U.S. EPA Coalbed Methane Outreach Program

United States Environmental Protection Agency

Pre-Feasibility Study for Methane Drainage and Utilization at the San Juaquin Mine, Antioquia Department, Colombia

U.S. Environmental Protection Agency

July 2017

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U.S. Environmental Protection Agency, Washington, DC USA

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This publication was developed at the request of the United States Environmental Protection Agency (USEPA), in support of the Global Methane Initiative (GMI). In collaboration with the Coalbed Methane Outreach Program (CMOP), Advanced Resources International, Inc. (ARI) authored this report under RTI International contract EP-BPA-16-H. Information included in the report is based on data obtained from the coal mine partner, Mina San Juaquin De Propiedad De Carbones San Fernando S.A.S (San Juaquin Mine), a subsidiary of Grupo Corporativo Vatia S.A.S (Vatia).

Acknowledgements

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Executive Summary

The U.S. Environmental Protection Agency's (USEPA) Coalbed Methane Outreach Program (CMOP) works with coal mines in the U.S. and internationally to encourage the economic use of coal mine methane (CMM) gas that is otherwise vented to the atmosphere. The work of USEPA also directly supports the goals and objectives of the Global Methane Initiative (GMI), an international partnership of 42 member countries and the European Commission that focuses on cost-effective, near-term methane recovery and use as a clean energy source. An integral element of the USEPA's international outreach in support of the GMI is the development of CMM pre-feasibility studies. These studies identify cost-effective project development opportunities through a high-level review of gas availability, end-use options, and emission reduction potential.

Mina San Juaquin De Propiedad De Carbones San Fernando S.A.S (San Juaquin Mine), a coal company in Colombia and a subsidiary of Grupo Corporativo Vatia S.A.S (Vatia), was selected as the recipient for a pre-feasibility study for CMM drainage at their San Juaquin Mine in the Amagá Basin of western Colombia. The mine was selected because it is one of the largest longwall mines in the country and experienced a significant mine explosion in 2010, which took the lives of 73 miners. The mine operates a ventilation system for mine gas management, but it does not currently employ any degasification techniques. To help mitigate future explosions, the San Juaquin Mine management is eager to evaluate pre-mine degasification techniques and methane abatement technologies.

The principal objective of this study is to determine the feasibility of a CMM capture and utilization project at the San Juaquin Mine. Specifically, this study aims to evaluate the technical and economic viability of methane drainage utilizing vertical pre-drainage boreholes drilled from the surface, and in-seam pre-drainage boreholes drilled from within mine workings, and to identify end-use options.

The primary market available for a CMM utilization project at the San Juaquin Mine is power generation using internal combustion engines. Given the relatively small CMM production volume, as well as the local terrain, constructing a pipeline to transport the gas to demand centers would be impractical. Based on gas supply forecasts performed in association with this pre-feasibility study, the mine could be capable of operating as much as 1.4 megawatts (MW) of electricity capacity.

CMM gas production profiles were generated for a total of 11 methane drainage scenarios, as highlighted in Exhibit 1. A drainage technology screening study was conducted to determine the optimum drainage approach and borehole spacing for the development of the proposed CMM project at the San Juaquin Mine.

Scenario	Drainage Approach	Seam(s)	Spacing Case
1 (V1)	Vertical	Manto 1, 2 & 3	10-ac
2 (V2)	Vertical	Manto 1, 2 & 3	20-ac
3 (V3)	Vertical	Manto 1, 2 & 3	40-ac
4 (V4)	Vertical	Manto 1, 2 & 3	80-ac
5 (V5)	Vertical	Manto 1, 2 & 3	160-ac
6 (H1)	In-Seam	Manto 1	1-bh/panel
7 (H2)	In-Seam	Manto 1	2-bh/panel
8 (H3)	In-Seam	Manto 1	3-bh/panel
9 (H4)	In-Seam	Manto 2	1-bh/panel
10 (H5)	In-Seam	Manto 2	2-bh/panel
11 (H6)	In-Seam	Manto 2	3-bh/panel

Exhibit 1: Summary of Drainage Scenarios Evaluated

Based on forecasted gas production, the breakeven cost of producing gas through vertical pre-drainage boreholes is estimated to be between USD[1] $80.57 and $146.26 per million British thermal unit (MMBtu). The breakeven cost of producing gas from in-seam boreholes is estimated to range from $9.67 to $10.63/MMBtu for the Manto 1 seam, and from $12.18 to $13.38/MMBtu for the Manto 2 seam. The results of the drainage technology screening study show the optimal drainage scenario for the CMM project at the San Juaquin Mine is two in-seam pre-drainage boreholes per panel (scenarios 7 and 10 for the Manto 1 and Manto 2 seams, respectively).

For the purpose of forecasting gas production for a CMM project at the mine, it is assumed that borehole development at each panel will take place up to five years before the panel is scheduled to be mined. Initial gas production is assumed to commence at the beginning of 2018, with boreholes ceasing gas production at the beginning of the year in which the panel is scheduled to begin mining activities. For the Manto 1 seam, a total of 20 panels will be mined through the end of 2058. For the Manto 2 seam, a total of 23 panels will be mined through the end of 2067.

Total gas production from the CMM project at San Juaquin Mine is anticipated to be 1,789 million cubic feet (MMcf) over the 50-year life of the project, with an average annual gas production rate of 35.8 MMcf per year. The results of the economic assessment are summarized in Exhibit 2. Based on these results, a CMM-to-power utilization project would be economically feasible, and the proposed project would generate a positive net present value (NPV) equal to $689,000. In addition, net emission reductions associated with the destruction of drained methane are estimated to total 631,000 tonnes of carbon dioxide equivalent (tCO_2e) over the life of the project.

Project Description	CMM Drained (MMcf)	Max Power Plant Capacity (MW)	Fuel Cost ($/MMBtu)	NPV-10 US$000	IRR (%)	Net CO_2e Reductions (Million metric tons)
2 in-seam horizontal boreholes per panel with up to 5 years of pre-drainage	1789	1.4	6.39	689	13%	0.631

Exhibit 2: Summary of Economic Results

[1] All monetary values presented throughout this report are stated in United States Dollars (USD).

1 Introduction

The U.S. Environmental Protection Agency's (USEPA) Coalbed Methane Outreach Program (CMOP) works with coal mines in the U.S. and internationally to encourage the economic use of coal mine methane (CMM) gas that is otherwise vented to the atmosphere. Methane is both the primary constituent of natural gas and a potent greenhouse gas when released to the atmosphere. Reducing emissions can yield substantial economic and environmental benefits, and the implementation of available, cost-effective methane emissions reduction opportunities in the coal industry can lead to improved mine safety, greater mine productivity, and increased revenues. The work of USEPA also directly supports the goals and objectives of the Global Methane Initiative (GMI), an international partnership of 42 member countries and the European Commission that focuses on cost-effective, near-term methane recovery and use as a clean energy source.

An integral element of the USEPA's international activities in support of the GMI is the development of CMM pre-feasibility studies. These studies identify cost-effective project development opportunities through a high-level review of gas availability, end-use options, and emission reduction potential. In recent years, the USPEA has sponsored feasibility and pre-feasibility studies in such countries as China, India, Kazakhstan, Mexico, Mongolia, Poland, Russia, Turkey and Ukraine.

The San Juaquin Mine was selected for this pre-feasibility study because it is one of the largest longwall mines in the country and experienced a significant mine explosion in 2010, which took the lives of 73 miners. Although the mine's ventilation system has been generally effective at reducing the methane concentration in the air throughout the mine workings, there is still a high risk of methane related accidents occurring. The San Juaquin Mine management views the implementation of modern degasification methods and methane abatement technology as being crucial to the safety of its workers and the future of its mining operations.

The principal objective of this study is to determine the feasibility of a CMM capture and utilization project at the San Juaquin Mine. Specifically, this study aims to evaluate the technical and economic viability of methane drainage utilizing vertical pre-drainage boreholes drilled from the surface, and in-seam pre-drainage boreholes drilled from within mine workings, and to identify end-use options. This pre-feasibility study is intended to provide an initial assessment of project viability. A Final Investment Decision (FID) should only be made after completion of a full feasibility study based on more refined data and detailed cost estimates, completion of a detailed site investigation, implementation of well tests, and possibly completion of a Front End Engineering & Design (FEED).

2 Background

2.1 The Colombian Coal Industry

Colombia is one of the world's most prominent high-quality bituminous coal producers. The nation's 6,746 million tonnes (Mt) of proved coal reserves are the greatest in South America (BP, 2016). Furthermore, Colombia's 85 Mt of coal production make it the continent's chief producer (BP, 2016). The northern departments of La Guajira and La Cesar are home to Colombia's largest coal deposits. El Cerrejón, located in La Guajira, is one of the world's largest open-pit coal mines, producing 33 Mt per year (Bloomberg, 2015). In 2013, El Cerrejón accounted for 43 percent of Colombia's export revenue, as well as 3.8 percent of global coal production (Cerrejon, 2013). La Cesar is Colombia's second-largest coal producing department and is home to two major mines: La Loma and La Jagua. In 2010, La Loma produced

18.1 Mt of coal and held 484 Mt of reserves (USEPA, 2015). Likewise, in 2009, La Jagua produced 4.4 Mt of coal and held 260 of reserves (USEPA, 2015). In addition to La Guajira and La Cesar, there are a number of smaller coal-producing departments scattered throughout Colombia's central interior.

Although Colombia holds enormous coal resources, the nation generates 70 percent of its electricity from hydropower (EIA, 2016). As a result, Colombia's coal production consistently exceeds its consumption. In 2014, Colombia only consumed 8 Mt of the 88 Mt of coal it produced (EIA, 2016). The resulting 80 Mt were exported, making Colombia the fifth-largest coal exporter in the world behind Indonesia, Australia, Russia, and the United States (EIA, 2016). Europe has historically been the largest destination for Colombian coal, but U.S. imports of Colombian coal grew by 8 percent between 2014 and 2015 (EIA, 2016). Additionally, in 2015, Colombian coal exported to Turkey and the Netherlands increased by 24 percent and 11 percent, respectively (World Coal, 2016).

The coal industry remains integral to Colombia's economy. From 2010 to 2015, coal production grew from 75 Mt to 85 Mt, and by 2020 production is expected to reach 105 Mt (BP, 2016); (World Coal, 2016). Colombia's exposure to growing export markets such as Turkey and Europe will also continue to support coal production growth. Because of the coal industry's impact on Colombia's economy, favorable policies and regulations exist to encourage capital investment. The Ministry of Mines and Energy (MinMinas) is Colombia's national mining authority with the capacity to regulate mining activities in accordance with Congressional laws (Latin Lawyer, 2016). In 2010, the National Mining Agency (ANM) was created to work in coordination with the Ministry of Mines and Energy to better administer Colombia's mineral resources, grant new mining titles, and help the private sector with public relations (Latin Lawyer, 2016); (Norton Rose Fulbright, 2011). Exhibit 3 illustrates the relationships between Colombia's relevant regulatory bodies.

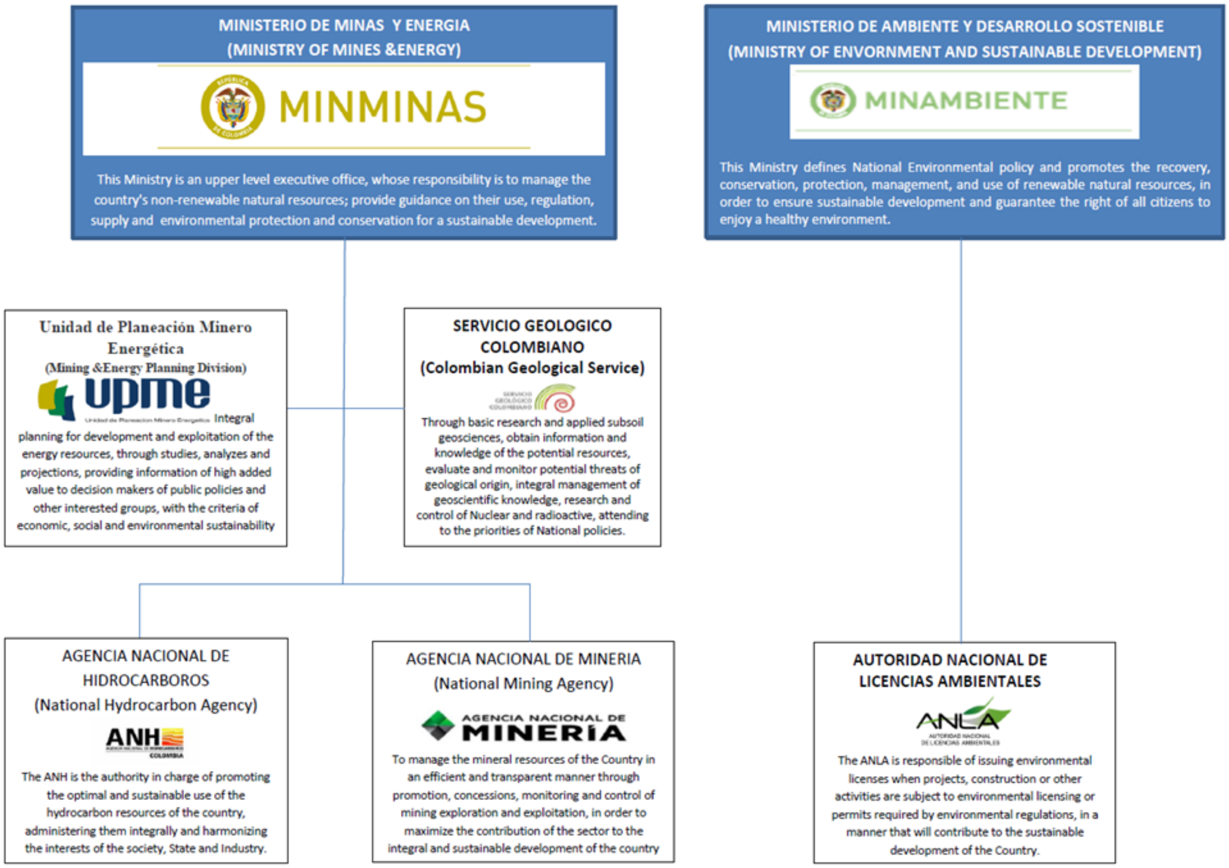

Exhibit 3: Diagram Showing the Relationships between Colombia's Mining and Hydrocarbon Regulatory Agencies

2.2 Coal Mine Methane in Colombia

Colombia's 6,746 Mt of proved coal reserves are the largest in South America (BP, 2016). By extension of these coal reserves, Colombia also holds significant coal mine and coalbed methane (CMM/CBM) utilization potential; CMM/CBM reserves are estimated to be between 11 to 35 trillion cubic feet (Tcf), compared to its 4.8 Tcf of proved natural gas reserves (ANH, 2011); (BP, 2016). Colombia's CMM/CBM industry, however, remains in its infancy, as substantial commercial utilization has not yet been realized.

With the majority of Colombia's coal production coming from the northern departments of La Guajira and La Cesar, the nation's CMM/CBM efforts target similar fields. U.S.-based Drummond Company is Colombia's most active CMM/CBM player. Drummond purchased two CMM/CBM lease blocks, one in La Cesar and one in La Guajira, and uses the two projects to conduct CMM/CBM utilization studies. The only active CMM/CBM project in Colombia is at the La Loma block in La Cesar, where Drummond currently operates a pilot project measuring methane emissions (ANH, 2011); (USEPA, 2015). Because there are no commercial scale CMM/CBM utilization projects in Colombia, coal mines continue to produce significant annual emissions, which have been rising at a rate of 40 to 50 percent per year over the last two decades, as shown in Exhibit 4. The potential for commercial CMM/CBM utilization to reduce greenhouse gas emissions remains one of the industry's most significant potential benefits.

	2000	2005	2010	2015▪
Mm^3	231	357	511	651
$MtCO_2e$*	3.9	6.1	8.7	11.1

*Global Warming Potential (100-year) used is 25, ▪Projected.

Exhibit 4: Table Showing Colombia's CMM Emissions (USEPA, 2015)

CMM/CBM project feasibility is not dictated strictly by the size of a country's total coal reserves. Geologic characteristics such as coal rank, coal composition, and coal saturation must align with economic factors affecting gas deliverability. The geologic characteristics of Colombia's coal are favorable, and potential for viable CMM/CBM projects is no longer believed to be limited to La Guajira and La Cesar. In 2015, the U.S. Trade and Development Agency (USTDA) awarded Generadora y Commercializadora de Energía del Caribe S.A. (GECELCA) a grant to fund a CMM/CBM feasibility project in Córdoba (USTDA, 2015).

Colombia's CBM industry enjoys similar regulations to those of the coal and natural gas industries and its oversight falls under the jurisdiction of Colombia's MinMinas and the Agencia Nacional de Hidrocarburos (ANH). However, based on discussions with Autoridad Nacional de Licencias Ambientales (ANLA), CMM seems to fall into a gray area and it is not clear whether it would require concession licenses from both the ANH and MinMinas. Colombia's regulatory agencies have historically committed to encouraging continued investment in the extractive industries and they are working on regulations to clarify the CMM ownership issue. Unlike oil and gas projects, however, private companies own and operate all of Colombia's coal mines.

In 2010, Colombia published its National Development Plan (NDP) 2010-2014. In it, the government identified the mining sector as a critical industry for economic growth, specifically mentioning CMM/CBM projects as an expansion area (MinMinas, 2010). As a result of NDP 2010-2014, the Colombian government published a 2011 decree describing its plan to increase natural gas production, particularly from gassy coal mines (EIA, 2016).

Despite extensive CMM/CBM potential and favorable regulatory conditions, Colombia's CMM industry does face challenges. First, many of Colombia's largest coal mines are surface mines, limiting CMM potential to pre-mine drainage. Secondly, low global natural gas prices make economic CMM utilization difficult to realize. And lastly, because CMM remains a relatively new energy resource, project-specific hurdles continue to plague developers.

The challenges associated with Colombian CMM utilization reflect common hurdles facing any young industry. Nevertheless, if Colombia is able to economically implement widespread CMM utilization, the impacts would be immense. Coal mine degasification related to CMM utilization would drastically increase safety conditions for Colombian coal miners. Additionally, commercial CMM utilization projects will significantly contribute to lowering Colombian greenhouse gas (GHG) emissions leading up to their 2030 Paris commitment. Finally, Colombian natural gas demand is expected to increase from 450 billion cubic feet (Bcf) per year in 2015, to 500 Bcf per year in 2020 (ARI, 2016). CMM utilization could provide a significant increase in Colombia's natural gas supply. For a nation historically tied to extractive industries, CMM utilization may represent a new, significant energy resource.

2.3 San Juaquin Coal Mine

The San Juaquin Mine is a coal and gas-outburst-prone mine currently producing approximately 180,000 tons per year with the potential for greater annual production after the expected incorporation of a neighboring idle mine. Mining operations began in April of 2008 with initial production of 80,600 tons per year. Since then the mine has consistently produced approximately 180,000 tons per year and has an estimated operational life span of over 50 years.

The mine is located in southwestern Antioquia, situated within the Amagá municipality. The Amagá municipality contains one of the most productive coalfields in the department of Antioquia. The mine area is bounded by two mountain chains and two major faults. To the west, a mountain chain, Moñtanas del Cerdo, and the Amagá Fault limit the deposition of commercial grade coal forming a natural mine boundary. To the east, a mountain chain, Moñtanas de Arena, and the Piedecuesta Fault also create a natural mine boundary.

Within the lease area there are several recreational farms that may limit the ability to drill degasification wells from the surface, but there are several areas readily available for drilling. There are also numerous smaller mines located within the Amagá municipality, some of which are abandoned. The mine currently has administration buildings, workshops, housing for the mine employees, recreational areas, and a coal processing facility on the lease site (see mine photos shown in Exhibit 5). The mining area is 23 miles (mi) from the city of Medellin and one mile away from town of Amagá. Exhibit 6 shows the locations of Antioquia Department, the town of Amagá, and the San Juaquin Mine.

Medellin is the capital of the department of Antioquia and the likely point of entry into Antioquia for anyone visiting the San Joaquin Mine from outside. The city is home to a modern international airport. The mine is easily accessible from nearby cities and towns by several paved roads that are in good condition. Travel time from Medellin to the San Juaquin Mine is approximately 30 minutes.

The surface above the mine is characterized as uneven, hilly, and mountainous with steep slopes present throughout the area. The mine area is crisscrossed by the Amagá River, along with several of its tributaries. Topographic relief in the mine area varies between approximately +4,370 feet (ft) in the west to over +5,249 ft in the east. In the eastern section of the mine area there are very steep slopes generally facing toward the west. As you progress further west through the mine area, the slopes become more gradual. Exhibit 7 illustrates the topography of the mine area.

Exhibit 5: Mine Photos

Exhibit 6: Location Map of the San Juaquin Mine

Exhibit 7: Map of San Juaquin Mine Area Showing Topographic Features

Amagá is classified as having a tropical climate with steady temperatures that vary throughout the year by only 25 degrees Fahrenheit (F). As observed in Amagá, the highest temperatures are in June with average temperatures of 83^{o} F and the lowest temperatures fall in January with average temperature of 76.5^{o} F. Precipitation is also consistently high throughout the year with the highest precipitation occurring in October (10.5-in average) and the lowest occurring in January (3.0-in average).

3 Summary of Mine Characteristics

3.1 Overview of Gas Resources and Current Gas Management

The existing mine boundary of the San Juaquin Mine currently covers an area of 1,206.7 acres (ac), and the mine anticipates future integration of a neighboring idle mine as part of its mining license. The coal mines in this region are notoriously gassy and prone to constant explosion related accidents, and the San Juaquin Mine is one of the gassiest. While the mine has implemented ventilation techniques for mine gas management, there is currently no methane drainage system in place.

The San Juaquin Mine utilizes a U-type ventilation system for mine gas management. The current ventilation system is generally sufficient for reducing the methane concentration in the mine workings, but there is still a high risk for methane related accidents. Currently the ventilation system has an average primary airflow of 22 cubic meters per minute (m^3/min) with a methane concentration that varies between 0.2 percent and 0.4 percent on average. To supplement the currently employed ventilation system, the mine has been considering utilizing pre-drainage boreholes drilled either from the surface (i.e., vertical boreholes) or from within mine workings (i.e., in-seam boreholes). In general, there is growing interest in pre-drainage of methane in Colombia as deeper and gassier coal seems are targeted for mining as surface resources are exhausted.

The Manto 1, Manto 2, and Manto 3 coal seams at the San Juaquin Mine are considered to be gassy with gas contents estimated to range from 248 to 251 standard cubic feet per short ton (scf/ton) within the project area. Based on these gas content values, it is estimated that the San Juaquin Mine holds approximately 8.1 Bcf of gas resources, as calculated in Exhibit 8.

Calculation of Initial Gas In Place for San Juaquin Mine								
Inputs								
Project Area Name	**Manto 1**		**Manto 2**		**Manto 3**		**Total**	
Project Area (A)	1,207	ac	1,207	ac	1,207	ac		
Pressure (PW)	710.3	psia	745.9	psia	767.2	psia		
Water Saturation (Sw)	1.00	dec	1.00	dec	1.00	dec		
Porosity (PHI)	0.020	dec	0.020	dec	0.020	dec		
Langmuir Volume (VL1)	12.2	scf/cf	12.2	scf/cf	12.2	scf/cf		
Langmuir Pressure (PL1)	152.8	psia	152.8	psia	152.8	psia		
Drainage Area (DA)	160	ac	160	ac	160	ac		
Adjust pressure to the mid-point of the zone.								
Zone thickness (DEZ) =	5.91	ft	4.59	ft	4.59	ft		
Zone mid-point =	2.95	ft	2.30	ft	2.30	ft		
Pressure adjustment =	0.433	psi/ft	0.433	psi/ft	0.433	psi/ft		
Pressure adjustment =	1.28	psi	0.99	psi	0.99	psi		
Adjusted pressure =	711.62	psia	746.85	psia	768.16	psia		
First, solve for gas concentration, C.								
C = (VLxP)/(PL+P)	10.06	scf/cf	10.56	scf/cf	10.56	scf/cf		
Then, solve for reservoir volume (RV).								
RV = NX x DEX x NY x NEY x NZ x NEZ	41,161,250	cf	32,014,305	cf	32,014,305	cf	105,189,861	cf
Then solve for sorbed gas.								
sorbed gas = RV x C x (1-PHI)	405,616,541	cf	331,400,339	cf	331,400,166	cf		
	or		or		or			
	405,617	mcf	331,400	mcf	331,400	mcf	1,068,417	mcf
Then calculate OGIP								
	Manto 1		Manto 2		Manto 3		Total	
OGIP = A / DA * sorbed gas / 10^6	3.1	bcf	2.5	bcf	2.5	bcf	8.1	bcf

Exhibit 8: Calculation of Gas-In-Place for San Juaquin Mine by Seam

3.2 Mine Geology

The San Juaquin Mine produces primarily sub-bituminous A coals that are Carboniferous in age and are mainly used as thermal coal in power plants. The coal seams found within the basin occur in several thin seams, three of which are present within the San Juaquin Mine. The three seams are designated as Manto 1, Manto 2, and Manto 3 with depths of 1,640 ft, 1,722 ft, and 1,772 ft, respectively. Manto 1 has a thickness of 5.9 ft, and Manto 2 and Manto 3 each have a thickness of about 4.6 ft. The exploited coal seams have an average dip of approximately 15 degrees to the south-southwest. Exhibit 9 is a representative stratigraphic column of the area showing the main geological units of the mining area. Exhibit 10 presents a pair of cross sections of the mine area showing the two major faults, Linimiento La Paella and Linimiento San Pedro, and a locally occurring intrusive body that affects the distribution of the coal seams.

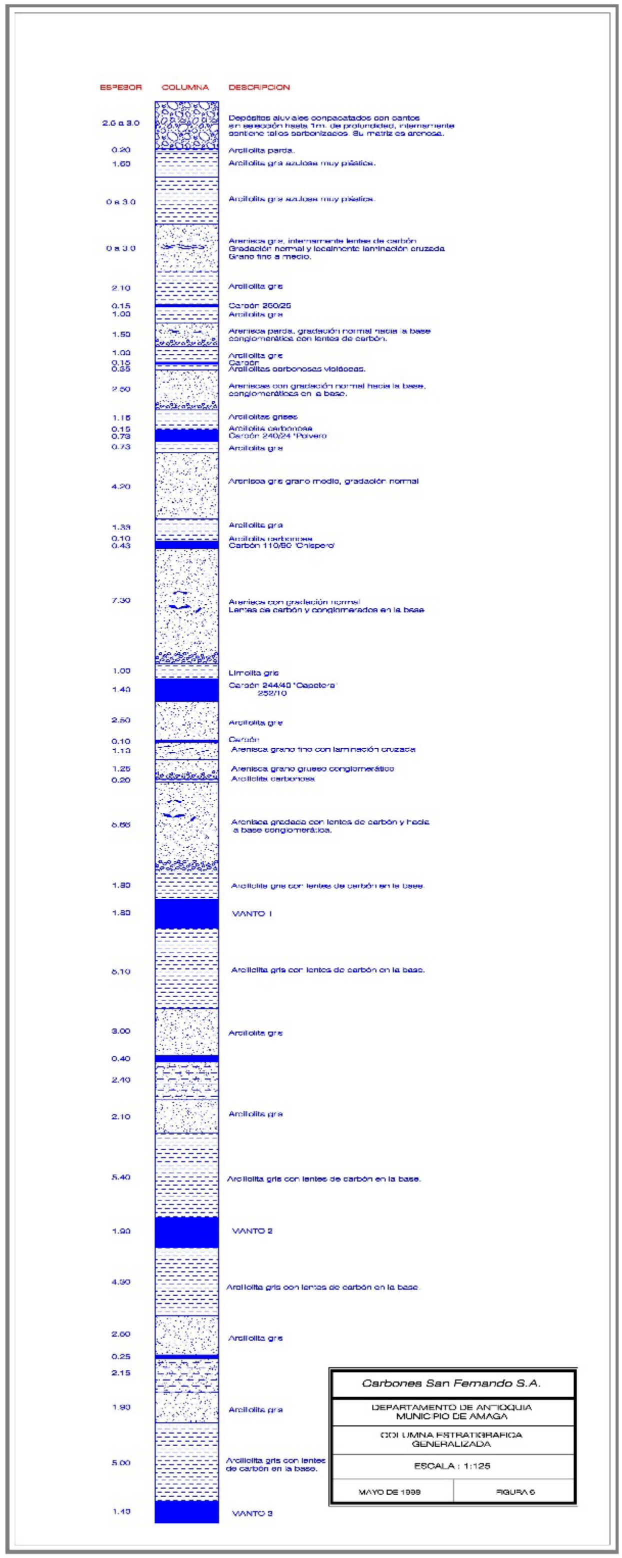

Exhibit 9: Main Geological Units of the Project Area

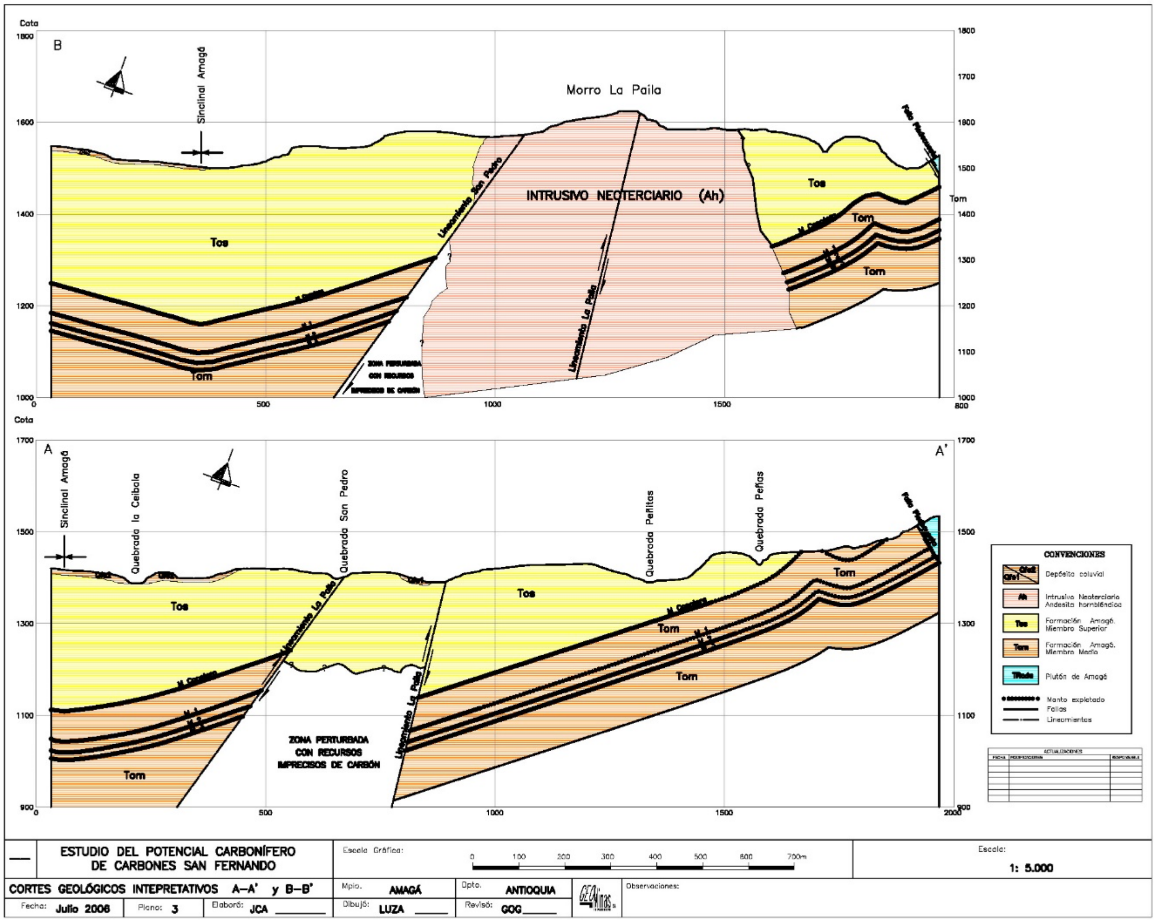

Exhibit 10: Cross Sections Depicting the Project Area Geology

3.3 Mine Operations

The San Juaquin Mine primarily uses a non-mechanized longwall mining method to extract coal along the strike of the coal seams. The mine blocks out longwall panels and then uses a drill and blast method to extract coal. These mining methods will remain the primary methods used for future exploitation of coal reserves. Production is carried out at two separate longwall faces at a time, in different seams, and current mine plans include mining in the Manto 1 and Manto 2 seams only. Under the assumption that the San Juaquin Mine will continue to use current mining methods, the mine would most likely utilize a longwall mining system designed for panels 2,297 ft in length by 591 ft in width. Exhibit 11 shows a map of the San Juaquin Mine boundary depicting the existing mine area currently delineated for development. Exhibit 12 and Exhibit 13 are mine development plans for the Manto 1 and Manto 2 seams, respectively, which show planned monthly mine progression beginning in 2011 and running through 2023. Under this plan the mine is expected to continue producing an average of 180,000 tons of coal per year.

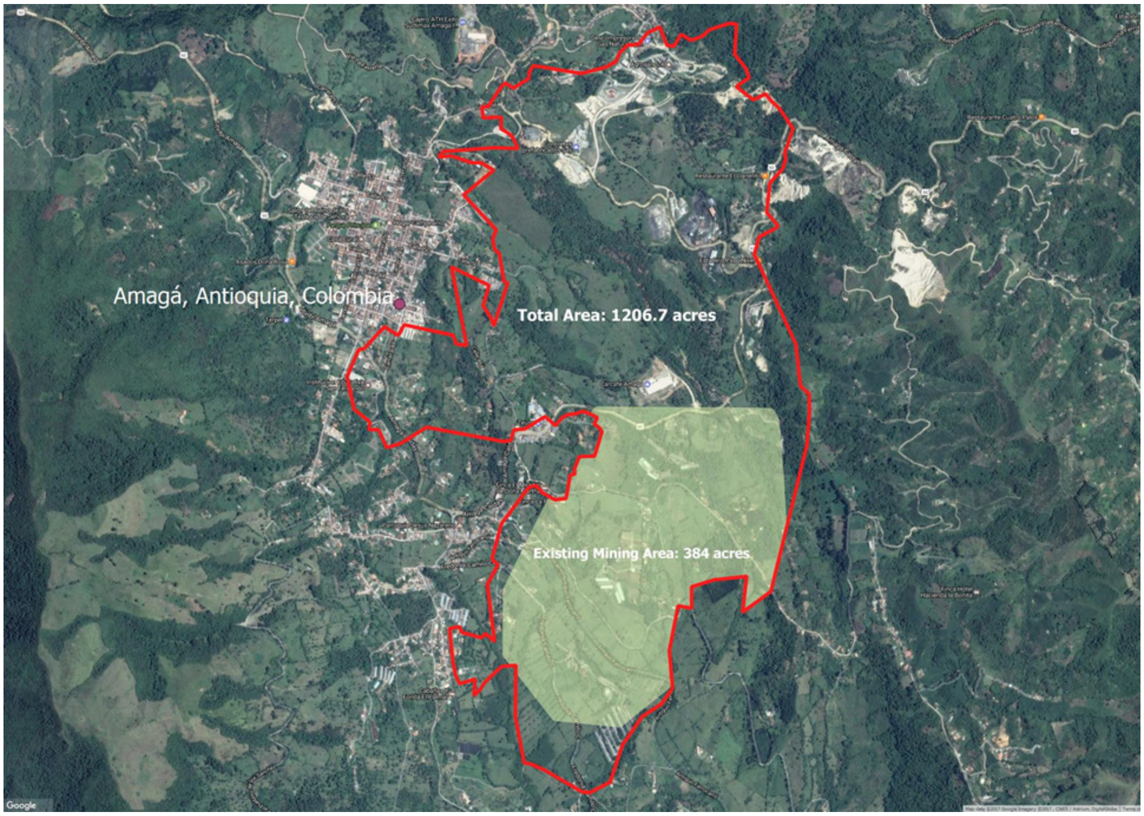

Exhibit 11: San Juaquin Mine Boundary and Existing Mining Area

Exhibit 12: San Juaquin Mine Plan by Month for the Manto 1 Seam

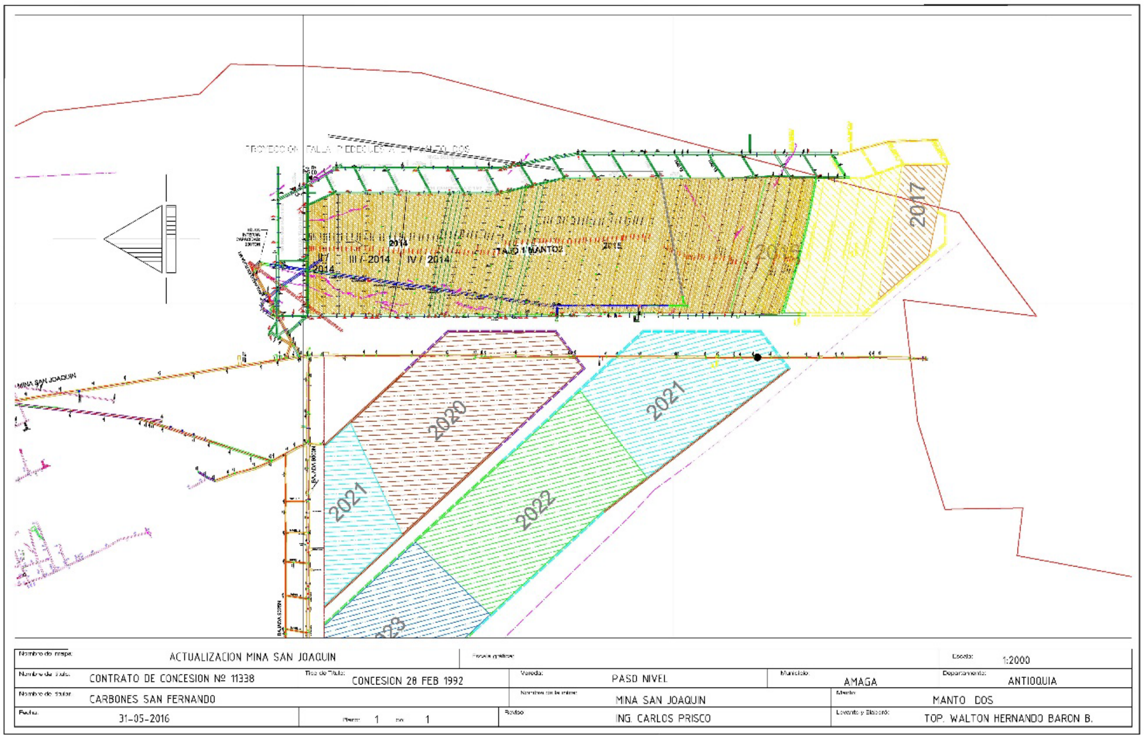

Exhibit 13: San Juaquin Mine Plan by Month for the Manto 2 Seam

4 Evaluation of Methane Drainage Concepts and Gas Forecast

The gas production profiles generated for each methane drainage scenario presented in this section will form the basis of the economic analyses performed in Section 7 of this report. Additionally, estimating the gas production volume is critical for planning purposes and the design of equipment and facilities.

4.1 Proposed Gas Drainage Concepts

Based on a detailed review of data provided by the mine, the following drilling options are proposed for methane drainage at the San Juaquin Mine.

4.1.1 Vertical Pre-Drainage Boreholes

In this development scenario, gas drainage is accomplished through the utilization of vertical boreholes drilled from the surface in advance of mining. The boreholes will target all three coal seams (Manto 1, Manto 2, and Manto 3) and five well spacing cases will be assessed, ranging from 10-ac to 160-ac per well.

4.1.2 In-Seam Pre-Drainage Boreholes

In this development scenario, in-seam gas drainage boreholes will be drilled in parallel to advance and flank the gate road developments. The long, directionally drilled boreholes will cover the entire length of each panel from a single setup location to shield and drain gas ahead of development galleries. These boreholes could be developed from mains or other adjacent galleries and drilled significantly in advance of mining. The ability to drain multiple mining levels for each panel from a single setup location will be advantageous at this mine property due to the use of multi-seam mining. Coordination of drilling operations with mine plans is vital to the success of an in-seam drainage program. For modeling purposes the longwall panels on all mining levels are assumed to be approximately 2,297 ft long with 591 ft wide faces.

4.2 Estimating Gas Production from Pre-Drainage Boreholes

Methane drainage engineers use reservoir simulations to optimize current drainage systems and assess the relative benefits of degasification alternatives. Simulations of drainage systems can derive, with relative confidence, the necessary borehole spacing and configurations based on time available for methane drainage and/or residual gas content targets. As modern longwall mining operations implement "just in time" management practices to balance costs incurred in gate road development with income earned from longwall shearer passes, reservoir simulation has become an important tool to aid in the optimization of methane drainage.

For the purposes of this pre-feasibility study, separate reservoir models were constructed to simulate gas production volumes from vertical pre-drainage boreholes and long in-seam pre-drainage boreholes. The following sections of this report discuss the construction of the gas drainage borehole models, the input parameters used to populate the reservoir simulation models, and the simulation results.

4.2.1 Simulation Models

For the vertical wells, a total of five triple-layer reservoir simulation models were constructed in order to calculate gas production from a single well located within the project area. The models were designed to simulate production from vertical pre-drainage boreholes drilled form the surface and spaced according to five well spacing cases: 10-ac, 20-ac, 40-ac, 80-ac and 160-ac. The models were each run for 30 years in order to simulate gas production rates and cumulative production volumes from a typical vertical borehole within the project area. Model grids were created to accommodate each of the well spacing cases. Each model grid consisted of 25 grid-blocks in the x-direction, 25 grid-blocks in the y-direction, and three grid-blocks in the z-direction. The grid block dimensions were 26.4 ft by 26.4 ft for the 10-ac well spacing case, 37.3 ft by 37.3 ft for the 20-ac well spacing case, 52.8 ft by 52.8 ft for the 40-ac well spacing case, 74.7 ft by 74.7 ft for the 80-ac well spacing case, and 105.6 ft by 105.6 ft for the 160-ac well spacing case. An example of the model layout for a vertical pre-drainage borehole is shown in Exhibit 14.

For the in-seam boreholes, a total of six single-layer models were constructed in order to calculate gas production for a longwall panel located within the project area. The models were designed to simulate production from long directionally drilled boreholes drilled into virgin areas from existing mine workings and spaced according to three well spacing cases: one borehole per longwall panel, two boreholes per longwall panel spaced 394 ft apart, and three boreholes per longwall panel spaced 197 ft apart. All boreholes are drilled into a coal block with a dip angle of 15 degrees and are assumed to be 2,296 ft in lateral length. The models were each run for five years in order to simulate gas production rates and cumulative production volumes from a typical longwall panel within the study area.

A typical longwall panel at the mine is estimated to have a face width of 590 ft and a panel length of 2,296 ft covering an aerial extent of 31 ac. Based on these dimensions, model grids were created to accommodate each of the well spacing cases. The model grid setup consisted of 25 grid-blocks in the x-direction, 50 grid-blocks in the y-direction, and one grid-block in the z-direction; the total area modeled is roughly 36 ac, which includes the 31 ac longwall panel area as well as a boundary area to account for migration of gas from coal seams of adjacent panels. An example of the model layout for one in-seam pre-drainage case is shown in Exhibit 14.

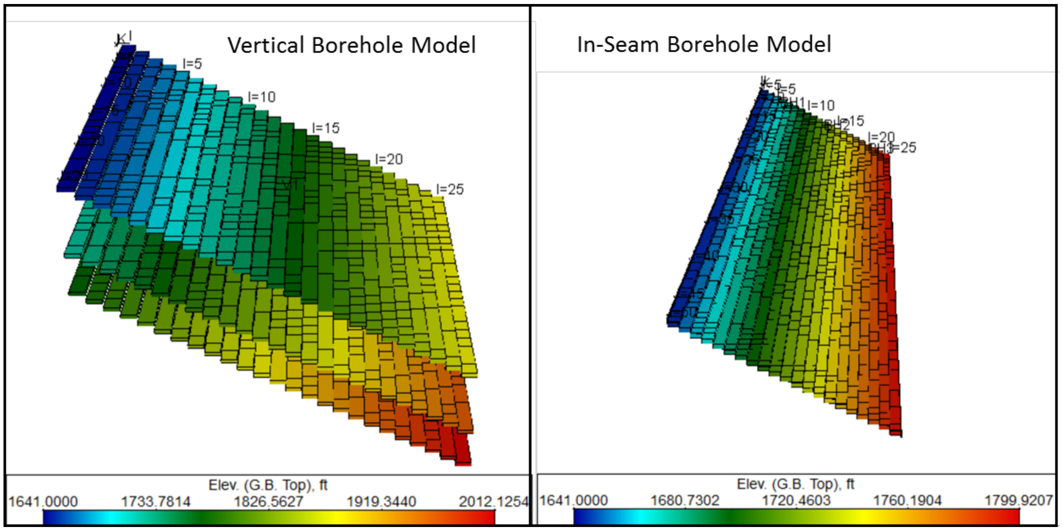

Exhibit 14: Example Model Layout for Vertical and In-Seam Pre-Drainage Borehole Concepts

4.2.2 Model Preparation and Runs

The input data used to populate the reservoir models were obtained primarily from the geologic and reservoir data provided by the San Juaquin Mine. Where appropriate, supplemental geological and reservoir data from analogous projects were also used. The input parameters used in the reservoir simulation study are presented in Exhibit 15, followed by a brief discussion of the most important reservoir parameters.

Reservoir Parameter	Value(s)			Source / Notes
	Manto 1	Manto 2	Manto 3	
Coal Depth (Top), ft	1641	1723	1772	Mine data
Coal Thickness, ft	5.9	4.6	4.6	Mine data
Coal density, g/cc	1.3	1.3	1.3	Assumption; Clean coal
Pressure Gradient, psi/ft	0.433	0.433	0.433	Assumption; Hydrostatic
Initial Reservoir Pressure, psia	712	747	768	Calculated from midpoint depth and pressure gradient
Initial Water Saturation, %	100	100	100	Assumption
Langmuir Volume, scf/ton	301	301	301	Assumption; Typical for High-Volatile A Bituminous
Langmuir Pressure, psia	153	153	153	Assumption; Typical for High-Volatile A Bituminous
In Situ Gas Content, scf/ton	248	250	251	Calculated from reservoir pressure and isotherm
Desorption Pressure, psia	712	747	768	Desorption pressure equal to initial reservoir pressure (fully saturated conditions)
Sorption Times, days	36	36	36	Assumption
Fracture Spacing, in	2.56	2.56	2.56	Assumption
Dip Angle of Face, degrees	15	15	15	Mine data
Absolute Cleat Permeability, md	0.5; 1.0; 5.0	0.5; 1.0; 5.0	0.5; 1.0; 5.0	Unknown; Three cases evaluated
Cleat Porosity, %	2	2	2	Assumption; Typical for coal rank
Relative Permeability	Curve	Curve	Curve	Assumption; See Exhibit 17
Pore Volume Compressibility, psi^{-1}	4.00E-04	4.00E-04	4.00E-04	Assumption
Matrix Shrinkage Compressibility, psi^{-1}	1.00E-06	1.00E-06	1.00E-06	Assumption
Gas Gravity	0.6	0.6	0.6	Assumption
Water Viscosity, centipoise (cP)	0.8	0.8	0.8	Assumption
Water Formation Volume Factor, reservoir barrel per stock tank barrel (RB/STB)	1.00	1.00	1.00	Calculation
Completion and Stimulation	Vertical pre-mine drainage boreholes: Assume skin factor of -2 (stimulation); In-seam horizontal boreholes: Assume skin factor of 2 (formation damage)			
Borehole Operation	Vertical pre-mine drainage boreholes: Bottomhole pressure of 30 psia; In-seam horizontal boreholes: Bottomhole pressure of 14.7 psia			
Borehole Spacing	Five cases for vertical pre-drainage boreholes: 10, 20, 40, 80, & 160 acres per well; Three cases for in-seam horizontal boreholes: 1, 2 & 3 boreholes per panel			

Exhibit 15: Reservoir Parameters for Pre-Drainage Borehole Simulation

4.3.2.1 Permeability

Coal bed permeability, as it applies to production of methane from coal seams, is a result of the natural cleat (fracture) system of the coal and consists of face cleats and butt cleats. This natural cleat system is sometimes enhanced by natural fracturing caused by tectonic forces in the basin. The permeability resulting from the fracture systems in the coal is called "absolute permeability" and is a critical input parameter for reservoir simulation studies. Absolute permeability data for the coal seams in the study area were not available. For the current study, three permeability cases were evaluated assuming permeability values of 0.5, 1, and 5 millidarcy (md), which are within the range of analogous coal seams of the same rank.

4.3.2.2 Langmuir Volume and Pressure

Reliable laboratory measured Langmuir volumes and pressures for the study area were not available. As a result, Langmuir volume and pressure values for isotherms typical of high-volatile A bituminous coal were utilized in the current study (Eddy, Rightmire, & Byrer, 1982). The corresponding Langmuir volume used in the reservoir simulation models for the project area is 301 scf/ton and the Langmuir pressure is 153 pounds per square inch absolute (psia). Exhibit 16 depicts the methane isotherm utilized in the pre-drainage borehole simulations.

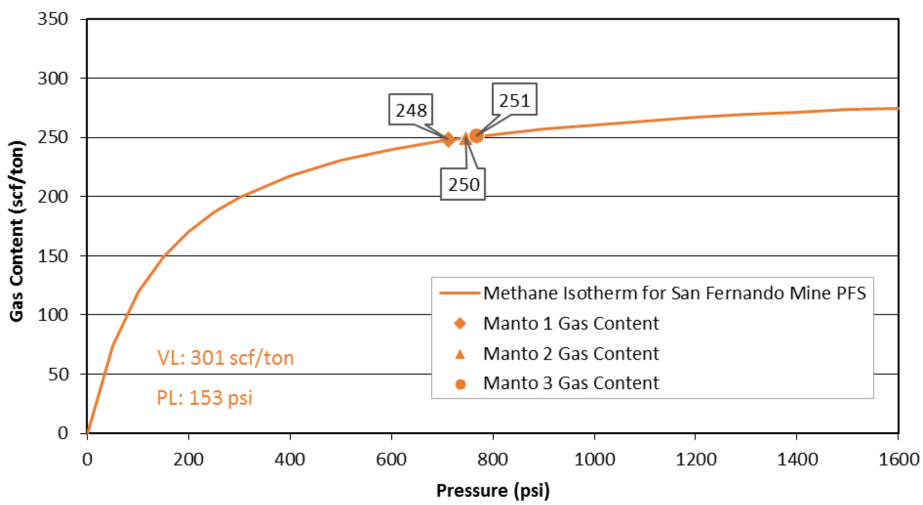

Exhibit 16: Methane Isotherm Used in Pre-Drainage Borehole Simulations

4.3.2.3 Gas Content

Limited gas content data were available for San Juaquin; however, due to issues with the methodology and experimental procedures, the accuracy of the data is questionable. After discussions with mine management, it was agreed that gas content data available did not accurately reflect in-situ gas content values at the working depth of the mine. Therefore, for the simulation study, initial gas content values of 248 scf/ton, 250 scf/ton, and 251 scf/ton, as calculated by the isotherm, were used for the Manto 1, Manto 2, and Manto 3, seams, respectively (Exhibit 16).

4.3.2.4 Relative Permeability

The flow of gas and water through coal seams is governed by permeability, of which there are two types, depending on the amount of water in the cleats and pore spaces. When only one fluid exists in the pore space, the measured permeability is considered absolute permeability. Absolute permeability represents the maximum permeability of the cleat and natural fracture space in coals and in the pore space in coals. However, once production begins and the pressure in the cleat system starts to decline due to the removal of water, gas is released from the coals into the cleat and natural fracture network. The introduction of gas into the cleat system results in multiple fluid phases (gas and water) in the pore space, and the transport of both fluids must be considered to accurately model production. To accomplish this, relative permeability functions are used in conjunction with specific permeability to determine the effective permeability of each fluid phase.

Relative permeability data for the coal of the project area was not available. Therefore, a relative permeability data set was used, which is typical for coals of similar age and rank. Exhibit 17 is a graph of the relative permeability curves used in the reservoir simulation of the study area.

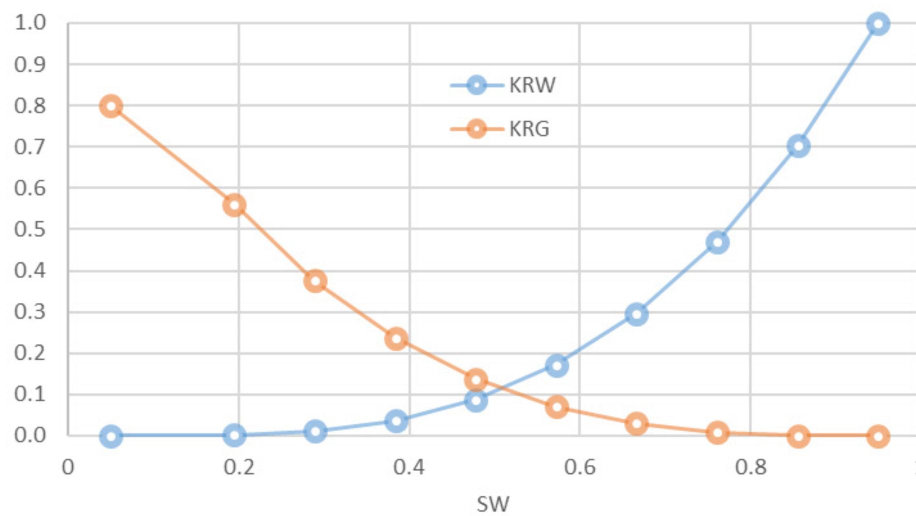

Exhibit 17: Relative Permeability Curve Used in Simulation

4.3.2.5 Coal Seam Depth and Thickness

The coal seams of the San Juaquin Mine range in depth from 1,641 ft to 1,772 ft with coal seams ranging between 4.6 ft and 5.9 ft in thickness. Based on mine data, the coal thickness is taken to be 5.9 ft, 4.6 ft, and 4.6 ft for Manto 1, Manto 2, and Manto 3, respectively. The depth to the top of each coal seam was taken to be 1,641 ft, 1,723 ft, and 1,772 ft for Manto 1, Manto 2, and Manto 3, respectively. All coal faces were assumed to dip by 15 degrees. The simulation models for vertical pre-mine drainage boreholes assume all three coal seams will be hydraulically fractured in each well. The simulation models for in-seam horizontal boreholes assume gas drainage will be coordinated with mine progression, which is currently limited to Manto 1 and Manto 2.

4.3.2.6 Reservoir and Desorption Pressure

Initial reservoir pressure was computed using a hydrostatic pressure gradient of 0.433 pounds per square inch per foot (psi/ft) and the midpoint depth of each coal seam. Because the coal seams are assumed to be saturated with respect to gas, desorption pressure is set equal to the initial reservoir pressure for the seam. The resulting initial and desorption pressures used in the model are 712 psia, 747 psia, and 768 psia for Manto 1, Manto 2, and Manto 3, respectively.

4.3.2.7 Porosity and Initial Water Saturation

Porosity is a measure of the void spaces in a material. In this case, the material is coal, and the void space is the cleat fracture system. Since porosity values for the coal seams in the mine area were not available, a value of 2 percent was used in the simulations. Typical porosity values for coal range between 1 percent and 3 percent. The cleat and natural fracture system in the reservoir was assumed to be 100 percent water saturated.

4.3.2.8 Sorption Time

Sorption time is defined as the length of time required for 63 percent of the gas in a sample to be desorbed. Since no desorption data were available, a 36-day sorption time was used in the simulation study. Production rate and cumulative production forecasts are typically relatively insensitive to sorption time.

4.3.2.9 Fracture Spacing

A fracture spacing of 2.56 in was assumed in the simulations. In the model, fracture spacing is only used for calculation of diffusion coefficients for different shapes of matrix elements and it does not materially affect the simulation results.

4.3.2.10 Borehole Spacing

As discussed previously, five cases were evaluated for the drainage approach using vertical boreholes. Simulation runs were conducted using well spacing of 10-, 20-, 40-, 80-, and 160-ac per well. Six cases were modeled for the drainage approach using in-seam horizontal boreholes (three each for Manto 1 and Manto 2). Simulation runs were conducted using one borehole per longwall panel, two boreholes per longwall panel spaced 394 ft apart, and three boreholes per longwall panel spaced 197 ft apart.

4.3.2.11 Completion

Vertical wells are projected to be drilled and completed to a depth of roughly 1,800 ft and completed in three stages corresponding to the Manto 1, Manto 2, and Manto 3 seams. Nearly all coal seams require some type of stimulation in order to initiate and sustain economic gas production. For modeling purposes, a skin factor of -2 is assumed for all vertical wells. Long in-seam boreholes with lateral lengths of 2,296 ft will be drilled into the longwall panels. For modeling purposes a skin factor of +2, representing formation damage, is assumed for all horizontal boreholes.

4.3.2.12 Well Operation

In the current study, vertical wells were allowed to produce for 30 years using a bottom-hole pressure constraint of 30 psia. Horizontal boreholes were allowed to produce for 5 years using an in-mine pipeline with a surface vacuum station providing a suction pressure of 14.7 psia. In CMM/CBM operations, low borehole pressure is required to achieve maximum gas content reduction.

4.2.3 Model Results

As noted previously, five reservoir models were created to simulate gas production from vertical pre-drainage boreholes and six models were created to simulate in-seam boreholes to drain methane from the San Juaquin Mine. Exhibit 18 shows a tabular summary of the simulation results for vertical well cases, and Exhibit 19 and Exhibit 20 summarize the simulation results of the in-seam borehole cases for Manto 1 and Manto 2, respectively.

Well Spacing	acres/well	10			20			40			80			160		
Permeability	md	0.5	1	5	0.5	1	5	0.5	1	5	0.5	1	5	0.5	1	5
Peak Gas Rate	Mscfd	1.4	2.7	12.3	1.3	2.7	12.4	0.9	2.6	12.4	0.4	1.6	12.3	0.4	0.7	12.2
Cumulative Gas Production																
1 Year	MMscf	0.1	0.2	2.5	0.1	0.2	1.3	0.1	0.2	0.8	0.1	0.2	0.7	0.1	0.2	0.6
5 Year	MMscf	0.7	2.6	16.6	0.5	1.3	17.7	0.4	0.9	13.2	0.4	0.7	6.5	0.4	0.7	3.7
10 Year	MMscf	2.7	7.4	25.4	1.3	4.9	32.8	0.9	2.4	34.5	0.7	1.5	24.6	0.7	1.3	11.6
20 Year	MMscf	7.6	14.6	34.4	5.0	14.3	50.3	2.4	9.1	64.6	1.5	4.4	66.8	1.3	2.7	45.4
30 Year	MMscf	11.6	19.5	39.2	9.8	22.1	60.8	5.2	18.3	84.5	2.8	9.3	100.3	1.9	4.9	89.0
Gas-In-Place	MMscf	65.7	65.7	65.7	131.9	131.9	131.9	264.8	264.8	264.8	532.5	532.5	532.5	1072.5	1072.5	1072.5
Recovery Factor (30-Yr)	%	17.6	29.6	59.7	7.4	16.8	46.1	2.0	6.9	31.9	0.5	1.8	18.8	0.2	0.5	8.3

Exhibit 18: Summary of Vertical Pre-Drainage Borehole Simulation Results

Well Spacing	wells/panel	1			2			3		
Permeability	md	0.5	1	5	0.5	1	5	0.5	1	5
Peak Gas Rate	Mscfd	19.4	32.0	89.5	49.1	73.4	137.4	79.9	108.2	167.6
Cumulative Gas Production										
1 Year	MMscf	7.1	11.7	32.7	17.9	26.8	50.2	29.2	39.5	61.2
3 Year	MMscf	12.0	20.4	45.6	27.9	38.5	61.8	41.2	51.8	70.9
5 Year	MMscf	24.4	35.7	61.3	43.3	54.1	73.0	56.6	65.6	78.1
Gas-In-Place	MMscf	91.2	91.2	91.2	91.2	91.2	91.2	91.2	91.2	91.2
Recovery Factor (5-Yr)	%	26.8	39.2	67.3	47.5	59.3	80.1	62.1	72.0	85.7

Exhibit 19: Summary of In-Seam Pre-Drainage Borehole Simulation Results for the Manto 1 Seam

Well Spacing	wells/panel	1			2			3		
Permeability	md	0.5	1	5	0.5	1	5	0.5	1	5
Peak Gas Rate	Mscfd	15.8	25.9	70.7	40.0	58.9	108.6	64.6	86.5	132.8
Cumulative Gas Production										
1 Year	MMscf	5.8	9.5	25.8	14.6	21.5	39.7	23.6	31.6	48.5
3 Year	MMscf	9.8	16.3	35.8	22.4	30.6	48.7	32.9	41.1	55.9
5 Year	MMscf	19.5	28.2	48.1	34.4	42.7	57.4	44.8	51.8	61.5
Gas-In-Place	MMscf	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6
Recovery Factor (5-Yr)	%	27.2	39.4	67.2	48.0	59.6	80.1	62.5	72.3	85.8

Exhibit 20: Summary of In-Seam Pre-Drainage Borehole Simulation Results for the Manto 2 Seam

One of the benefits of pre-drainage is the reduction of methane content in the coal seams prior to mining. Exhibit 21 through Exhibit 25 show, as an example, the simulated reduction in in-situ gas content over time for Manto 3 for each of the various vertical well spacing cases. Exhibit 26 through Exhibit 28 illustrate, as an example, the simulated reduction in in-situ gas content in Manto 1 over time utilizing in-seam pre-drainage boreholes. Both examples assume a permeability of 1 md.

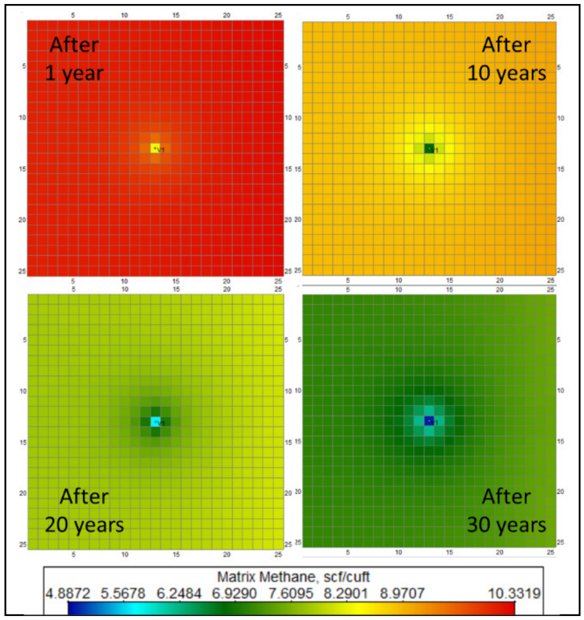

Exhibit 21: Reduction in In-Situ Gas Content Over Time for Vertical Pre-Drainage Borehole with 10-Acre Spacing

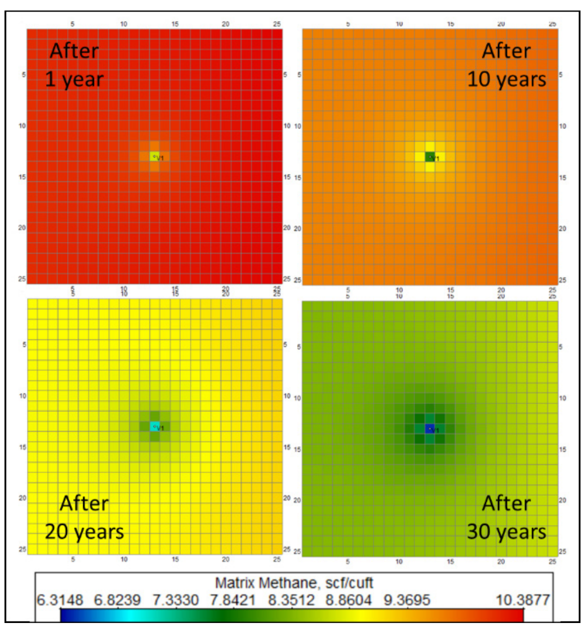

Exhibit 22: Reduction in In-Situ Gas Content Over Time for Vertical Pre-Drainage Borehole with 20-Acre Spacing

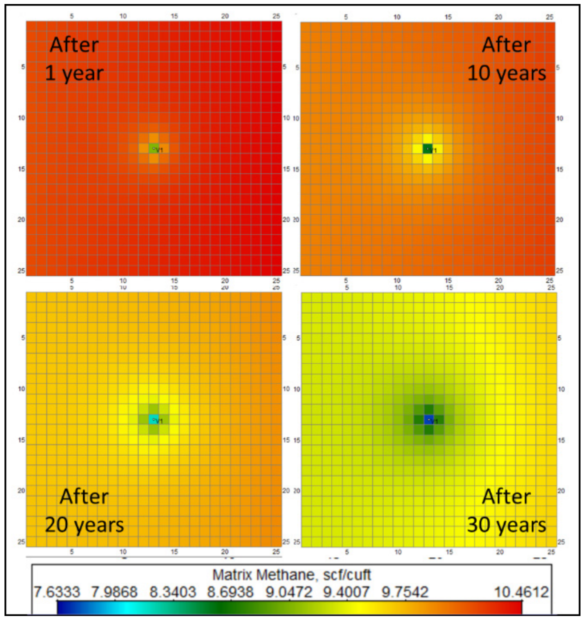

Exhibit 23: Reduction in In-Situ Gas Content Over Time for Vertical Pre-Drainage Borehole with 40-Acre Spacing

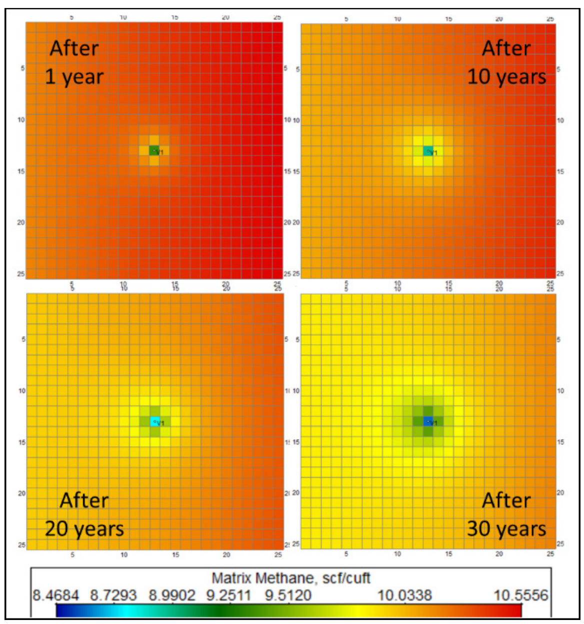

Exhibit 24: Reduction in In-Situ Gas Content Over Time for Vertical Pre-Drainage Borehole with 80-Acre Spacing

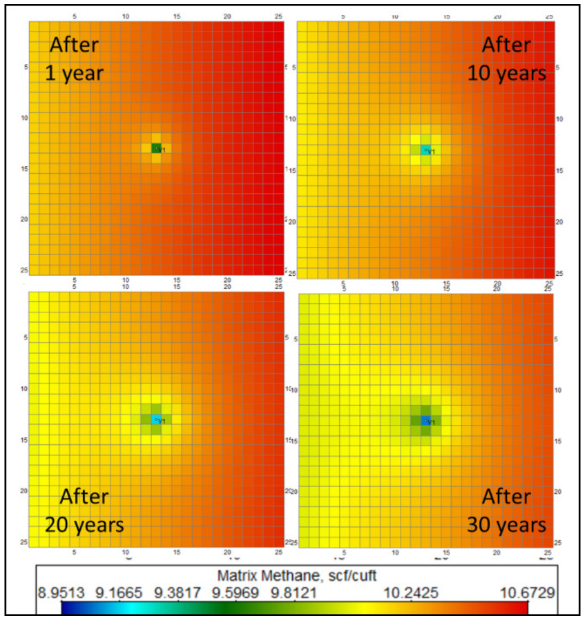

Exhibit 25: Reduction in In-Situ Gas Content Over Time for Vertical Pre-Drainage Borehole with 160-Acre Spacing

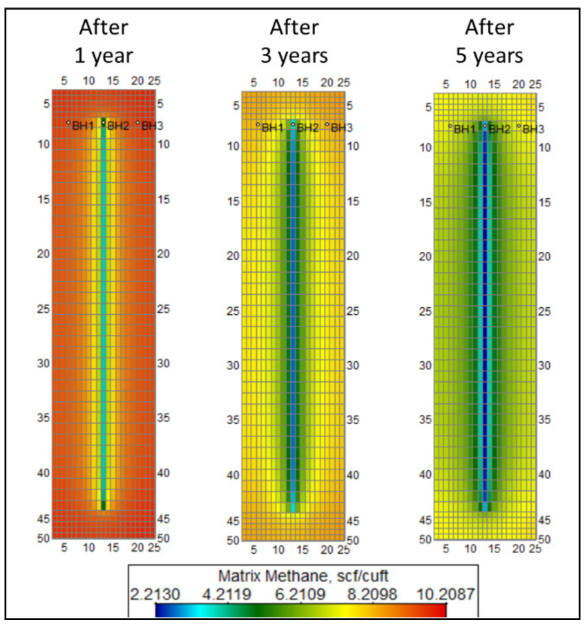

Exhibit 26: Reduction in In-Situ Gas Content Over Time for One In-Seam Pre-Drainage Borehole Per Panel

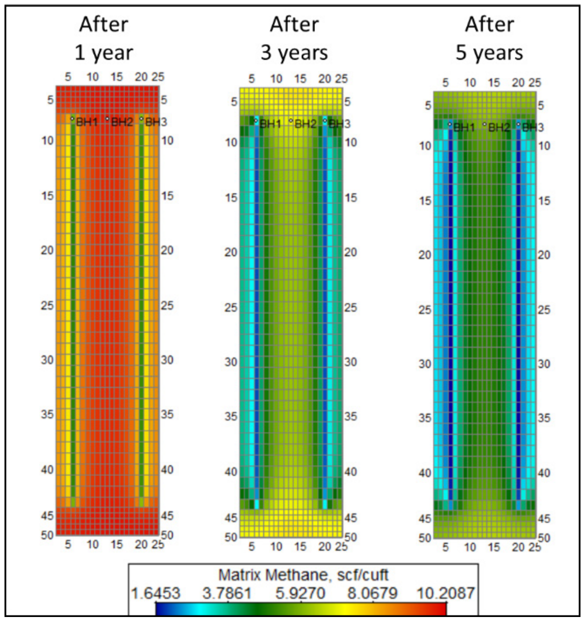

Exhibit 27: Reduction in In-Situ Gas Content Over Time for Two In-Seam Pre-Drainage Boreholes Per Panel

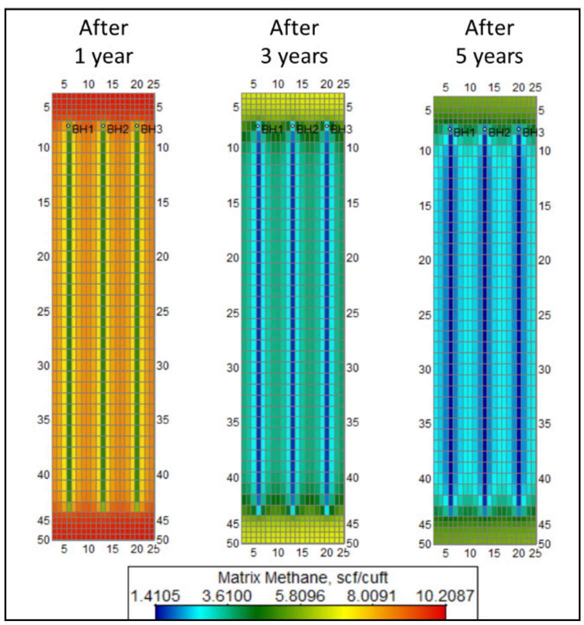

Exhibit 28: Reduction in In-Situ Gas Content Over Time for Three In-Seam Pre-Drainage Boreholes Per Panel

4.2.4 Development of the Production Type Well

It is recognized that coal seam permeability can vary considerably over a license area. To capture this variability, and to adequately model the effect of drilling numerous wells with varying production potential, a "type well" was developed using the range of permeability values modeled. The production stream for the type well was constructed by combining the production streams of the three permeability cases modeled in the following percentages: 50 percent of the 1 md production stream, 35 percent of the 0.5 md production stream, and 15% of the 5 md case. The percentages assigned to each permeability case are based on experience in producing CBM basins in the U.S. For example, the prolific high permeability "fairway" portion of the San Juan Basin, which produces about 80 percent of the gas in the basin, represents about 10 percent of the total basin area.

The type well results for the vertical and in-seam pre-drainage concepts are presented in Exhibit 29 and Exhibit 30, respectively. Exhibit 31 is a tabular summary of type well results showing peak average annual gas production rate, cumulative gas production, and percent of gas recovered. Exhibit 32 is a chart comparing the reduction in in-situ gas content over time for the composite type wells.

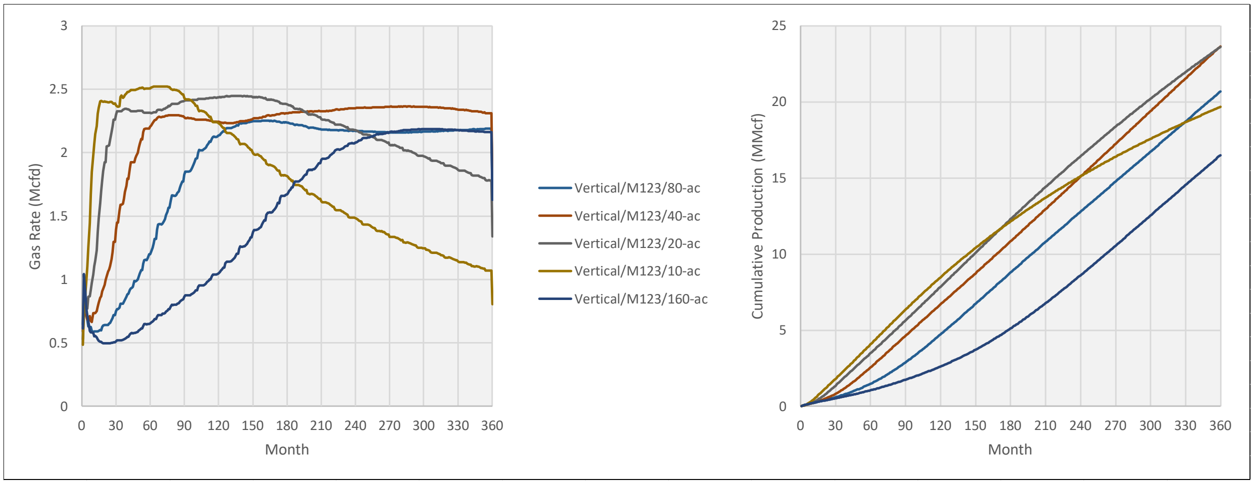

Exhibit 29: Composite Type Well – Monthly Gas Production Rates and Cumulative Production for Vertical Borehole Cases

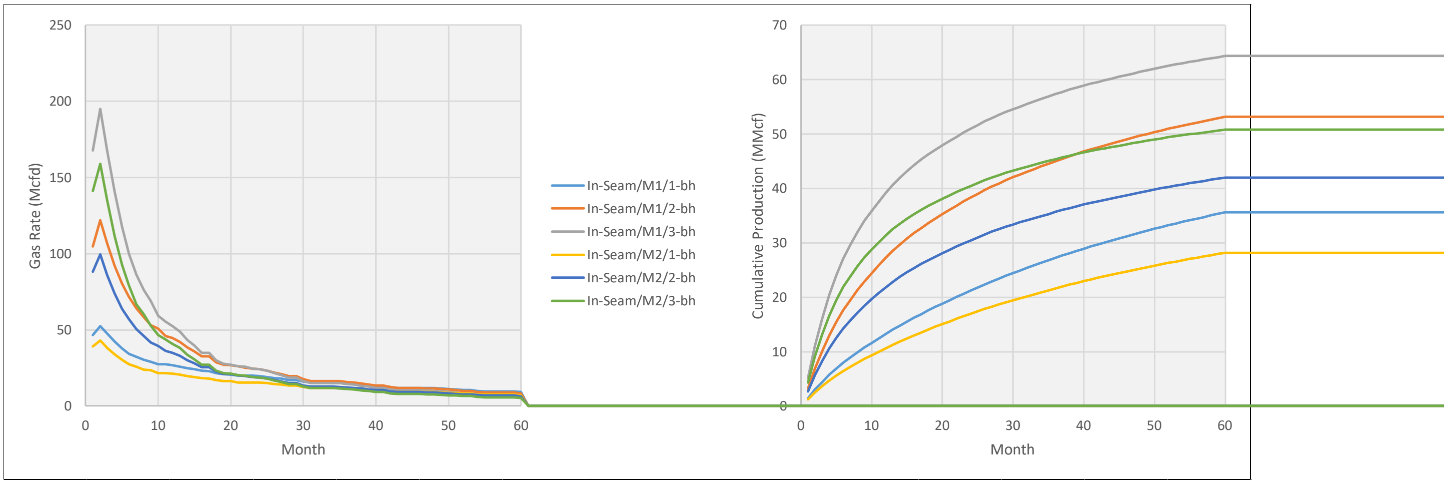

Exhibit 30: Composite Type Well – Monthly Gas Production Rates and Cumulative Production for In-Seam Borehole Cases

Scenario		V1	V2	V3	V4	V5	H1	H2	H3	H4	H5	H6
Seams		M123	M123	M123	M123	M123	M1	M1	M1	M2	M2	M2
Well Spacing		10-ac	20-ac	40-ac	80-ac	160-ac	1-bh	2-bh	3-bh	1-bh	2-bh	3-bh
Peak Avg. Annual Gas Rate	Mscfd	2.5	2.4	2.4	2.2	2.2	36.2	74.6	107.3	29.1	59.8	85.8
Cumulative Gas Production												
1 Year	MMscf	0.5	0.3	0.3	0.2	0.2	13.2	27.2	39.2	10.6	21.8	31.3
3 Year	MMscf	2.2	1.8	1.1	0.7	0.6	27.2	45.0	57.3	21.6	35.7	45.4
5 Year	MMscf	4.1	3.5	2.6	1.5	1.1	35.6	53.2	64.3	28.1	42.0	50.8
10 Year	MMscf	8.5	7.8	6.7	4.7	2.6						
20 Year	MMscf	15.1	16.4	15.1	12.8	8.6						
30 Year	MMscf	19.7	23.6	23.6	20.7	16.5						
Gas-In-Place	MMscf	65.7	131.9	264.8	532.5	1072.5	91.2	91.2	91.2	71.6	71.6	71.6
Recovery Factor	%	29.9%	17.9%	8.9%	3.9%	1.5%	39.1%	58.3%	70.6%	39.3%	58.6%	70.9%

Exhibit 31: Summary of Composite Type Well Results

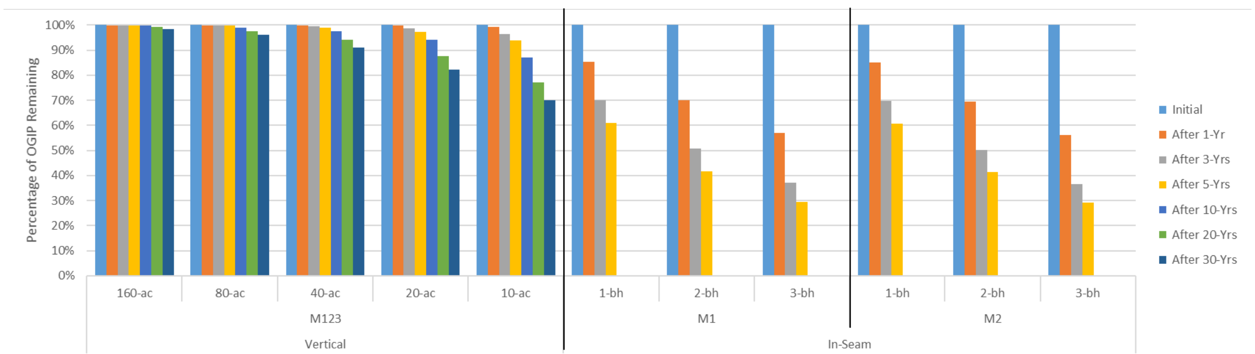

Exhibit 32: Reduction in In-Situ Gas Content Over Time for Composite Type Wells

5 Market Information

5.1 Coal Mine and Coalbed Methane (CMM and CBM) Market

Along with its large proved reserves of coal, Colombia is thought to also possess significant CMM and CBM resources. The ANH currently estimates the country's CMM/CBM resources to be between 11 and 35 Tcf (ANH, 2011). Despite this large estimated resource base, there have been no commercial CMM/CBM projects implemented in the country to date.

The majority of CMM projects around the world currently use the produced gas to generate power at the mine site. Many of these projects supply electricity to mine operations in order to lower operating costs by reducing power purchases from the grid. It is likely that future CMM projects in Colombia will also be power projects. Therefore, market for CMM will depend on how well it can compete against the cost of other types of power generation in Colombia, principally hydroelectric, coal, and natural gas. A review of Colombia's electricity sector reveals a number of factors that suggest there is a potentially strong market for CMM projects. These factors are:

1) **High electricity prices**: Colombia has some of the highest electricity tariffs for residential and industrial customers in South America. The ability for mines to generate power on-site using CMM will provide both lower costs and a more stable electricity supply for mining operations.

2) **Reliability of hydroelectricity**: Hydropower currently accounts for about 70 percent of the country's electrical generation capacity; however, hydropower can be adversely affected by El Niño/La Niña-related events, as experienced during the last several years. CMM power projects would provide a secure source of electricity.

3) **Increasing natural demand coupled with declining gas production:** Over the past decade, demand for natural gas in Colombia has increased 60 percent, turning Colombia from a net exporter of natural gas into a net importer of natural gas. Exacerbating the supply/demand imbalance is the fact that gas production in the country has fallen about 10 percent over the past five years. Therefore, it is likely that any CMM produced would be readily absorbed by the market, provided there were adequate means of transporting the gas to customers.

4) **Increased coal production:** Coal is expected to continue driving Colombian economic growth, with coal production estimated to grow 20 percent by 2020 (World Coal, 2016). In concert with the increase in coal production, there will also be an increase in Colombia's CMM emissions as existing mines get deeper and new ones are opened. These increased CMM emissions should present good opportunities for CMM utilization projects.

5) **Colombia's signing of the Paris Agreement:** Colombia is a signatory to the Paris Agreement and has committed to reducing its GHG emissions by 20 percent by 2030. The implementation of CMM projects will be helpful, if not essential, in the nation's ability to meet this goal, especially if coal production increases as forecast.

While there are a number of factors promoting and supporting the development of CMM projects in Colombia, there are also a number of challenges facing the implementation of CMM projects, including:

1) **Relatively small and un-mechanized underground mines**: Despite several methane-related explosions at underground mines in recent years, most of the underground mines in Colombia are

not considered gassy. The small size of the mines and the limited rate of advance removes the incentive to improve mine safety through pre- and post-drainage CMM projects.

2) **Inadequate characterization of CMM reservoir properties**: Limited work in the country has been performed to assess key reservoir properties governing the flow of methane through coal seams (e.g., gas content, permeability, gas saturation, etc.), making it difficult to accurately determine reserves and project economics.

3) **Limited access to service providers**: Most CMM projects require some type of drilling, either wells drilled from the surface for pre-drainage wells and/or gob wells, or in-mine horizontal/cross-measure boreholes. While Colombia does have some drilling rigs that could drill surface-based wells, there are no drilling companies that can provide in-mine drilling services.

5.2 Natural Gas Market

5.2.1 Natural Gas Market Policy and Reforms

Colombia historically offered attractive regulations in order to encourage both domestic exploration and attract foreign investment. When the ANH was formed in 2003, it took over the regulatory role previously held by state-owned Ecopetrol. In addition, following the creation of the ANH, it was made possible for private companies to own 100 percent stakes in oil and gas fields with less than 60 million barrels of reserves (Open Oil, 2012). In March of 2011, the Colombian government published a decree outlining plans to increase domestic natural gas production, specifically production from shale or coal mine methane gas fields (EIA, 2016). These policies, combined with increasing natural gas demand due to power shortages related to hydroelectric failures have made natural gas a priority for the Colombian government.

5.2.3 Natural Gas Market Pricing

Colombia's Regulatory Commission of Energy and Gas (CREG) was created by Article 74 of Law 142 of 1994 in order to regulate public services, including electricity and natural gas prices (CREG, 2016). Urban areas in Colombia are classified as one of six socioeconomic strata. The two lowest rate strata are made up of those citizens who do not use much electricity. These citizens receive natural gas at a subsidized price, with the subsidies financed by citizens in the two uppermost socioeconomic strata (CREG, 2016). Citizens who exist in the middle two socioeconomic strata receive natural gas at market prices (Exhibit 33). In 2014, the average market price for Colombian citizens purchasing natural gas was $8.2 per thousand cubic feet (Mcf) (NATURGAS, 2014).

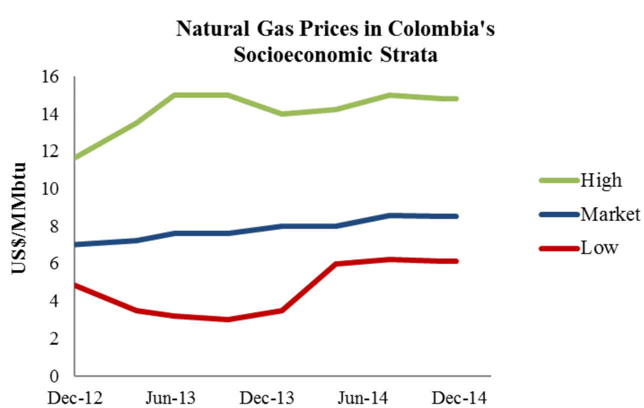

Exhibit 33: Approximated Natural Gas Prices (US$/MMBtu) in Colombia's Various Socioeconomic Strata. Figure adapted from data via (NATURGAS, 2014)

5.3 Electricity Market

5.3.1 Overview

In 2014, Colombia produced over 64,000 gigawatt-hours (GWh) of electricity (ProColombia, 2015). Of Colombia's total power production, 70 percent comes from hydroelectric facilities, while 10 percent comes from thermal natural gas, and 7 percent from thermal coal (ProColombia, 2015). The figures for natural gas and coal are expected to increase as El Niño-related hydroelectric power shortages bolster thermal power demand.

Colombian electricity production, both hydroelectric and thermal, is expected to steadily increase from 2016 to 2027. Urban population growth and economic expansion will contribute to Colombia's rising demand for power. Likely concentrated in Colombia's cities, the UPME expects power demand to grow by over 3 percent annually through 2027 (MaRS, 2015). Colombia's growing electricity demand will almost certainly remain strong moving into the 2020's.

5.3.2 Electricity Market Pricing

Colombia's average residential energy prices are among the highest in Latin America, higher than Chile, Brazil, and Peru (Exhibit 34) (MaRS, 2015). At $0.192 per kilowatt-hour (kWh), Colombia's residential energy tariff is the highest in Latin America (MaRS, 2015). In addition, Colombia's industrial energy prices, which average $0.126/kWh, are also high, though slightly lower than those of Chile and China (MaRS, 2015).

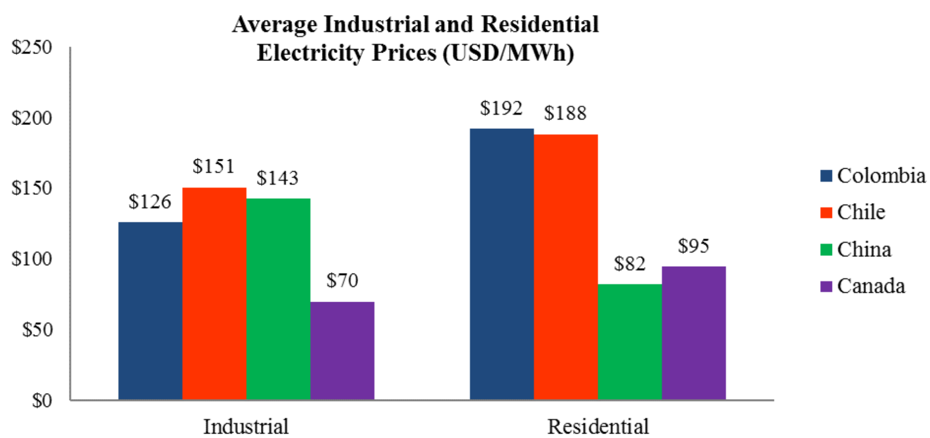

Exhibit 34: Figure Showing How Colombia's Average Industrial and Residential Electricity Prices Compare to those of Chile, China, and Canada (MaRS, 2015)

6 Opportunities for Gas Use

Pre-drainage boreholes are the preferred recovery method for producing high-quality methane gas from coal seams because the recovered methane is not contaminated with ventilation air from the working areas of the mine (USEPA, 2013). The drained gas from the San Juaquin Mine is expected to have a methane concentration of 91 percent, which is considered medium- to high-quality gas for utilization purposes. This section briefly explores each available option for CMM utilization.

6.1 CMM Utilization Options for Consideration

6.1.1 Power Generation

Mine management has stated its preference for on-site power generation using CMM. The electricity generated by a CMM power plant would be used at the mine, while the excess power could be sold to the local electric grid. There is a strong case to use the CMM for power generation. CMM-to-power is the most widely used CMM technology worldwide, and the knowledge, expertise, and experience are widely available to support cost-effective implementation, operation, and maintenance of a CMM power plant. Industrial power prices are also attractive for CMM to power projects. A generally accepted breakeven cost for CMM-based power projects is USD $0.04 to 0.06 per kWh. The electricity price paid by the average industrial user in Colombia USD $0.126 per kWh, thus there is a potential margin of USD $0.07 to 0.09 per kWh.

There are several other advantages for power production at the mine. Suppliers deliver turn-key solutions with the gas engine/generator/control system combinations in prefabricated containers. These plants are modular and can be easily expanded if gas availability increases. The ability to offset high power prices at mines has been another reason CMM-to-power projects are very attractive. The technical challenges of wheeling excess power to the grid are easily overcome because mines are large users of electricity with access to high voltage interconnects or even electricity substations at the mine.

6.1.2 Pipeline Sales

Although in-seam drainage should produce high-quality CMM, natural gas pipeline sales are infeasible due to the lack of a well-developed natural gas pipeline infrastructure to transport CMM to natural gas markets. Despite the relatively high market prices natural gas in Colombian ($8.2 per thousand cubic feet on average in 2014), this may not be enough to offset the cost of laying a pipeline to demand centers, especially given the challenging local terrain and the relatively small CMM production volumes forecasted from the project.

6.1.3 Industrial Use

There are no industrial operations adjacent to the mine, and it would be very expensive to lay a pipeline to an industrial user considering the terrain.

6.1.4 Boiler Fuel

Coal boilers are typically used at many mines for heating and hot water in mine buildings and for heating mine shafts. However, according to San Juaquin Mine management, there is currently no need for heating or process fuel at the mine.

6.1.5 Compressed Natural Gas (CNG)

There is growing interest in CNG as demonstrated by Colombia's existing fleet of 530,000 natural gas-fueled vehicles, which includes vehicles ranging from garbage trucks to taxi cabs (AAPG, 2016). As of 2016, 32 percent of taxis in Bogotá were fueled by CNG, and vehicle conversions to CNG throughout Colombia increased at an average annual rate of 12 percent from 2010 to 2014 (AAPG, 2016). While use of CMM as a vehicle fuel represents a potential market for San Juaquin gas, CNG at this time is not economically feasible as it requires significant capital costs to upgrade gas quality and compress the gas. Capex to manage the residual gas flow at the mine could total USD $3 million for the necessary CNG infrastructure, with an additional USD $1-2 million per year of Opex at the mine.

6.1.6 Flaring

Should San Juaquin Mine move forward with a CMM project, a good strategy may be to incorporate a flare into the project to reduce emissions when the primary utilization technology is unavailable, for example when gas engines are down for maintenance. However, flaring should not be the only CMM reduction strategy pursued at the mine.

6.2 Recommendation for CMM Utilization

After consideration of possible options for CMM utilization at the San Juaquin Mine, power generation is the most viable option, considering current market conditions in Colombia and the priorities of mine management. Therefore, for this pre-feasibility study, the Economic Analysis in Section 7 focuses on CMM power generation. Based on gas supply forecasts, the mine could be capable of operating as much as 1.4 MW of electricity capacity.

7 Economic Analysis

7.1 Drainage Technology Screening Study

The initial objective of the economic analysis is to determine the optimum drainage concept and borehole spacing for the development of the proposed CMM project at the San Juaquin Mine. Based on the reservoir simulation results for each of the borehole spacing cases, project costs were estimated and a series of cash flows were generated to determine the most economically viable drainage concept and borehole spacing. The optimized drainage approach and borehole spacing pattern are used to forecast gas production for the project, which is then input into the economic model to determine if the proposed project is economically feasible.

7.1.1 Economic Assumptions

Cost estimates were developed for goods and services required for the development of a CMM project at the San Juaquin Mine. These estimates were based on a combination of known average development costs of analogous projects in the Americas, and other publicly available sources. All economic results are presented on a pre-tax basis. The input parameters and assumptions used in the economic analysis are summarized in Exhibit 35. A more detailed discussion of each input parameter is provided below.

PHYSICAL & FINANCIAL FACTORS	Units	Value
Gas Price	$/MMBtu	6.00
Royalty	%	4.8
Price Escalation	%	3
Cost Escalation	%	3
Calorific Value of Gas	Btu/cf	928
CAPITAL EXPENDITURES	**Units**	**Value**
Vertical Well Cost (Well & Facilities)	$MM	0.75
Drainage System		
Well Cost	$/borehole	100,000
Surface Vacuum Station	$/hp	1000
Vacuum Pump Efficiency	hp/Mcfd	0.035
Gathering & Delivery System		
Gathering Pipe Cost	$/ft	40
Gathering Pipe Length	ft	4000
Satellite Compressor Cost	$/hp	1000
Compressor Efficiency	hp/Mcfd	0.035
Pipeline Cost	$/ft	55
Pipeline Length	ft	500
OPERATING EXPENSES	**Units**	**Value**
Vertical Pre-Drainage O&M	$/Mcf	2
In-Seam Pre-Drainage O&M	$/Mcf	0.1
Field Fuel Use (gas)	%	5

Exhibit 35: Summary of Economic Input Parameters and Assumptions

7.1.1.1 Physical and Financial Factors

Gas Price

The gas price utilized in the economic evaluation is USD $6.00 per million British thermal unit (MMBtu), which represents the current price for natural gas in the Colombian market.

Royalty

In Colombia, oil and gas resources are owned by the national government. All companies engaged in the exploration and extraction of oil and gas must pay the ANH a royalty at the production field, determined by the Ministry of Mining. Per Law 756, issued in 2002, new oil and gas discoveries must pay a royalty of 8 percent for production up to 5,000 barrels of crude per day (monthly average), which is equivalent to 28,500 Mcf of natural gas per day based on a conversion factor of 5.7 Mcf of natural gas per barrel of oil equivalent. Additionally, based on Decree 4923 of 26 December 2011, royalties on unconventional hydrocarbons (including CMM/CBM) are equivalent to 60 percent of those on conventional oil, resulting in an effective royalty rate of 4.8 percent for the CMM project at San Juaquin Mine (EY, 2016).

Price and Cost Escalation

All prices and costs are assumed to increase by 3 percent per annum.

Calorific Value of Gas

The drained gas is assumed to have a calorific value of 928 Btu/cf. This is based on a calorific value of 1,020 Btu/cf for pure methane adjusted to account for lower methane concentration of the CMM gas, which is assumed to be 91 percent for drained gas.

7.1.1.2 Capital Expenditures

Capital expenditures include the cost of vertical wells and in-seam drainage boreholes, as well as surface facilities and vacuum pumps used to bring the drainage gas to the surface. The major input parameters and assumptions associated with the project are as follows:

Well Cost

A vertical pre-drainage borehole drilled from the surface is assumed to cost $750,000 per well, including all drilling, completion, and facilities costs. An in-mine borehole with a lateral length of 2,296 ft is assumed to cost $100,000 per well. The cost of roughly $40 per foot is representative of costs observed for analogous projects.

Surface Vacuum Station

Vacuum pumps draw gas from the wells into the gathering system. Vacuum pump costs are a function of the gas flow rate and efficiency of the pump. To estimate the capital costs for the vacuum station, a pump cost of $1000 per horsepower (hp) and a pump efficiency of 0.035 hp per thousand standard cubic feet per day (Mscfd) are assumed. Total capital cost for the surface vacuum station is estimated as the product of pump cost, pump efficiency, and peak gas flow (i.e., $/hp x hp/Mscfd x Mscfd).

The gathering system consists of the piping and associated valves and meters necessary to get the gas from within the mine to the satellite compressor station located on the surface. The major input parameters and assumptions associated with the gathering system are as follows:

Gathering System Cost

The gathering system cost is a function of the piping length and cost per foot. For the proposed project, we assume a piping cost of $40/ft and 4,000 ft of gathering lines.

The delivery system consists of the satellite compressor and the pipeline that connects the compressor to the sales system leading to the utilization project. The major input parameters and assumptions associated with the delivery system are as follows:

Satellite Compressor Cost

Satellite compressors are used to move gas through the pipeline connected to the end-use project. Similar to vacuum pump costs, compression costs are a function of the gas flow rate and efficiency of the compressor. To estimate the capital costs for the compressor, we assume a compressor cost of $1000/hp and an efficiency of 0.035 hp/Mscfd. As with the vacuum pump costs, the maximum gas flow rate is used in the calculation of compression cost. Total capital cost for the compressor is estimated as the product of compressor cost, compressor efficiency, and peak gas flow (i.e., $/hp x hp/Mscfd x Mscfd).

Pipeline Cost

The cost of the pipeline to the sales system is a function of the pipeline length and cost per foot. For the proposed project, we assume a pipeline cost of $55/ft and length of 500 ft.

7.1.1.3 Operating Expenses

Normal Operating and Maintenance Costs

The normal operating and maintenance cost associated with vertical pre-drainage wells is assumed to be $2.00/Mscf, and the operating and maintenance costs for vacuum pumps and compressors associated with in-seam pre-drainage boreholes are assumed to be $0.10/Mscf.

Fuel Use

For the proposed project, it is assumed that CMM is used to power the vacuum pumps and compressors in the gathering and delivery systems. Total fuel use is assumed to be 5 percent, which is deducted from the gas delivered to the end use.

7.1.2 Drainage Technology Selection

Utilizing the gas production profiles generated in the reservoir simulation portion of this study, discounted cash flow analyses were performed on each of the 11 drainage concepts, as highlighted in Exhibit 36. At a market gas price of $6.00/MMBtu, none of the cases evaluated were economically feasible. Because of this, a breakeven gas price was calculated for each drainage technology and well spacing case.

Based on the forecasted gas production, the breakeven cost of producing gas through vertical pre-drainage boreholes is estimated to be between $80.57 and $146.26/MMBtu. The breakeven cost of producing gas from in-seam boreholes is estimated to range from $9.67 to $10.63/MMBtu for the Manto 1 seam, and from $12.18 to $13.38/MMBtu for the Manto 2 seam. The results of the drainage technology screening study show the lowest costs are associated with in-seam pre-drainage with two boreholes drilled per panel (highlighted in orange in Exhibit 36).

Scenario	Well Type	Seam(s)	Well Case	Breakeven Gas Price ($/MMBtu)
V1	Vertical	M123	10-ac	85.95
V2	Vertical	M123	20-ac	80.57
V3	Vertical	M123	40-ac	86.98
V4	Vertical	M123	80-ac	105.26
V5	Vertical	M123	160-ac	146.26
H1	In-Seam	M1	1-bh	10.63
H2	In-Seam	M1	2-bh	9.67
H3	In-Seam	M1	3-bh	10.08
H4	In-Seam	M2	1-bh	13.38
H5	In-Seam	M2	2-bh	12.18
H6	In-Seam	M2	3-bh	12.69

Exhibit 36: Summary of Drainage Technology Screening Study Results

7.2 Project Development Scenario

Based on the results of the drainage technology screening study, the optimal development scenario for the CMM project at the San Juaquin Mine incorporates the use of two in-seam pre-drainage boreholes per panel. Exhibit 37 and Exhibit 38 show a conceptual mine layout and development plan for the Manto 1 and Manto 2 seams, respectively. Each mine plan shows the panels that have been mined (shaded in blue), the panels that have already been delineated for mining but have yet to be mined (shaded in green), and possible panels for future mining (shaded in red). The mine plan diagrams also show the year each panel is anticipated to be mined based on the development schedule provided by the San Juaquin Mine. Gas production at the mine is assumed to commence at the beginning of 2018, with each borehole producing gas for up to five years before being mined through. For the Manto 1 seam, the plan shows 20 remaining panels to be mined through the end of 2058. For the Manto 2 seam, the plan shows 23 remaining panels to be mined through the end of 2067.

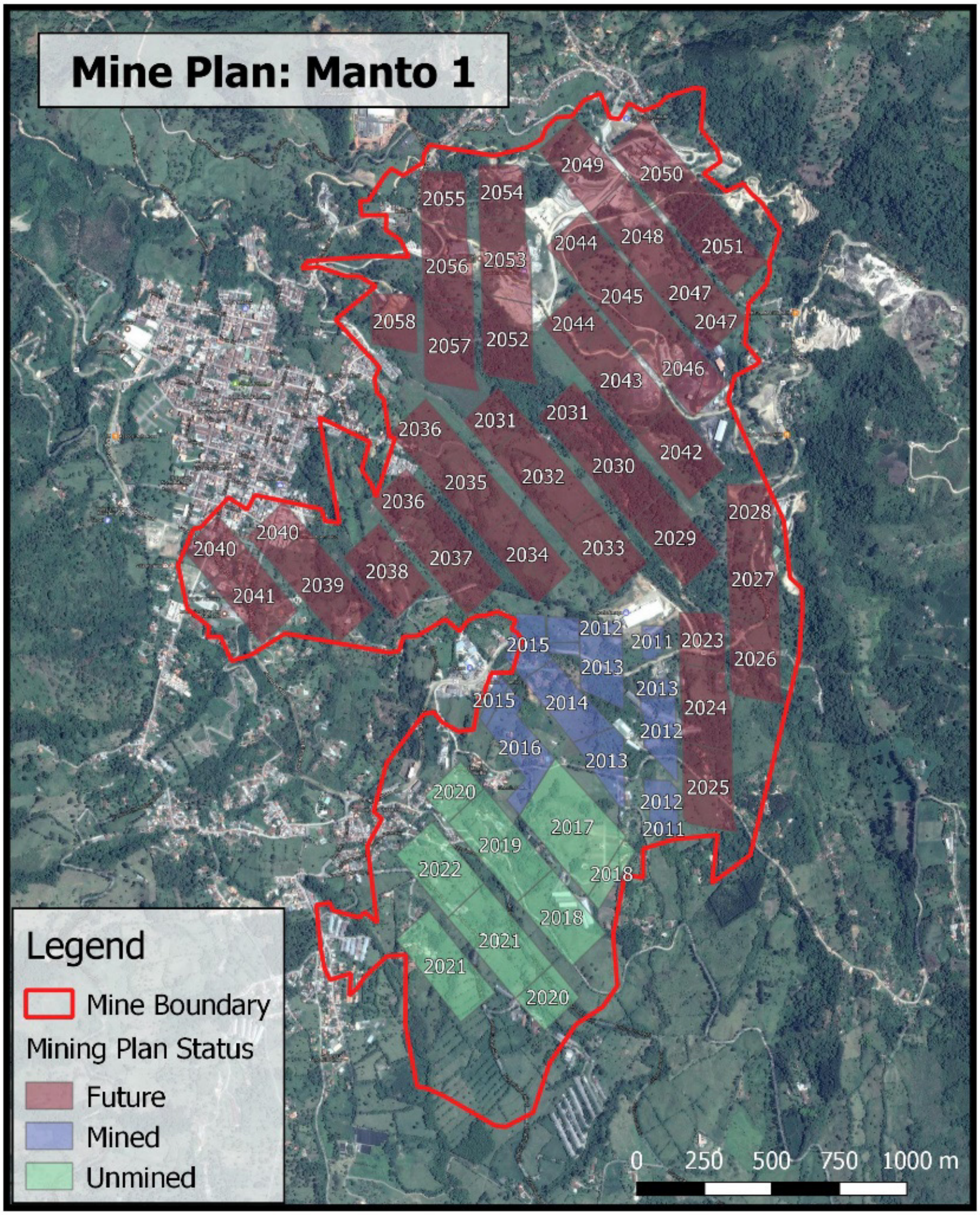

Exhibit 37: Conceptual Mine Layout and Development Schedule for the Manto 1 Seam

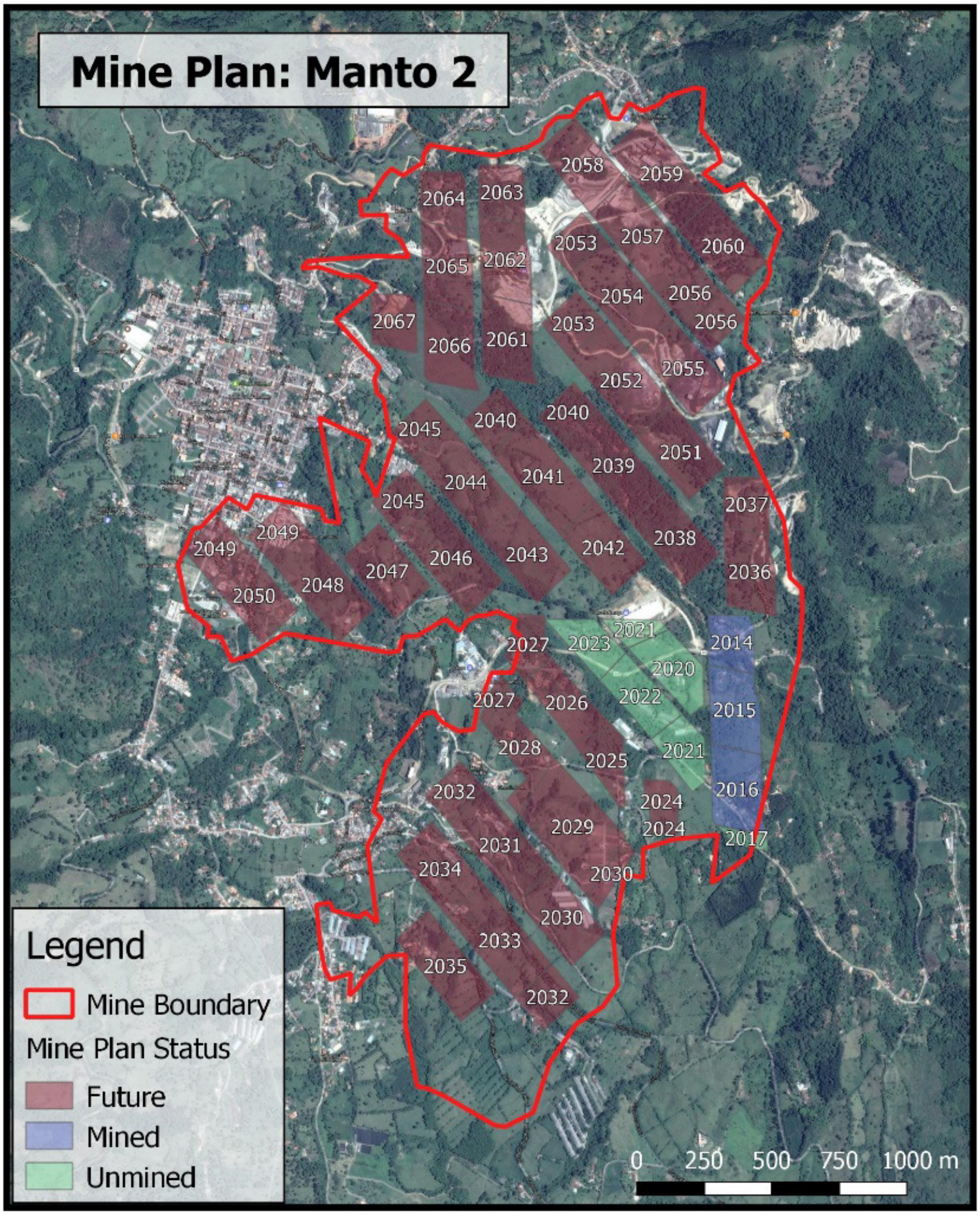

Exhibit 38: Conceptual Mine Layout and Development Schedule for the Manto 2 Seam

7.2 Gas Production Forecast

A gas production forecast was developed using the simulation results and the optimized development scenario, as discussed above. The CMM production forecast generated for the San Juaquin Mine is shown in Exhibit 39, along with the number of producing boreholes. Based on this forecast, total gas production over the 50-year life of the CMM project is anticipated to be 1,789 million cubic feet (MMcf), with an average annual gas production rate of 35.8 MMcf per year.

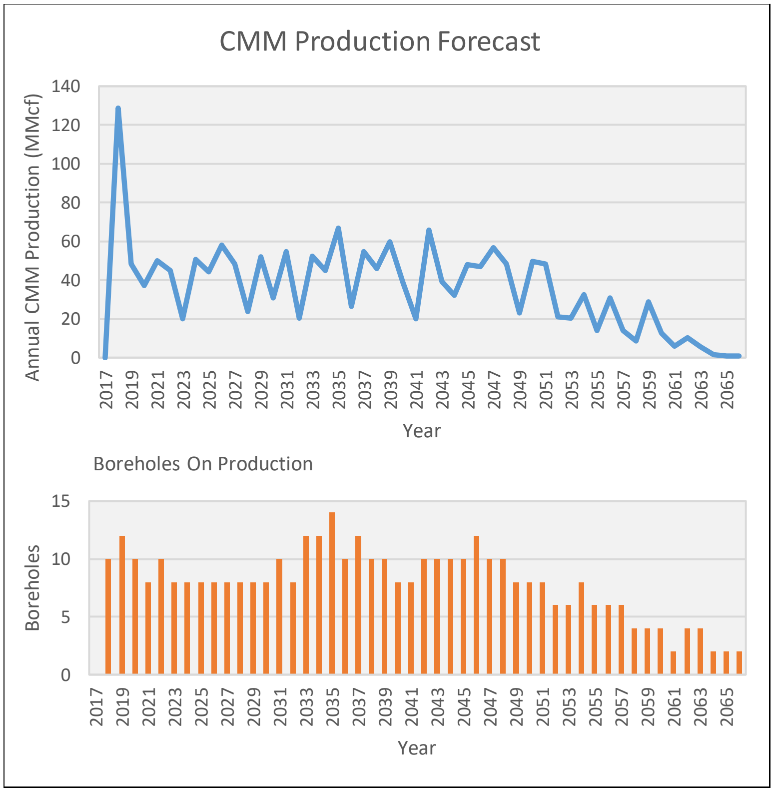

Exhibit 39: CMM Production Forecast for San Juaquin Mine

7.3 Project Economics

7.3.1 Economic Assessment Methodology

The economic and financial performance of the proposed CMM drainage and utilization project were evaluated using key inputs discussed in the following sections of this report. A simple discounted cash flow model of CMM drainage and power sales was constructed to evaluate project economics. Key performance measures that were used for evaluating the project included net present value (NPV) and internal rate of return (IRR). The results of the analyses are presented on a pre-tax basis.

7.3.2 Additional Economic Assumptions

The assumptions used to calculate project economics are generally the same as those used earlier in the drainage technology screening study (see Section 7.1). For the evaluation of project economics, additional economic assumptions were used (as highlighted in orange in Exhibit 40) in order to evaluate the production of electricity and emissions reductions associated with the project. A more detailed discussion of the additional input parameters is provided below.

PHYSICAL & FINANCIAL FACTORS	Units	Value
Royalty	%	4.8
Price Escalation	%	3
Cost Escalation	%	3
Calorific Value of Gas	Btu/cf	928
Power Sales Price	$/kWh	0.126
Generator Efficiency	%	35
Run Time	%	90
Global Warming Potential of CH_4	tCO_2e	25
CO_2 from Combustion of 1 ton CH_4	tCO_2	2.75
CAPITAL EXPENDITURES	**Units**	**Value**
Drainage System		
Well Cost	$/ft	40
Surface Vacuum Station	$/hp	1000
Vacuum Pump Efficiency	hp/Mcfd	0.035
Gathering & Delivery System		
Gathering Pipe Cost	$/ft	40
Gathering Pipe Length	ft/well	1000
Satellite Compressor Cost	$/hp	1000
Compressor Efficiency	hp/Mcfd	0.035
Pipeline Cost	$/ft	55
Pipeline Length	ft	500
Power Plant	$/kW	1300
OPERATING EXPENSES	**Units**	**Value**
Field Fuel Use (gas)	%	5
In-Seam Pre-Drainage O&M	$/Mcf	0.1
Power Plant O&M	$/kWh	0.02

Exhibit 40: Summary of Additional Economic Input Parameters and Assumptions

The drained methane can be used to fuel internal combustion engines that drive generators to make electricity for use at the mine or for sale to the local power grid. The major cost components for the power project are the cost of the engine and generator, as well as costs for gas processing to remove solids and water, and the cost of equipment for connecting to the power grid.

7.3.2.1 Physical and Financial Factors

Electricity Price

The effective electricity sales price received for the power produced is $0.126/kWh, which represents the latest available average industrial electricity price in Colombia.

Generator Efficiency and Run Time

Typical electrical power efficiency is between 30 percent and 44 percent and run time generally ranges between 7,500 to 8,300 hours annually (USEPA, 2011). For the proposed power project an electrical efficiency of 35 percent and an annual run time of 90 percent, or 7,884 hours, were assumed.

Global Warming Potential of Methane

A global warming potential of 25 is used. This value is from the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC, 2013).

Carbon Dioxide from Combustion of Methane

Combustion of methane generates carbon dioxide (CO_2). Estimating emission reductions from CMM projects must account for the release of CO_2 from combustion when calculating net CO_2 emission reductions.

7.3.3.2 Capital Expenditures

Power Plant Cost Factor

The power plant cost factor, which includes capital costs for gas pretreatment, power generation, and electrical interconnection equipment, is assumed to be $1,300 per kilowatt (kW).

7.3.3.3 Operating Expenses

Power Plant Operating and Maintenance Cost

The operating and maintenance costs for the power plant are assumed to be $0.02/kWh.

7.3.3 Economic Results

The economic results for the proposed project are summarized in Exhibit 41. Based on these results, a CMM-to-power utilization project at the mine would be economically feasible, and the proposed project would generate a positive NPV-10 equal to $689,000. Although power combined with CMM drainage is already economic, removing the cost of mine degasification from the economics as a sunk cost would further reduce the marginal cost of power. In addition, net emission reductions associated with the destruction of drained methane are estimated to total 631,000 tonnes of carbon dioxide equivalent (tCO_2e) over the life of the project.

Project Description	CMM Drained (MMcf)	Max Power Plant Capacity (MW)	Fuel Cost ($/MMBtu)	NPV-10 US$000	IRR (%)	Net CO_2e Reductions (Million metric tons)
2 in-seam horizontal boreholes per panel with up to 5 years of pre-drainage	1789	1.4	6.39	689	13%	0.631

Exhibit 41: Summary of Project Economic for CMM Project at the San Juaquin Mine

8 Conclusions, Recommendations and Next Steps

This pre-feasibility study proposes two methane drainage approaches for the San Juaquin Mine. The study further provides a high level estimate of gas production using these methods and an economic analysis of using the CMM to generate power. After consideration of possible options for CMM utilization at the San Juaquin Mine, power generation was selected as the best option for the mine given market conditions and mine management priorities. As the analysis shows, pre-drainage using long in-seam drainage boreholes will be the most effective option for the San Juaquin Mine in terms of gas drainage and economics. As proposed in this study, the CMM project at San Juaquin Mine is anticipated to reduce emissions of methane by more than 28,300 tonnes (tCH_4) over the 50-year life of the project, while offering a return on investment (ROI) of 85% over the same period.

It is recommended that San Juaquin Mine management pursue the development of a small (i.e., less than 1-MW) power project using CMM from a pilot project focused on a few longwall panels. The power plant could grow as gas availability increases, as more panels are developed in the future. It is recommended that the following steps be undertaken for San Juaquin Mine management to move toward project development:

- Develop a clear mine layout for the entire coal license area with exact panel dimensions and coal production forecasts.
- Take core samples throughout the license area and conduct isotherm and gas desorption analyses to obtain accurate measure of gas content, permeability, and porosity of the coals. This will inform a more thorough gas production forecast.
- Confirm the ability of the San Juaquin Mine to sell excess electricity to the power grid and establish a confirmed price for an interconnect to the grid.
- Conduct pilot tests for in-mine drainage boreholes as proposed in this study to develop more accurate forecasts for methane concentration and volumetric throughput.
- Investigate and analyze more thoroughly all utilization options including power production to confirm the economic and technical feasibility of CMM-to-power and the viability of alternatives and their competitiveness with power generation.
- Begin investigation of financing options to confirm available sources of project finance so that the mine can determine the appropriate sources and mix of financing, including the mix of debt and equity.

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