U.S. EPA
Coalbed Methane
OUTREACH PROGRAM

Pre-Feasibility Study for Methane Drainage and Utilization at the Casa Blanca Coal Mine, Cundinamarca Department, Colombia

U.S.Environmental Protection Agency

September 2019

Pre-Feasibility Study for Methane Drainage and Utilization at the Casa Blanca Mine

Cundinamarca Department

Colombia

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

EPA 430-R-19-014

September 2019

Disclaimer

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-18-H-0010. Information included in the report is based on data obtained from the coal mine partner, UniMinas S.A.S (Casa Blanca Mine), a subsidiary of C.I. Milpa S.A.

Acknowledgements

This report was prepared for the USEPA. This analysis uses publicly available information in combination with information obtained through direct contact with mine personnel, equipment vendors, and project developers. USEPA does not:

a) make any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any apparatus, method, or process disclosed in this report may not infringe upon privately owned rights;
b) assume any liability with respect to the use of, or damages resulting from the use of, any information, apparatus, method, or process disclosed in this report; nor
c) imply endorsement of any technology supplier, product, or process mentioned in this report.

Table of Contents

Figures

Tables

Acronyms/Abbreviations

ACM	Asociación Colombiana de Minería (Colombian Mining Association)
ANH	Agencia Nacional de Hidrocarburos (National Hydrocarbons Agency)
ANM	Agencia Nacional de Minería (National Mining Agency)
ARI	Advanced Resources International
ASTM	American Society for Testing and Materials
Bbl	Barrel
Bcf	Billion cubic feet
Bmt	Billion metric tons
BTU	British thermal units
C	Celsius
CH_4	Methane
CMM/CBM	Coal Mine Methane/Coal Bed Methane
CMOP	US EPA Coalbed Methane Outreach Program
CNG	Compressed Natural Gas
FEED	Front End Engineering & Design
FID	Final Investment Decision
ft	Feet
GECELCA	Generadora y Commercializadora de Energía del Caribe (Generation and Commercialization of Caribbean Energy in South America)
GHG	Greenhouse Gas
GMI	Global Methane Initiative

Ha	Hectares
hp	Horsepower
in	Inch
IRR	Internal Rate of Return
ISO	International Organization for Standardization
km	Kilometer
kW	Kilowatt
kWh	Kilowatt hour
lb	Pound
m	Meter
m^3	Meter cubed
mbgs	Meters below ground surface
md	Millidarcy
mm	Millimeter
Mscfd	Thousand standard cubic feet per day
MiniMinas	Minesterio de Minas y Energía (Ministry of Mines and Energy)
MW	Megawatt
NDP	National Development Plan
NPV	Net Present Value
psi/ft	Pounds per square inch per foot
psia	Pounds per square inch absolute
RETIE	Reglamento Técnico de Instalaciones Eléctricas (Technical Regulation of Electrical Installations)
scf	Standard cubic feet
SIN	Sistema Interconectado Nacional (National Interconnected System)
tpy	Tons per year
Tcf	Trillion cubic feet
USEPA	United States Environmental Protection Agency
USTDA	United States Trade and Development Agency

Executive Summary

The U.S. Environmental Protection Agency's (USEPA) Coalbed Methane Outreach Program (CMOP) works with coal mines in the United States 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 (GHG) when released to the atmosphere. Reducing emissions can yield substantial economic and environmental benefits, and the implementation of available, cost-effective methane emission 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 45-member countries and the European Commission that focuses on cost-effective, near-term methane recovery and use as a clean energy source. These studies identify cost-effective project development opportunities through a high-level review of gas availability, end-use options, and emission reduction potential. This study assists mine operators in evaluating options for CMM capture and use while also presenting a preliminary financial analysis and laying the foundation for a more detailed feasibility study that will ultimately lead to CMM project development and GHG emission reductions.

UniMinas S.A.S, a commercial and industrial subsidiary of C.I. Milpa S.A., was selected as the recipient for a pre-feasibility study for CMM drainage at their Casa Blanca Mine located in the Cundinamarca Department of central Colombia. The mine was selected for this pre-feasibility study because it is a part of one of the largest mining complexes in the country consisting of 37 small mine operations producing nearly 500,000 tons of metallurgical coal per year. Multiple mine explosions in the area in recent years have heightened the region's desire to create a safer working environment for coal miners. The Casa Blanca Mine management views the implementation of modern degasification methods and methane abatement technology as a crucial element 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 Casa Blanca Mine. Specifically, this study aims to evaluate the technical and economic viability of methane pre-drainage utilizing long, directionally-drilled horizontal boreholes drilled from within the mine workings, and to identify end-use options.

While several potential options exist for the use of CMM at the Casa Blanca Mine, onsite power generation is the most viable option based on comparable operations and preliminary market data provided by the mine. Given the relatively small CMM production volume, as well as the mountainous terrain, constructing a pipeline to transport the gas to demand centers would be impractical. While there has been interest in compressed natural gas (CNG) for vehicle fuel, CNG at this time is not economically feasible as it requires significant capital costs to upgrade gas quality and compress the gas. Based on gas supply forecasts performed in association with this pre-feasibility study, the mine could be capable of producing as much as 4.0 megawatts (MW) of electricity capacity.

CMM gas production profiles were generated and reservoir models were developed for two permeability cases – 1 millidarcy (md) and 5 md – since actual permeability is unknown in the study area. The models predicted borehole gas flow rate and gas content reduction as a function of time for a 6-year period, which is the time it will take for mining to reach a depth of approximately 300 m based on current mining activity. The borehole spacing required to reduce the residual gas content by 60 percent and the gas and water production for each permeability case were derived from the numerical models and presented in Table ES 1, which highlights the results for a single borehole. The reservoir size for the two permeability cases are 17 meters (m) x 130 m and 130 m x 130 m for the 1 md and 5 md cases, respectively. This explains the differing gas and water production and the equivalent gas content reduction values for the two scenarios.

Permeability (md)	Time (years)	Gas Content Reduction (%)	Borehole Spacing (m)	Total Gas Production (MMcf)	Average Gas Production Rate (Mcf/d)	Total Water Production (MBbls)
1	6	60	17	4.0	1.8	1.7
5	6	60	130	30.9	14.1	12.8

Table ES 1: Summary of Simulation Results and Borehole Production Rates.

For the purpose of forecasting CMM production at the mine, it is assumed that long, directionally drilled horizontal boreholes are drilled in 2019 with the pre-drainage period running from 2020 through 2025. Individual borehole laterals are assumed to extend through all 12 coal seams with a longitudinal borehole distance ranging between 194 m to 220 m. To accomplish these tasks among others, it is assumed the mine will contract an underground directional drilling service with the ability to support the initial phase of the project.

Two economic scenarios were evaluated in this study and are described in more detail in Section 7. One scenario's gas drainage system involves in-mine directional drilling of horizontal pre-drainage boreholes, which adds to the cost of the project and decreases returns. This scenario will not be the focus of this study because it results in unfavorable economics, due to the mine not absorbing operational drilling costs. In the second scenario, referred to as the power plant only scenario, the costs of the gas drainage system will be absorbed by the mining operation as operational costs. Both scenarios use the same permeability scenarios but differ regarding project operational costs. For the power plant only scenario, the economic results in Table ES 2 show the 5 md development scenario as the more favorable outcome in terms of net present value (NPV), internal rate of return (IRR), payback, and net CO_2e reductions. Wells are spaced more closely in the 1 md development scenario, which results in higher drainage system costs associated with the project. In these development scenarios, the costs of the gas drainage system are absorbed by the mining operation as operational costs. Higher NPV and IRR values are present in the power plant only scenario because of this cost absorption. It is also important to note that in the power plant only scenario, the cost of gas purchased is not included. There is a net reduction potential between 340,585 and 347,607 tons of carbon dioxide equivalent (tCO_2e) in the development scenarios in Table ES 2. These reductions are derived from the estimated combustion of roughly 15,137 to 15,449 tons of methane during the life of the 6-year project.

Development Scenario	Borehole Spacing (m)	Max Power Plant Capacity (MW)	NPV-10 ($,000)	IRR (%)	Payback (years)	Net CO_2e Reductions (tCO_2e)
1 md	17	4.0	45	10.3%	3.5	340,585
5 md	130	4.0	408	13.0%	3.0	347,607

Table ES 2: Summary of Economic Results for Power Plant (Only) (pre-tax).

As a pre-feasibility study, this report is intended to provide an initial assessment of project feasibility. Further site-specific analysis is necessary to develop a "bankable" feasibility study acceptable to project investors, banks, and other sources of finance. Section 8 provides further guidance for UniMinas S.A.S. to aid in their assessment of a CMM capture and use project. Foremost among these recommendations is the need to clearly define the geology, gas production forecasts, ventilation system, and gas utilization opportunities for the Casa Blanca Mine.

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 45-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 USEPA has sponsored feasibility and pre-feasibility studies in such countries as China, India, Kazakhstan, Mexico, Mongolia, Poland, Russia, Turkey, and Ukraine.

The Casa Blanca Mine was selected for this pre-feasibility study because it is a part of one of the largest mining complexes in the country that has been operational for over 30 years. Consisting of 37 small mine operations producing nearly 500,000 tons of metallurgical coal per year (tpy) the selected area emits approximately 1,846 tons of methane gas into the atmosphere annually. Limited infrastructure and technical knowledge have thus far prevented the mines from installing a methane drainage system, which would provide an environmental and safety benefit for the mines.

Multiple mine explosions occurring in recent years, including one nearby Casa Blanca, have heightened the region's desire to create a safer working environment for coal miners. Although the mine's ventilation system has been generally effective at reducing the methane concentration in the air throughout the mine workings to date, there is still a high risk of methane related accidents occurring, especially as mining activity moves to deeper levels. The Casa Blanca 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 Casa Blanca Mine. Specifically, this study aims to evaluate the technical and economic viability of methane pre-drainage utilizing long, directionally drilled horizontal 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 Colombian Coal Industry

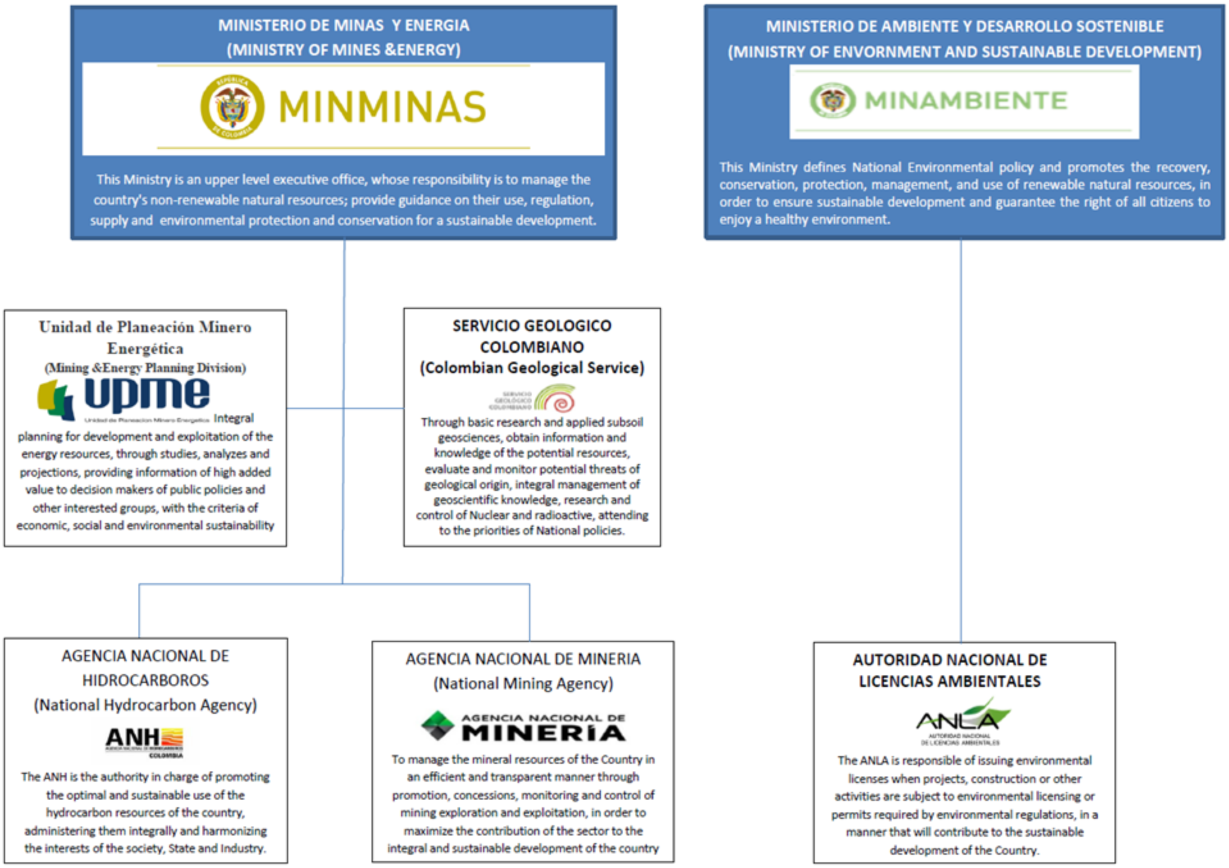
In 2017, Colombia was South America's largest coal producer and largest reserve holder with its 5.4 billion short tons of proven coal reserves. It is the fourth-largest coal exporter in the world, following Australia, Indonesia, and Russia. The country exported 113 million tons of coal in 2017, with 6.1 million tons exported to the United States, which accounted for 78% of total U.S. coal imports. Colombia's coal is highly sought after because it is relatively clean–burning, low sulfur content coal (EIA, 2019). The high-quality thermal coal has a calorific value of about 13.068 British thermal units per pound (BTU/lb), making it one of the higher calorific values in the world. Roughly 94% of all produced coal was exported in 2016 with major destinations for thermal coal in Turkey (17.8%), Netherlands (17.3%), Chile (7.5%), and Mexico (6.8%) among others. With such large export values, Colombia represents approximately 10% of the total seaborne coal trade worldwide. Coal accounted for 67.5% of Colombia's mining GDP, 1.36% of total GDP, and 87.7% of the total mining royalties collected in 2017 (ANM, 2018).

Roughly 90% of the mining occurs in the northern departments of Guajira and Cesar, with remaining production occurring in the interior departments of Boyacá, Cundinamarca, Norte de Santander, and Santander (EIA, 2019). 92.75% of coal production is extracted from open-pit mining areas in the Cesar and La Guajira, while the remaining 7.25% is extracted from underground mines in the interior departments (ANM, 2018). Over 92% of coal production is carried out by three companies: Cerrejón, Drummond, and Prodeco. Table 1 identifies major coal production areas and owners throughout Colombia's coal-producing departments.

Mine	Type	Department	Mine Owner	2017 Production (Mt)
Zona Norte	Surface	La Guajira	Cerrejón Coal Company	16.98
Oreganal	Surface	La Guajira	Cerrejón Coal Company	6.15
Carbones del Cerrejón	Surface	La Guajira	Cerrejón Coal Company	5.2
Patilla	Surface	La Guajira	Cerrejón Coal Company	3.83
La Loma	Surface	Cesar	Drummond	13.66
El Descanso	Surface	Cesar	Drummond	18.82
El Hatillo	Surface	Cesar	Murray Energy Corporation	0.63
Calenturitas	Surface	Cesar	Glencore/Prodeco	9.85
La Francia	Surface	Cesar	Murray Energy Corporation	2.97
N/A	Underground	Cundinamarca	UniMinas	0.22
N/A	Underground	Boyacá	Sanoha	0.07

Table 1: Coal Production in 2017 (Megatonnes (Mt)) By Major Operators in Different Colombian Departments (ANM, 2018).

The country's coal mines are exclusively owned and operated by private companies, but there are important regulatory bodies that interact with the coal industry in various capacities (GMI, 2015). In general, regulations and policies tend to be favorable to the mining industry because of its economic significance to the country. The Ministry of Mines and Energy (MinMinas) is Colombia's original 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 MinMinas 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). Figure 1 illustrates the relationship between Colombia’s relevant regulatory bodies.



MINISTERIO DE MINAS Y ENERGIA
(MINISTRY OF MINES &ENERGY)

This Ministry is an upper level executive office, whose responsibility is to manage the country's non-renewable natural resources; provide guidance on their use, regulation, supply and environmental protection and conservation for a sustainable development.

MINISTERIO DE AMBIENTE Y DESARROLLO SOSTENIBLE
(MINISTRY OF ENVORNMENT AND SUSTAINABLE DEVELOPMENT)

This Ministry defines National Environmental policy and promotes the recovery, conservation, protection, management, and use of renewable natural resources, in order to ensure sustainable development and guarantee the right of all citizens to enjoy a healthy environment.

Unidad de Planeación Minero Energética
(Mining &Energy Planning Division)

Integral planning for development and exploitation of the energy resources, through studies, analyzes and projections, providing information of high added value to decision makers of public policies and other interested groups, with the criteria of economic, social and environmental sustainability

SERVICIO GEOLOGICO COLOMBIANO
(Colombian Geological Service)

Through basic research and applied subsoil geosciences, obtain information and knowledge of the potential resources, evaluate and monitor potential threats of geological origin, integral management of geoscientific knowledge, research and control of Nuclear and radioactive, attending to the priorities of National policies.

AGENCIA NACIONAL DE HIDROCARBOROS
(National Hydrocarbon Agency)

The ANH is the authority in charge of promoting the optimal and sustainable use of the hydrocarbon resources of the country, administering them integrally and harmonizing the interests of the society, State and Industry.

AGENCIA NACIONAL DE MINERIA
(National Mining Agency)

To manage the mineral resources of the Country in an efficient and transparent manner through promotion, concessions, monitoring and control of mining exploration and exploitation, in order to maximize the contribution of the sector to the integral and sustainable development of the country

AUTORIDAD NACIONAL DE LICENCIAS AMBIENTALES

The ANLA is responsible of issuing environmental licenses when projects, construction or other activities are subject to environmental licensing or permits required by environmental regulations, in a manner that will contribute to the sustainable development of the Country.

Figure 1: Chart Depicting the Relationship Between Various Mining and Hydrocarbon-Relate Regulatory Agencies in Colombia (USEPA, 2017).

2.2 CMM/CBM in Colombia

Colombia’s large coal reserves are thought to contain significant coal mine and coalbed methane resources (CMM and CBM). National studies currently estimate its methane resources to be between 11 and 35 trillion cubic feet (Tcf), although not all of the gas is considered economically recoverable (ANH, 2011) (Table 2). The first Colombian CBM test wells were drilled by GeoMet Operating Company on two coal leases near El Cerrejón. The test well in the northeastern Cerrejón block was drilled to 910 meters and intersected about 60 m of net coal. The southwestern block (or La Loma/La Jagua) core encountered 27 m of net coal at depths between 300 and 550 m, with additional coal in sections below the bottom of the well (Schwochow, 1997).

Region	Mineable Coal in Place (Bmt)	Potential Gas in Place (Tcf)
Cesar	6.6	2.3 - 6.3
Guajira	4.5	2.5 - 10
Boyacá	1.7	2.1 - 5
Cundinamarca	1.5	2 - 5
Valle del Santander	0.2	0.1 - 6.2
Norte de Santander	0.8	0.9 - 1.2
Cordoba	0.7	0.4 - 0.5
Antioquia	0.5	0.3 - 0.4
Santander	0.8	0.5 - 0.7
Total Recovery Potential	**17.3**	**11 - 35.3**

Table 2: Mineable Coal in Place (Billion Metric Tons (Bmt)) No Deeper Than 300 m and Potential Total Gas in Place (Tcf) (ANH, 2011).

More recently, there has been significant activity related to CMM and CBM. U.S.-based Drummond Company started CMM/CBM exploration programs on two operating lease blocks, one in Guajira and one in Cesar. In 2017, the U.S. Trade and Development Agency (USTDA) published the results of a CMM/CBM feasibility project in Córdoba (USTDA, 2015). The study's objective was to inform the Generadora y Commercializadora de Energía del Caribe S.A. (GECELCA) of the project's potential before the company makes a drilling decision. GECELCA hopes the project will increase regional methane utilization, help supply the Colombian natural gas market, and reduce the area's overall greenhouse gas (GHG) emissions (USTDA, 2015).

A pre-feasibility study was conducted in 2017 through the USEPA's Coalbed Methane Outreach Program (CMOP) and the Global Methane Initiative (GMI) at the San Juaquin Mine in Antioquia Department. The site was selected as it is one of the largest longwall mines in the country and one that experienced a large explosion in 2010 that took the lives of 73 miners. Colombia wants to develop and enhance safety in the mines, as the coal mining industry has reported 1,129 emergency situations and 1,332 deaths in the country since 2005. If adjusted to include accidents associated with illegal coal extraction activities, which are prevalent in Colombia, the total would be substantially higher. Explosions account for over 25% of all the deadly accidents and are largely preventable issues that are caused by low awareness of methane-related risks, insufficient technical expertise with ventilation, incomplete regulation, and inadequate adherence to existing rules on mining safety.

While the majority of coal production is currently surface-mined, it is expected that mining will move underground as coal demand remains strong. This anticipated trend provides opportunities for CMM/CBM development (UNECE, 2017). 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 (Table 3). The potential for commercial CMM/CBM utilization to reduce greenhouse gas emissions (GHG) remains one of the industry's most significant potential benefits alongside increased mine safety. As a Non-Annex I Party to the Kyoto Protocol, Colombia is eligible to host mitigation projects under the Clean Development Mechanism and can secure project revenues from the sale of GHG emissions reduction credits (GMI, 2015).

	2000	2005	2010	*2015-
Mm^3	231	357	511	651
MtCO$_2$e	3.9	6.1	8.7	11.1

*Table 3: A Global Warming Potential (GWP) (100-Year) of 25 is Used for Mtco$_2$e Calculation. *Data for 2015 is Projected (GMI, 2015).*

Colombian laws permit the National Hydrocarbons Agency (ANH), an administrative body under the MinMinas, to award areas for exploration and production of hydrocarbons, including CBM. The ANM, another administrative body under MinMinas, is responsible for managing Colombia's mineral resources. In 2010, Colombia published its National Development Plan (NDP) 2010-2014, which identified the mining sector as a critical industry for economic growth, specifically mentioning CMM/CBM projects as an area for expansion and promotion (UPME, 2017). Because 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). That same decree also set forth a 40 percent reduction in government royalties applicable to unconventional hydrocarbons, which includes CBM (GMI, 2017). The following NDP (2014-2018) included a green growth policy, which contains sectoral targets for reducing GHG emissions in the short (2020) and medium term (2025-2030) (UPME, 2017). The most recent NDP (2018-2022) notes that coal is a necessary component of energy generation that will be developed with high environmental standards to remain a suitable energy resource in Colombia (Gobierno de Colombia, 2018).

The CMM/CBM industry in Colombia has shown promising gas resources alongside regulatory support, but it still faces various challenges before it can be fully developed. Many of the mines in Colombia are open-pit, surface mines, which only allow for pre-drainage opportunities. For developers in underground mines there is often inadequate mining data and expertise, limiting opportunities for CMM/CBM. Most importantly, CMM/CBM resources must be cost-competitive with conventional natural gas and other competing energy resources. Reducing GHG emissions through CMM and CBM development will meaningfully help Colombia reach its reduction goals leading up to its 2030 Paris commitment. In the case of Colombia's national priorities, where coal production is expected to remain strong, developing CMM/CBM in an eco-efficient, cost-effective way will increase the country's energy security while maintaining strong exports of their coal resources.

2.3 Guachetá Mining Area

Guachetá has a mild climate that is generally warm and temperate. The average annual temperature is 13.8 °Celsius (C) and average rainfall is 904 millimeters (mm). The driest months of the year are from December to March, while rain is more common in April, May, September, October and November. Temperatures vary by 1.4 °C throughout the year between the hottest time of the year in March and the coldest in July.

Located near the municipality of Guachetá are 37 small mine operations producing 492,000 tons of metallurgical coal per year (tpy). In the area, approximately 1,846 tons of methane gas are emitted into the atmosphere annually from the mining operations. Limited infrastructure and technical knowledge have thus far prevented the mines from installing methane drainage and/or methane destruction/utilization systems, which would provide an environmental and safety benefit for the mines.

Multiple mine explosions occurring in recent years, including one nearby the town of Guachetá, have heightened the region's desire to create a safer working environment for coal miners. The Casa Blanca Mine, operated by UniMinas, is one of the largest mining operations in the area working to increase efficiency, production and safety at their mine complex by studying the potential of pre-mine drainage.

The mines are located within the Checua-Lenguazaque Syncline in the Ubaté province of the Department of Cundinamarca (Sarmiento, 2008). The rocks along the western flank of the syncline are characterized by steep dips of more than 45 degrees SE, which remain constant for long distances. Guachetá is in the Altiplano Cundiboyacense 118 kilometers (km) northeast of the country's capital, Bogotá. The coal seams are found in the Guaduas formation within the larger 600-km-long coal belt of Colombia's East Cordillera (Hiltmann, 1988).

The area selected for this study covers 1,707 hectares, of which 1,100 hectares correspond to mining contracts 2505 (UniMinas) and 867T (Promincarg) as shown in Figure 2. Topographic relief in the mine area varies between approximately +8,795 ft. in the west to +10,015 ft in the east. Guachetá lies west at the base of the mountain range and has paved and unpaved roads that allow access between the mines, the town and other cities in the region. There is also a railway system located near Guachetá (Figure 3). In 2011, China proposed a rail system through Colombia that would serve as an alternative to the Panama Canal, but sentiments surrounding project execution were largely pessimistic due to the mountainous terrain of central Colombia and the high expenses involved with operating a new railway (Railway Technology, 2011). Companies can access the mines from different cities nearby: from Bogotá the distance is approximately 112 km to the northwest, from Tunja 64 km to the west, and from Ubaté 30 km to the east (UPTC, 2017).

Figure 2: Overhead View of the Guachetá Mining Area: Mining Contracts 2505 UniMinas and 867T Promincarg.

As part of a larger effort to understand the CBM resources available in the municipalities of Samacá and Guachetá, a study conducted near Guachetá found an estimated potential of 0.91 billion cubic feet (Bcf) of gas resources distributed throughout 3,970 acres (Libertad, 2013). The study zone, named El Santuario, is the highlighted section furthest southwest on the map in Figure 4. This area coincides with the Casa Blanca Mine nearby the municipality of Guachetá.

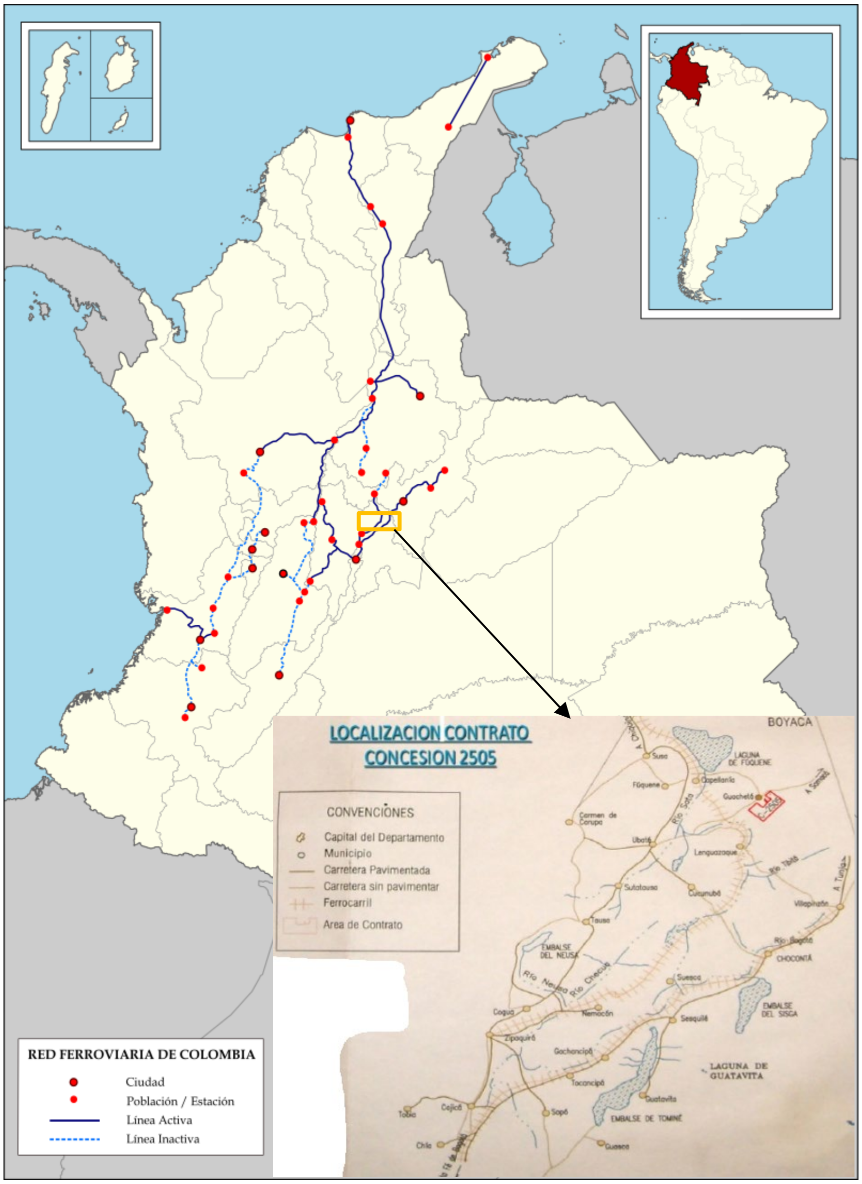


Figure 3: Map of Colombia's Active and Inactive Railway Routes (Railroads, 2010) (UPTC, 2015).

El Santuario was identified as one of the more promising sites for the testing and advancement of CBM drilling based on relevant considerations that included access roads, water availability, information on the presence of methane, and favorable geological conditions. Samples obtained from the El Santuario and the Loma Redonda sectors included 55 different samples of material both from mine faces and from core samples taken from the Samacá-2 and Ráquira-1 wells. Gas desorption measurements that incorporated lost gas and residual gas were carried out in accordance with standards of the U.S. Bureau of Mines to determine gas content in the area.

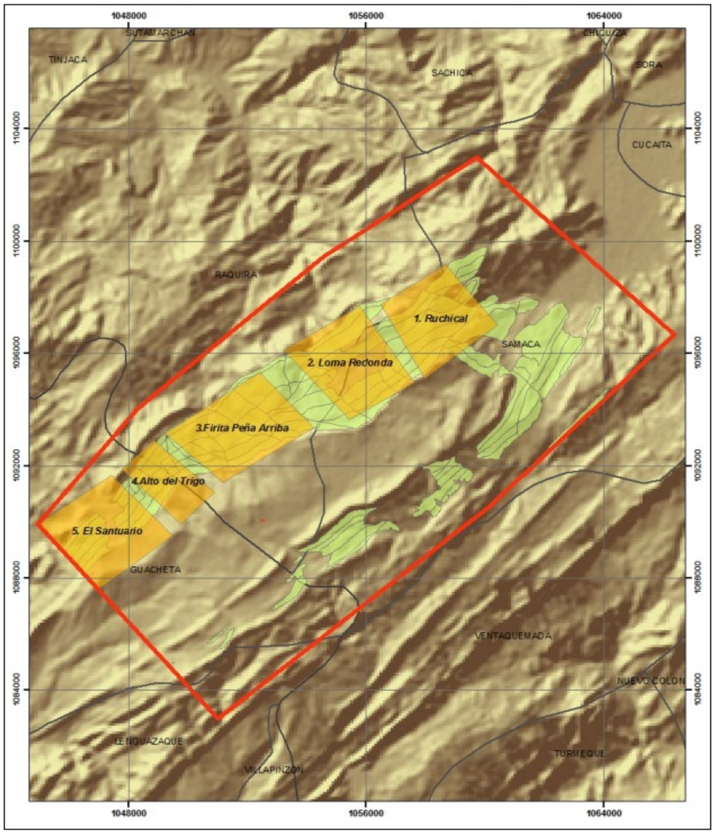


Figure 4: The Altiplano Cundiboyacense Region of Colombia, and the Approximate Location of the Mine (Quora, 2018).

According to measurements, the highest methane gas concentrations are located in the northern section of mine concession 2505, operated by UniMinas, and the southern and central sections of mine concession 867T, operated by Promincarg. It is estimated that concession 867T had methane emissions of approximately 7,850 tCO_2e. Extraction operations at concession 2505 involves 750 people and operations at concession 867T involves 420 people. Table 4 lists most of the mines by the different zones for UniMinas and Prominicarg. Table 5 presents the methane emissions from these mines, as well as the actual hourly measurements of ventilation air. The estimated emissions are based on coal production multiplied by an emission factor (m^3CH_4/Ton coal). Overall, higher CH_4 production is seen near the adjoining areas of the UniMinas and Prominicarg lease blocks, which marks the most promising areas for CMM/CBM development. Some of the highest potential areas based on measurements of hourly CH_4 production are the Yacimiento - San Miguel, El Curubo, Bocatoma and El Volcán -El Mortiño mines.

Zone	UniMinas S.A.S.	Promincarg S.A.S.
North Zone	Carbones GyD	Bocamina la Joya
	La Ceci	El Roble
	El Robie	Bocamina Forigua Cisquera 2
	La Virgen (BM1 & BM2)	Bocamina Cisquera de a 66
	Futuro 2	Bocamina El Roble Pidero 2
	San Miguel	Bocamina Vidriosa
	Esperaza 6	Bocamina El Zuncho
	Jabonera 1 & 2	Bocaminia Buenavista
	El Rubi Callejón	Bocamina Bellavista 2
	Rinconcito	Bocamina La Tapias
Central Zone		El Porvenir
	Tierra Alta	El Manzano
	Los Pinos	Siete Bancos- Nelson (closed)
	Carboquality Ltd.	El Volcán
		El Mortiño
	Sociedad González	
South Zone		Diamante 7
	BM Zuncho 2 Cisquera 2	
	La Esperanza 3	La Mana
	BM Siete Bancos	
	Esperaza 2	Bocatoma
	Túnel Casa Blanca	
	La Mejía	

Table 4: Mines Grouped into General Zones Based on Location. Gassiest Mines Found in North Zone of UniMinas and South and Central Zones of Prominicarg (UNECE, 2018).

Operator	Mine Name	CH_4 %	Q (outflow) (m^3/hour)	CH_4 Production (m^3/hour)	CH_4 Production (m^3/year)	Coal Production (tpy)	Tons Emitted (tCO_2e /year)
Promincarg	**Bocatoma**	0	3,240	0.0	1,175,731	10,284	19,693
	Mina El Volcán -El Mortiño	0.7	13,392	92.5	503,845	1,644	8,440
	La Mana	0.25	16,020	49.7	423,263	14,400	7,090
	Canales	0.35	3,339	11.6	190,356	1,236	3,188
	Piedro y Bolas	0.3	4,860	14.4			
UniMinas	**Yacimiento San Miguel**	0.57	1,872	106.5	932,663	14,592	15,622
	Inversiones Siatoba	0.6	3,140	62.8	-	-	-
	Mina La Ceci	0.4	16,133	59.9	427,991	11,520	7,169
	La Virgen	0.7	5,371	36.9	322,922	4,080	5,409
	Rinconcito S.A.S.	0.2	1,494	29.5	258,163	28,080	4,324
	Futuro Dos	0.4	5,616	22.2	194,089	4,488	3,251
	El Curubo	0.15	7,643	22.1	637,976	3,600	10.686.1
	Rubi El Callejon	0.25	2,918	10.1	88,071	7,920	1,475
	Tierra Alta	0.2	4,363	8.6	-	-	-
	Esperanza 3	0.05	10,764	5.3	-	-	-
	Los Pinos	0.05	7,128	1.6	119,367	2,400	1,999
	Jabonera 1	0.6	11,189	0.6	405,985	4,728	6,800
	Jabonera 2	0	6,350	0.0			
	Esperanza 2	0	3,733	0.0	-	-	-
	Carbones GyD	-	-	-	549,888	10,560	9,211

Table 5: Mines in Different Operators' Concessions. Yearly Production is Based on Hourly Measurements and the Tons Emitted is a Function of Coal Production and Methane Content in the Coals (UNECE, 2018).

There are 12 lithofacies in the Guaduas formation that can be grouped in 4 depositional systems: 1) interbedding sandstones, siltstones, claystones, and at times thin coal beds, which are believed to be lagoon deposits based on lateral continuity and organic content; 2) interbedding of sandstone and claystones with plant debris and coal, and a depositional environment interpreted as tidal flats based on heterogeneous stratification and cross-bedding; 3) claystones, coal, and sandstones that make up a great percentage of the stratigraphic record and are classified as an alluvial flooding flat; 4) sandstones deposited in a meandering alluvial system based on sedimentary structures, specifically cross-bedding (Jorge, 2016).

Figure 5 provides a visual representation of what the depositional setting may have looked like at one point in time during deposition. As expected, plant matter is deposited into anoxic environments to form peat mires before undergoing further changes depending on exposure to metamorphic processes. These coals show an inverse linear trend where volatile matter decreases and the reflectance of vitrinite increases, indicating that coals during the coalification process release gases due to the gain of temperature and lithostatic pressure (Figure 6).

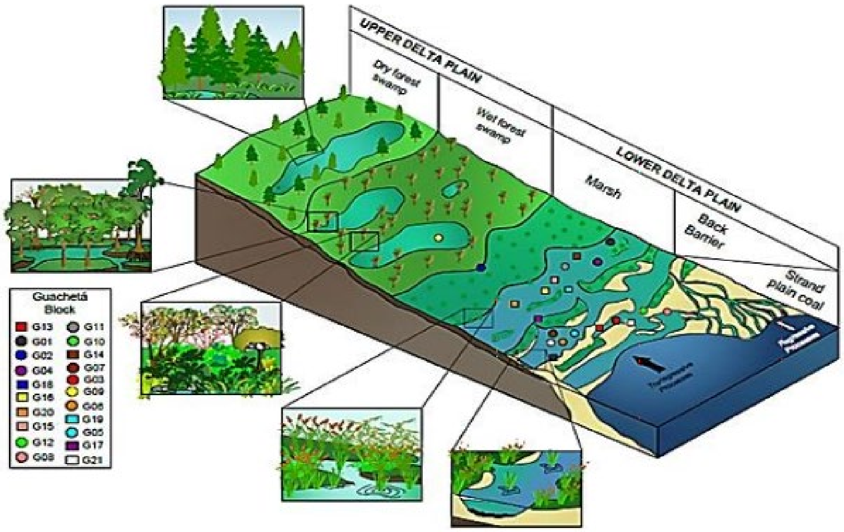


Figure 5: Depositional Environment of Guaduas Formation, Guachetá Block (UPTC, 2017).

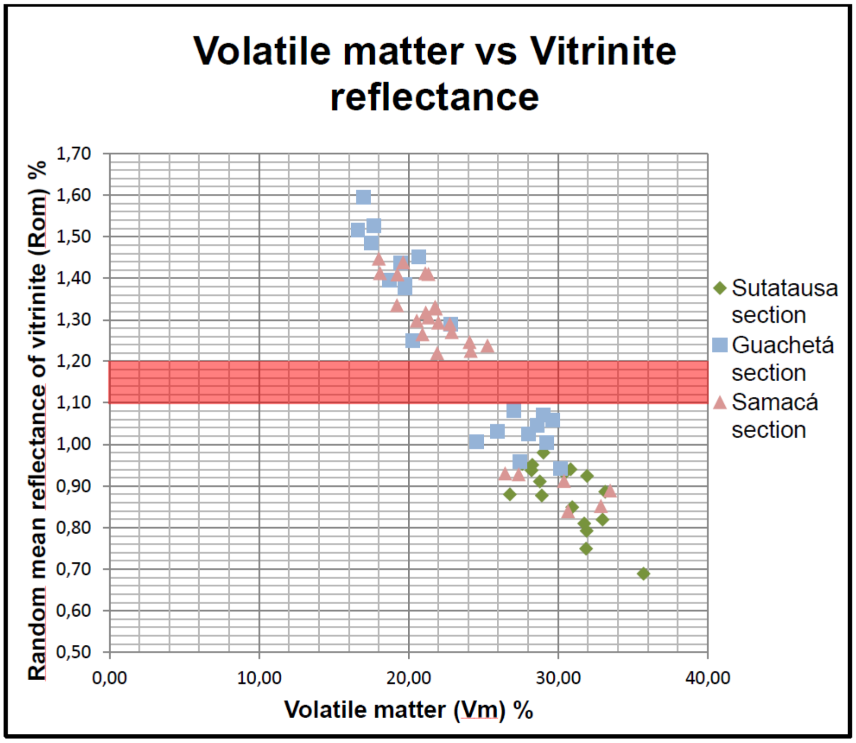


Figure 6: Comparison Between Samples and their Relation Between Volatile Matter and the Random Reflectance of Vitrinite, which is Trending In an Inversely Linear Fashion (UPTC, 2017).

The high-quality coals prevalent in northern Colombia are also found in the central, mountainous region of the country. In a study to determine the depositional environment of different coal seams in the Guaduas formation, Milpa S.A. allowed the Universidad Pedagógica y Tecnológica de Colombia (UPTC) to take 21 samples from 17 coal seams in the Guachetá mining area, marked in red in Figure 7 (UPTC, 2017). Researchers at UPTC then classified the coal based on the different coal features (Table 6), including: thickness, moisture, total moisture, ash, volatile matter, fixed carbon, swelling index and sulfur percentages.

The coals sample from the Guachetá mining area were higher rank in comparison with other blocks in the region (Samacá and Sutatausa) and show a non-linear decrease in moisture and volatile matter with an increase in coal rank. Coal rank is important, especially in central Colombia, because the coal's high quality can justify further shipping distances to ports when compared to mines closer to major export hubs along the northern coast. The coals generally show low moisture, ash and sulfur levels, which contribute to higher overall calorific values.

UPTC used two different classification methods for the coal samples (Table 7): one in accordance with the American Society for Testing and Materials (ASTM) and the other with the International Organization for Standardization (ISO) (IEA, 2014). Similar to the general characterization of the coals of Cundinamarca and Boyacá regions in Table 9, a majority of the coals sampled near Casa Blanca Mine are of bituminous grade. In addition to these coal classifications, a study of the over 60 coal samples in the Checua-Lenguazaque area revealed calorific values ranging from 2,415 Btu/lb to 15,759 Btu/lb with an average heating value of 12,506 Btu/lb (Bedoya, 2019). The coal seams range in thickness from roughly 0.25 m to 2 m depending on the seam and are interbedded between thicker layers of clays, brown limonites, and sandstones that are 0.5 m to 30 m thick (Figure 8).

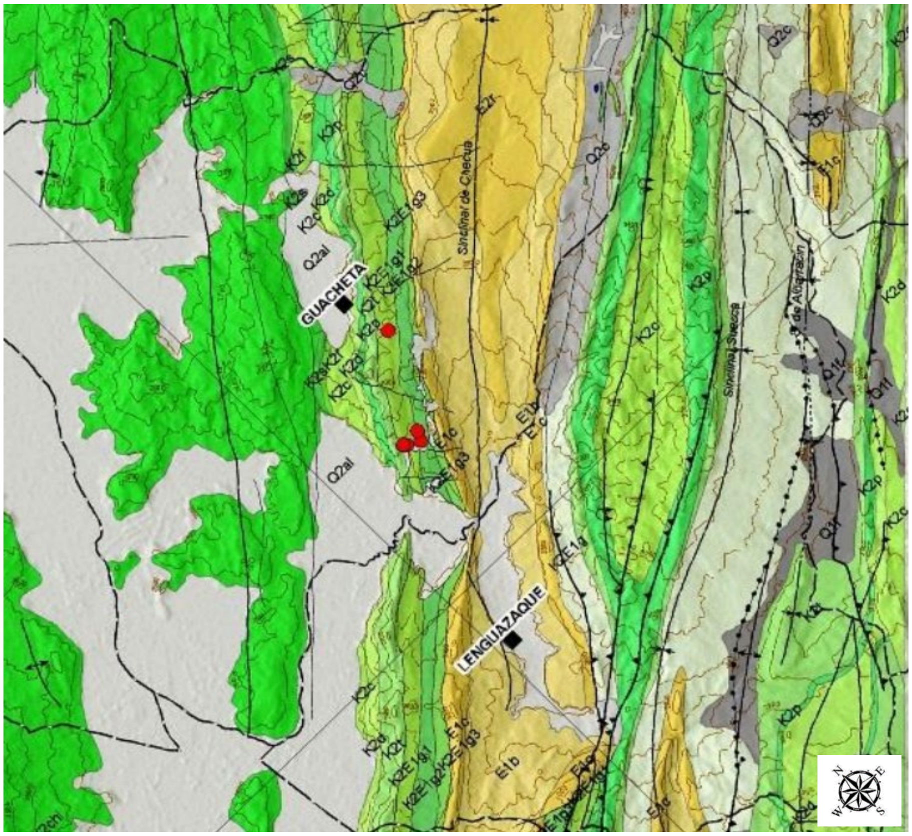


Figure 7: Geologic Map of Guachetá Mining Area with Red Points Indicating Where Samples were Taken (UPTC, 2017).

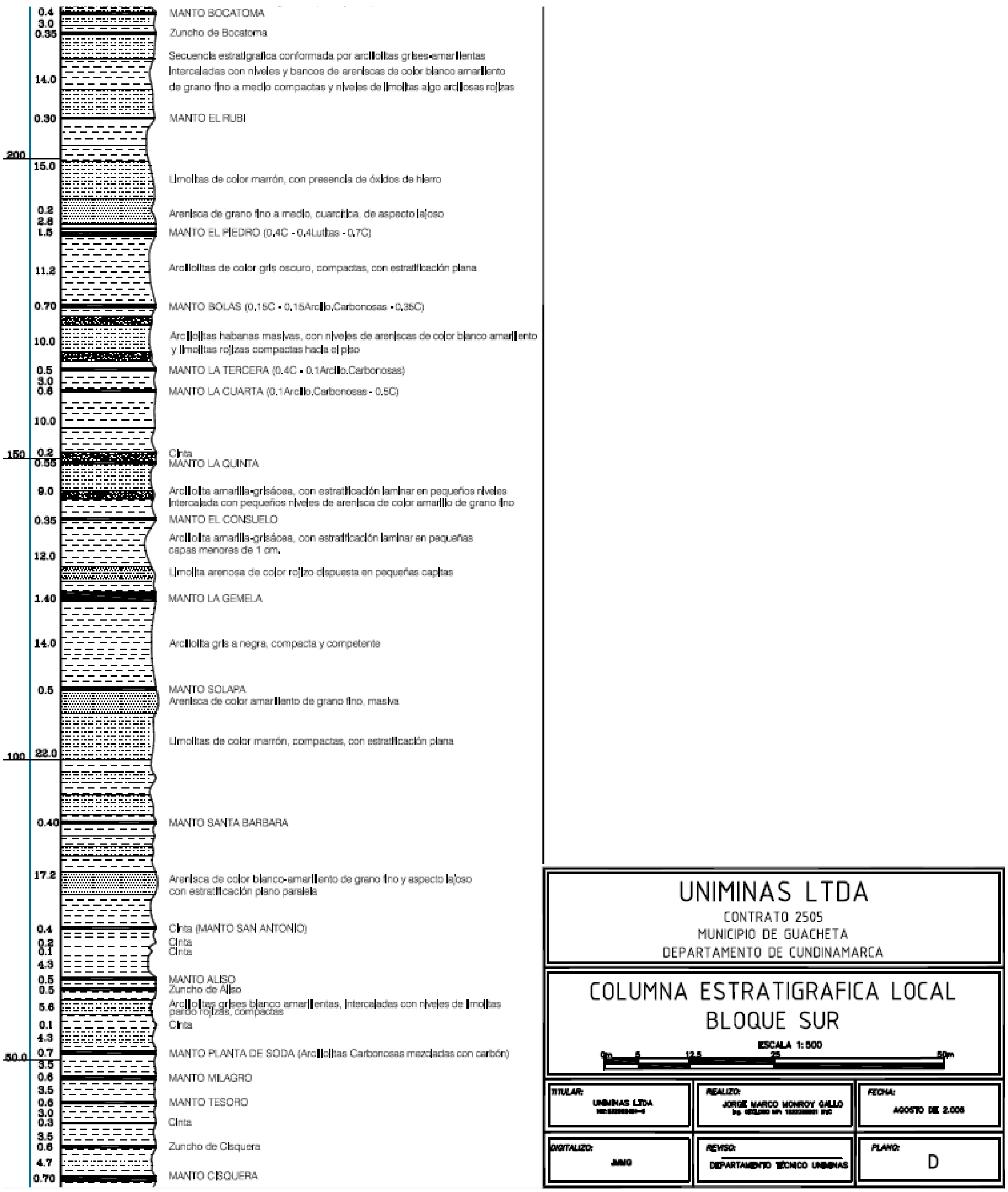
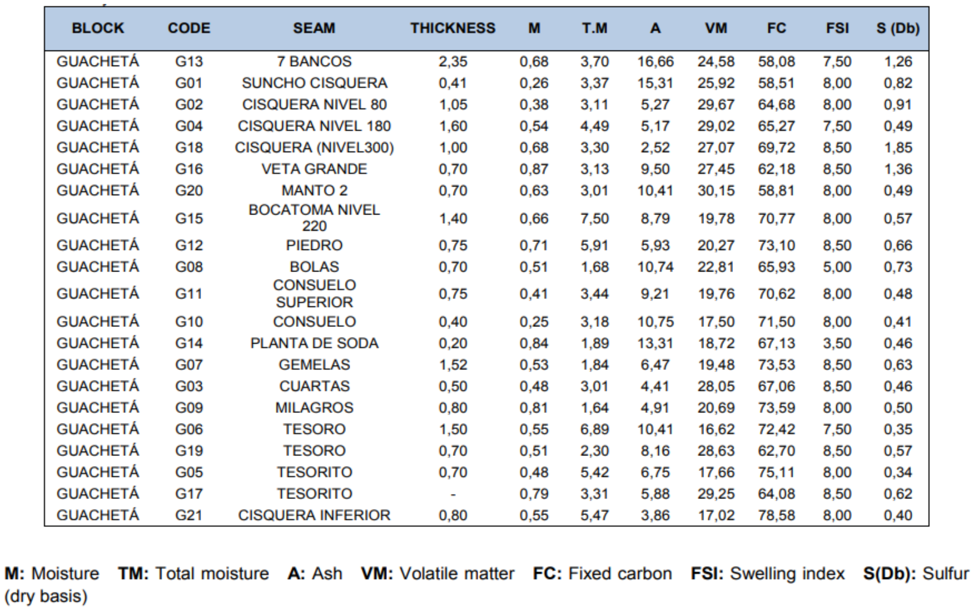


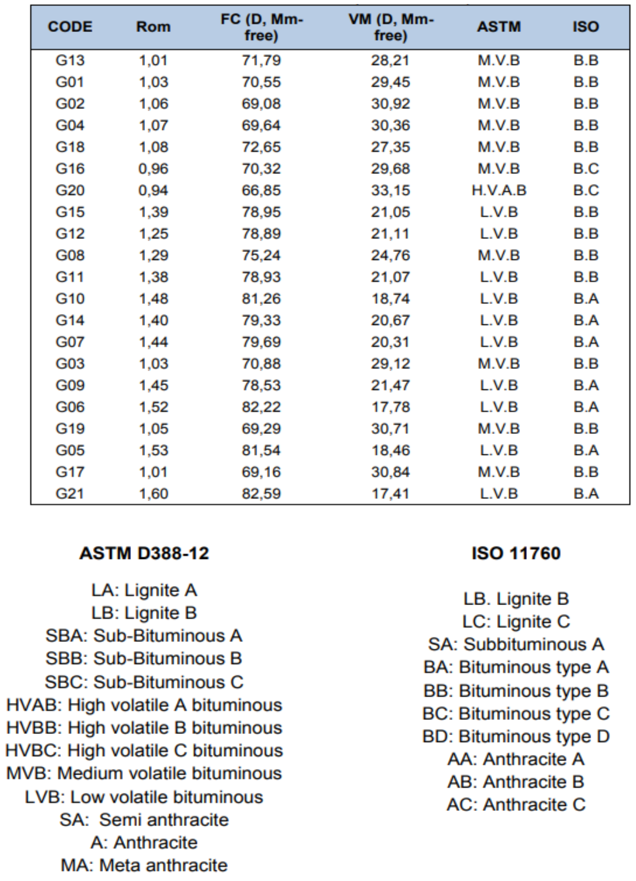
Figure 8: Stratigraphic Column of Guachetá Block in the Study Area (Bedoya, 2019).



BLOCK	CODE	SEAM	THICKNESS	M	T.M	A	VM	FC	FSI	S (Db)
GUACHETÁ	G13	7 BANCOS	2,35	0,68	3,70	16,66	24,58	58,08	7,50	1,26
GUACHETÁ	G01	SUNCHO CISQUERA	0,41	0,26	3,37	15,31	25,92	58,51	8,00	0,82
GUACHETÁ	G02	CISQUERA NIVEL 80	1,05	0,38	3,11	5,27	29,67	64,68	8,00	0,91
GUACHETÁ	G04	CISQUERA NIVEL 180	1,60	0,54	4,49	5,17	29,02	65,27	7,50	0,49
GUACHETÁ	G18	CISQUERA (NIVEL300)	1,00	0,68	3,30	2,52	27,07	69,72	8,50	1,85
GUACHETÁ	G16	VETA GRANDE	0,70	0,87	3,13	9,50	27,45	62,18	8,50	1,36
GUACHETÁ	G20	MANTO 2	0,70	0,63	3,01	10,41	30,15	58,81	8,00	0,49
GUACHETÁ	G15	BOCATOMA NIVEL 220	1,40	0,66	7,50	8,79	19,78	70,77	8,00	0,57
GUACHETÁ	G12	PIEDRO	0,75	0,71	5,91	5,93	20,27	73,10	8,50	0,66
GUACHETÁ	G08	BOLAS	0,70	0,51	1,68	10,74	22,81	65,93	5,00	0,73
GUACHETÁ	G11	CONSUELO SUPERIOR	0,75	0,41	3,44	9,21	19,76	70,62	8,00	0,48
GUACHETÁ	G10	CONSUELO	0,40	0,25	3,18	10,75	17,50	71,50	8,00	0,41
GUACHETÁ	G14	PLANTA DE SODA	0,20	0,84	1,89	13,31	18,72	67,13	3,50	0,46
GUACHETÁ	G07	GEMELAS	1,52	0,53	1,84	6,47	19,48	73,53	8,50	0,63
GUACHETÁ	G03	CUARTAS	0,50	0,48	3,01	4,41	28,05	67,06	8,50	0,46
GUACHETÁ	G09	MILAGROS	0,80	0,81	1,64	4,91	20,69	73,59	8,00	0,50
GUACHETÁ	G06	TESORO	1,50	0,55	6,89	10,41	16,62	72,42	7,50	0,35
GUACHETÁ	G19	TESORO	0,70	0,51	2,30	8,16	28,63	62,70	8,50	0,57
GUACHETÁ	G05	TESORITO	0,70	0,48	5,42	6,75	17,66	75,11	8,00	0,34
GUACHETÁ	G17	TESORITO	-	0,79	3,31	5,88	29,25	64,08	8,50	0,62
GUACHETÁ	G21	CISQUERA INFERIOR	0,80	0,55	5,47	3,86	17,02	78,58	8,00	0,40

M: Moisture **TM:** Total moisture **A:** Ash **VM:** Volatile matter **FC:** Fixed carbon **FSI:** Swelling index **S(Db):** Sulfur (dry basis)

Table 6: Proximate Analyses of the Guachetá Block Coals (UPTC, 2017).



CODE	Rom	FC (D, Mm-free)	VM (D, Mm-free)	ASTM	ISO
G13	1,01	71,79	28,21	M.V.B	B.B
G01	1,03	70,55	29,45	M.V.B	B.B
G02	1,06	69,08	30,92	M.V.B	B.B
G04	1,07	69,64	30,36	M.V.B	B.B
G18	1,08	72,65	27,35	M.V.B	B.B
G16	0,96	70,32	29,68	M.V.B	B.C
G20	0,94	66,85	33,15	H.V.A.B	B.C
G15	1,39	78,95	21,05	L.V.B	B.B
G12	1,25	78,89	21,11	L.V.B	B.B
G08	1,29	75,24	24,76	M.V.B	B.B
G11	1,38	78,93	21,07	L.V.B	B.B
G10	1,48	81,26	18,74	L.V.B	B.A
G14	1,40	79,33	20,67	L.V.B	B.A
G07	1,44	79,69	20,31	L.V.B	B.A
G03	1,03	70,88	29,12	M.V.B	B.B
G09	1,45	78,53	21,47	L.V.B	B.A
G06	1,52	82,22	17,78	L.V.B	B.A
G19	1,05	69,29	30,71	M.V.B	B.B
G05	1,53	81,54	18,46	L.V.B	B.A
G17	1,01	69,16	30,84	M.V.B	B.B
G21	1,60	82,59	17,41	L.V.B	B.A

ASTM D388-12

LA: Lignite A
LB: Lignite B
SBA: Sub-Bituminous A
SBB: Sub-Bituminous B
SBC: Sub-Bituminous C
HVAB: High volatile A bituminous
HVBB: High volatile B bituminous
HVBC: High volatile C bituminous
MVB: Medium volatile bituminous
LVB: Low volatile bituminous
SA: Semi anthracite
A: Anthracite
MA: Meta anthracite

ISO 11760

LB. Lignite B
LC: Lignite C
SA: Subbituminous A
BA: Bituminous type A
BB: Bituminous type B
BC: Bituminous type C
BD: Bituminous type D
AA: Anthracite A
AB: Anthracite B
AC: Anthracite C

Table 7: Classification of Coals with the ASTM and ISO Norms (Guachetá Block) (UPTC, 2017).

3. Summary of Casa Blanca Mine Characteristics

3.1 Overview of Current Gas Management and Gas Resources

UniMinas is one of the largest coal mining companies operating within the Guachetá mining area and agreed to have this pre-feasibility study conducted at their Casa Blanca Mine. UniMinas is a title holder of mining contract 2505 and was created in 1998 with the purpose of carrying out the extraction of minerals in all its phases, especially the exploitation of coking quality coal. They are a subsidiary of C.I. Milpa S.A., a producer of metallurgical coke in Colombia, and are seeking to aggregate some of the area's smaller operators into one larger, more efficient operation within the Casa Blanca Mine. UniMinas and Promincarg, the main miners in the area, do not have licenses for CMM/CBM projects, but Safety Decree 1886, Article 59 establishes that mines with high concentrations of methane gas must drain the gas if it is viable to use. To comply with the regulation, mines must conduct studies to measure the gas characteristics in the coal seams. Significantly higher levels of methane are found in the northern zone of mining contract 2505 and southern zone of mining contract 867T; over 66,000 m^3 via ventilation air in August of 2016 was produced north of the El Reposo fault in the San Miguel Mine (Moore, 2016).

The Casa Blanca mine has a professional engineer and a methane specialist who implement the Occupational Health and Safety Management System for mining personnel. The mines have ventilation plans, but most need a redesign. Too many auxiliary fans are used without complying with the required safety specifications, as there is no continuous monitoring of the atmospheric conditions in the mine. These fans also do not have auxiliary power generation plants that guarantee a continuous supply of energy to the fans in the mines. No risk zones have been identified that are prone to sudden gas outbursts because there has not been a comprehensive measurement of methane gas in the mine area.

Information on the gas content and coal characteristics of the Gauduas formation in the Altiplano Cundiboyacense region, where the Casa Blanca mine complex is located (Figure 9), is shown in Table 8 and Table 9.

Depth (m)	Gas Content (ft^3/ton)
5-25	5
25-50	N/A
50-100	5-30
100-200	60-80
200-30	10-100
300-400	10-150
400-500	50-150
500-600	50-300
600-700	100-300

Table 8: Depth Versus Gas Content in the Gauduas Formation in Altiplano Cundiboyacense (Martínez, 2015).

Basin	Coal Rank	Calorific Value (Btu/ft)	Carbon Content (%)	Volatile Material (%)	Ash (%)	Moisture (%)
Cundi-Boyacá	Bituminous	8,112-13,914	56.6	31.1	10.5	4.2

Table 9: Laboratory Analyses of the Coal Found in the Cundi-Boyacá Basin Based on Conducted Sampling (Martínez, 2015).

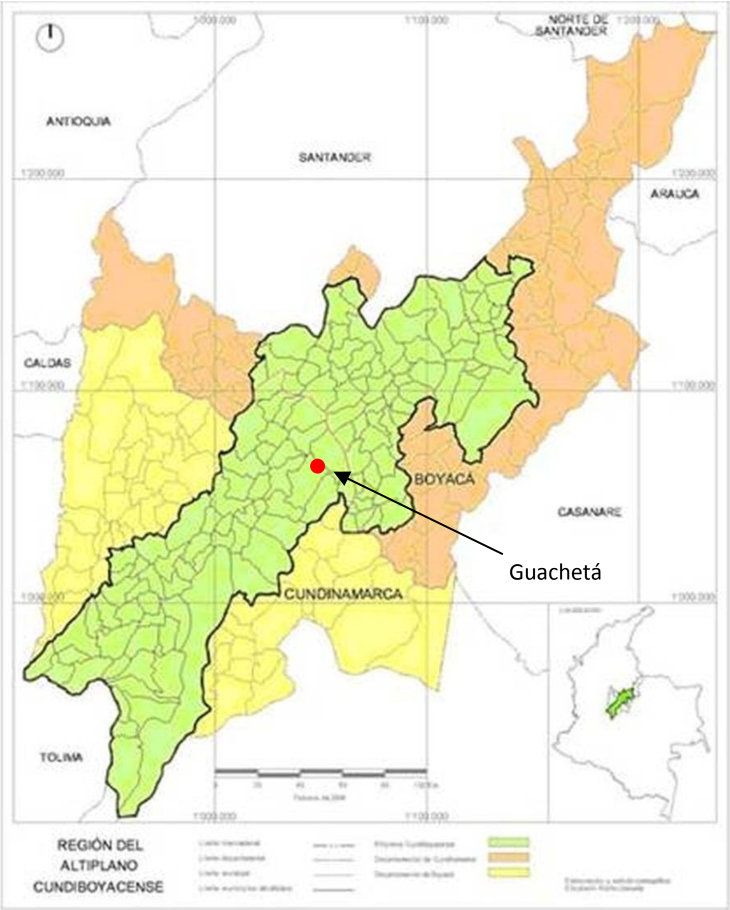


Figure 9: The Altiplano Cundiboyacense Region of Colombia, and the Approximate Location of the Mine (Quora, 2018).

In the Cundinamarca area there are 4 wells that were drilled to a depth of 400 m deep to measure coal seam gas contents. The highest methane volume measured was 221 ft^3/ton as shown in Figure 10 (Bedoya, 2019). Two unrelated, additional wells in the region are the Samacá-2 and Ráquira-1 wells. The two wells, named after the municipalities in which they were drilled, are both located in the Department of Boyacá. Samples from those two wells were used in the analysis to produce the gas content estimates for two different sectors within the Cundinamarca-Boyacá region, including the gas desorption curve shown in Figure 11 (Libertad, 2013). The gas measurements from the wells in Boyacá reach higher than 250 ft^3/ton, not including residual gas, and help confirm the gas resource potential in the greater area.

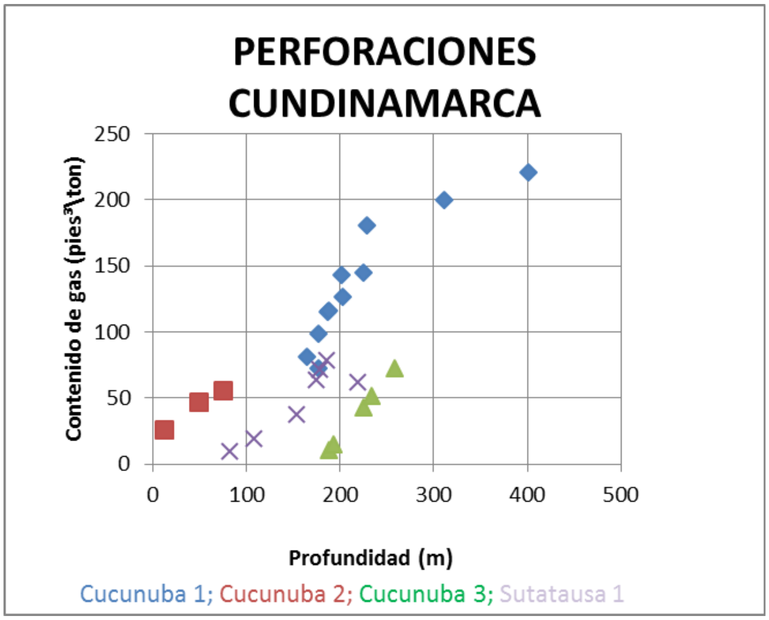


Figure 10: Gas Content versus Depth for 4 Wells Drilled in the Cundinamarca Area (Bedoya, 2019).

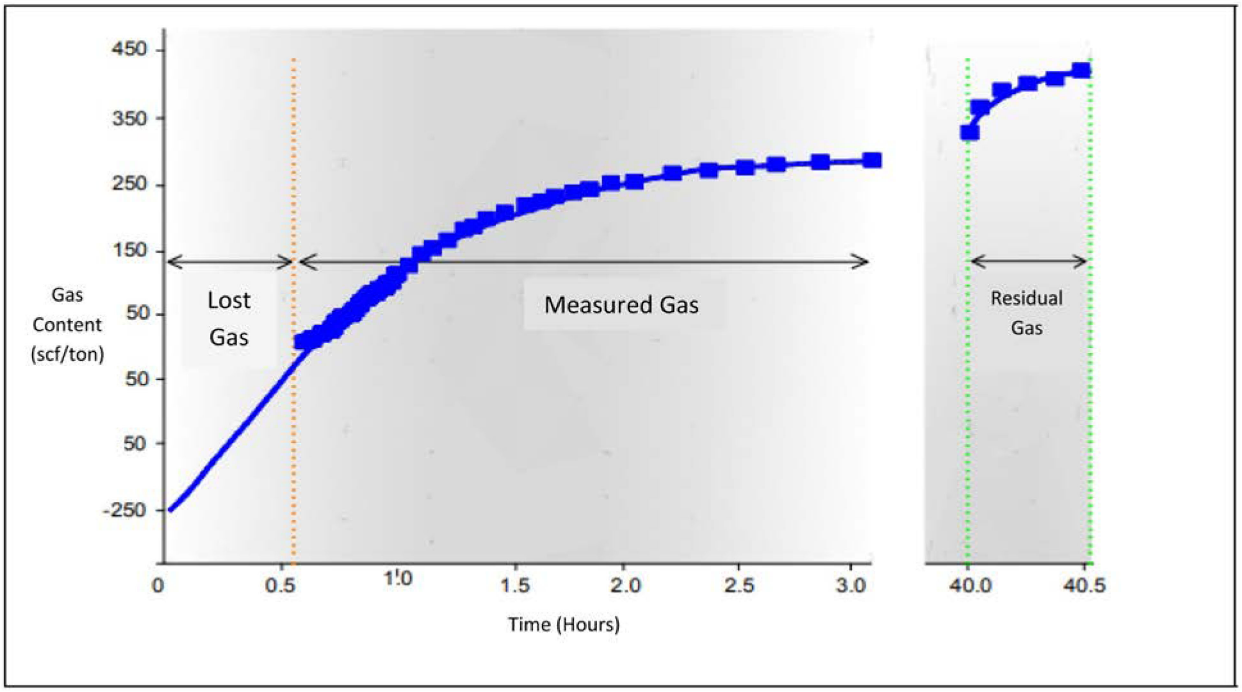


Figure 11: Desorption Curve with Gas Content Intervals on Lost, Measured and Residual Gas Over Time in the Cundinamarca-Boyacá Region (Libertad, 2013).

3.2 Mine Geology and Operations

3.2.1 Mine Geology

There are 12 seams being mined within the Casa Blanca Mine coal block, of which all are thermal or coking quality. The thermal coal is mined for domestic use in Colombia, while the metallurgical coal is exported. The depths of the mines range from 100 m to 300 m and seam thickness ranges from 0.3 m to 2 m (Libertad, 2013). Some of the seams pinch out over a fault, and all seams of the Guaduas formation were deposited throughout the upper Cretaceous and lower Tertiary period during the regression of the Cretaceous seas.

3.2.2 Mine Operations

3.2.2.1 Mine Operator

C.I. Milpa S.A. is a Colombian producer and provider of metallurgical coke to companies in the steel, cement, and smelting industries, among others. The roots of Milpa date back to the 1800's when ancestors of the company's current partners mined metallurgical coal for Colombia's first iron and steel company. Today, Milpa provides resources for Colombian industry and exports its high-quality metallurgical coke to roughly 25 countries. UniMinas S.A.S., a subsidiary of Milpa, operates and extracts coal from the Casa Blanca tunnel, which is the longest underground mining tunnel in Colombia at 5 km in length (Semana, 2017). UniMinas is the main operator of mining contract 2505, which overlays the Casa Blanca Mine. The subsidiary is a pioneer in mining mechanization in Colombia and has new concession proposals in other mining areas that will allow it to expand operational capacity and provide more metallurgical coal for Milpa's coking operations and exports.

3.2.2.2 Casa Blanca Mine

The largest mine in the Guachetá mining area, Casa Blanca, produces approximately 96,000 tpy while the smaller mines produce between 6,000 tpy and 12,000 tpy. The Casa Blanca Mine has one tunnel approximately 4-5 km long that acts as the main access road to the eastern side of the mine where it connects with the different mined coal seams. The tunnel, named Casa Blanca by UniMinas, was advanced through a combination of blasting and cutting by mining machinery (UPTC, 2015). Cuts are initiated directly into the 12 coal layers found in the mining project at the end of the larger tunnel. The tunnel entrance is situated 5 km east of the border of the municipality of Guachetá. This tunnel is accessible from town by way of roads that are not paved in some areas but are all in good condition.

At present, smaller mining operations are originating from the surface and mine downwards over time within coal seams. However, there is a limit to how deep these smaller operations can reach from the surface. The proposed plan incorporates inclines below the Casa Blanca tunnel, which are incrementally developed over time as resources become exhausted. The first level, Level Minus One, is planned to be developed roughly 130 m below the Casa Blanca tunnel (Figure 12). Coal extraction will be carried out in the 12 seams between the Casa Blanca tunnel and the Level Minus One incline 130 m below and will require about 6 years. After the resources are exhausted between the tunnel and the Minus One Level, a new level, roughly 260 m below the Casa Blanca tunnel, will be developed. The same process of extraction is proposed for the deeper Minus Two Level. These inclines and levels below the Casa Blanca tunnel are expected to improve coal production and ventilation by aggregating the smaller mines into one larger, more efficient mining operation.

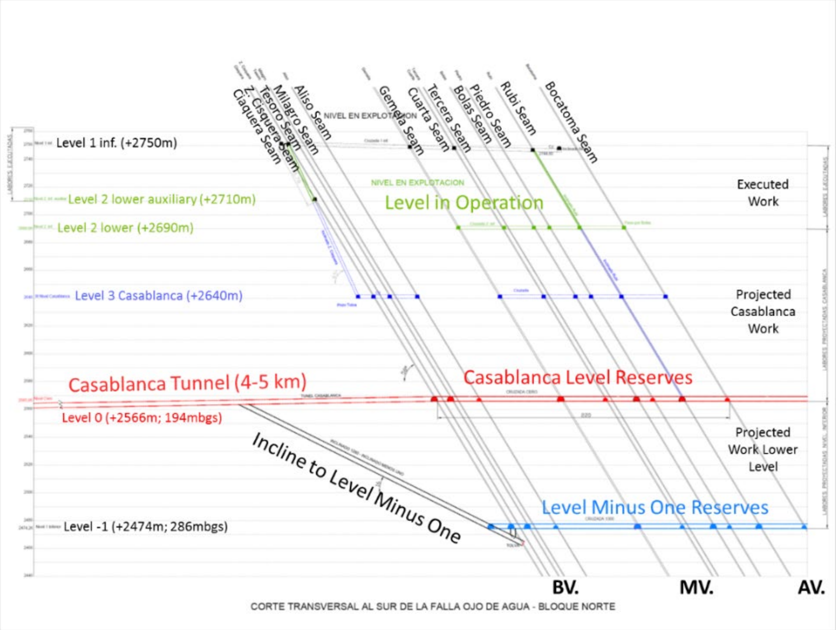


Figure 12: Cross-sectional view of the current and proposed drilling plan.

A rock cutter (Figure 13) is used in areas with higher amounts of coal reserves, while extraction of coal is carried out manually in thinner coal seams with a jackhammer device. Coal is transported within the Casa Blanca mine through the main galleries in minecarts that are powered to the mine mouth by one or more of the mine's seven electric motors, 5 being 24.4 kW T-80 models in Figure 14 and 2 being 14 kW T-50 models in Figure 15 (UPTC, 2015). In general, mines under operation by UniMinas carry out the transportation of coal through a combination of manual pushing and locomotive power. The mine's electrical circuit is in good condition and was built in compliance with the safety standards establish by Colombia's regulating body of electrical installations, Reglamento Técnico de Instalaciones Eléctricas (RETIE). The required electrical load for the locomotives and ventilation system is 440 kW. Both natural and mechanical ventilation systems are in place to keep mine air safe for the workers in the mines. The mine has over 15 ventilation fans working to keep air levels safe alongside trained personnel who monitor and measure the air quality in the mine.

Figure 13: Rock Cutting Machine, Named Rozadoratipo EMRP-2-400-2-22, Used to Create the Casa Blanca Tunnel (UPTC, 2015).

LOCOMOTORA T-80

Modelo T80

Características Técnicas

Peso aprox. en Servicio (Kg)	7500
Esfuerzo tracción (Kg) al 25% de adherencia	1875
Esfuerzo tracción (Kg) al 16% de adherencia	1200
Número motores de tracción	2
Potencia unihoraria total (Kw)	24,4
Tensión de batería (V)	108
Capacidad descarga en 5h (Ah)	875
Número elementos de batería	54
Radio mínimo de curvas (m)	8
Longitud con parachoques (mm)	3750
Ancho (mm)	985
Alto (mm)	1750
Velocidad a plena carga en horizontal (km/h)	10

Figure 14: One of the 7, T-80 Engines Used to Power the Transport of Coal within the Mine (UPTC, 2015).

LOCOMOTORA T-50

Modelo T50

Características Técnicas

Peso aprox. en Servicio (Kg)	4800
Esfuerzo tracción (Kg) al 25% de adherencia	1200
Esfuerzo tracción (Kg) al 16% de adherencia	768
Número motores de tracción	2
Potencia unihoraria total (Kw)	14
Tensión de batería (V)	96
Capacidad descarga en 5h (Ah)	575
Número elementos de batería	48
Radio mínimo de curvas (m)	8
Longitud con parachoques (mm)	3220
Ancho (mm)	880
Alto (mm)	1285
Velocidad a plena carga en horizontal (km/h)	8

Figure 15: One of the 2, T-50 Engines Used to Power the Transport of Coal within the Mine (UPTC, 2015).

Given the large number of mine operations ongoing in the area, the activities at the Casa Blanca Mine may not fully represent the overall mine operations throughout the entirety of the aggregated mines. Other mines in the interest area, in general, have U-type ventilation systems with only one intake shaft and one exhaust shaft.

Figure 16: Photos Near the Entrance to the Tunnel at Casa Blanca Mine (UNECE, 2018).

4. Recommended Methane Drainage Approach and Future Methane Drainage Projections

The 2505 concession covers an area of 807 hectares (Ha) having a block width of 2.35 km (running northwest to southeast) and a block length of 4.1 km (running southwest to northeast) that parallels the bedding planes of the coal seams. The mining plan for the 2505 concession operated by UniMinas has three phases, with the first two occurring on the southern section of the block, and the third phase running all the way to the northeastern edge of the northern block (Figure 17). The mine is expected to become gassier as operators move northward within the block.

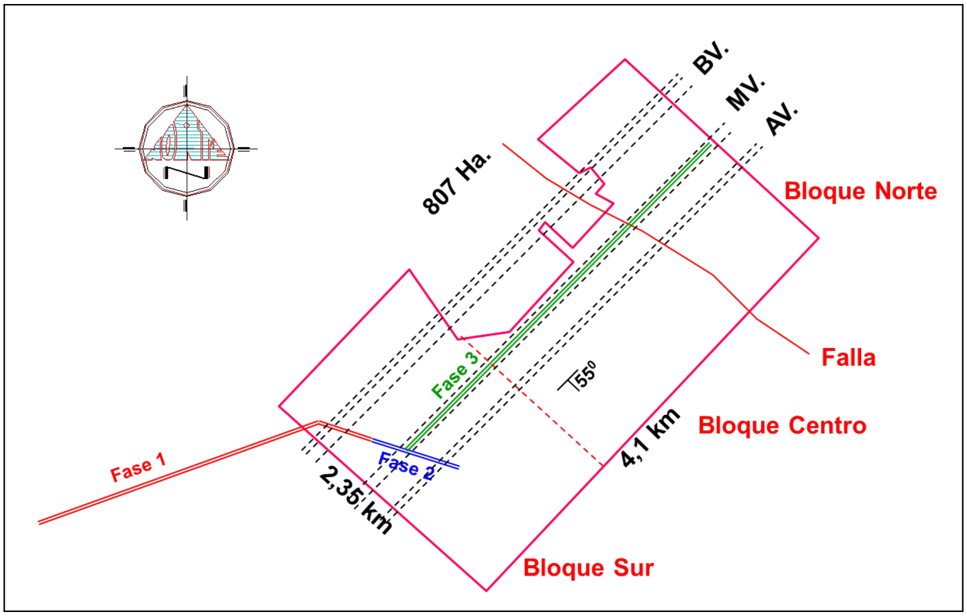


Figure 17: Plan View of Mining Plan for the 2505 Concession (UNECE, 2018).

4.1 Recommended Methane Drainage Approach Using Long, Directionally Drilled Horizontal Boreholes for Pre-Mine Drainage

Based on a detailed review of data provided by the mine, the recommended methane drainage approach for the Casa Blanca Mine area incorporates the use of long, directionally drilled horizontal boreholes for pre-mine drainage. As shown in Figure 18, all coal faces dip to the southeast at 45-55 degrees and run parallel to the 4.1 km block length running from southwest to northeast. Long, directionally drilled horizontal pre-drainage boreholes are assumed to be drilled from an in-mine drilling room located at the bottom of the Level Minus One incline and drilled to a depth of 65 m below the Minus One Level (350 m below ground level) (Figure 19). Individual borehole laterals are assumed to extend through all 12 coal seams with a longitudinal borehole distance ranging between 194 m to 220 m.

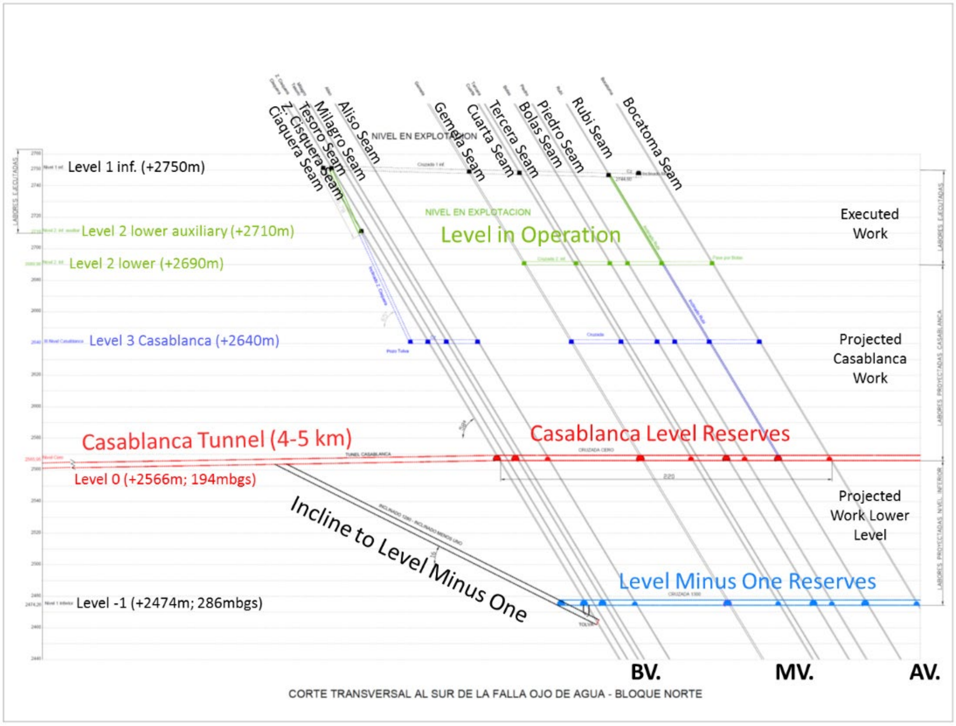


Figure 18: Mine Plan Elevation View (Looking NE).

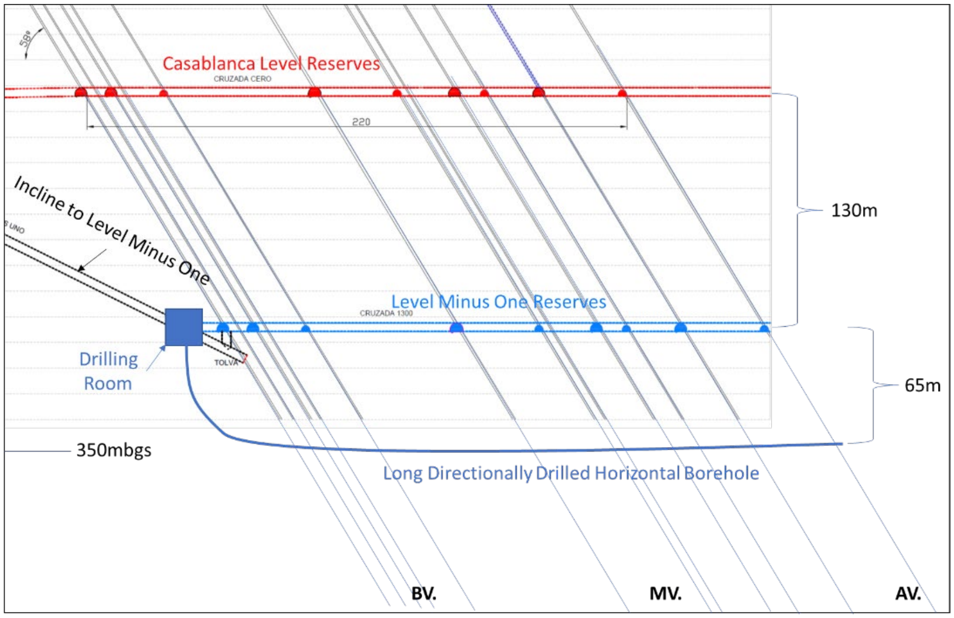
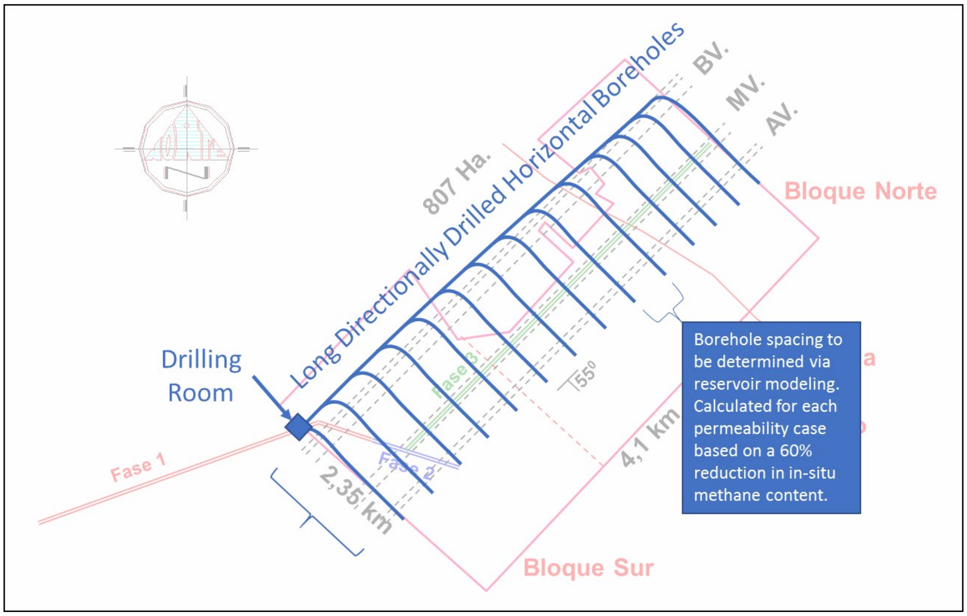


Figure 19: Elevation View (Looking NE) Showing Horizontal Borehole Placement Below Level -1.

Figure 20 illustrates a plan view of the mine block showing an example horizontal borehole with multiple laterals branching from the main borehole and extending northwest to southeast through all 12 coal seams. To determine the optimal borehole spacing to facilitate methane drainage, reservoir simulation was used to calculate the spacing required to achieve a 60 percent reduction in residual gas content over a 6-year drainage period.



Borehole spacing to be determined via reservoir modeling. Calculated for each permeability case based on a 60% reduction in in-situ methane content.

Figure 20: Plan View Showing Example Placement of Long, Directionally Drilled Horizontal Pre-Drainage Boreholes.

4.2 Future Methane Drainage Projections

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, a reservoir model was constructed in COMET3, a specialized simulator for CBM/CMM reservoirs, to simulate gas production volumes from horizontal pre-drainage boreholes. The following sections of this report discuss the construction of the gas drainage borehole model, the input parameters used to populate the reservoir simulation model, and the simulation results.

4.2.1 Reservoir Modeling to Derive Borehole Spacing as a Function of Gas Content Reduction

Multiple reservoir models were developed to simulate long, directionally drilled horizontal boreholes extending through all 12 coal seams placed at various spacing intervals. The intent of this exercise was to determine the borehole spacing required to achieve the 60 percent residual gas content reduction target over a 6-year pre-drainage period. Zero-flow boundaries were created along the flanks of the borehole such that the width of the reservoir model was equal to the borehole spacing.

4.2.1.1 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 Casa Blanca 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 Table 10, followed by a brief discussion of the most important reservoir parameters.

Reservoir Parameter	**Value(s)**	**Source / Notes**
Borehole Depth, ft	1150	Mine data
Borehole Diameter, in	3.0	Mine data
Coal Density, g/cc	1.3	Assumption; Clean coal
Pressure Gradient, psi/ft	0.433	Assumption; Hydrostatic
Initial Reservoir Pressure, psia	498	Calculated at borehole depth using pressure gradient
Initial Water Saturation, %	100	Assumption
Langmuir Volume, scf/ton	330	Curve fit to maximum desorption-based gas contents using Langmuir equation
Langmuir Pressure, psia	275	Curve fit to maximum desorption-based gas contents using Langmuir equation
In Situ Gas Content, scf/ton	213	Calculated from reservoir pressure and isotherm; Assumes 100% gas saturation
Desorption Pressure, psia	498	Desorption pressure equal to initial reservoir pressure
Sorption Times, days	0.167	Calculated from desorption-based gas content measurement data (Libertad, 2013)
Fracture Spacing, in	2.56	Assumption
Dip Angle of Face, degrees	55	Mine data
Absolute Cleat Permeability, md	1; 5	Unknown; Two cases evaluated
Cleat Porosity, %	2	Assumption; Typical for coal rank
Relative Permeability	Curve	Assumption; See curve (Figure 22)
Pore Volume Compressibility, psi $^{-1}$	4.00E-04	Assumption
Matrix Shrinkage Compressibility, psi $^{-1}$	1.00E-06	Assumption
Gas Gravity	0.6	Assumption
Water Viscosity, centipoise (cP)	0.8	Assumption
Water Formation Volume Factor, reservoir barrel per stock tank barrel (RB/STB)	1.00	Calculation
Completion and Stimulation	Long, directionally drilled horizontal boreholes; Assume skin factor of 2 (formation damage)	
Pressure Control	In-mine pipeline with surface vacuum station providing vacuum pressure of 6 psia	

Borehole Spacing	Calculated for each permeability case based on a 60% reduction in in-situ methane content over a 6-year drainage period

Table 10: Reservoir Parameters for Pre-Drainage Borehole Simulation.

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, two cases were evaluated assuming permeability values of 1 and 5 millidarcy (md), which is within the range of analogous coal seams of the same rank.

Langmuir Volume and Pressure

Reliable laboratory measured Langmuir volumes and pressures for the study area were not available. As a result, an isotherm was constructed using the Langmuir equation where a curve was fit to match the maximum values from desorption-based gas content measurements performed at four wells drilled in the Cundinamarca area (Bedoya, 2018). The corresponding Langmuir volume used in the reservoir simulation models for the project area is 330 scf/ton and the Langmuir pressure is 275 pounds per square inch absolute (psia). Figure 21 depicts the methane isotherm utilized in the pre-drainage borehole simulations.

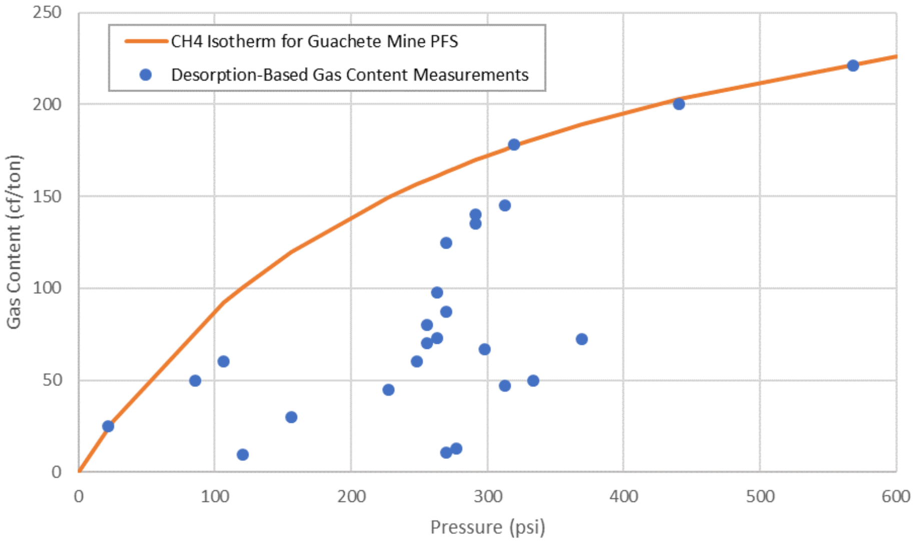


Figure 21: Methane Isotherm Used in Pre-Drainage Borehole Simulations.

Gas Content

As noted above, desorption-based gas content measurements from four wells located in the interior Department of Cundinamarca were available showing gas contents ranging from 10 to 221 scf/ton with an average of 84 scf/ton. For the simulation study, in-situ gas content at the working depth of the mine was estimated to be 213 scf/ton as calculated from the isotherm based on a reservoir pressure of 498 psia. Reservoir pressure was calculated by multiplying reservoir depth by the normal hydrostatic gradient of 0.433 pounds per square inch per foot (psi/ft) in the simulation.

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. Figure 22 is a graph of the relative permeability curves used in the reservoir simulation of the study area.

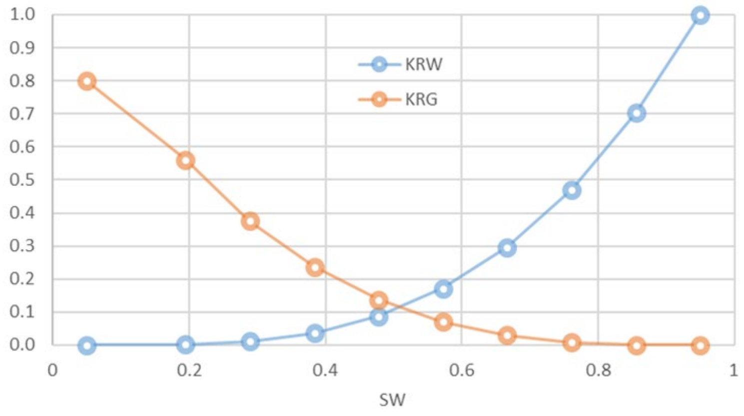


Figure 22: Relative Permeability Curve Used in Simulation.

Borehole and Coal Seam Characteristics

Twelve coal seams ranging in thickness from 0.98 ft to 4.92 ft are present in the Casa Blanca Mine area. Based on mine data, all coal faces dip to the southeast by 55 degrees and run parallel to the 4.1 km block length positioned in the southwest to northeast direction. Long, directionally drilled horizontal pre-drainage boreholes are drilled from an in-mine drilling room at a depth of 1150 ft, or roughly 350 meters below ground surface (mbgs) and have a 3-inch (in) diameter. Individual borehole laterals extend through all 12 coal seams with a longitudinal borehole distance ranging between 194 m to 220 m, depending on the location throughout the block. Table 11 summarizes coal seam thickness and longitudinal distance along the borehole as modeled.

Model Layer	Coal Seam	Thickness (ft)	Distance Longitudinal to Borehole (ft)
1	Manto Bocatoma	2.46	738
2	Manto El Rubi	0.98	680
3	Manto El Piedro	4.92	616
4	Manto Bolas	2.30	574
5	Manto La Tercera	1.64	539
6	Manto la Cuarta	1.97	527
7	Manto La Gemela	4.59	452
8	Manto Aliso	3.28	205
9	Manto Milagro	1.97	156
10	Manto Tesoro	1.97	142
11	Zuncho de Cisquera	1.97	118
12	Manto Cisquera	2.30	101

Table 11: Summary of Coal Seam Thickness and Longitudinal Distance Along the Horizontal Borehole.

Reservoir and Desorption Pressure

Initial reservoir pressure was computed using a hydrostatic pressure gradient of 0.433 psi/ft and a borehole depth of 1,150 ft. The borehole depth was based on information from the mine and the pressure gradient of 0.433 psi/ft is a common industry assumption in the absence of well test-derived pressure gradients. 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 is 498 psia.

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 systems in the reservoir were assumed to be 100 percent water saturated.

Sorption Time

Sorption time is defined as the length of time required for 63 percent of the gas in a sample to be desorbed. A sorption time of four hours (0.167 days) was estimated from the available desorption-based gas content measurement data (Libertad, 2013). Production rate and cumulative production forecasts are typically relatively insensitive to sorption time.

Fracture Spacing

A fracture spacing of 2.56 in was assumed in the simulations based on analogous projects throughout the Americas. 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.

Borehole Spacing

As discussed previously, multiple reservoir models were developed to simulate long, directionally drilled in-mine horizontal boreholes with laterals extending northwest to southeast through all 12 coal seams at various borehole spacings. The intent of this exercise was to determine the borehole spacing required to achieve the 60 percent residual gas content reduction target over a 6-year drainage time.

Borehole Completion and Stimulation

Long, directionally drilled horizontal boreholes will be drilled to a depth of roughly 1,150 ft and intersect all 12 coal seams. For modeling purposes, a skin factor of +2, representing formation damage, is assumed for all horizontal boreholes.

Pressure Control

Horizontal boreholes were allowed to produce for 6 years using an in-mine pipeline with a surface vacuum station providing a suction pressure of 6 psia. In CMM/CBM operations, low borehole pressure is required to achieve maximum gas content reduction.

4.2.1.2 Model Results and Borehole Production Rates

Reservoir models were developed for the 1 md and 5 md permeability cases. The models predicted borehole gas flow rate and gas content reduction for each case as a function of time for a 6-year period (2190 days) as shown in Figure 23 and Figure 24. The borehole spacing required to reduce the residual gas content by 60 percent and the gas and water production for each permeability case were derived from the numerical models and presented in Table 12.

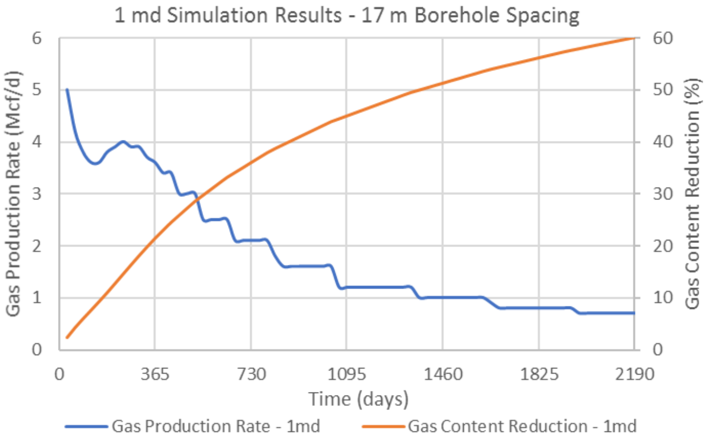


Figure 23: Borehole Simulation Results for the 1 md Permeability Case Showing Optimal Borehole Spacing of 17 m.

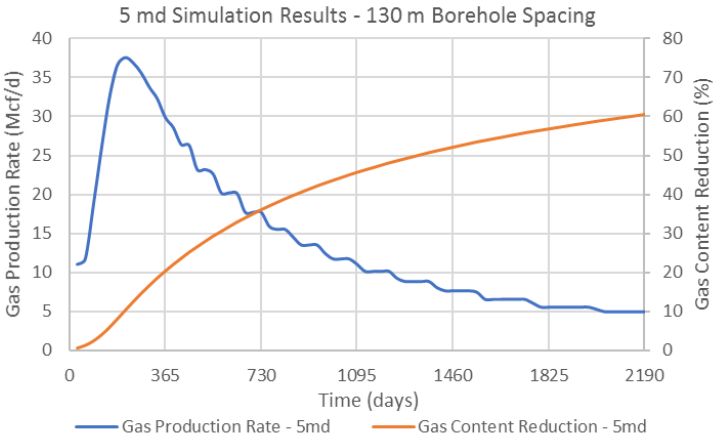


Figure 24: Borehole Simulation Results for the 5 md Permeability Case Showing Optimal Borehole Spacing of 130 m.

Permeability (md)	Time (years)	Gas Content Reduction (%)	Borehole Spacing (m)	Total Gas Production (MMcf)	Average Gas Production Rate (Mcf/d)	Total Water Production (MBbls)
1	6	60	17	4.0	1.8	1.7
5	6	60	130	30.9	14.1	12.8

Table 12: Summary of Simulation Results and Borehole Production Rates.

4.2.2 Mine Methane Drainage System Production Rates

Table 13 summarizes the projected annual directional drilling and gas collection pipeline requirements for the drainage plan as proposed. Directional drilling requirements for the 1 md development scenario are substantially greater since borehole laterals must be spaced much closer (17 m versus 130 m) than in the 5 md development scenario. This pre-feasibility study assumes that all boreholes are placed in 2019 with the pre-drainage period running from 2020 through 2025. To accomplish this task, it is assumed the mine will contract an underground directional drilling service with the ability to support the initial phase of the project with multiple drills to perform this work.

Development Scenario	Borehole Spacing (m)	Borehole Drilled (m)	Gathering Pipeline Laid (m)
1 md	17	56,620	16,400
5 md	130	17,680	16,400

Table 13: Summary of Borehole Drilling and Gathering Pipeline Requirements.

Figure 25 and Figure 26 present the annual methane production forecast from degasification of the mine with the recommended methane drainage approach. The forecast predicts recovery of 968 MMcf and 988 MMcf of CMM for the 1 md and 5 md development scenarios, respectively.

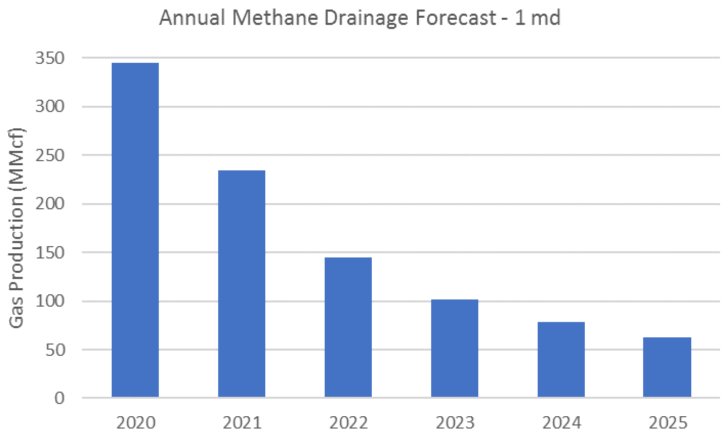


Figure 25: Mine Methane Drainage Forecast for 1 md Development Scenario.

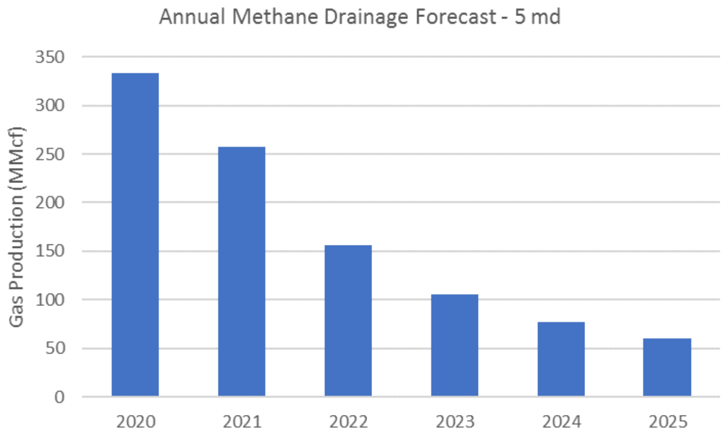


Figure 26: Mine Methane Drainage Forecast for 5 md Development Scenario.

5. Market Information

5.1 CMM and CBM Market

While the departments of Cundinamarca and Boyacá have shown CBM potential, no licenses have been awarded in these areas. Potential total gas in place in Cundinamarca is between 2 and 5 Tcf, but the markets for both CMM and CBM are still in the development stages in Cundinamarca and in Colombia as a whole. Recent political and economic developments affecting Cundinamarca may bode well for CMM/CBM:

- Colombia's constitutional court recently ruled that local referendums that ban mining and oil extraction cannot halt energy projects, which is expected to give life and future security to mine development in the country, according to the Colombian Mining Association (ACM) (Reuters, 2018).
- Royalties established under law 756 of 2002 are subject to a sliding scale based on gross production on an individual field basis (Gran Tierra, 2010). Smaller scale CBM development in

central Colombia will no longer be required to pay a flat 20% royalty fee but will pay a fee based on gross production. The royalty starts with a base rate of 8% for gross production of less than 5,000 barrels of oil per day and increases in a linear fashion from 8% to 20% for gross production between 5,000 and 125,000 barrels of oil per day. To determine the royalties for gas fields, conversion factor is applied to determine the production of gas in barrels of oil equivalent (BOE).

- Coal mines in the Cundinamarca area consumed roughly 23 million kWh in 2017 alone. Those coal power plants operating within the department have an efficiency rate between 23 and 28%, leading to higher overall electricity costs for mines. CBM/CMM presents an opportunity to decrease operating costs at smaller mines, especially given mine operators' interest in using methane gas for on-site power generation (Bedoya, 2019).
- The national target of a 20-30% reduction in GHG emissions by 2030 will require mitigation in several key sectors, mining being one of them. The mountainous terrain in Cundinamarca is not well suited for intermittent sources of wind and solar power generation. Additional hydro plants will be brought online, but those plants have been less reliable during El Niño drought conditions. In 2016, El Niño-induced droughts forced Colombians to ration their energy use during peak hours, as the power source was operating at only 60% of its usual capacity during one of the drought periods (UNECE, 2017); (NREL, 2018). As weather conditions continue to threaten hydroelectric generators' production capabilities, which make up nearly 70% of the country's total generating capacity, it can be expected that more reliable sources of energy like thermal production via coal and natural gas will come online in the future.
- Act 1886 of 2015 describes how mine operators must include the use of methane for on-site power or oxidation in their work plan if there are producible, high concentrations of methane found within the mining project. If a mine exceeds its energy capacity on-site, it can sell surplus energy to the grid.

While CMM/CBM development has seen promising regulatory, environmental, and economic advances in Colombia, there are still several challenges that impede project development in Cundinamarca and Colombia more broadly:

- There is inadequate information in Colombia about CMM/CBM reservoirs (e.g., gas content and saturation, permeability, flow rate etc.), which prohibits concession certification on international markets. This lack of knowledge extends to sufficiency of ventilation systems, as some mines in Colombia lack enough ventilation and personnel to deal with associated ventilation issues and measurements.
- Average mines in the Cundinamarca area are small (2,000-4,000 t/month) and are typically not able to justify the large investments required in equipment and machinery for CBM projects. Areas where multiple small coal mines are combined among a few well-known operators present a better project economics for CBM opportunities, especially when higher contents of methane are found at relatively shallow depths.
- Enriching through VAM is considered a mining activity and it thus regulated by ANM but degassing from the surface is not considered a mining activity and thus falls within ANH's

oversight. The two agencies tend to compete with one another, which has led to slower development of projects.

- In cases where methane oxidation is the best solution, the price of carbon to break even would need to reach $10.31 USD for 10 years and could drop to $4.36 USD after year 11. It is estimated that the Cundinamarca area for coal extraction produced 160,179 tCO_2e in 2016 and 151,530 tCO_2e in 2017. However, there are currently no incentives for use or destruction of CMM/ ventilation air methane VAM) (Bedoya, 2019). Development is also tied to the price of coal; if prices go roughly below $73 USD/ton, many small mine operations must stop production because of the costs associated with transporting coal to the coast for export (UPME, 2017). The success and development of CBM/CMM resources will ultimately depend on its ability to compete with the cost of other major sources of power generation in Colombia, namely hydropower, natural gas and coal.

5.2 Natural Gas Market

Colombia's natural gas production has substantially risen in recent years because of increased international investment in exploration and development. Ecopetrol, the Colombian national oil company, is the primary producer of gas resources and recently made its biggest discovery in three decades with its partner Anadarko at offshore Gorgon-1 in May of 2017. Gas supplies are concentrated amongst Ecopetrol, BP, and Chevron in the Cusiana-Cupiagua and Chuchupa fields. Colombia has roughly 3,100 miles of natural gas pipelines that services major fields and demand centers (EIA, 2019).

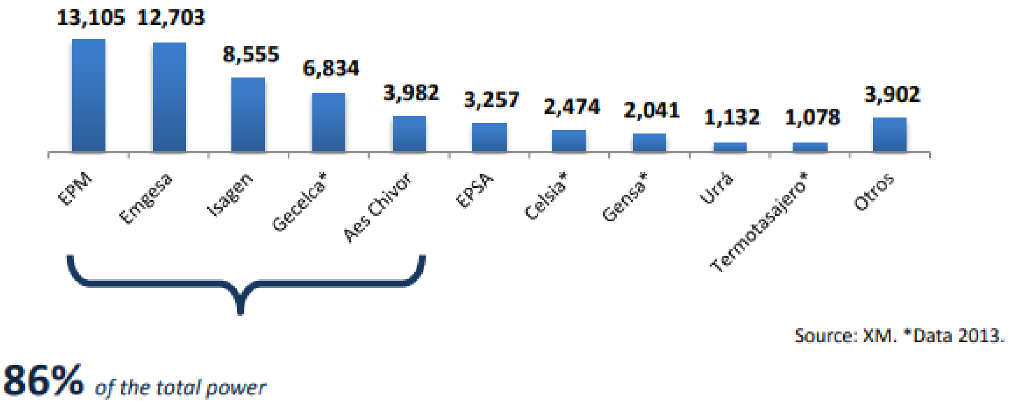
As a result of uncertainty in hydroelectric sources of energy, thermal power generation grew roughly 9.4% between 2010 and 2014. Natural gas contributes significantly to thermal power generation and its consumption is correlated with growth in thermal generation, as the production of natural gas grew 6.8% over a ten-year span (ProColombia, 2015). The government is seeking to add 3,841 megawatts (MW) of natural gas fired capacity by 2028 to be a solution to the frequent brownouts that are triggered by increasing electricity consumption in the country (Oil Price, 2018).

Due to the remote nature of many regions of Colombia, access to natural gas, whether subsidized or not, can be expensive. Average market prices, consequently, remain significantly higher than those in the United States. Average market prices for Colombian citizens purchasing natural gas at the end of 2014 were $8.2/MMBtu (NATURGAS, 2014). The highest two socioeconomic tiers, however, pay large contributions to ensure affordable natural gas reaches the lowermost socioeconomic strata.

5.3 Electricity Market

Much like Colombia's general energy mix, Cundinamarca garners large sources of electric power from hydro-powered plants and thermal plants. The region's mountainous terrain, combined with high levels of rainfall, creates favorable conditions for dam construction for hydroelectric power. The Guavio and Pagua hydro plants offer 1,200 and 600 MW of total effective capacity respectively to Cundinamarca and surrounding demand regions. Cundinamarca is a part of the National Interconnect System (SIN), which covers roughly 48% of the national territory and 96% of the country's population (Energy Net). The planning, supervision and control of resource generation, interconnection and transmission on the SIN is undertaken by various subsidies of XM, a public utility corporation regulated by the Energy and

Gas Regulation Commission (CREG) (EIA, 2019). A few of the major power generating agents are shown in Figure 27.



Source: XM. *Data 2013.

Figure 27: Main Power Generating Agents (GWh) in 2014. ISAGEN's Construction of the Hidrosogamoso Hydroelectric Plant (820 MW) Made it the Country's Second Largest Producer in 2015 (ProColombia, 2015).

Non-regulated users, or those that consume more than 55 MW hours (MWh)/month, can sign bilateral contracts with energy dealers where prices and quantities are negotiated freely between the two parties. Mining and quarrying make up roughly 20% of energy demand in the country's non-regulated market (ProColombia, 2015). Those in the regulated category are subject to regulated rates subject to a general pricing structure established by CREG, which was created in 1994 through Laws 142 and 143. Law 143 established the plan that governs generation, transmission, distribution, and commercialization of electricity as well as the guidelines that were instrumental to the beginning of the Wholesale Electricity Market (MEM) in 1995 (EIA, 2019).

Alongside national electricity demand growth, Colombia will aim to meet the needs of increasing electricity demands from surrounding countries. Its vast energy resources and regional network connectedness have allowed it to become a net exporter of more than 700 GWh of electricity to Ecuador, Peru, and Venezuela along with planned expansion of transmission lines to Panama (MaRS, 2015).

6. Gas Use Opportunities for the Casa Blanca Mine

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 Casa Blanca Mine is expected to have a methane concentration of 90-95 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 for two reasons. First, on site utilization of the gas is the only option allowed under current regulations. Second, the mine would like to use electricity generated on site to power their engines. 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, 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 Casa Blanca 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 the Casa Blanca 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. In addition, without a carbon price and available carbon trading scheme there is no incentive to install flares.

6.2 Recommendation for CMM Utilization

After consideration of possible options for CMM utilization at the Casa Blanca Mine, power generation is the most viable option, considering the priorities of mine management and the current legislation that only allows on site usage of the gas. 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 4 MW of electricity capacity. The mine's current electrical capacity is roughly 440 kW, which would be satisfied by the additional power generation from the proposed project.

7. Economic Analysis

7.1 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.

7.2 Economic Assumptions

Cost estimates were developed for goods and services required for the development of a CMM project at the Casa Blanca 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 Table 14. A more detailed discussion of each input parameter is provided below.

PHYSICAL & FINANCIAL FACTORS	**Units**	**Value**
Royalty	%	4.8
Price Escalation	%	3
Cost Escalation	%	3
Heating Value of Drained Gas	Btu/cf	928
Electricity Price	$/kWh	0.126
Generator Efficiency	%	35
Run Time	%	85
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		
Borehole Drilling Cost	$/ft	40
Borehole Drilling Length	ft	185,714 (1md) 57,990 (5md)
Surface Vacuum Station	$/hp	1000
Vacuum Pump Efficiency	hp/Mcfd	0.035
Gathering & Delivery System		
Gathering Pipe Cost	$/ft	40
Gathering Pipe Length	ft	16,400
Contingency Fee (capex)	%	10
Power Plant	$/kW	1300
Development Fee	%	15
OPERATING EXPENSES	**Units**	**Value**
Field Fuel Use (gas)	%	5
Drainage System O&M	$/Mcf	0.1
Water Treatment/Disposal	$/Bbl	0.05
Power Plant O&M	$/kWh	0.03
Contingency Fee (opex)	%	10

Table 14: Summary of Economic Input Parameters and Assumptions.

7.2.1 Physical and Financial Factors

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 30,000 Mcf of natural gas per day based on a conversion factor of 6 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 Casa Blanca Mine (EY, 2016).

Price and Cost Escalation

All prices and costs are assumed to increase by 3 percent per annum based on analogous projects in the Americas.

Heating Value of Drained Gas

The drained gas is assumed to have a heating value of 928 Btu/cf. This is based on a heating 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.

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 (MARS, 2015).

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 85 percent, or 7,446 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. For each ton of CH_4 combusted, 2.75 tCO_2 is emitted, resulting in a net emission reduction of 22.25 tCO_2e per ton of CH_4 destroyed.

7.2.2 Capital Expenditures

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

Borehole Cost

In-mine borehole costs are estimated at $40 per foot with a total of 185,714 ft drilled assuming a permeability of 1 md and 57,995 ft drilled for the 5 md case.

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 16,400 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. We assume the power plant is located within the mine area resulting in a delivery system cost of zero.

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).

CAPEX Contingency Fee

A 10 percent contingency is fee is added for unforeseen additional costs.

Development Fee

A fee is included to account for the cost of project development including staff costs, equipment, office space, transportation, and other resources necessary to plan and develop the project. The fee is estimated at 15 percent of the cost of the power plant based on experience in the field.

7.2.3 Operating Expenses

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.

Drainage System Operating and Maintenance Costs

Operating and maintenance costs for vacuum pumps and compressors associated with in-mine horizontal pre-drainage boreholes are assumed to be $0.10/Mscf.

Water Treatment/Disposal

The cost associated with water treatment and disposal is $0.05/Bbl.

Power Plant Operating and Maintenance Cost

The operating and maintenance costs for the power plant are assumed to be $0.03/kWh.

OPEX Contingency Fee

A 10% contingency is fee is added for unforeseen additional costs.

7.3.3 Economic Results

There are two different economic scenarios evaluated in this study. The two are differentiated by whether the mine will absorb the operational costs of the drainage system or not. The first scenario is the power plant only scenario and the economic results are summarized in Table 15. In this project scenario, the costs of the gas drainage system will be absorbed by the mining operation as operational costs. Higher NPV and IRR values are present in the power plant only scenario because of this cost absorption. It is also important to note that in the power plant only scenario, the cost of gas purchased is not included. It is assumed that the mining operation will provide the CMM for free to the power plant. Should the mining operation wish to internalize the price of gas as a revenue and charge a fee, then the power project would need to show a cost of gas purchased as an operating cost, which would likely reduce the IRR's.

The results for the scenario where the gas drainage system costs are not absorbed by the mine operation are presented in Table 16. The gas drainage system involves in-mine directional drilling of horizontal pre-drainage boreholes, which adds to the cost of the project and decreases returns. Max power plant capacity and net CO_2e reductions are the same for both project scenarios because those values are largely reliant on the quantity of gas production, which is the same for the different project scenarios because the same two development scenarios are used to calculate results from the two economic scenarios. The discount rate used for all NPV calculations in the results tables is 10%.

Development Scenario	Borehole Spacing (m)	Max Power Plant Capacity (MW)	NPV-10 ($,000)	IRR (%)	Payback (years)	Net CO_2e Reductions (tCO_2e)
1 md	17	4.0	45	10.3%	3.5	340,585
5 md	130	4.0	408	13.0%	3.0	347,607

Table 15: Summary of Economic Results for Power Plant (Only) (pre-tax).

Development Scenario	Borehole Spacing (m)	Max Power Plant Capacity (MW)	NPV-10 ($,000)	IRR (%)	Payback (years)	Net CO_2e Reductions (tCO_2e)
1 md	17	4.0	-9,020	-19.8%	na	340,585
5 md	130	4.0	-3,037	-5.2%	na	347,607

Table 16: Summary of Economic Results for Power Plant and Gas Drainage System (pre-tax).

8 Conclusions, Recommendations, and Next Steps

This pre-feasibility study proposes a methane pre-drainage approach for the Casa Blanca 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 Casa Blanca Mine, power generation was selected as the best option for the mine given current legislation and mine management priorities. As the analysis shows, pre-drainage using long, directionally drilled horizontal boreholes can effectively lower the residual gas content of coal seams prior to future mining. As proposed in this study, the CMM project at the Casa Blanca Mine is anticipated to reduce emissions of methane by more than 340,000 tCO_2e over the 6-year life of the project.

It is recommended that Casa Blanca 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 single mining level. The power plant could grow as gas availability increases as more boreholes are drilled prior to development of additional mine levels. It is recommended that the following steps be undertaken for Casa Blanca Mine management to move toward project development:

- Develop technical knowledge and in-house expertise through participation in international CMM events and interaction with CMM experts.
- 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.
- Implement continuous monitoring of methane levels and atmospheric conditions of the mine to optimize ventilation system operation and comply with required safety specifications.
- Confirm the ability of the Casa Blanca 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.

Works Cited

ANH. (2011). Potential Resources of Unconventional Hydrocarbons in Colombia. ANH Unconventional Hydrocarbons Workshop. Bogota, June 8, 2011. http://www.anh.gov.co/Sala-de-Prensa/Presentaciones/Dr.%20Rodolfo%20Guzm%C3%A1n,%20Director,%20Arthur%20D'%20Little.pdf

ANM. (2018). Coal. Agencia Nacional de Minería. http://miningincolombia.anm.gov.co/images/Presentaciones/FACT-SHEET---COAL-2018.pdf

Bedoya, Ruben Dario Chanci. (2019). Information request from Unindad de Planeación Minero Energética (UPME). March 5, 2019.

EIA (2016.1): "U.C. coal exports declined 23% in 2015, as coal imports remained steady." March 7, 2016. www.eia.gov/todayinenergy/detail.php?id=25252.

EIA. (2019). Country Analysis Executive Summary: Colombia. U.S. Energy Information Administration. https://www.eia.gov/beta/international/analysis_includes/countries_long/Colombia/pdf/colombia_exe.pdf

GECELCA (2017): Coal Mine Methane Recovery in Córdoba, Colombia – prepared by Raven Ridge Resources, Incorporated – for Gecelca S.A. E.S.P.

GMI. (2015). Colombia. Coal Mine Methane Country Profiles. Global Methane Initiative Ch. 8. https://www.globalmethane.org/documents/Toolsres_coal_overview_ch8.pdf

GMI. (2017): Legal and Regulatory Status of CMM Ownership in Key Countries: Considerations for Decision Makers. GMI.

Gran Tierra Energy Inc. (2010). Form 10-K 2010. Retrieved from SEC EDGAR website https://www.sec.gov/Archives/edgar/data/1273441/000114420411010891/v210811_10k.htm

Gobierno de Colombia. Bases del Plan Nacional de Desarrollo: 2018-2022. Pacto Por Colombia, Pacto Por la Equidad. https://colaboracion.dnp.gov.co/CDT/Prensa/BasesPND2018-2022n.pdf

Hiltmann, W., and Knorn, H. (1988). The coal deposit of Tibita, Colombia – geologic and coal petrographic investigation: International Journal of Coal Geology, v. 10, no. 4, p. 361. https://www.sciencedirect.com/science/article/abs/pii/0166516288900109

Jorge-E., Mariño M., & Erika, Amaya. (2016). Lithofacies cyclicity determination in the guaduas formation (Colombia) using Markov chains. *Earth Sciences Research Journal*, *20*(3), B1-B9. https://dx.doi.org/10.15446/esrj.v20n3.44429

Latin Lawyer (2016): Colombia. *Dentons Cardenas & Cardenas*. April 4, 2016.

Libertad y Orden. (2013). Exploración Gas Metano Asociado al Carbón. Área Checua- Lenguazaque. Guachetá – Samacá. Servicio Geológico Colombiano. p. 19-136. http://recordcenter.sgc.gov.co/B9/22004001024621/documento/pdf/2105246211101000.pdf

MARS. (2015). Market Information Report: Colombia. MaRS Advanced Energy Centre. October 2015. https://www.marsdd.com/wp-content/uploads/2016/08/MaRS_Market_Insights_Market_Information_Report_Colombia.pdf

Martínez, Jorge Eliécer Mariño. (2015). *Gas Asociado Al Carbon (CBM o GMAC)*: Geología, contenidos, reservas, minería y posibilidades en Colombia. Universidad Pedadgógica y Tecnológica de Colombia. P. 125-126.

Moore, Tim. (2016). A review of coalbed methane (CBM) and coal mine methane (CMM) as applied to Colombia. Consorcio Eg-Carbón-Metano. Presented Bogotá, Colombia, September 2016.

NATURGAS (2014): Prices of natural gas city gate. 2014. www.naturgas.com.co/tecnico/Precios%20de%20gas%20natural%20en20puerta_2014.

Norton Rose Fulbright (2011): "The Creation of a National Mining Agency." September, 2011. www.nortonrosefulbright.com/knowledge/publications/59316/the-creation-of-a-national-mining-agency.

NREL. (2018). Competition in Colombia Sparks Renewable Energy Expansion. August 31, 2018. https://www.nrel.gov/news/program/2018/competition-in-colombia-sparks-renewable-energy-expansion.html

Oil Price. (2018). A Natural Gas Crisis Looms Over Colombia. By Smith, Matthew. April 21, 2018. https://oilprice.com/Energy/Natural-Gas/A-Natural-Gas-Crisis-Looms-Over-Colombia.html

Quora. (2018). Map of Altiplano Cundiboyacense. Accessed through Mauricio Ardila Echeverría. https://www.quora.com/What-are-the-best-cities-to-live-near-Bogota

Railroads of Colombia. (2010). Adapted from *Colombia Transportation Map*. (2008). Perry-Castañeda Library Map Collection. Creative Commons.

Railway Technology. (2011). Colombia's Rail Alternative to the Panama Canal. Interview between Elisabeth Fischer and Henry Posner III, April 13, 2011. https://www.railway-technology.com/features/feature116112/

Reuters. (2018). Court say Colombia votes cannot block mining, oil projects. October 11, 2018. https://www.reuters.com/article/us-colombia-mining-court/court-says-colombia-votes-cannot-block-mining-oil-projects-idUSKCN1ML35V

Sarmiento - Pérez, Gustavo, et al. (2008). Landscape evolution and origin of Lake Fúquene (Colombia): Tectonics, erosion and sedimentation processes during the Pleistocene. Geomorphology. 100. p. 563-575.

https://www.researchgate.net/publication/223481279_Landscape_evolution_and_origin_of_Lake_Fuquene_Colombia_Tectonics_erosion_and_sedimentation_processes_during_the_Pleistocene

Semana. (2017). Pequeña y Mediana Minería: Mina Familiar. 8/11/2017. https://www.semana.com/contenidos-editoriales/carbon-la-base-de-todo-/articulo/historia-de-milpa-compania-pionera-en-mineria-subterranea-en-america-latina/535809.

UNECE. (2017). Coal Mine Methane and its Strategic Role in Climate Change Mitigation - CMM Policies in Colombia. Presented by Raymond Pilcher. June 13, 2017. Kazakhstan. https://www.unece.org/fileadmin/DAM/energy/se/pp/eneff/8th_IFESD_Astana_2017/13_June/CMM_Climate_change/01_Pilcher.pdf

UNECE. (2018). Fact Finding Mission Colombia. Submitted by Drabik, Michal and Pilcher, Raymond. March 2018. https://www.unece.org/fileadmin/DAM/energy/images/CMM/CMM_CE/Mission_Report_11_-17_March_2018__Bogota__Colombia_-_Final__compressed_.pdf

UPME. (2017). Build a Model for Colombia for the Utilization or Oxidation of Methane Gas from the Ventilation Ducts (VAM) of Underground Coal Mines. Presentation: CH_4 - Coal.

UPTC. (2015). Informe de la Práctica a la Mina Túnel Casa Blanca-UniMinas. p. 1-12. https://www.scribd.com/document/275224168/Informe-Ventilacion-Uniminas-Guacheta?language_settings_changed=English

UPTC. (2017). Sebastian, Juan, et al. Paleoenvironments of Coals Using Organic Petrography and Their Relationship With Physicochemical Properties, Guaduas Formation, Checua-Lenguazaque Syncline. p. 31-94. https://repositorio.uptc.edu.co/handle/001/1875

USEPA. (2017). Pre-Feasibility Study for Methane Drainage and Utilization at the San Juaquin Mine, Antioquia Department, Colombia. U.S. EPA Coalbed Methane Outreach Program. July, 2017. https://www.epa.gov/sites/production/files/2017-07/documents/san-juaquin-colombia-pre-feas.pdf

USTDA. (2015, June 25). USTDA Advances Coal Mine Methane Recovery in Colombia. United States Trade and Development Agency. http://www.ustda.gov/news/pressreleases/2015/ustda-advances-coal-mine-methane-recovery-colombia