythe to Castaic.

All six system combinations were modeled using the common system configuration listed in the table above. The following sections list the results for the individual systems modeled for each of the three rate cases.

5.2 Five Points Production / Castaic Storage

The conceptual Five Points production site was situated [redacted] miles north of the Castaic Storage takeoff. The following table lists the pipeline configuration determined for each rate case.

Table 5.2.1 – Resulting Five Points Pipeline Requirements

Segment Description	Length (miles)	Proposed Pipeline Requirements		
		[redacted] Rate Case	[redacted] Rate Case	[redacted] Rate Case
HP Local Storage	*	None	[redacted]	[redacted]
Five Points to Castaic Storage Take-Off	[redacted]	[redacted]	[redacted]	[redacted]

*HP Local Storage composed of [redacted] pipe within the production facility.

[redacted] were modeled from Five Points to the storage site lateral connection for the [redacted] rate case to maintain supply to demand centers without exceeding [redacted] at the production site. Additionally, [redacted] miles of HP storage in conjunction with flow to seasonal storage was required to dampen the daily production swings (this is equivalent to [redacted] million cubic feet of volume).

The [redacted] rate case only marginally reduced the pipeline requirement. The variability from the power plants remained the same as the [redacted] rate case which was adversely affected by the significant distance between to Five Points and the LA Basin.

The [redacted] rate case reduced the system throughput to allow residual pressure storage in the pipeline to accommodate daily pressure variations. This eliminated the need for the parallel transmission line and local high pressure storage at the production facility.

The following table shows the operating envelope required by the compressors at Five Points and Castaic.

Table 5.2.2 – Resulting Five Points Compressor Requirements

Equipment Location	Proposed Compressor Requirements		
	[redacted] Rate Case	[redacted] Rate Case	[redacted] Rate Case
Five Points Production	[redacted]	[redacted]	[redacted]
Castaic Storage	[redacted]	[redacted]	[redacted]

Compressor performance assumes [redacted] psig from the electrolyzer hydrogen production, [redacted] psi reserve pressure in underground storage, and 80% compressor efficiency. Selection of specific compressor sets are beyond the scope of this study. The following figures show the calculated performance requirements for the Five Points Production and Castaic Storage system.

[redacted]

Figure 5.2.1 – Five Points Production System Discharge

[redacted]

Figure 5.2.2 – Castaic Storage System Connection

The compression at Castaic draws from the pipeline at a minimum pressure of [redacted] psig and maintains the formation up to [redacted] psig to supply the pipeline.

5.3 Mojave Production / Castaic Storage

The conceptual Mojave production site was situated [redacted] miles north of the Santa Clara junction. The following table lists the pipeline configuration determined for each rate case.

Table 5.3.1 – Resulting Mojave [redacted] Requirements

Segment Description	Length (miles)	Proposed Pipeline Requirements		
		[redacted] Rate Case	[redacted] Rate Case	[redacted] Rate Case
HP Local Storage	*	[redacted]	[redacted]	[redacted]
Mojave to LA Basin	[redacted]	[redacted]	[redacted]	[redacted]

*HP Local Storage composed of [redacted] within the production facility.

[redacted] was modeled from Mojave to the LA Basin for the [redacted] rate case to maintain supply to demand centers without exceeding [redacted] psig at the production site. Additionally, [redacted] miles of HP storage in conjunction with flow to seasonal storage was required to dampen the daily production swings (this is equivalent to [redacted] million cubic feet of volume).

The [redacted] rate case only marginally reduced the pipeline requirement. The variability from the power plants remained the same as the [redacted] rate case however less high-pressure storage was required at the lower rates.

The [redacted] rate case reduced the system throughput enough to reduce overall discharge pressure to the LA Basin with a moderate amount of local high pressure storage at the production facility ([redacted] million cubic feet). This also reduced the transmission line to [redacted]

The following table shows the operating envelope required by the compressors at Mojave and Castaic.

Table 5.3.2 – Resulting Mojave Compressor Requirements

Equipment Location	Proposed Compressor Requirements		
	[redacted] Rate Case	[redacted] Rate Case	[redacted] Rate Case
Mojave Production	[redacted]	[redacted]	[redacted]
Castaic Storage	[redacted]	[redacted]	[redacted]

The following figures show the calculated performance requirements for the Mojave Production and Castaic Storage system.

[redacted]

Figure 5.3.1 – Mojave Production System Discharge

[redacted]

Figure 5.3.2 – Castaic Storage System Connection

The conceptual compression at Castaic draws from the pipeline at a minimum pressure of [redacted] psig and maintains the formation up to [redacted] psig to supply the pipeline.

5.4 Blythe Production / Castaic Storage

The conceptual Blythe production site was situated [redacted] miles east of the LA Basin. The following table lists the pipeline configuration determined for each rate case.

Table 5.4.1 – Resulting Blythe Pipeline Requirements

Segment Description	Length (miles)	Proposed Pipeline Requirements		
		[redacted] Rate Case	[redacted] Rate Case	[redacted] Rate Case
HP Local Storage	*	None	[redacted]	[redacted]
Blythe to Whitewater	[redacted]	[redacted]	[redacted]	[redacted]
Whitewater to LA Basin	[redacted]	[redacted]	[redacted]	[redacted]

*HP Local Storage composed of [redacted] pipe within the production facility.

[redacted] were modeled from Blythe to the Whitewater area continuing with [redacted] to the LA Basin for the [redacted] rate case to maintain supply to demand centers without exceeding [redacted] the production site. Additionally, [redacted] miles of HP storage was required to dampen the daily production swings as flow through the LA Basin core pipe switched directions between Blythe and Castaic.

The [redacted] rate case reduced the pipeline requirement such that only [redacted] was required to Whitewater with [redacted] miles of HP storage (this was equivalent to [redacted] million cubic feet). The variability from the power plants remained the same as the [redacted] rate case however less high-pressure storage was required at the lower rates.

The [redacted] rate case reduced the system throughput enough to require only [redacted] from Blythe with no local high pressure storage at the production facility. Feeding the LA Basin from two directions (production and seasonal storage) acted to stabilize the pressure variations.

The following table shows the operating envelope required by the compressors at Blythe and Castaic.

Table 5.4.2 – Resulting Blythe Compressor Requirements

Equipment Location	Proposed Compressor Requirements		
	[redacted] Rate Case	[redacted] Rate Case	[redacted] Rate Case
Blythe Production	[redacted]	[redacted]	[redacted]
Castaic Storage	[redacted]	[redacted]	[redacted]

The following figures show the calculated performance requirements for the Blythe Production and Castaic Storage system.

[redacted]

Figure 5.4.1 – Blythe Production System Discharge

[redacted]

Figure 5.4.2 – Castaic Storage System Connection

The compression at Castaic draws from the pipeline at a minimum pressure of [redacted] psig and maintains the formation up to [redacted] psig to supply the pipeline.

5.5 Delta Production / Delta Storage

The conceptual Delta production site was situated [redacted] miles upstream of the LA Basin with intermediate compression proposed in the Las Vegas area for the [redacted] rate case. Delta Storage and the intermediate compressor station (if applicable) were modeled to discharge at [redacted].

The following table lists the pipeline configuration determined for each rate case.

Table 5.5.1 – Resulting Delta Pipeline Requirements

Segment Description	Length (miles)	Proposed Pipeline Requirements		
		[redacted] Rate Case	[redacted] Rate Case	[redacted] Rate Case
Delta to Las Vegas	[redacted]	[redacted]	[redacted]	[redacted]
Intermediate LV Compressor*		No	No	Yes
Las Vegas to LA Basin	[redacted]	[redacted]	[redacted]	[redacted]

[redacted] was modeled from Delta to the LA Basin with intermediate compression for the [redacted] rate case to maintain supply to demand centers. Since all production was directed through underground storage, no local high-pressure storage was required.

The [redacted] rate case eliminated the requirement for intermediate compression with [redacted] The [redacted] rate case reduced the system throughput enough to require only [redacted] from Delta to the LA Basin.

For all rate cases, the constant supply of hydrogen gas at [redacted] allowed for stable feed pressures downstream. Despite the hydraulic distance, the required pipeline size was relatively less than the other system configurations. However, this also required significantly higher compressor power at the production site.

The following table shows the operating envelope required by the compressors at Delta and the intermediate compression station near Las Vegas.

Table 5.5.2 – Resulting Delta Compressor Requirements

Equipment Location	Proposed Compressor Requirements		
	[redacted] Rate Case	[redacted] Rate Case	[redacted] Rate Case
Delta Production	[redacted]	[redacted]	[redacted]
Intermediate Compression	[redacted]	[redacted]	[redacted]

[redacted] The following figures show the calculated performance requirements for the intermediate compressor station.

[redacted]

The conceptual compression at Las Vegas draws from the pipeline originating from Delta for a minimum suction pressure of [redacted] psig at the highest demand rate. The majority of operating conditions center about the average demand rate with typical suction pressures between [redacted] psig.

Peak production horsepower was also during peak available power from the solar system. Horsepower for this system can also be optimized by splitting flow between the underground storage and the pipeline. However, the full production rate into the cavern was used as a conceptual design case.

5.6 Mojave Production / Delta Storage

The conceptual Mojave production site was situated [redacted] miles from Delta Storage. [redacted] miles from Mojave, a junction was modeled to connect this pipeline to the LA Basin. The following table lists the pipeline configuration determined for each rate case.

Table 5.6.1 – Resulting Mojave / Delta Pipeline Requirements

Segment Description	Length (miles)	Proposed Pipeline Requirements		
		[redacted] Rate Case	[redacted] Rate Case	[redacted] Rate Case
HP Local Storage	*	None	[redacted]	[redacted]
Mojave to Palmdale Junction	[redacted]	[redacted]	[redacted]	[redacted]
Delta to Las Vegas	[redacted]	[redacted]	[redacted]	[redacted]
Intermediate LV Compressor		No	No	Yes
Las Vegas to Palmdale	[redacted]	[redacted]	[redacted]	[redacted]
Palmdale Junction to LA Basin	[redacted]	[redacted]	[redacted]	[redacted]

*HP Local Storage composed of [redacted] pipe within the production facility.

[redacted] was modeled to connect Mojave to Delta for the [redacted] rate case to allow daily transfers between the production site, the storage site, and the LA Basin. Additionally, [redacted] miles of HP storage was required to dampen Delta seasonal storage from the daily production swings.

The [redacted] rate case reduced the pipeline requirement and eliminated the need for intermediate compression. Less high-pressure storage was required at the lower rates since the pipeline to Delta represented a significant volume.

The [redacted] rate case reduced the system throughput enough to require [redacted] from Mojave and Delta with no local high pressure storage at the production facility. The following table shows the operating envelope required by the compressors at Blythe and Castaic.

Table 5.6.2 – Resulting Mojave / Delta Compressor Requirements

Equipment Location	Proposed Compressor Requirements		
	[redacted] Rate Case	[redacted] Rate Case	[redacted] Rate Case
Mojave Production	[redacted]	[redacted]	[redacted]
Delta Storage	[redacted]	[redacted]	[redacted]
Intermediate Compression	[redacted]	[redacted]	[redacted]

The following figures show the calculated performance requirements for the Mojave Production and Delta Storage system.

[redacted]

Figure 5.6.1 – Mojave Production System Discharge

[redacted]

Figure 5.6.2 – Delta Storage System Connection

The conceptual compression at Delta draws from the pipeline at a minimum pressure of [redacted] and maintains the formation up to [redacted] to supply the pipeline. Compressors at Delta work in conjunction with the intermediate compressors.

5.7 Blythe Production / Phoenix Storage

The conceptual Blythe production site was situated [redacted] miles west of Phoenix. Production was discharge into the line toward Phoenix with additional compression at Blythe to move gas toward the LA Basin. The following table lists the pipeline configuration determined for each rate case.

Table 5.7.1 – Resulting Blythe / Phoenix Pipeline Requirements

Segment Description	Length (miles)	Proposed Pipeline Requirements		
		[redacted] Rate Case	[redacted] Rate Case	[redacted] Rate Case
HP Local Storage	*	[redacted]	[redacted]	[redacted]
Phoenix to Blythe	[redacted]	[redacted]	[redacted]	[redacted]
Blythe to Whitewater	[redacted]	[redacted]	[redacted]	[redacted]
Whitewater to LA Basin	[redacted]	[redacted]	[redacted]	[redacted]

*HP Local Storage composed of [redacted] pipe within the production facility.

[redacted] was modeled from Blythe to the Phoenix area and [redacted] from Blythe to the LA Basin for the [redacted] balance flow between production and seasonal storage [redacted] miles o[redacted] million cubic feet). Compressors supplied continuous flow to the LA Basin demand centers, which optimized the compressor and pipeline sizing across the system.

The [redacted] rate case reduced the pipeline requirement to [redacted] with [redacted] miles of HP storage ([redacted] million cubic feet).

The [redacted] rate case reduced the system throughput enough to require only [redacted] from Blythe with [redacted] miles ([redacted] million cubic feet) of local high pressure storage at the production facility.

The following table shows the operating envelope required by the compressors at Blythe and Phoenix.

Table 5.7.2 – Resulting Blythe / Phoenix Compressor Requirements

Equipment Location	Proposed Compressor Requirements		
	[redacted] Rate Case	[redacted] Rate Case	[redacted] Rate Case
Blythe Production	[redacted]	[redacted]	[redacted]
Blythe Intermediate Compression	[redacted]	[redacted]	[redacted]
Phoenix Storage	[redacted]	[redacted]	[redacted]

The following figures show the calculated performance requirements for the Blythe Production and Phoenix Storage system.

[redacted]

Figure 5.7.1 – Blythe Production System Discharge

[redacted]

Figure 5.7.2 – Phoenix Storage System Connection

The conceptual compression at Phoenix draws from the pipeline at a minimum pressure of [redacted] psig and maintains the formation up to [redacted] psig to supply the pipeline.

[redacted]

Figure 5.7.3 – Blythe Booster Compression toward LA Basin

Although the conceptual intermediate compression at Blythe was modeled separately from the production compressors, the compression requirements towards the LA Basin stay entirely within the process conditions of the production compressors. Therefore, these compressors can be physically the same units and manifolded to serve both purposes.

5.8 Seasonal Storage Requirements (All Systems)

Castaic, Delta, and Phoenix locations were all modeled as potential seasonal storage solutions for the respective systems described above. The daily production and demand were compared for each rate case to determine the idealized flow into and out of seasonal storage. These flows were also integrated to determine the total required volume for the seasonal storage facility. The following charts illustrate the results of that methodology for each rate case.

[redacted]

Figure 5.8.1 – Totalized Production and Demand

The totalized demand remained relatively linear for each case compared to the significant change of hydrogen production throughout the year due to differences in seasonal solar output. The difference between the production and demand for each case was used to determine the total required working volume of hydrogen storage throughout the system. The following figure is the result of these calculations with the minimum value for each case normalized to zero.

[redacted]

Figure 5.8.2 – Annual Working Volume of Hydrogen Storage

Minimum working volume occurred in spring with the bulk of storage occurring in summer. Maximum working volume occurred in fall and remained stable until winter demand outpaced production.

Daily cycles of production and demand differences were intended to be absorbed by the local high-pressure storage at each production site and the overall pipeline system. The seasonal storage data was idealized by using a daily average of the storage working volume and comparing this to the instantaneous value to determine the net flow out of seasonal storage.

[redacted]

Figure 5.8.3 – Average Daily Rates Required from Storage

The values in the figure above match the average slope (change in working volume) of Figure 5.8.2 which is also the daily average difference between production and demand. This follows the trend of flowing out of seasonal storage during winter months while flowing into seasonal storage during summer. Intermediate spikes of flow out of storage occur when daily hydrogen production is lacking compared to the relatively constant demand based on the meteorological model used by Technip.

Note that these values are idealized averages from the tabulated basis data and do not incorporate the hydraulic and transient effects used in the simulated pipeline systems. The following table summarizes the resulting parameters of this idealized approach. Since the same production and demand data sets were used for each system location, these values apply to all proposed system combinations (which the exception of Delta Production / Delta Storage since this system was modeled with all hydrogen volume passing through the cavern without daily high-pressure storage).

Table 5.8 – Resulting Seasonal Storage Requirements

	[redacted] Rate Case	[redacted] Rate Case	[redacted] Rate Case
Minimum Working Volume	[redacted]	[redacted]	[redacted]
Proportion of Production Volume	[redacted]	[redacted]	[redacted]
Minimum Injection Rate (Compression into Cavern)	[redacted]	[redacted]	[redacted]
Minimum Withdraw Rate (Flow out of Cavern)	[redacted]	[redacted]	[redacted]
Modeled Injection Rate	[redacted]	[redacted]	[redacted]
Modeled Withdraw Rate	[redacted]	[redacted]	[redacted]

Comparing the idealized seasonal storage requirements to the modeled parameters confirms the simulated system results for each rate case. The minimum rates represent perfect control and coordination hydrogen production and delivery at optimal rates.

A pipeline simulation was developed for each system to provide a more accurate expectation of realistic controls responding to dynamic conditions. The modeled injection rates are higher than the minimum rates to account for simulated pressure controls that must respond to increased production. Likewise, the modeled withdraw rates were higher to account for the transience of the system hydraulics reacting to a drop in pressure due to increased demand.

Finally, the minimum working volume of seasonal storage represents the variance in gross annual production and demand cycles for the particular data set to maintain continuous hydrogen supply to the LA Basin. While this was consistent with the simulation results, further analysis of potential additional storage may be conducted by SCG to provide appropriate contingency for a utility-scale hydrogen economy. Maximum available capacity and viability of each modeled seasonal storage location (Castaic, Delta, and Phoenix) is beyond the scope of this analysis.

6. Attachments

6.1 Overall Hydraulic Results Summary Table

6.2 SPS Master Model Screenshot

6.3 SPS Mojave / Delta Model Screenshot

6.4 System Process Flow Diagrams

[redacted]

[redacted]