HYDRAULIC ANALYSIS
REPORT 8143-M-003

HYDROGEN PIPELINE STUDY
TRANSPORTATION SYSTEM

MEDIUM AND HIGH RATES

Prepared For:

SOUTHERN CALIFORNIA GAS COMPANY

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Table of Contents

1. Executive Summary

1.1 Background

In support of the Southern California Gas Company's (SCG) 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 system concept that can produce, transport, and deliver hydrogen gas at-scale to the LA Basin. Three demand scales were considered representing "Low" ([redacted] metric tons per year), "Medium" ([redacted] metric tons per year), and "High" rates ([redacted] metric tons per year). The "Low" demand rate is presented in detail in SPEC Report 8143-M-002. This report presents the Medium and High demand rates.

Five potential production locations were selected by SCG as well as two potential underground storage facilities. A selection of these regions were used to provide sufficient land area to produce green hydrogen via photovoltaic solar power resulting in three system configurations, identified as Systems 7, 8, and 9 (Systems 1 – 6 are part of the "Low" hydraulic study). This report provides the hydraulic basis of design for the gas pipeline system that would receive hydrogen from the various production sites, flow at transmission pressure, and deliver to demand centers in the LA Basin.

Transient hydraulic modeling and controls were developed as part of the "Low" rate analysis. For the "Medium" and "High" rates, this basis was scaled using steady-state hydraulic modeling to determine the size and quantity of pipelines to connect the production regions, the underground storage sites, and the LA Basin demand center. Basis and conclusions are documented in this report, including pipeline sizing, trunk line routes, and average system movements between seasonal production scenarios.

1.2 Summary of System Results

The proposed system configurations for the two "Medium" and one "High" demand scenarios modeled are included in Section 4 of this report. System 7 represents and expansion of the System 6 scenario developed in the "Low" rate analysis with increased hydrogen production in the Mojave area and [redacted] to and from Delta, Utah. System 8 eliminates the need for the Delta pipeline and rather connects to storage in the San Joaquin Valley near Five Points with [redacted] and no intermediate compressor station. If San Joaquin Valley hydrogen storage proves viable, System 8 represents a significant reduction to pipeline scope over System 7.

System 9 uses both Five Points and Delta pipeline systems combined with additional production at Blythe and Whitewater. This represents a [redacted] buildout of the available land at the five production sites identified by SCG (Five Points, Mojave, Whitewater, Blythe, and Delta) to achieve [redacted] of green hydrogen production.

1.3 Units and Abbreviations

MMt/yr = million metric tons of hydrogen per year

2. System Description and Approach

2.1 System Options

Five potential production sites were considered for creating green hydrogen to feed the LA Basin via pipeline. No single production site had sufficient available land area to satisfy the "Medium" production / demand rate, so a combination of regions were considered with interconnecting high-pressure truck lines were used. Two underground storage sites were also considered for seasonal storage of hydrogen and to serve as backup if one production region ceased for an extended time. For the "Medium" rate, two. Three systems were modeled and analyzed:

System 7 – Production in Mojave and Utah, Storage in Delta

System 8 – Production in Mojave and Five Points, Storage in San Joaquin

System 9 – Production in All Locations, Storage in Delta and San Joaquin

Systems 7 and 8 were based on seasonal storage either in the Delta, Utah salt cavern storage site (currently under development) or in a potential storage option in the San Joaquin Valley, California. These sites are adjacent to their respective production sites and were used for regional production and seasonal storage for their respective systems. Mojave was used for both systems since it represents the largest, California-based, potential production area out of those identified by SCG.

System 9 was based on a full build-out of hydrogen production in all five sites, including Blythe, Whitewater, and both storage sites. The following table summarizes the "Medium" and "High" average annual production rate distributions for the three systems.

Table 2.1 – Annual Production per Site for Each System Configuration

Production Site	System 7	System 8	System 9
Five Points	[redacted]		
Mojave*			
Whitewater			
Blythe			
Delta			
Total			
Storage Option	Delta	San Joaquin Valley	Delta and SJV

*Due to the large production region at Mojave, this site was split between Mojave North and Mojave South (Adelanto) [redacted].

Every [redacted] of hydrogen production requires approximately [redacted] of land for solar generation, electrolysis and compression facilities. Annual production was developed to accommodate available land in each selected production site. Details regarding facility layouts, distribution, and land acquisitions are beyond the scope of this report. This hydraulic analysis begins at a single discharge point for each production site.

2.2 Pipeline Routing and Lengths

Pipelines were routed using desktop Geographic Information System (GIS) data to develop a feasible path from each production location to the demand center within the LA Basin. 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 from each significant feature in the pipeline model. System 7 originates at Delta and excludes the pipeline from Five Points (B_2 is closed). System 8 originates from Five Points and excludes the Delta pipeline and intermediate compressor (B_1). System 9 includes Delta, Five Points, and the flow from Blythe. All lengths are in miles.

[redacted]

Figure 2.2 – Overall Pipeline Lengths between Features (Systems 7 - 9)

2.3 Design Pressures and Temperatures

The proposed system was modeled with a pressure rating of [redacted] Discharge pressures from each production locations were limited to [redacted] psig. Delivery pressure to the demand location was maintained at [redacted] psig. The regulators at Santa Clarita Junction and Chino Hills Junction limit pressure into the LA Basin to [redacted] psig.

2.4 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 majority of trunk line was modeled as [redacted] pipe with the LA Basin piping (BL1, BL2, and BL3) consisting of [redacted]. The following table lists the nominal pipe sizes, wall thickness, and inner diameters used in the model. Actual pipeline wall may be thinner depending the selected steel grade in the final design.

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]

The system was modeled with all [redacted]. Pipeline diameters and number of parallel "looped" pipes were selected to keep the simulation running within the design pressures discussed in Section 2.3.

2.5 Hydrogen Storage Solutions

A transient pipeline model was developed to simulate the controls associated with a solar-only energy source with hydrogen production in Mojave and seasonal storage in Delta (See System 6 in SPEC Report 8143-M-002). Analysis of this configuration was used to determine the storage requirements based on the Low Demand conditions ([redacted]/yr) and was scaled to the production rates used in the Medium and High Demand scenarios. This resulted in [redacted] miles of [redacted] high pressure gas storage per one million metric tons of annual hydrogen production required to stabilize the daily energy production swing from solar. Likewise, the seasonal storage was required to withdraw into the pipeline system up to the average system demand rate to compensate for decline in production site output at night. The seasonal storage required a minimum capacity of [redacted] of the total annual demand.

These storage solutions were assumed to be in-place for this hydraulic analysis. Hydraulic scenarios were developed for each system configuration to account for both seasonal movements and storage back-up conditions.

2.6 Steady-State Gas Pipeline Modeling

DNV GL Synergi Pipeline Simulator version 10.7 was used to in this calculation. A complete model was built from each production site to the LA Basin. Sections were segregated for the respective system so the same model could be used for consistency. The BWRS equation of state was selected to model pure hydrogen with a base viscosity of 0.0084 centipoise.

3. Hydrogen Production Scenarios

SCG has requested five production locations to be considered for five separate pipeline systems. The following figure shows the locations of these production sites, required area of PV solar farm, and the main trunk lines routed to the LA Basin.

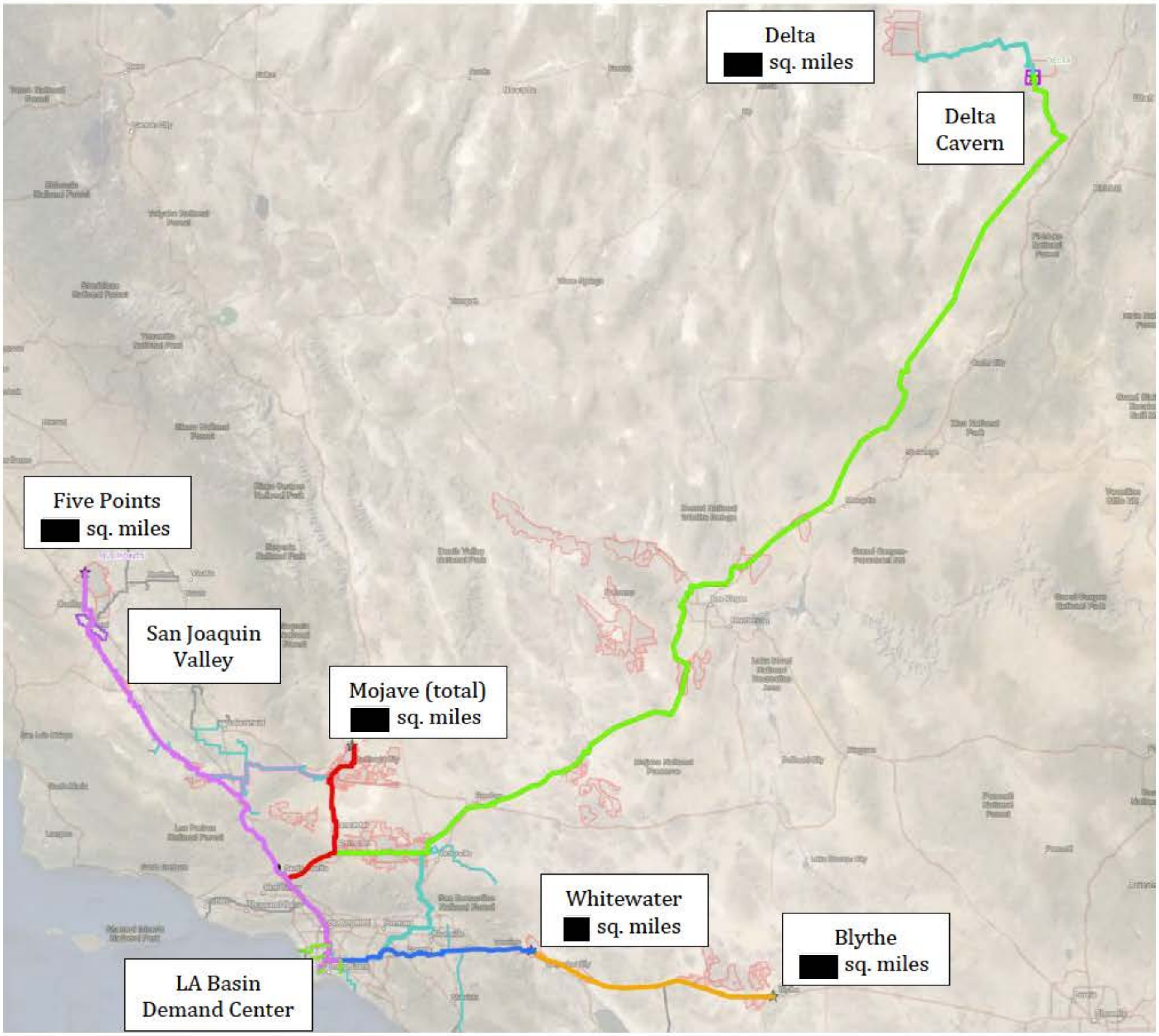

Figure 3 – Proposed Hydrogen Production Sites and Trunk Line Routes

3.1 Basis and Approach

Development and modeling of individual production characteristics (optimized wind/solar and solar only), demand centers (power plants, refineries, vehicle fueling, and blending), and daily gas transportation needs were simulated extensively for the Low Demand case ([redacted]/yr). Parameters from this analysis were scaled for the Medium ([redacted]/yr) and High [redacted]/yr) Demand cases to determine the required system design to transport these volumes of hydrogen to the LA Basin. These parameters include the following:

- Maximum production discharge pressure of [redacted] psig
- Minimum delivery pressure to storage (SJV or Delta) of [redacted] psig
- Maximum storage discharge pressure of [redacted] psig
- Minimum suction pressure to intermediate compressor station of [redacted] psig
- Maximum discharge pressure from intermediate compressor of [redacted] psig
- Pressure regulation into the LA Basin of [redacted] psig
- Delivery pressure into the LA Basin (at Ports) of [redacted] psig

In addition to the average demand throughputs, three additional scenarios were run for each system:

- A "winter" case reduced the production rate to [redacted] of average while maintaining constant demand. This required additional flow from seasonal storage.
- A "summer" case increased the production rate to [redacted] of average while also increasing the demand to [redacted] of average. The surplus was moved into seasonal storage.
- A "backup" case considered a significant loss of regional production where nearly all demand was provided by storage.

The following table lists the steady-state hydraulic cases used to represent the scenarios listed above for the two Medium (Systems 7 and 8) and the High (System 9) Demand rates.

Table 3.1.1 – Steady-State Flow for Medium Demand Case (System 7)

Production Sites	Case #1	Case #2	Case #3	Case #4
	Average	Winter	Summer	Back-up
	MMt/yr	MMt/yr	MMt/yr	MMt/yr
FPP Five Points	[redacted]			
MP Mojave				
AP Adelanto				
WP Whitewater				
BP Blythe				
DP Delta				
Total Production				
Out of UCS				
Out of SJVS				
LA Demand				

Table 3.1.2 – Steady-State Flow for Medium Demand Case (System 8)

Production Sites	Case #5	Case #6	Case #7	Case #8
	Average	Winter	Summer	Back-up
	MMt/yr	MMt/yr	MMt/yr	MMt/yr
FPP Five Points	[redacted]			
MP Mojave				
AP Adelanto				
WP Whitewater				
BP Blythe				
DP Delta				
Total Production				
Out of UCS				
Out of SJVS				
LA Demand				

Table 3.1.3 – Steady-State Flow for High Demand Case (System 9)

Production Sites	Case #9	Case #10	Case #11	Case #12	Case #13
	Average	Winter	Summer	Back-up	Back-up
	MMt/yr	MMt/yr	MMt/yr	MMt/yr	MMt/yr
FPP Five Points	[redacted]				
MP Mojave					
AP Adelanto					
WP Whitewater					
BP Blythe					
DP Delta					
Total Production					
Out of UCS					
Out of SJVS					
LA Demand					

These steady-state calculations were used iteratively to determine the required pipeline size and quantity between each system node.

3.2 Pipeline Segment Descriptions

The following table list the pipeline segments used for the LA Basin trunk lines in the model.

Table 3.2.1 LA Basin Pipeline Segment Descriptions

Segment Tag	Length (miles)	Source	Destination
BL1	[redacted]	[redacted]	[redacted]
BL2	[redacted]	[redacted]	[redacted]
BL3	[redacted]	[redacted]	[redacted]

The LA Basin pipelines are used for all Medium and High system models. The following table lists the pipeline segments used for the production trunk lines in the model with the applicable system indicated.

Table 3.2.2 Trunk Pipeline Segment Descriptions

Segment Tag	Length (miles)	Source	Destination	Connected System
BP	[redacted]	[redacted]	[redacted]	9 only
DP	[redacted]	[redacted]	[redacted]	7 and 9
FPP	[redacted]	[redacted]	[redacted]	8 and 9
KJ	[redacted]	[redacted]	[redacted]	8 and 9
KN	[redacted]	[redacted]	[redacted]	8 and 9
MK	[redacted]	[redacted]	[redacted]	8 and 9
ML1	[redacted]	[redacted]	[redacted]	All
ML2	[redacted]	[redacted]	[redacted]	All
ML3	[redacted]	[redacted]	[redacted]	7 and 9
ML4	[redacted]	[redacted]	[redacted]	7 and 9
MP	[redacted]	[redacted]	[redacted]	All
MT	[redacted]	[redacted]	[redacted]	All
WBT	[redacted]	[redacted]	[redacted]	9 only
WT	[redacted]	[redacted]	[redacted]	All

4. Results

Each system was modeled and simulated to operate with the rates listed in Table 3.1. The truck line from each production center was increased until the pipeline system was able to meet the design requirements. The following figures and tables show the proposed design configurations for these systems based on these calculations.

[redacted]

Figure 4.1 – System 7 Configuration (Delta Pipeline, Storage, and Production)

[redacted] were required to transport the [redacted] rate from Delta down to California. [redacted] would cause either the Las Vegas Intermediate Compressor station or the Delta storage facility to discharge beyond their respective design parameter. Once into the LA Basin, [redacted] were used to carry the volume to the demand center.

Table 4.1.1 –Medium Demand System 7 Configuration Pipe Selection

Segment Tag	Quantity	OD (in)	WT (in)	ID (in)
BL1	[redacted]	[redacted]	[redacted]	[redacted]
BL2	[redacted]	[redacted]	[redacted]	[redacted]
BL3	[redacted]	[redacted]	[redacted]	[redacted]
BP				
DP	[redacted]	[redacted]	[redacted]	[redacted]
FPP				
KJ				
KN				
MK				
ML1	[redacted]	[redacted]	[redacted]	[redacted]
ML2	[redacted]	[redacted]	[redacted]	[redacted]
ML3	[redacted]	[redacted]	[redacted]	[redacted]
ML4	[redacted]	[redacted]	[redacted]	[redacted]
MP	[redacted]	[redacted]	[redacted]	[redacted]
MT	[redacted]	[redacted]	[redacted]	[redacted]
WBT				
WT	[redacted]	[redacted]	[redacted]	[redacted]

Table 4.1.2 –Medium Demand Calculated Pressures with System 7 Configuration

Production Sites	**Case #1**	**Case #2**	**Case #3**	**Case #4**
	Average	Winter	Summer	Back-up
	psig	psig	psig	psig
Mojave North	[redacted]	[redacted]	[redacted]	-
Mojave South	[redacted]	[redacted]	[redacted]	-
Delta Production	[redacted]	[redacted]	[redacted]	[redacted]
Las Vegas Compressor	[redacted]	[redacted]	[redacted]	[redacted]
Delta Storage	-	[redacted]	[redacted]	[redacted]
CHJ Downstream	[redacted]	[redacted]	[redacted]	[redacted]
SCJ Downstream	[redacted]	[redacted]	[redacted]	[redacted]

[redacted]

Figure 4.2 – System 8 Configuration (Five Points Pipeline, Storage, and Production)

Moving seasonal storage from Delta to the San Joaquin Valley reduces the required pipeline both in length but also in quantity ([redacted] in System 7) and eliminates the need for an intermediate compressor station. The direction from Five Points into the LA Basin also include the route from Kern Junction to Santa Clarita. Preliminary results revealed [redacted] along this route would take the place of [redacted] through Mojave because of the shorter distance to Santa Clarita. Overall, the System 8 configuration represents a significant reduction in project scope from the System 7 configuration if storage at the San Joaquin Valley proves viable.

Table 4.2.1 –Medium Demand System 8 Configuration Pipe Selection

Segment Tag	Quantity	OD (in)	WT (in)	ID (in)
BL1	[redacted]			
BL2	[redacted]			
BL3	[redacted]			
BP				
DP				
FPP	[redacted]			
KJ	[redacted]			
KN	[redacted]			
MK	[redacted]			
ML1	[redacted]			
ML2	[redacted]			
ML3				
ML4				
MP	[redacted]			
MT	[redacted]			
WBT				
WT	[redacted]			

Table 4.2.2 –Medium Demand Calculated Pressures with System 8 Configuration

Production Sites	Case #5	Case #6	Case #7	Case #8
	Average	Winter	Summer	Back-Up
	psig	psig	psig	psig
Five Points	[redacted]			
Mojave North	[redacted]			
Mojave South	[redacted]			
San Joaquin Valley Storage	[redacted]			
CHJ Downstream	[redacted]			
SCJ Downstream	[redacted]			

[redacted]

Figure 4.3 – System 9 Configuration

Increasing the overall system capacity from [redacted] to [redacted] required a combination of both System 7 (Delta Pipeline) and System 8 (Five Points Pipeline). These systems remained relatively unchanged from their Medium Demand cases. A third pipeline route from Riverside connects Blythe and Whitewater production sites. This route is composed of a [redacted] from Blythe to Whitewater, then [redacted] from Whitewater to Chino Hills Junction. The [redacted] corridors into the LA demand center increased with [redacted] from the north and [redacted] from the east.

Table 4.3.1 –High Demand System 9 Configuration Pipe Selection

Segment Tag	Quantity	OD (in)	WT (in)	ID (in)
BL1	[redacted]			
BL2				
BL3				
BP				
DP				
FPP				
KJ				
KN				
MK				
ML1				
ML2				
ML3				
ML4				
MP				
MT				
WBT				
WT				

Table 4.3.2 –High Demand Calculated Pressures with System 9 Configuration

Production Sites	Case #9	Case #10	Case #11	Case #12	Case #13
	Average	Winter	Summer	Back-Up	Back-Up
	psig	psig	psig	psig	psig
Five Points	[redacted]				
Mojave North					
Mojave South					
WP Whitewater					
BP Blythe					
DP Delta					
LVC Las Vegas					
SJVS San Joaquin Valley					
UCS Delta					
CHJ Downstream					
SCJ Downstream					

5. Attachments

5.1 Pipeline Production Hydraulic Summary Tables

5.2 System Diagrams

5.3 SPS Model Screen Shot and Input Data

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]