U.S. EPA
Coalbed Methane
OUTREACH PROGRAM

Pre-Feasibility Study for Methane Drainage and Utilization at the Conchas Mine Complex

Coahuila, Mexico

U.S. Environmental Protection Agency
September 2015

Pre-Feasibility Study for Methane Drainage and Utilization at the Conchas Mine Complex
Coahuila, Mexico

Sponsored by:
US Environmental Protection Agency, Washington, DC USA

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September 2015

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 based on information obtained from the coal mine partner, Minera del Norte S.A. de C.V. (MINOSA).

Acknowledgements

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Executive Summary

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

Minera del Norte S.A. de C.V. (MINOSA), a leading coal company in Mexico and a subsidiary of Grupo Acerero del Norte (GAN), was selected as the recipient for a pre-feasibility study for CMM drainage at their Conchas Mine Complex in the southern Sabinas Basin of Mexico. The objectives of this pre-feasibility study are to perform an initial assessment of the technical and economic viability of methane drainage utilizing vertical pre-drainage boreholes drilled from the surface, and to identify end-use options.

The Conchas Mine Complex covers an area of 27 square kilometers (km^2) and includes three mines named Mine IX, Mine X, and Mine XI. The coal mines in this region are notoriously gassy and MINOSA's existing mines are among the gassiest. Specific emission rates of about 50 cubic meters per tonne (m^3/t) of coal mined are projected for the Conchas mines. While MINOSA has implemented drainage programs at their mines in the northern portion of the Sabinas Basin, the Conchas Mine Complex is relatively new and does not currently employ pre-drainage techniques. MINOSA was ultimately selected for this pre-feasibility study based on the level of commitment they have demonstrated to employ modern degasification methods and methane abatement technologies, and the high likelihood of project implementation and resulting methane reductions.

The primary market available for a CMM utilization project at the Conchas Mine Complex is power generation using internal combustion engines. Given the relatively small CMM production volume, constructing a pipeline to transport the gas to demand centers would be impractical. Based on gas supply forecasts, the mine could be capable of operating as much as 72 megawatts (MW) of electricity capacity.

Pre-drainage boreholes are assumed to begin production three to five years prior to the initiation of mining activities. Gas production profiles were generated for a total of four project development cases:

- Case 1: 60 acre well spacing with 3 years of pre-drainage
- Case 2: 60 acre well spacing with 5 years of pre-drainage
- Case 3: 120 acre well spacing with 3 years of pre-drainage
- Case 4: 120 acre well spacing with 5 years of pre-drainage

The proposed pre-drainage project will target both the A and B seams with vertical boreholes drilled from the surface. With a project area of 6,672 acres (ac) (27 km^2) a total of 112 and 56 wells could be drilled under the 60 ac and 120 ac well spacing cases, respectively. At an assumed drilling rate of four wells per month, drilling of the entire project area would require 28 months and 14 months for the 60 ac and 120 ac well spacing cases, respectively.

Based on the forecasted gas production, the breakeven cost of producing CMM through vertical pre-drainage boreholes is estimated to be between $2.67 and $4.09 per million British thermal units (MMBtu). The results of the economic assessment indicate the lowest pre-drainage costs are associated with the 120 ac well spacing case, with 5 years of pre-drainage (Case 4) preferred over 3 years (Case 3).

In terms of utilization, the power production option is economically feasible under the optimal development scenario. More rigorous engineering design and costing would be needed before making a final determination of the best available utilization option for the drained methane. The breakeven power sales price, inclusive of the cost of methane drainage, is estimated to be between $0.089 and $0.114 per kilowatt-hour (kWh). The results of the economic assessment indicate the lowest power price is associated with the 120 ac well spacing case, with 5 years of pre-drainage (Case 4). With electricity rates for medium-size industry in Mexico averaging $0.095/kWh over the first half of 2015, utilizing drained methane to produce electricity would generate profits of $6 per megawatt-hour (MWh) of electricity produced, based on the breakeven power sales price for Case 4 of $0.089/kWh.

A CMM-to-power utilization project at the Conchas Mine Complex is economically feasible, and removing the cost of mine degasification from downstream economics, as a sunk cost, would reduce the marginal cost of electricity and improve the economics even further. Net emission reductions associated with the destruction of drained methane are estimated to average just over 722,000 tonnes of carbon dioxide equivalent (tCO_2e) per year.

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 emission reduction opportunities in the coal industry can lead to improved mine safety, greater mine productivity, and increased revenues. The work of CMOP and USEPA also directly supports the goals and objectives of the Global Methane Initiative (GMI), an international partnership of 42 member countries and the European Commission that focuses on cost-effective, near-term methane recovery and use as a clean energy source.

An integral element of CMOP's international outreach in support of the GMI is the development of CMM pre-feasibility studies. These studies provide a cost-effective first step to project development and implementation by identifying project opportunities through a high-level review of gas availability, end-use options, and emission reduction potential. In recent years, CMOP has sponsored feasibility and pre-feasibility studies in such countries as China, India, Kazakhstan, Mongolia, Poland, Russia, Turkey and Ukraine.

Minera del Norte S.A. de C.V. (MINOSA), a leading coal company in Mexico and a subsidiary of Grupo Acerero del Norte (GAN), was selected as the recipient for a pre-feasibility study for CMM drainage at their Conchas Mine Complex (mines IX, X, and XI) in the southern Sabinas Basin of Mexico. The coal mines in this region are notoriously gassy and these mines are among the gassiest. Specific emission rates of about 50 cubic meters per tonne (m^3/t) of coal mined are projected for the Conchas mines. While MINOSA has implemented drainage programs at their mines in the northern portion of the Sabinas Basin, the

Conchas Mine Complex is relatively new and does not currently employ pre-drainage techniques. The objectives of this pre-feasibility study are to perform an initial assessment of the technical and economic viability of methane drainage utilizing vertical pre-drainage boreholes drilled from the surface, and to identify end-use options.

MINOSA was ultimately selected for this pre-feasibility study based on the level of commitment they have demonstrated to employ modern degasification methods and methane abatement technologies, and the high likelihood of project implementation and resulting methane reductions. MINOSA's gas drainage program entails a range of degasification methods including surface vertical pre-drainage wells, surface to inseam directional drilling, surface gob wells, and in-mine long hole directional boreholes, which is proving very effective. On the utilization and abatement side, MINOSA has installed flaring units at three of its mines in northern Mexico, Mine VII (Sabinas Basin), the Esmeralda Mine (Saltillo Basin), and Mine VI (Sabinas Basin). Additionally, MINOSA recently signed an agreement with Caterpillar to purchase six 1.5 megawatt (MW) reciprocating engines to generate power from the produced gas.

This pre-feasibility study is intended to provide an initial assessment of project viability. A Final Investment Decision (FID) should only be made after completion of a full feasibility study based on more refined data and detailed cost estimates, completion of a detailed site investigation, implementation of well tests, and possibly completion of a Front End Engineering & Design (FEED).

2 Background

2.1 The Mexican Coal Industry

Compared to petroleum and natural gas, coal is a relatively small component of Mexico's energy production and consumption. While oil and natural gas represented 45 percent and 40 percent of total primary energy consumption in 2014, respectively, coal accounted for only eight percent (BP, 2015). The primary use for coal in Mexico is steel production and electric power generation. While natural gas is still the dominant feedstock for electricity generation, coal-fired power generation is on the rise having increased to 320 trillion British thermal units (Btu) in 2013 from just under 250 trillion Btu in 2008 (EIA, 2014).

At the end of 2014, Mexico's total proved reserves of coal were 1,211 million tonnes (Mt) (ranked 24th globally), with 71 percent being anthracite or bituminous coal and the remaining 29 percent being sub-bituminous or lignite (BP, 2015). According to USEPA (2015), the majority of Mexico's coal reserves are located in the northeast in Coahuila State, with additional resources located in Sonora (in northwest Mexico) and Oaxaca (southern Mexico).

In 2014, Mexico ranked 23rd in global coal production with 13.8 Mt of production (BP, 2015). Between 1981 and 2014, Mexico's coal production increased by 10.8 Mt for a compound average growth rate (CAGR) of 4.7 percent (Exhibit 1). However, year-over-year production is down 8.9 percent, and current production is down 27 percent from the peak of 19.0 Mt reached in 2011.

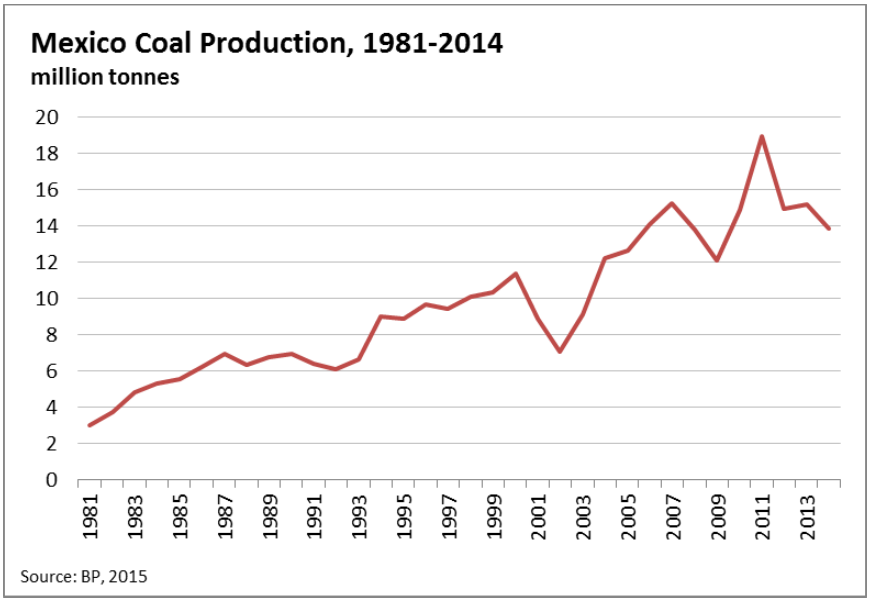

Exhibit 1: Coal Production in Mexico

2.2 Coal Mine Methane in Mexico

Despite the small scale of Mexico's coal industry, the coal mines of northern Mexico are notoriously gassy. Estimates of emissions related to coal mining activities in Mexico fluctuate annually, and also vary depending on the organization producing the estimate. USEPA (2012) estimates Mexico's CMM emissions to range between 121 million cubic meters (Mm^3) to 159 Mm^3 per annum, while independent experts in Mexico estimate annual CMM emissions upwards of 208 Mm^3 (Santillan, 2013). To put these numbers into perspective, the international standard for a "gassy" mine is 10 m^3/t, whereas the estimated 208 Mm^3 represents an average specific emission rate of approximately 50 m^3/t of coal mined (CDM, 2014). Based on the high specific emission rate of Mexico's coal mines, it is evident coal producers face significant challenges related to the management of methane. As a result, coal companies such as MINOSA are working to address methane issues through the employment of a holistic approach targeting gas drainage systems and mine ventilation air (USEPA, 2015).

According to the GMI International CMM Projects Database, two active CMM recovery projects and three proposed CMM recovery projects are currently underway in Mexico. Four of the five projects target underground mines, where the active projects use captured methane for boiler fuel and flaring, while the proposed projects are designed to use captured methane for power generation and flaring (GMI, 2015). Specific details regarding active CMM projects in Mexico – as well as additional information on CMM emissions and development potential, opportunities and challenges to greater CMM recovery, and profiles of individual mines – can be found in USEPA's Coal Mine Methane Country Profiles[1], which were developed in support of GMI.

2.3 MINOSA

Minera del Norte S.A. de C.V. (MINOSA), Mexico's principal producer of metallurgical coal is a subsidiary of Altos Hornos de Mexico (AHMSA), a large integrated steel company based in Coahuila state, which is in

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[1] USEPA (2015). Coal Mine Methane Country Profiles: Chapter 21 – Mexico. Updated June 2015, available: http://www.epa.gov/cmop/docs/cmm_country_profiles/Toolsres_coal_overview_ch21.pdf

turn controlled by Grupo Acerero del Norte (GAN), a corporation focusing on steel production, and the mining of coal and copper. MINOSA was formerly the name of the subsidiary operating AHMSA's iron ore mines and Minerales Monclova (MIMOSA) operated AHMSA's coal interests. GAN now operates all company-owned mines under MINOSA. The GAN mines together produced about 82 percent of Mexico's coal in 2013 (USEPA, 2015).

MINOSA currently operates underground and open pit mines located in the Sabinas sub-basin. In addition to the mines, the company also operates two coal washing plants. The coal is medium to high volatile in rank and is used to supply steelmaking operations owned by GAN in the city of Monclova, located 140 kilometers (km) from MINOSA'S mines. MINOSA'S coal reserves in the Sabinas sub-basin are estimated at 240 Mt and reserves in the Saltillito Basin are estimated at 60 Mt (Aguirre, 2008).

MINOSA operates five underground mines in the gassy coals of the Upper Cretaceous Los Olmos Formation in the state of Coahuila in northern Mexico and has been draining the coal beds prior to mining through in-seam horizontal boreholes since 1992 (Brunner, 1999). MINOSA has several active CMM gas drainage projects and has been very progressive in their pursuit of reducing methane emissions from their mining operations. In addition to a boiler operation at the Esmeralda Mine, MINOSA began operating the first CMM flare at an active coal mine in September 2011 (CDM, 2014).

3 Summary of Mine Characteristics

MINOSA is currently planning to develop a new mine area, "Conchas Sur", which is located in the southern Sabinas Basin of Mexico near the city of Sabinas (Exhibit 2). This new mine area, referred to as the Conchas Mine Complex throughout this report, covers an area of 27 km^2 and includes three mines named Mine IX, Mine X, and Mine XI. The coal mines in this region are notoriously gassy and MINOSA's existing mines are among the gassiest. Specific emission rates of about 50 m^3 per tonne of coal mined are projected for the Conchas mines. While MINOSA has implemented drainage programs at their mines in the northern portion of the Sabinas Basin, the Conchas Mine Complex is relatively new and does not currently employ pre-drainage techniques.

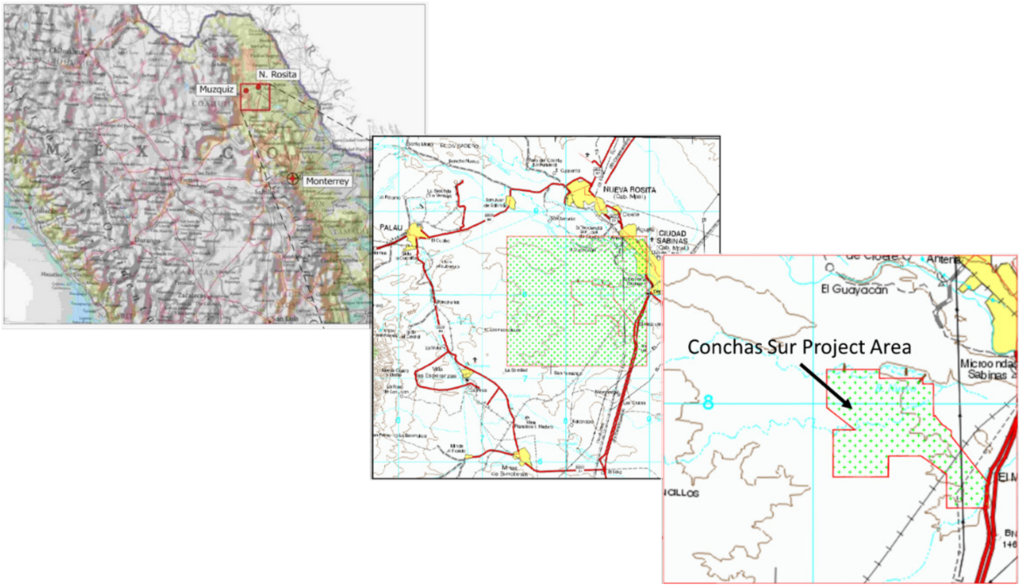
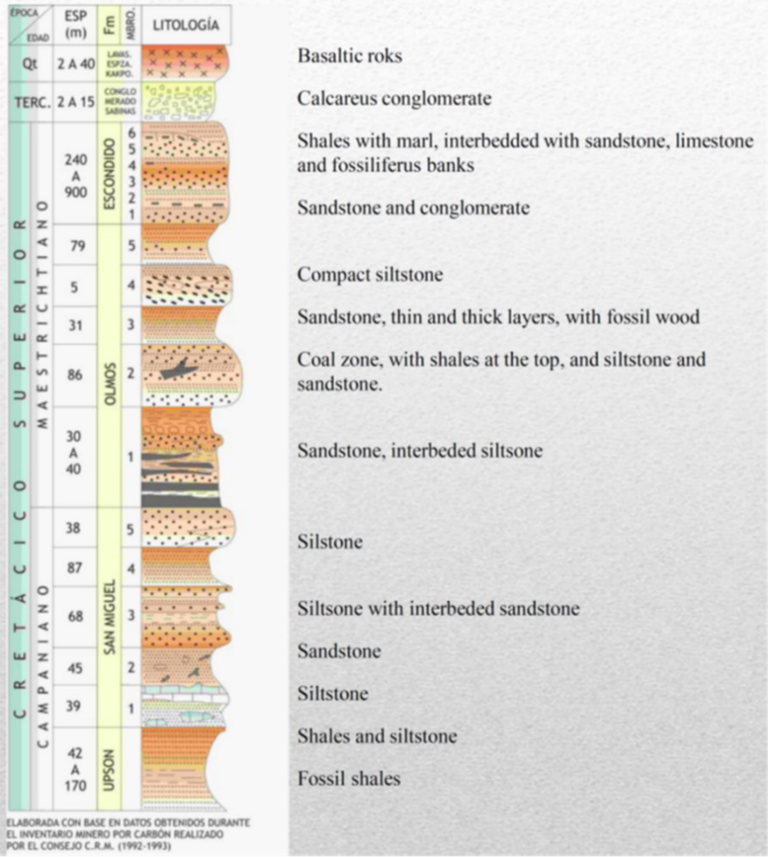


Exhibit 2: Location Map of Conchas Mine Complex

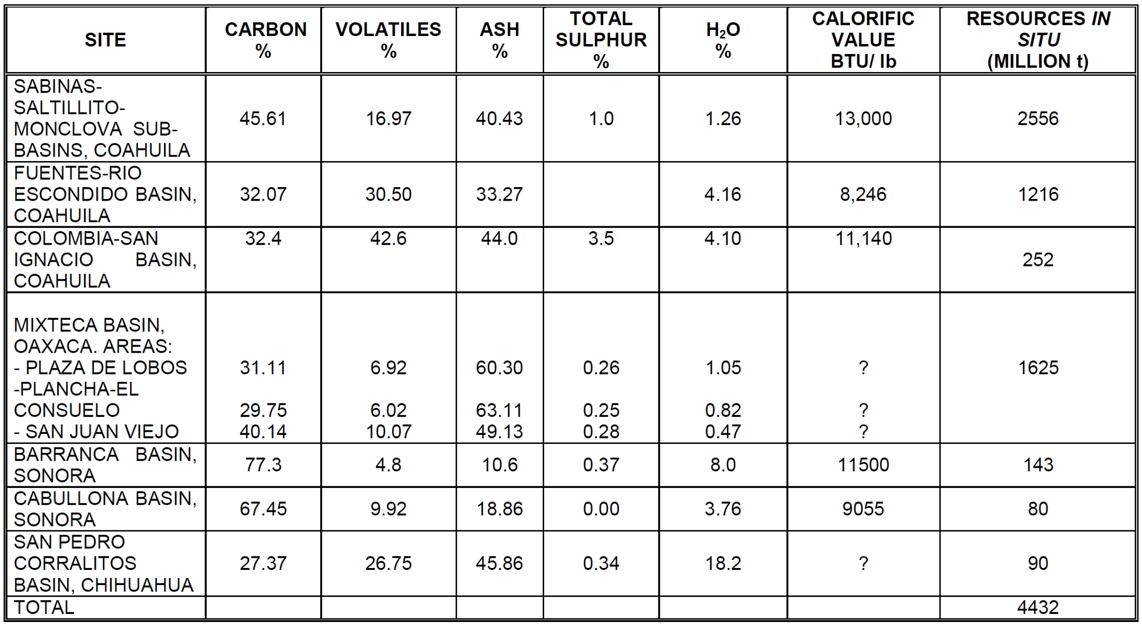
The geological history of Mexico shows that there have been three events that were suitable for the development and formation of coal beds. The first event happened from the Upper Triassic to Middle Jurassic Epochs; the second event took place at the end of the Late Cretaceous Epoch during the Maestrichtian Age; and the third event occurred during the Eocene Epoch, Lutetian - Bartonian Age (see Exhibit 3) (Aguirre, 2008).

The anthracitic coals of Oaxaca and Sonora belong to the Triassic-Jurassic event and have little economic importance because of its structural set up. The coals of the basins known as Sabinas and Fuentes-Rio Escondido in Coahuila, Ojinaga and San Pedro Corralitos in Chihuahua, and Cabullona in Sonora belong to the Cretaceous event. The lignite seams of Colombia-San Ignacio in Coahuila belong to the latest event of the Eocene (Querol-Suñé, 2006). Due to their economic potential, the Maestrichtian coals in the Coahuila State have been the most explored and developed coals in Mexico. Most of the coals in the Sabinas and Monclova sub-basins are metallurgical, whereas the coals from the Fuentes – Río Escondido basins are steam coals, which are used to generate electricity (Aguirre, 2008). Exhibit 4 presents typical coal characteristics by basin (Querol-Suñé, 2006).



ELABORADA CON BASE EN DATOS OBTENIDOS DURANTE EL INVENTARIO MINERO POR CARBÓN REALIZADO POR EL CONSEJO C.R.M. (1992-1993)

Exhibit 3: Main Geological Units of the Project Area



SITE	CARBON %	VOLATILES %	ASH %	TOTAL SULPHUR %	H_2O %	CALORIFIC VALUE BTU/ lb	RESOURCES *IN SITU* (MILLION t)
SABINAS-SALTILLITO-MONCLOVA SUB-BASINS, COAHUILA	45.61	16.97	40.43	1.0	1.26	13,000	2556
FUENTES-RIO ESCONDIDO BASIN, COAHUILA	32.07	30.50	33.27		4.16	8,246	1216
COLOMBIA-SAN IGNACIO BASIN, COAHUILA	32.4	42.6	44.0	3.5	4.10	11,140	252
MIXTECA BASIN, OAXACA. AREAS:							
- PLAZA DE LOBOS	31.11	6.92	60.30	0.26	1.05	?	1625
-PLANCHA-EL CONSUELO	29.75	6.02	63.11	0.25	0.82	?	
- SAN JUAN VIEJO	40.14	10.07	49.13	0.28	0.47	?	
BARRANCA BASIN, SONORA	77.3	4.8	10.6	0.37	8.0	11500	143
CABULLONA BASIN, SONORA	67.45	9.92	18.86	0.00	3.76	9055	80
SAN PEDRO CORRALITOS BASIN, CHIHUAHUA	27.37	26.75	45.86	0.34	18.2	?	90
TOTAL							4432

Exhibit 4: Characteristics and Resources of Coal in Mexico by Basin [after Flores-Galicia (1991) as presented in Querol-Suñé (2006)]

The Sabinas sub-basin is known to contain gassy coals, and two mineable seams, colloquially known at the "Double Seam" (see Exhibit 5), are present at shallow depth (less than 500 meters, m), are well cleated, and have high natural fracture permeability. Gentzis, Klinger, Murray & Santillan (2006) characterize the Sabinas coals as follows:

- Average total coal thickness of 2.2 m with high ash content (32 wt%)
- High vitrinite content (>86 vol%) showing high diffusivity (average tau value is 56 hours)
- High natural fracture permeability (>30 md) in the mine sites
- Average desorbed gas content of this medium-volatile bituminous coal ($R_o$max = 1.30%) is highest in Mine V (Esmeralda Mine at >9.0 cm^3/g)
- Maximum methane adsorption at an equivalent depth of 300 m is 15 cm^3/g (as-received basis)
- Gas concentration is mainly methane (98%) with a heating value of 38.21 MJ/m^3 (1026 Btu/ft^3)
- Coal is under-pressured, likely undersaturated, and reported to be dry, with possibly free gas in the cleat/fracture system

Mine characteristics and reservoir parameters specific to the Conchas Mine Complex are discussed in more detail in the reservoir simulation section (see section 4.3.2 Model Preparation and Runs).

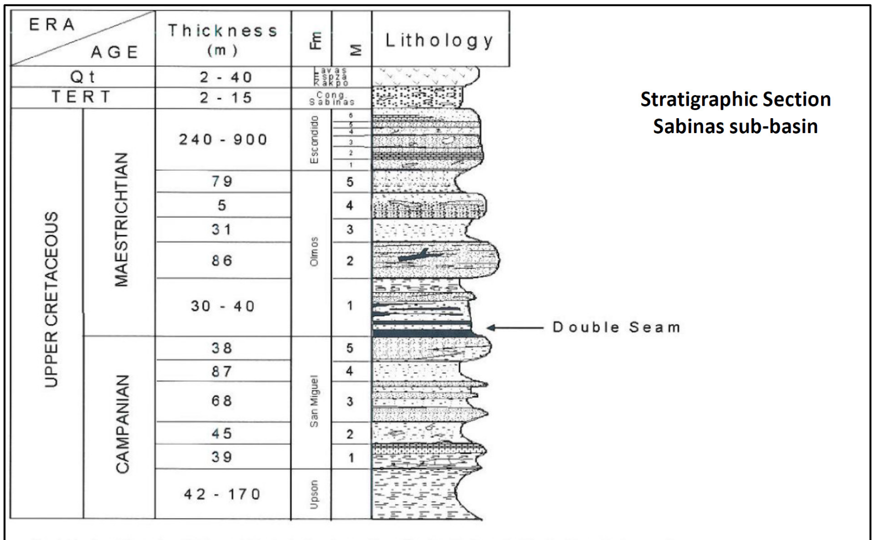


Fig. 2. Stratigraphic section, Sabinas sub-basin showing the position of the "Double Seam" within the Upper Cretaceous Los Olmos Formation.

Gentzis, Murray et al.
CSPG Bulletin Vol.54 No. 3 2006

Exhibit 5: Sabinas Sub-Basin Stratigraphic Section

To initiate development of the resources at the Conchas Mine Complex, MINOSA has developed a preliminary mining plan covering 27 km^2. As shown in Exhibit 6, the mine plan is laid out to include Mine IX, Mine X, and Mine XI, with a proposed mine life of 25 years. No additional details about the mining method proposed for the Conchas mines are available. However, it is likely that development at mines IX, X, and XI will proceed in a similar manner as MINOSA's other nearby mines such as mines 5, 6, and 7. Under this assumption, the Conchas mines would most-likely utilize a longwall mining system designed for panels between 800 m to 2,800 m in length by 200 m to 300 m in width. Exhibit 7 profiles MINOSA's mines 5, 6, and 7, and based on the historical production observed at these mines, it is reasonable to assume coal production for the three mines at the Conchas Mine Complex will be on the order of 5 Mt/yr.

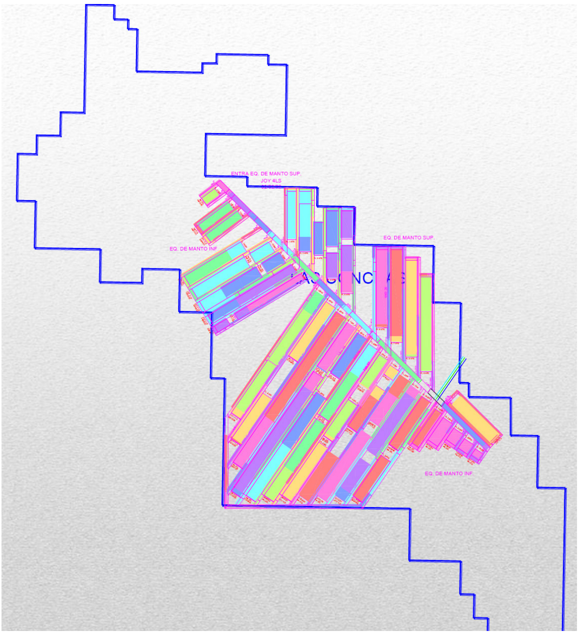
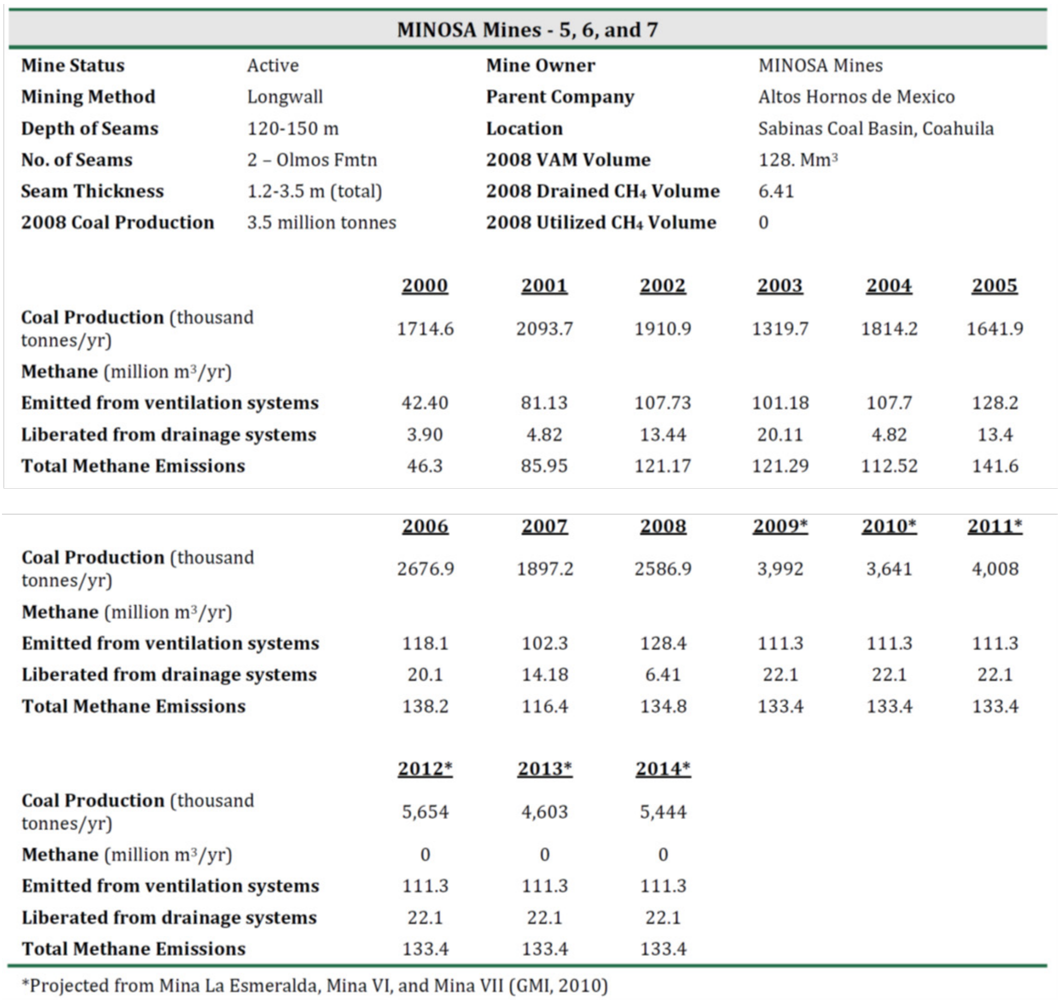


Exhibit 6: Conchas Mine Complex Proposed Mining Plan



MINOSA Mines - 5, 6, and 7

Mine Status	Active	**Mine Owner**	MINOSA Mines
Mining Method	Longwall	**Parent Company**	Altos Hornos de Mexico
Depth of Seams	120-150 m	**Location**	Sabinas Coal Basin, Coahuila
No. of Seams	2 – Olmos Fmtn	**2008 VAM Volume**	128. Mm^3
Seam Thickness	1.2-3.5 m (total)	**2008 Drained CH_4 Volume**	6.41
2008 Coal Production	3.5 million tonnes	**2008 Utilized CH_4 Volume**	0

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009*	2010*	2011*	2012*	2013*	2014*
Coal Production (thousand tonnes/yr)	1714.6	2093.7	1910.9	1319.7	1814.2	1641.9	2676.9	1897.2	2586.9	3,992	3,641	4,008	5,654	4,603	5,444
Methane (million m^3/yr)													0	0	0
Emitted from ventilation systems	42.40	81.13	107.73	101.18	107.7	128.2	118.1	102.3	128.4	111.3	111.3	111.3	111.3	111.3	111.3
Liberated from drainage systems	3.90	4.82	13.44	20.11	4.82	13.4	20.1	14.18	6.41	22.1	22.1	22.1	22.1	22.1	22.1
Total Methane Emissions	46.3	85.95	121.17	121.29	112.52	141.6	138.2	116.4	134.8	133.4	133.4	133.4	133.4	133.4	133.4

*Projected from Mina La Esmeralda, Mina VI, and Mina VII (GMI, 2010)

Exhibit 7: Profile of MINOSA's Mines V, VI, and VII (USEPA, 2015)

4 Gas Resources

4.1 Overview of Gas Resources

Based on both historical evidence and current desorption testing, the Sabinas sub-basin in northern Mexico contains gassy coals in the Upper Cretaceous Los Olmos Formation (Gentzis, Murray, & Klinger, 2005). Degasification of coal for mining purposes was first tested in the 1940's and in the early 1990's a degasification program was implemented at the Pasta de Conchos Mine to help reduce the methane concentration of the mine's ventilation air, which at the time was greater than one percent. Additionally, Petróleos Mexicanos (PEMEX) has studied the coalbed methane (CBM) potential of the Coahuila coals, but the data has not been released publically (Querol-Suñé, 2006).

Mexico's CBM resources are concentrated in the northern states of Coahuila and Sonora (USEPA, 2015). CBM resource estimates for the Sabinas and Saltillito basins vary from between 4.2 trillion cubic feet (Tcf) to 7.5 Tcf, with some estimates as high as 8.8 Tcf (Querol-Suñé, 2006). MINOSA reports in situ gas contents in the Sabinas Basin ranging from 343 standard cubic feet per ton (scf/ton) to 480 scf/ton, with in situ gas contents in the Saltillito Basin ranging from 411 scf/ton to 618 scf/ton (Querol-Suñé, 2006). Despite the limited amount of data available on the CMM and CBM resources in Mexico, the basins of Coahuila are the most prospective for methane recovery projects based on their relatively high gas contents, moderate permeability, and relatively shallow depth (USEPA, 2015).

Based on the results of gas desorption tests performed in conjunction with the coring program, the coal seams of the Conchas Mine Complex are gassy. As shown in Exhibit 8, the gas content of the upper seam (Seam A) ranges from 4.59 m^3/t to 15.92 m^3/t, with the gas content of the lower seam (Seam B) ranging from 5.88 m^3/t to 16.85 m^3/t (MINOSA, 2014).

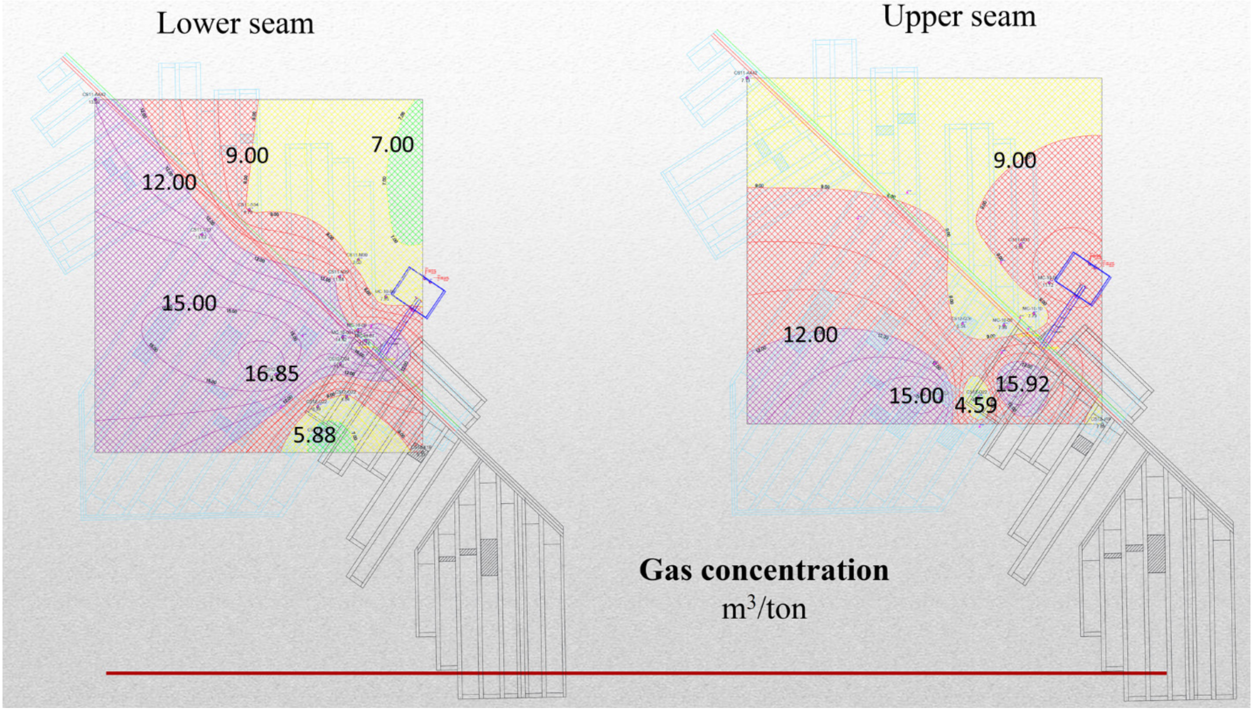


Exhibit 8: Gas Concentration of Lower and Upper Seams

4.2 Proposed Gas Drainage Approach

The objectives of this pre-feasibility study are to perform an initial assessment of the technical and economic viability of methane drainage utilizing vertical pre-drainage boreholes drilled from the surface, and to identify end-use options. The gas production profiles generated for the vertical pre-drainage boreholes will form the basis of the economic analyses performed in Section 7 of this report. Additionally, estimating the gas production volume is critical for planning purposed and the design of equipment and facilities.

Exhibit 9 illustrates the conceptual gas drainage approach proposed for the Conchas Mine Complex. In this example, gas drainage is accomplished through the utilization of vertical boreholes drilled in advance of mining. The boreholes will target seams A and B, and two well spacing scenarios will be assessed (60 ac and 120 ac well spacing).

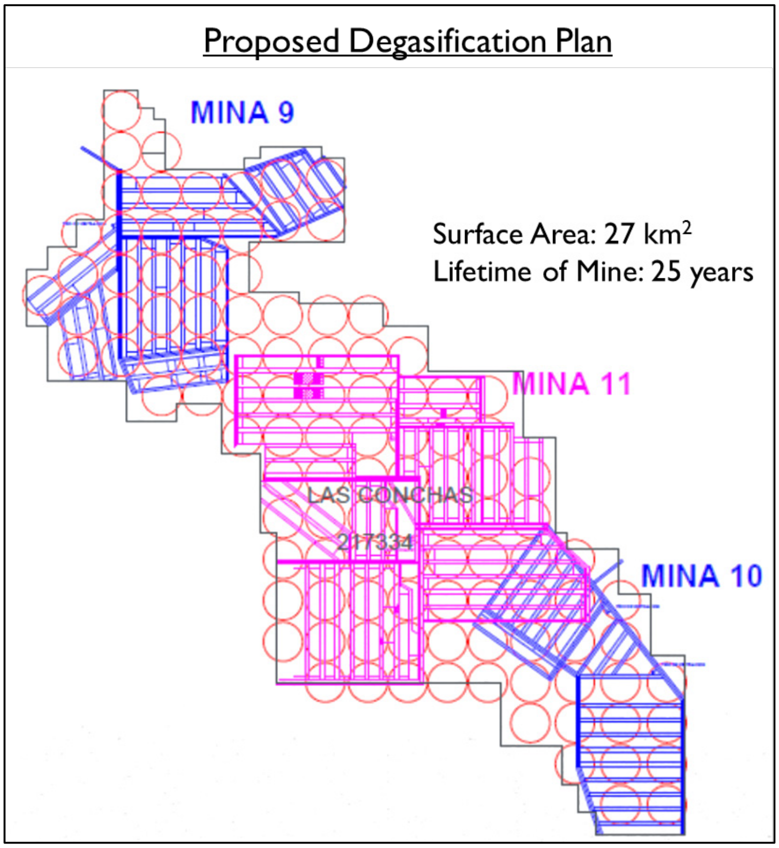


Exhibit 9: Proposed Degasification Plan for the Conchas Mine Complex

4.3 Estimating Production from Vertical Pre-Drainage Boreholes

Two reservoir models designed to simulate gas production volumes from vertical pre-drainage boreholes were constructed. The following sections of this report discuss the construction of the gas drainage borehole models, the input parameters used to populate the reservoir simulation models, and the simulation results.

4.3.1 Simulation Model

A total of two dual-layer reservoir simulation models were constructed in order to calculate gas production from a single well located within the project area. The models were designed to simulate production from vertical pre-drainage boreholes drilled from the surface and spaced according to two well spacing cases: 60 ac and 120 ac. The models were each run for ten years in order to simulate gas production rates and cumulative production volumes from a typical borehole within the project area.

Model grids were created to accommodate each of the well spacing scenarios. Each model grid consisted of 13 grid-blocks in the x-direction, 13 grid-blocks in the y-direction, and two grid-blocks in the z-direction. The grid block dimensions were 124.4 feet (ft) by 124.4 ft for the 60 ac well spacing case and 175.9 ft by 175.9 ft for the 120 ac well spacing cases. An example of the model layout for a vertical pre-drainage borehole is shown in Exhibit 10.

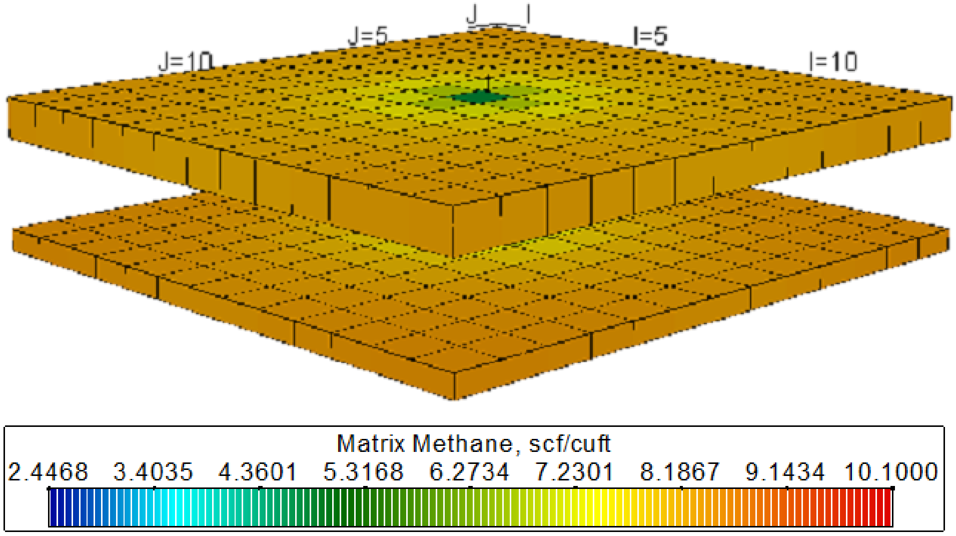


Exhibit 10: Example Layout for Vertical Pre-Drainage Borehole Simulation Model

4.3.2 Model Preparation and Runs

The input data used to populate the reservoir models were obtained primarily from the geologic and reservoir data provided by MINOSA. Any unknown reservoir parameters were obtained from analogs within the Sabinas Basin. The input parameters used in the reservoir simulation study are presented in Exhibit 11, followed by a brief discussion of the most important reservoir parameters.

Reservoir Parameter	Value(s)	Source / Notes
Avg. Coal Depth, ft Seam A Seam B	 820 853	Analog (La Esmeralda Mine)
Avg. Coal Thickness, ft Seam A Seam B	 10.10 5.28	Based on mine data
Coal density, ton/ac-ft	1836	Assumption
Pressure Gradient, psi/ft	0.310	Analog (field test at nearby property in 1990)
Initial Reservoir Pressure, psia	260	Calculated from avg. depth and pressure gradient
Initial Water Saturation, %	20	Analog (Gentzis, Klinger, Murray, & Santillan, 2006)
Langmuir Volume, scf/ton	534	Analog (La Esmeralda Mine)
Langmuir Pressure, psia	297	Analog (La Esmeralda Mine)
In Situ Gas Content, scf/ton	237	Analog (La Esmeralda Mine); equivalent to 95% saturation
Desorption Pressure, psia	238	Calculated from isotherm and in-situ gas content
Sorption Times, days	2.4	Analog (field test at nearby property in 1990)
Fracture Spacing, in	0.04	Analog (field test at nearby property in 1990)
Absolute Cleat Permeability, md	33.6	Analog (field test at nearby property in 1990)
Cleat Porosity, %	0.5	Analog (La Esmeralda Mine)
Relative Permeability	see Exhibit 13	Analog (La Esmeralda Mine)
Pore Volume Compressibility, psi^{-1}	7.3E-05	Analog (La Esmeralda Mine)
Matrix Shrinkage Compressibility, psi^{-1}	4.4E-07	Analog (La Esmeralda Mine)
Gas Gravity	0.575	Analog (Gentzis, Klinger, Murray, & Santillan, 2006)
Water Viscosity, centipoise (cP)	0.44	Assumption
Water Formation Volume Factor, reservoir barrel per stock tank barrel (RB/STB)	1.00	Calculation
Completion and Stimulation	Assumes skin factor of -3 (vertical, fracture stimulated wells)	
Well Operation	Wells are pumped off utilizing a bottom-hole pressure constraint of 25 psia	
Well Spacing	60 ac per well based on mine degasification plan (base case) and 120 ac per well (alternative case)	

Exhibit 11: Reservoir Parameters for Vertical Pre-Drainage Borehole Simulation

4.3.2.1 Permeability

Coal bed permeability, as it applies to production of methane from coal seams, is a result of the natural cleat (fracture) system of the coal and consists of face cleats and butt cleats. This natural cleat system is sometimes enhanced by natural fracturing caused by tectonic forces in the basin. The permeability resulting from the fracture systems in the coal is called "absolute permeability" and is a critical input parameter for reservoir simulation studies. Absolute permeability data for the coal seams in the study area were not provided. For the current study, permeability values were assumed to be 33.6 millidarcy (md) based on the results of field tests conducted at a nearby property.

4.3.2.2 Langmuir Volume and Pressure

Laboratory measured Langmuir volumes and pressures for the study area were not available. However, Langmuir volume and pressure values used in reservoir simulation history matching conducted for the La Esmeralda Mine were utilized in the current study. The corresponding Langmuir volume used in the reservoir simulation models for the project area is 534 scf/ton and the Langmuir pressure is 297 pounds per square inch absolute (psia). Exhibit 12 depicts the methane isotherm utilized in the vertical pre-drainage borehole simulations.

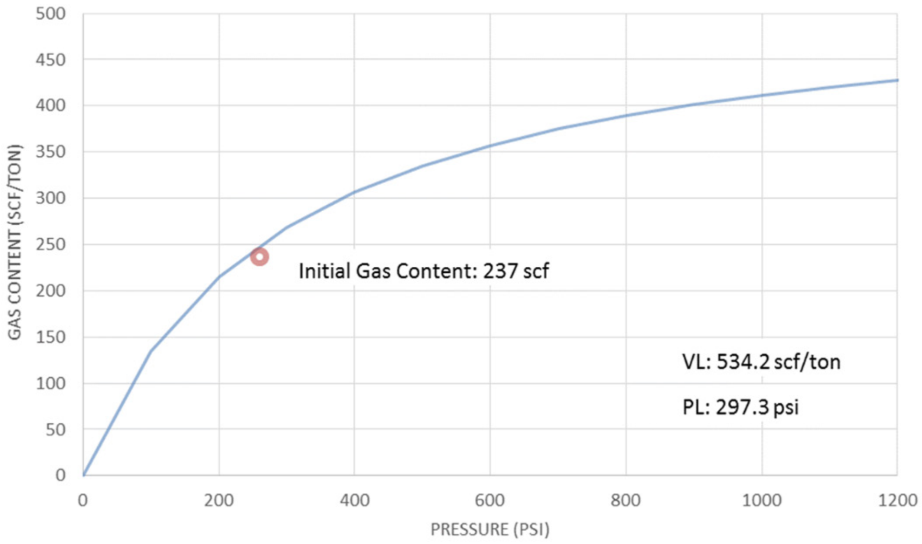


Exhibit 12: Methane Isotherm Used in Vertical Pre-Drainage Borehole Simulation

4.3.2.3 Gas Content

Gas desorption analyses performed during the coring program indicate a high level of dispersion. Based on data provided by the mine, the methane gas content of the upper seam (Seam A) ranges from 162 scf/ton to 562 scf/ton and the methane gas content of the lower seam (Seam B) ranges from 208 scf/ton to 595 scf/ton. For modeling purposes, a gas content of 237 scf/ton was used, which represents a gas saturation of 95% (Exhibit 12). This assumption is based on reservoir simulation history matching conducted for the La Esmeralda Mine.

4.3.2.4 Relative Permeability

The flow of gas and water through coal seams is governed by permeability, of which there are two types, depending on the amount of water in the cleats and pore spaces. When only one fluid exists in the pore space, the measured permeability is considered absolute permeability. Absolute permeability represents the maximum permeability of the cleat and natural fracture space in coals and in the pore space in coals. However, once production begins and the pressure in the cleat system starts to decline due to the removal of water, gas is released from the coals into the cleat and natural fracture network. The introduction of gas into the cleat system results in multiple fluid phases (gas and water) in the pore space, and the transport of both fluids must be considered in order 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, the relative permeability curve used in the simulation study was obtained from the results of reservoir simulation history matching performed in association with a CMM project at the La Esmeralda Mine. Exhibit 13 is a graph of the relative permeability curves used in the reservoir simulation of the study area.

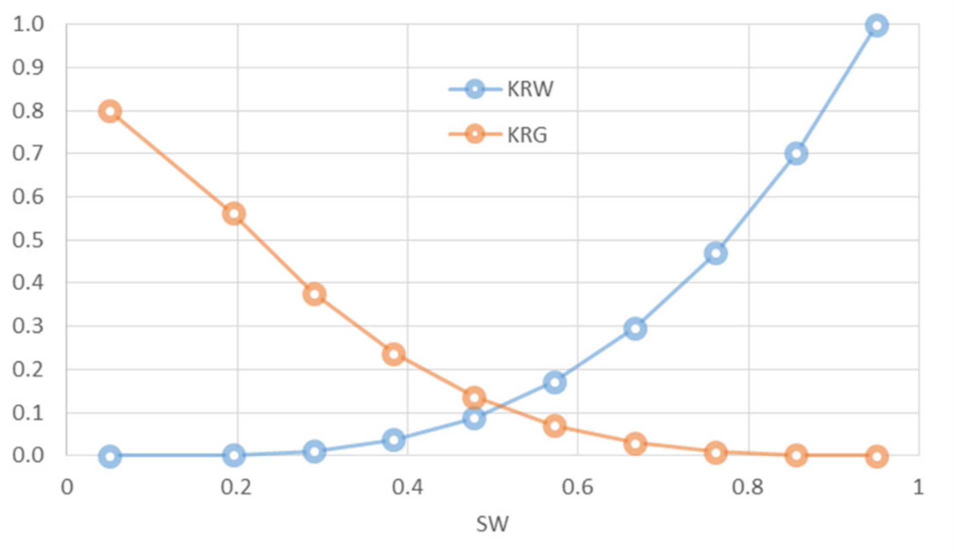


Exhibit 13: Relative Permeability Curve Used in Simulation

4.3.2.5 Coal Seam Depth and Thickness

Based on data from nearby mines, the coal seams of the Conchas Mine Complex range in depth from 820 ft to 860 ft with coal seams ranging between 5.3 ft and 10.1 ft in thickness. The model assumes two individual zones, corresponding to the A and B seams, will be hydraulically fractured in each well. Based on mine data, the coal thickness is taken to be 10.10 ft and 5.28 ft for Seam A and Seam B, respectively. The depth to the top of the coal reservoir was assumed to be 820 ft and 853 ft for the A and B seams, respectively. Exhibit 14 presents a representative stratigraphic column for the project area.

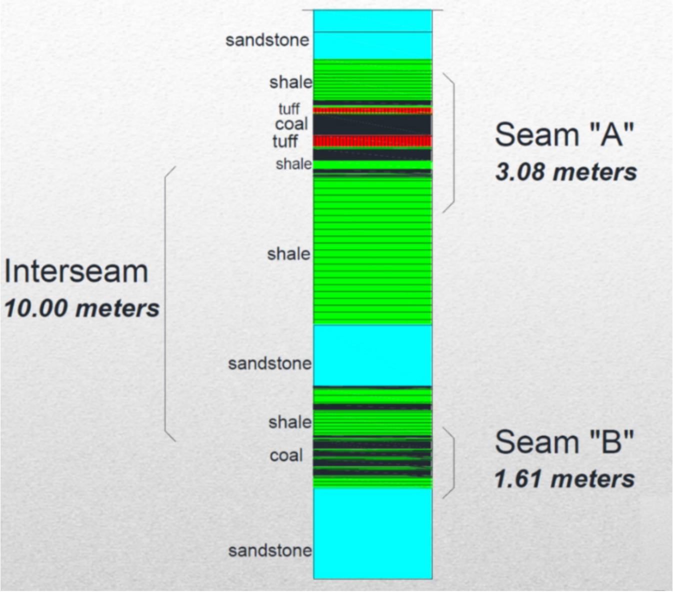


Exhibit 14: Representative Stratigraphic Column at the Conchas Mine Complex

4.3.2.6 Reservoir and Desorption Pressure

Using a hydrostatic pressure gradient of 0.310 pounds per square inch per foot (psi/ft) and the midpoint depth of the coal seams, an initial average reservoir pressure of 260 pounds per square inch absolute (psia) was computed for the vertical pre-drainage borehole model. Because the coal seams are assumed to be undersaturated with respect to gas, an average desorption pressure was calculated using the methane isotherm. The resulting desorption pressures used in the model was 238 psia.

4.3.2.7 Porosity and Initial Water Saturation

Porosity is a measure of the void spaces in a material. In this case, the material is coal, and the void space is the cleat fracture system. Since porosity values for the coal seams in the project area were not available, a value of 0.5 percent was used in the simulations, which is based on porosity values used in reservoir simulations for the CMM project at the La Esmeralda Mine. The cleat and natural fracture system in the reservoir was assumed to be 20 percent water saturated. This assumption is based on work by Gentzis et al. (2006), which reported the coal of the Sabinas sub-basin to be dry, with possibly free gas in the cleat/fracture system.

4.3.2.8 Sorption Time

Sorption time is defined as the length of time required for 63 percent of the gas in a sample to be desorbed. In this study a 2.4 day sorption time was used, which was based on field test results at a nearby mine. Production rate and cumulative production forecasts are typically relatively insensitive to sorption time.

4.3.2.9 Fracture Spacing

A fracture spacing of 0.04 inches (in) was assumed in the simulations, which is consistent with data from field tests conducted at a nearby mine. In the model, fracture spacing is only used for calculation of diffusion coefficients for different shapes of matrix elements and it does not materially affect the simulation results.

4.3.2.10 Well Spacing

Based on the proposed degasification plan a base well spacing case of 60 ac was utilized in the simulations. Additionally, due to the high permeability present in the coal seams, an alternative well spacing case of 120 ac was run.

4.3.2.11 Completion

Vertical wells are projected to be drilled and completed to a depth of roughly 875 ft and completed in two stages corresponding to the A and B seams. Nearly all coal seams require some type of stimulation in order to initiate and sustain economic gas production. For modeling purposes, a skin value of -3 is assumed.

4.3.2.12 Well Operation

In the current study, wells were pumped off utilizing a bottom-hole pressure constraint of 25 psia. In coal mine methane operations, low well pressure is required to achieve maximum gas content reduction. The wells were allowed to produce for a total of 10 years.

4.3.3 Model Results

As noted previously, two reservoir models were created to simulate gas production for the study area located at the Conchas Mine Complex. Each of the models was run for a period of 10 years and the resulting gas production profiles and reduction in methane of the coal seams were calculated. Simulated gas production rate and cumulative gas production for an average well within the project area are shown in Exhibit 15, and Exhibit 16 presents a tabular summary of the simulation results for the vertical pre-drainage borehole model.

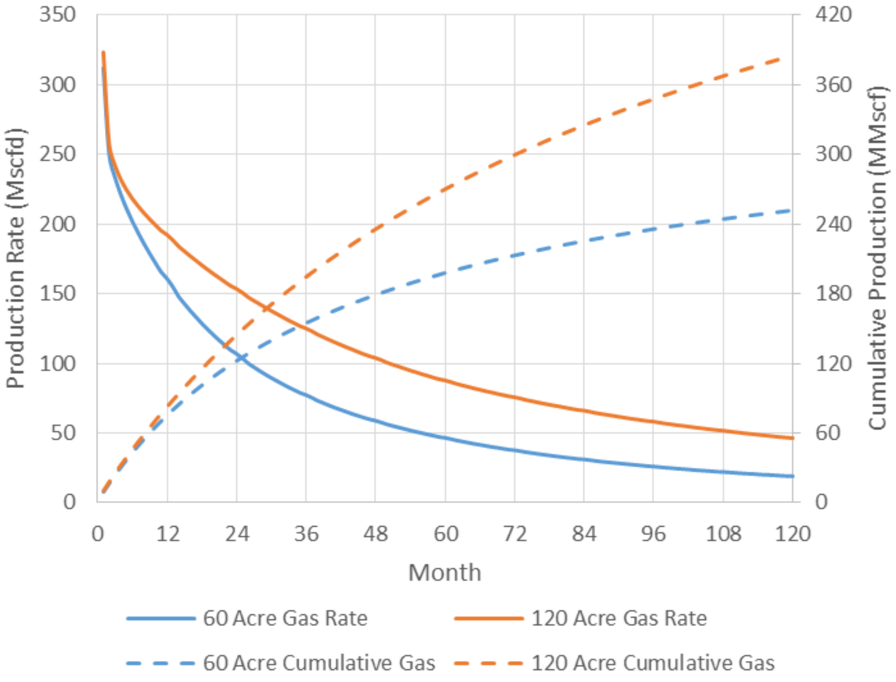


Exhibit 15: Simulated Gas Production Profiles for Vertical Pre-Drainage Boreholes

Well Spacing	ac	60	120
Peak Gas Rate	Mscfd	312	323
Cumulative Gas Production			
1 Year	MMscf	76	82
3 Year	MMscf	155	194
5 Year	MMscf	198	270
10 Year	MMscf	252	385
Methane Concentration	%	98%	98%
CH4-In-Place	Bcf	401	802
Recovery Factor (10-Yr)	%	63%	48%

Exhibit 16: Summary of Pre-Drainage Simulation Results for Single Well

One of the benefits of pre-drainage is the reduction of methane content in the coal seams prior to mining. Exhibit 17 and Exhibit 18 show the simulated reduction in in-situ gas content in Seam A and Seam B, respectively, over time utilizing vertical pre-drainage boreholes.

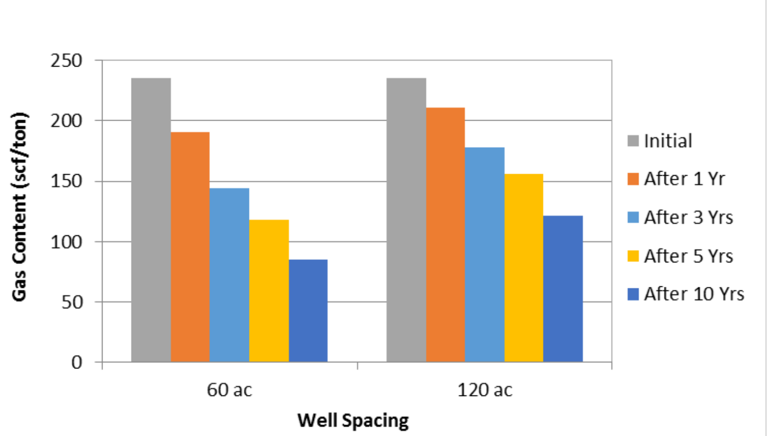


Exhibit 17: Simulated Reduction in In-Situ Gas Content for Seam A

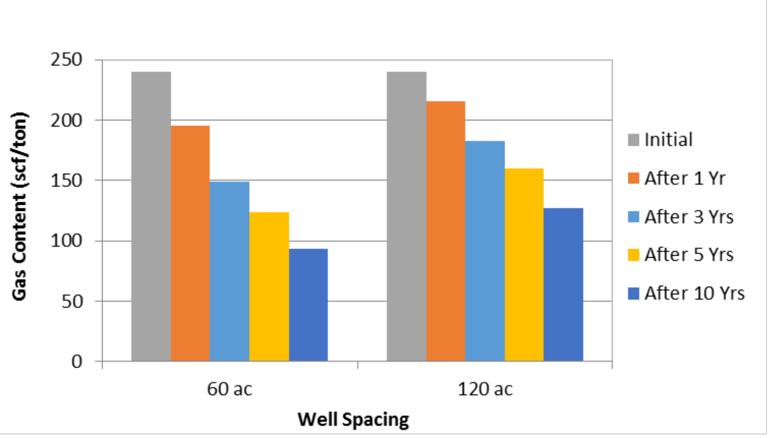


Exhibit 18: Simulated Reduction in In-Situ Gas Content for Seam B

5 Market Information

As noted in USEPA's CMM country profile of Mexico (USEPA, 2015), methane captured from coal mines would compete directly with other supplies of natural gas, which come from various natural gas basins and as associated gas from increasing onshore and offshore oil production. CMM and CBM prices are expected to be competitive with natural gas and other resources, including coal, due to rising natural gas prices and increasing gas demand for expanding power generation capacity.

Currently, markets for CMM in Mexico are limited due to legal requirements that hydrocarbon resources be handled through contracts with PEMEX, which is the state owned oil and gas monopoly. CMM projects under development in Mexico are currently limited to utilization in coal mine operations or local power generation and not to pipeline sales. However, the Mexican government has recently proposed new regulations for the oil and gas industry which are intended to further liberalize the sector and promote private investment and development. The passage of this new legislation should provide added incentives for CMM and CBM development projects (USEPA, 2015). The recent market reforms are highlighted in the following excerpts from USEPA's CMM Country Profiles[2] and white paper on CMM ownership policy[3]:

- Mineral exploration and mining in Mexico are regulated by the Mining Law of 1992 (as amended in 2006), which establishes that all minerals found in Mexican territory are owned by the Mexican nation, and that private parties may exploit such minerals (except oil and nuclear fuel minerals) through mining licenses, or concessions, granted by the Federal Government.
- Until the change in the mining law in 2006, only PEMEX had the right to exploit Mexico's natural gas resources, including CBM. Therefore, coal mines did not have the right to sell CMM or to use CMM to generate heat or electricity on site.
- Following a methane-related explosion at the Pasta De Conchos Mine in February 2006, Mexico's Congress and Senate amended the Mining Law (April 2006), allowing coal mines to recover and use CBM, CMM, abandoned mine methane (AMM), and ventilation air methane (VAM) from their coal mining operations for any purpose. The amendment also allowed the concessionaires to sell the gas to PEMEX through a contract (Flores, 2007).
- The regulations were further adjusted by an amendment to the Mining Law on June 26, 2006, which allows holders of coal mineral concessions to recover and use methane in order to stop methane venting. Methane can be used on-site and/or delivered to PEMEX, which is required to pay justifiable market rates for recovery, transportation, operation, and maintenance plus a reasonable profit. Holders of CMM concessions are contracted to report on the start and suspension of any activities, collect geological data, report on discovery of non-associated gas, and deliver captured, non-self-consumed CMM to PEMEX (Flores, 2007; Latin Petroleum, 2006).
- A new law, "Safety for Underground Mines" (NOM-STPS-032-2008), was passed in 2008 and contained rules for obtaining permits and authorizations that grant the use and recovery of coalmine gas (Cabrera, 2009; Briseno, 2009). The Secretaria de Energía (SENER) is the agency in charge of authorizing and monitoring CBM/CMM activity, and issues permission for the recovery and utilization of CBM. SENER will also issue contracts for the delivery of gas to PEMEX, establish

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[2] USEPA (2015). Coal Mine Methane Country Profiles: Chapter 21 – Mexico. Updated June 2015, available: http://www.epa.gov/cmop/docs/cmm_country_profiles/Toolsres_coal_overview_ch21.pdf

[3] USEPA (2014). Legal and Regulatory Status of CMM Ownership in Key Countries: Considerations for Decision Makers. July 2014, available: http://www.epa.gov/cmop/docs/CMM-Ownership-Policy-White-Paper-July2014.pdf

terms for payment for the delivery of gas, and is charged with developing policies for recovery and utilization of CBM (Roldan, 2009).
- The Mexican government recently staked out three large regions and designated them for CBM development. This is in response to the changes to the Mining Law passed in 2006, and seeks to assert the primacy of CBM resources in these areas. Until the concessions are put up for auction, the reservation of these areas will be an impediment to other mining development (Wood, 2007). One of the designated regions encompasses much of Coahuila state, including the Conchas Mine Complex project area.

6 Opportunities for Gas Use

CMM, which is essentially natural gas, is the cleanest burning and most versatile hydrocarbon energy resource available. It can be used for power generation in either base load power plants or in combined cycle/co-generation power plants, as a transportation fuel, as a petrochemical and fertilizer feedstock, as fuel for energy/heating requirements in industrial applications, and for domestic and commercial heating and cooking.

Given the relatively small CMM production volume, constructing a pipeline to transport the gas to demand centers would be impractical. As noted in the Market Information section, the primary market available for a CMM utilization project at the Conchas Mine Complex is power generation using internal combustion engines. Based on gas supply forecasts, the mine could be capable of operating as much as 72 MW of electricity capacity.

Generating electricity on site is attractive, because the input CMM gas stream can be utilized as-is, with minimal processing and transportation. Additional generating sets can be installed relatively cheaply and infrastructure for the power plant is already planned.

7 Economic Analysis

7.1 Project Development Scenario

In order to assess the economic viability of the degasification options presented throughout this report, it is necessary to define the project scope and development schedule. Pre-drainage boreholes were assumed to begin production three to five years prior to the initiation of mining activities. Gas production profiles were generated for a total of four project development cases:

- Case 1: 60 ac well spacing with 3 years of pre-drainage
- Case 2: 60 ac well spacing with 5 years of pre-drainage
- Case 3: 120 ac well spacing with 3 years of pre-drainage
- Case 4: 120 ac well spacing with 5 years of pre-drainage

The proposed pre-drainage project will target both the A and B seams with vertical boreholes drilled from the surface. With a project area of 6,672 ac (27 km^2) a total of 112 and 56 wells will be drilled for the 60 ac and 120 ac well spacing cases, respectively. At an assumed drilling rate of four wells per month drilling of the entire project area would require 28 months and 14 months for the 60 ac and 120 ac well spacing cases, respectively.

7.2 Gas Production Forecast

Gas production forecasts were developed using the simulation results (Exhibit 15) and the development cases discussed above. The gas production forecast for each project development case is shown in Exhibit 19.

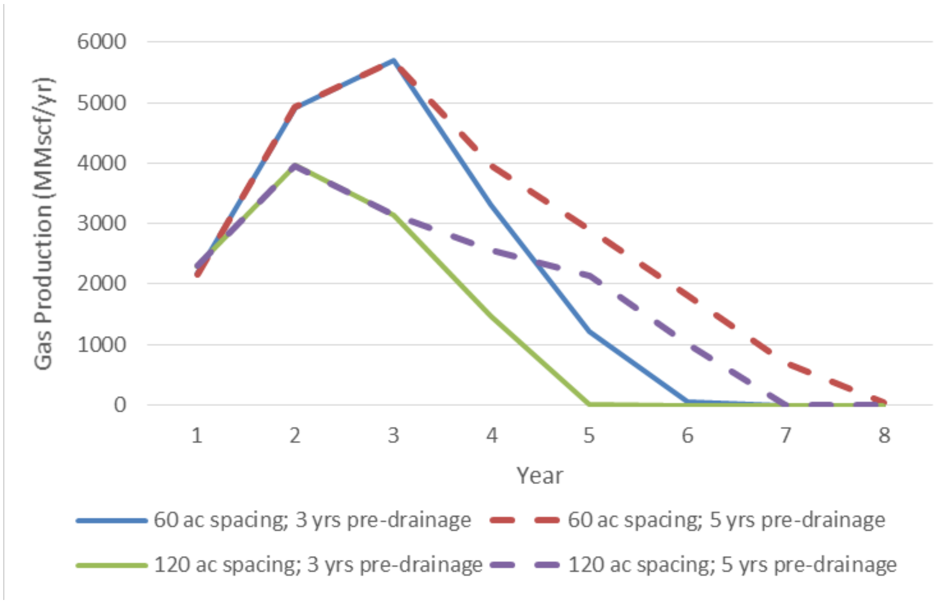


Exhibit 19: Gas Production Forecast by Development Scenario

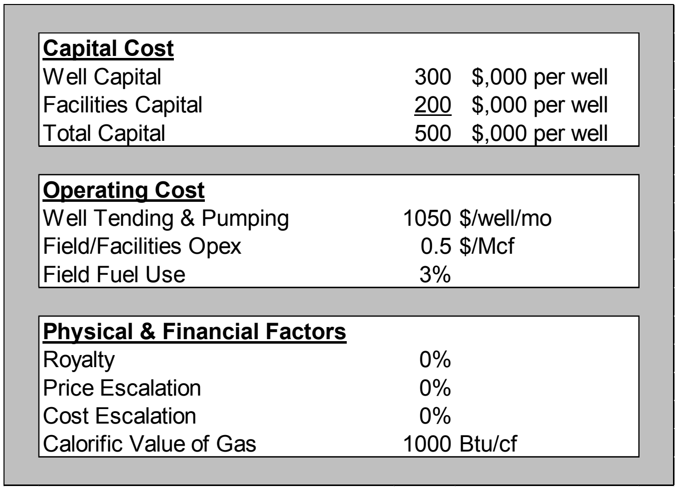
7.3 Project Economics

7.3.1 Economic Assessment Methodology

For each of the proposed project development cases, discounted cash flow analyses were performed for the upstream portion (i.e., CMM production) and the downstream portion (i.e., electricity production). A breakeven gas price was calculated in the upstream segment where the present value of cash outflows is equivalent to the present value of cash inflows. The breakeven gas price was then used in the downstream segment to calculate the fuel cost for the power plant. Likewise, a breakeven electricity price was calculated for the downstream segment, which can be compared to the current price of electricity observed at the mine in order to determine the economic feasibility of each potential development case. The results of the analyses are presented on a pre-tax basis.

7.3.2 Upstream (CMM Project) Economic Assumptions and Results

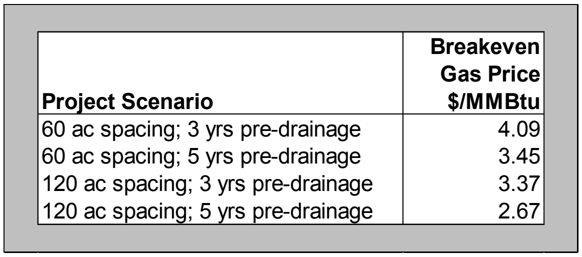
Cost estimates for goods and services required for the development of the CMM project associated with the Conchas Mine Complex were based on a combination of known average development costs of analogous projects in the region and the U.S., and other publically available sources (USEPA, 2011). A more detailed analysis should be conducted if this project advances to the full-scale feasibility study level. The capital cost assumptions, operating cost assumptions, and physical and financial factors used in the evaluation of upstream economics are provided in Exhibit 20.



Capital Cost		
Well Capital	300	$,000 per well
Facilities Capital	200	$,000 per well
Total Capital	500	$,000 per well
Operating Cost		
Well Tending & Pumping	1050	$/well/mo
Field/Facilities Opex	0.5	$/Mcf
Field Fuel Use	3%	
Physical & Financial Factors		
Royalty	0%	
Price Escalation	0%	
Cost Escalation	0%	
Calorific Value of Gas	1000	Btu/cf

Exhibit 20: Summary of Input Parameters for the Evaluation of Upstream Economics (CMM Project)

The economic results for the CMM pre-drainage project are summarized in Exhibit 21. Based on the forecasted gas production, the breakeven cost of producing gas through vertical pre-drainage boreholes is estimated to be between $2.67 and $4.09 per million British thermal units (MMBtu). The results of the economic assessment indicate the lowest pre-drainage costs are associated with the 120 ac well spacing case, with 5 years of pre-drainage (Case 4) preferred over 3 years (Case 3).

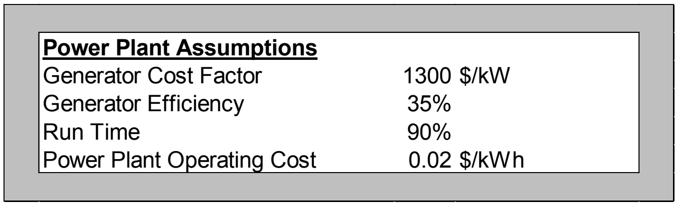


Project Scenario	Breakeven Gas Price $/MMBtu
60 ac spacing; 3 yrs pre-drainage	4.09
60 ac spacing; 5 yrs pre-drainage	3.45
120 ac spacing; 3 yrs pre-drainage	3.37
120 ac spacing; 5 yrs pre-drainage	2.67

Exhibit 21: Breakeven Gas Price

7.3.3 Downstream (Power Project) Economic Assumptions and Results

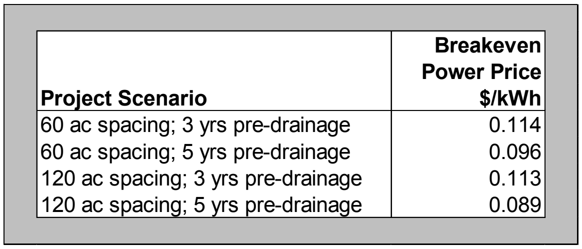
The drained methane can be used to fuel internal combustion engines that drive generators to make electricity for use at the mine. The major cost components for the power project are the cost of the engine and generator, as well as costs for gas processing to remove solids and water, and the cost of equipment for connecting to the power grid. The assumptions used to assess the economic viability of the power project are presented in Exhibit 22.



Power Plant Assumptions		
Generator Cost Factor	1300	$/kW
Generator Efficiency	35%	
Run Time	90%	
Power Plant Operating Cost	0.02	$/kWh

Exhibit 22: Summary of Input Parameters for the Evaluation of Downstream Economics (Power Project)

The economic results for the power project are summarized in Exhibit 23. The breakeven power sales price, inclusive of the cost of methane drainage, is estimated to be between $0.089 and $0.114 per kilowatt-hour (kWh). Based on a breakeven gas price of $2.67/MMBtu (Case 4), the mine could generate power at a price equivalent to $0.089/kWh. With electricity rates for medium-size industry in Mexico averaging $0.095/kWh over the first half of 2015 (SIE, 2015), a CMM-to-power utilization project at the mine would be economically feasible.



Project Scenario	**Breakeven Power Price $/kWh**
60 ac spacing; 3 yrs pre-drainage	0.114
60 ac spacing; 5 yrs pre-drainage	0.096
120 ac spacing; 3 yrs pre-drainage	0.113
120 ac spacing; 5 yrs pre-drainage	0.089

Exhibit 23: Breakeven Power Price

8 Conclusions, Recommendations and Next Steps

As a pre-feasibility study, this document is intended to provide a high level analysis of the technical feasibility and economics of the CMM project at the Conchas Mine Complex. The analysis performed reveals that methane drainage using vertical pre-drainage boreholes is feasible, and could provide the mine with additional benefits beyond the sale of gas or power, such as improved mine safety and enhanced productivity.

Based on the forecasted gas production, the breakeven cost of producing CMM through vertical pre-drainage boreholes is estimated to be between $2.67 and $4.09/MMBtu. The results of the economic assessment indicate the lowest pre-drainage costs are associated with the 120 ac well spacing case, with 5 years of pre-drainage (Case 4) preferred over 3 years (Case 3).

In terms of utilization, the power production option is economically feasible under the optimal development scenario. More rigorous engineering design and costing would be needed before making a final determination of the best available utilization option for the drained methane. The breakeven power sales price, inclusive of the cost of methane drainage, is estimated to be between $0.089 and $0.114/kWh. With current industrial electricity rates in Mexico averaging $0.095/kWh over the first half of 2015, utilizing drained methane to produce electricity would generate profits of $6 per megawatt-hour (MWh) of electricity produced, based on the breakeven power sales price of $0.089/kWh, which is associated with the optimal development scenario (Case 4).

The power production option is economically feasible, and removing the cost of mine degasification from downstream economics, as a sunk cost, would reduce the marginal cost of electricity and improve the economics even further. In addition, net emission reductions associated with the destruction of drained methane are estimated to average just over 722,000 tonnes of carbon dioxide equivalent (tCO_2e) per year. Should MINOSA wish to continue with the proposed drainage plan, ARI recommends the following steps:

Step 1: Refine Pre-feasibility Analysis

Review the data and determine if more detailed and accurate data are required or are necessary. In addition, it will be beneficial to obtain more accurate costing information for Mexico, including costs for drilling and completion for vertical pre-drainage wells and installed capital costs and operating costs for packaged gas engines.

Step 2: Detailed Engineering & Design

If the results of the refined prefeasibility study are promising, the next step is to move forward with detailed engineering and design for a pilot well program.

Step 3: Pilot Well Program

The pilot well program would likely take the form of one or more 5-well clusters drilled on a fairly tight spacing (40 acres or less). Contiguous well patterns are important indicators of full scale production potential because they quickly achieve efficient dewatering of the continued well, an important criterion for coalbed methane production. Detailed plans should be developed for all phases of the drilling program including drilling, completion, stimulation, artificial lift, water disposal, and production operations.

Step 4: Full Feasibility Study including Field Development Plan

The results of the project will inform the development of a full feasibility study. In addition to further defining the elements of the pre-feasibility study including the project economics, the feasibility study should include reservoir simulation and data analysis to support the construction of the full field development plan.

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