U.S. EPA
Coalbed Methane
OUTREACH PROGRAM

Pre-feasibility Study for Coal Mine Methane Drainage and Utilization at the KWK "Pniówek" Coal Mine, Poland

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Acronyms/Abbreviations

ARI	Advanced Resources International, Inc.
Bcf	Billion Cubic Feet
cc	Cubic centimeter
CDM	Clean Development Mechanism
CMOP	US EPA Coalbed Methane Outreach Program
CMM	Coal Mine Methane
CH_4	Methane
CO_2	Carbon Dioxide
EU ETS	European Union Emissions Trading Scheme
ft	Feet
GMI	Global Methane Initiative
Ha	Hectare
Hg	Mercury
km	Kilometer
kW	Kilowatt
kWh	Kilowatt hour
m	Meters
m^3	Cubic meters
m^3/h	Cubic meters per hour
m^3/min	Cubic meters per minute
m^3/t	Cubic meters per metric tonne
Mcf	Thousand cubic feet
MMBtu	Million British Thermal Units
MMcf	Million cubic feet
MMSCF	Million Standard Cubic Feet
MSCFD	Thousand Standard Cubic Feet per Day
Mta	Million (metric) tonnes per annum
MtCO2e	Metric tonnes of CO_2 equivalent
MW	Megawatt
PL	Langmuir pressure (psia);
psi	Pounds per square inch
psia	Pounds per square inch absolute
SCF	Standard Cubic Feet
Sub-bit	Sub-bituminous coal
Tons	Short tons
Tonnes	Metric tonnes
USEPA	US Environmental Protection Agency
VAM	Ventilation air methane
VL	Langmuir volume (scf/ton

Metric/Imperial Unit Conversions

Metric	**Imperial**
1 hectare	2.47 acres
1 centimeter (cm)	0.4 inches
1 meter	3.281 feet
1 cubic meter (m^3)	35.3 cubic feet (ft^3)
1 metric tonne	2,205 pounds
1 short ton	2,000 pounds
1 short ton	907.185 kilograms
1 kilo calorie (kcal)	3.968 Btu (British Thermal Units)
252,016 kcal	1 MMBtu (million British Thermal Units)
159 litres	1 Barrel (bbl)
1 MegaPascal (MPa)	145 psi
1.01325 bar	1 atmosphere or 14.696 psi

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 sponsorship and publication 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.

Jastrzębska Spółka Węglowa SA (JSW SA), one of the largest coal mining companies in Poland, was selected for a pre-feasibility study for CMM drainage at one of its gassiest mines, the "Pniówek" Coal Mine. While JSW SA has been an early-adopter of CMM utilization (e.g., power generation, boilers, and cooling) in Poland, the company has not studied pre-mine drainage technologies to a great extent. They recently purchased an in-mine directional drill from Valley Longwall, which was delivered in March 2014. They are seeking assistance to help design the drilling program, including wellbore length, wellbore azimuths, wellbore spacing, gas/water gathering and collection design, piping, and utilization options.

A pre-feasibility study at the "Pniówek" Coal Mine will be instrumental in the implementation of a full scale drainage program at the mine that would not only significantly reduce methane emissions, but would also increase gas availability and help support the mine's long-term economic viability. A study at the "Pniówek" Coal Mine will also be useful for neighboring mines owned by other companies experiencing similar gassy conditions that have also requested assistance on pre-mine drainage design. In addition, both Polish ministry officials and private coal companies have stressed that pre-mine drainage is of prime and critical interest because without it many Polish mines will be forced to close because high gas emissions are resulting in excessive idling of coal operations. Furthermore, implementation of European Union policies to reduce greenhouse gas emissions (GHG) will result in additional costs for coal mining companies that fail to reduce methane emissions.

The "Pniówek" Coal Mine is located in the south-western part of the Upper-Silesian Coal Field, which is in south-western Poland, approximately 10 kilometers (km) from the border of Poland and the Czech Republic and 350 km south-west of the capital, Warsaw. Mining in the Upper Silesian Coal Field has occurred since 1740, and due to its coking coal resources it continues to be the most profitable coal basin in the country. The concession area of the "Pniówek" Coal Mine, and more specifically O.G Krzyżowice III, covers an area of 28.5 square kilometers (km^2) and extends to a depth of 1,100 meters (m) below the surface.

The "Pniówek" Coal Mine was selected for this pre-feasibility study because it is the gassiest mine in Poland and JSW SA realizes that an aggressive pre-mine drainage program will substantially reduce the methane content of the coal in advance of mining, thus making the mining environment safer and more productive. The principal objective of this pre-feasibility study is to assess the technical and economic viability of methane drainage utilizing long, in-seam directional drilling at the "Pniówek" Coal Mine and using the drained gas to produce electricity for onsite consumption.

The use of longhole directional drilling will allow for longer length and more accurate placement of boreholes for improved in-seam methane drainage efficiency. In addition, longhole directional drilling allows for the implementation of innovative gob gas drainage techniques that may be more efficient than cross-measure boreholes and at lower cost than superjacent techniques. Other benefits of longhole directional drilling include the ability to steer boreholes to stay in-seam, flank projected gateroads, or hit specific targets such as adjacent coal seams or gas bearing strata. This technique promotes a more focused, simplified gas collection system with improved recovered gas quality because of the reduced amount of wellheads and pipeline infrastructure. Additionally, the proposed drainage approach is less labor intensive, can be accomplished away from mining activity with proper planning, and provides additional geologic information (such as coal thickness, faults, and other anomalies, etc.) prior to mining.

The primary market available for a CMM utilization project at the "Pniówek" Coal Mine is power generation using internal combustion engines. Given the relatively small CMM production volume, as well as the requirement for gas upgrading, 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 6.9 megawatts (MW) of electricity capacity.

At the mine, the coal deposit is split into seven sections (B, C, K, N, P, S, and W) with five operating shafts covering the area. Based on the data received, gas drainage approaches for longwall panels in two mine sections (designated hereafter as PW and W) were explored in more detail. Pre-drainage boreholes were assumed to be drilled and begin production three to five years prior to the initiation of mining activities at each panel. CMM gas production profiles were generated for a total of four project development cases:

- Case 1: PW panels with 3 years of pre-drainage
- Case 2: PW panels with 5 years of pre-drainage
- Case 3: W panels with 3 years of pre-drainage
- Case 4: W panels with 5 years of pre-drainage

Under all four development cases it is assumed a total of 12 longwall panels will be mined. Production at one longwall panel will be initiated every four months until a maximum of six panels are in operation. Once a longwall panel has been mined through, production at another panel begins (assuming a face transfer time of three months) until a total of 12 longwall panels have been mined.

For the development of the PW panels, an in-seam flanking borehole is drilled and put on production either 3 years (Case 1) or 5 years (Case 2) prior to the commencement of longwall mining at each panel. After pre-drainage is completed, longwall mining operations begin along with gob production from the four horizontal gob boreholes drilled above each panel. For PW panels, mining of each panel is completed in 130 days based on a longwall face advance rate of 7.7 meters per day (m/d). As a result, the total project life for development of PW panels is 9 and 13 years for Case 1 and Case 2, respectively.

For the development of the W panels, dual purpose horizontal gob boreholes are drilled and put on production either 3 years (Case 3) or 5 years (Case 4) prior to the commencement of longwall mining at each panel. After pre-drainage is completed, longwall mining operations begin along with gob production from the three dual purpose horizontal gob boreholes drilled above each panel. For W panels, mining of each panel is completed in 303 days based on a longwall face advance rate of 3.3 m/d. As a result, the total project life for development of W panels is 10 and 14 years for Case 3 and Case 4, respectively.

Based on the forecasted gas production, the breakeven cost of producing CMM through in-seam drainage boreholes is estimated to be between USD $405 and $614 per thousand cubic meters ($/1000m^3) ($12.36 and $18.73 per million British thermal unit, MMBtu) for PW panels, and between $105 and $117/1000m^3 ($3.21 and $3.58/MMBtu) for W panels. The results of the economic assessment indicate the lowest CMM production costs are associated with the W panels with three years of pre-drainage (Case 3).

In terms of utilization, the power production option appears to be economically feasible. 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 price is estimated to be between $0.157 and $0.172 per kilowatt-hour (kWh) for PW panels, and between $0.059 and $0.070/kWh for W panels. The results of the economic assessment indicate the lowest power price is associated with the W panels with five years of pre-drainage (Case 4). As of mid-2015 the average rate of electricity for medium size industrial customers was $0.0928/kWh. When compared to the breakeven power sales price for Case 4 of $0.059/kWh, utilizing drained methane to produce electricity would generate profits of more than $33 per MWh of electricity produced.

The power production option appears to be 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 combustion of drained methane are estimated to average just over 110,000 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 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. In recent years, CMOP has sponsored feasibility and pre-feasibility studies in such countries as China, India, Kazakhstan, Mongolia, Poland, Russia, Turkey and Ukraine.

The principal objective of this pre-feasibility study is to assess the technical and economic viability of methane drainage utilizing long, in-seam directional drilling at the "Pniówek" Coal Mine. The "Pniówek" Coal Mine is an excellent candidate for increased methane use and abatement, and was chosen for this pre-feasibility study on the following basis:

- The mining area represents one of the largest coal reserves in Poland having estimated reserves of 101.3 million tonnes (Mt) of coal. Annual coal production is around 5.16 Mt.
- "Pniówek" mine already recovers CMM and utilizes the gas in a 10 megawatt (MW) electric power project and evaporative cooling system for the mine.
- At present, the mine is the gassiest mine in Poland and is considered a Category IV methane hazard. The mine is currently capturing gas by methane drainage methods; the methane drainage drilling technique allows it to capture 38 percent of the available gas, however, the remaining 62 percent is released into the ventilating air during mining and exhausts at the surface to the atmosphere.
- In order to ensure the safety of all 5,296 employees, JSW SA supports the exploration of new methane drainage techniques.

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

Specific details regarding active CMM projects in Poland, 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, which were developed in support of GMI.[1] The following excerpts from USEPA's CMM Country Profile for Poland summarize Poland's coal industry and CMM in Poland.

2.1 Poland's Coal Industry

Poland ranks ninth globally in coal production and produced 143.5 Mt in 2012, accounting for 1.82 percent of global production (Table 1). Hosting the second largest coal reserves in the European Union, coal

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[1] USEPA (2015). Coal Mine Methane Country Profiles: Chapter 27 – Poland. Updated June 2015, available: http://www.epa.gov/cmop/docs/cmm_country_profiles/Toolsres_coal_overview_ch27.pdf

provides for two-thirds of Poland's energy demand and over 75 percent (inclusive of peat) of its primary energy production (EIA, 2013).

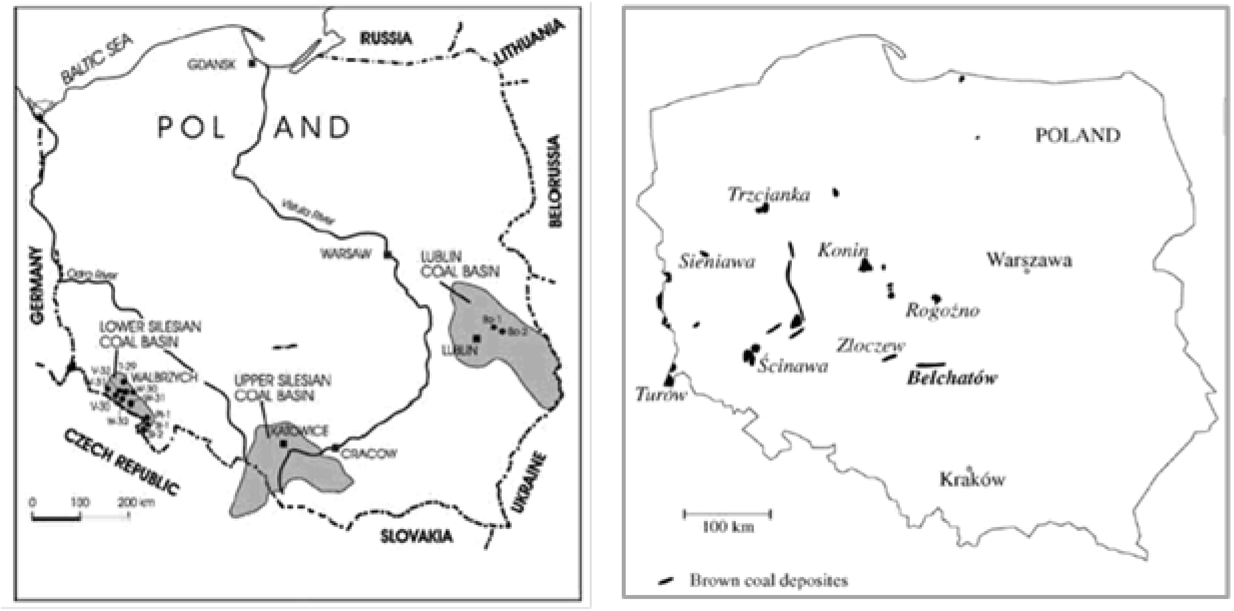
Indicator	Anthracite & Bituminous (million tonnes)	Sub-bituminous and Lignite (million tonnes)	Total (million tonnes)	Global Rank (# and %)
Estimated Proved Coal Reserves (2011)	4,176	1,287	5,463	16 (0.615%)
Annual Coal Production (2012)	79.2	64.3	143.5	9 (1.82%)

Source: *EIA (2013)

Table 1: Poland's Coal Reserves and Production

The World Energy Council estimated proven Polish coal reserves for anthracite and bituminous in 2011 at 4,178 Mt and reserves for lignite and sub-bituminous of 1,287 Mt (WEC, 2014). An in-country estimate from 2002 estimated reserves of 63,000 Mt and 14,000 Mt, for hard coal and lignite, respectively (Palarski, 2003).

As seen in Figure 1, Poland's hard coal reserves are located in three fields: the Upper and Lower Silesian Basins, and the Lublin Basin. Currently, only the Upper Silesian Basin is the major coal producer, while the Lower Silesian Basin is completely abandoned, and only one mine is operational in the Lublin Basin. Lignite basins are located in central and western Poland, with four basins currently used in production (WEC, 2014).



Location of Hard Coal Basins

Poland's Lignite Deposits

Source: Volkmer, 2008

Figure 1: Poland's Major Coal Basins

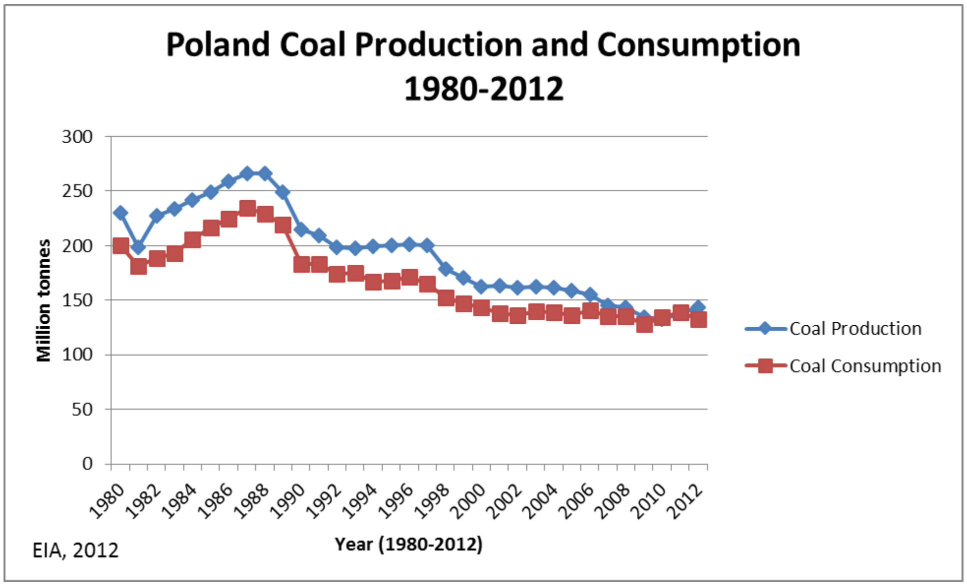


Figure 2: Coal Production and Consumption in Poland (1980-2012)

As shown in Figure 2, Polish coal production levels have been falling since 1989. Poland consumes almost all of the coal it produces, while exporting only a small amount. The Polish government has attempted to revitalize the industry by restructuring the coal sector, as discussed in more detail in the following section.

2.1.1 Restructuring of the Poland Coal Industry

Coal is one of Poland's largest industries and employers, but inefficiencies have resulted in large annual losses, spurring the government to reform the sector. In 1998, the government introduced a five-year (1998-2002) Hard Coal Sector Reform Program, which reduced employment from 248,000 to 140,000 by the end of 2002. Table 2 illustrates Poland's declining mine statistics from 2004 to 2008, with the statistics from JSW SA shown in bold. In November 2003, the government introduced a second program to further consolidate and reform Poland's coal sector – Program of Restructuring of the Hard Coal Mining Sector for 2003 to 2006 (World Bank, 2004). Poland received a World Bank loan of $100 million in 2004 to support the restructuring program, requiring a workforce reduction of 25,500 mining sector jobs from 2004 to 2006 and for voluntary closure of inefficient mines (World Bank, 2007).

Company	**Number of Mines, 2004***	**Number of Mines, 2008****
Kompania Weglowa (KW)	23 (51 Mt/yr)	16
Katowicki Holding Weglowy (KHW)	9 (19 Mt/yr)	6
Jastrzebska Coking Coal Company (JSW)	**5 (14 Mt/yr)**	**6**

Independent Mines: Bogdanka, Budryk, and Jaworzno	3 (11 Mt/yr)	NA

Source: *World Bank (2004), **DOC (2008)

Table 2: Poland's Coal Mines, 2004 vs. 2008

The restructuring program also planned to privatize the country's coal industry by 2006. Privatization of the coal industry was, however, halted by the Polish government in 2006. The World Bank-supported restructuring program was suspended by the Polish government in 2006 because the coal industry had become more profitable and only two mines had been closed through the project. The Polish government decided that any further mine closures would be handled by the mine companies and not by the Mine Restructuring Company (SRK). The loan balance was returned (World Bank, 2007).

The restructuring program led to substantial changes in Poland's three major coal basins. Specifically, the Lower Silesian Coal Basin was closed, there were significant reductions of coal production in the Upper Silesian Basin, and the efficient Lublin Coal Basin was the only basin open for production and subsequent expansion. Post restructuring, the Polish coal industry has experienced periods of profitability. However, market forces and increasing foreign coal imports threaten the domestic coal industry. Poland's goal of commercializing and privatizing the mining companies was completed by 2009 (Suwala, 2010).

2.2 Coal Mine Methane in Poland

The GMI CMM Projects Database currently identifies three active and four proposed CMM recovery projects in Poland (GMI, 2014). Poland has extensive experience in CMM recovery and utilization. Specifically, the project at JSW SA's "Pniówek" Coal Mine, where this pre-feasibility study is focused, implements three onsite end-uses: electricity, heating, and cooling. A cogeneration power-cooling system supplies power to the central air conditioning system and was the first of its kind upon its launch (UNECE, 2009). In addition to JSW SA, Kompania Weglowa has implemented a power project using CMM at the Knurow-Szczyglowice Mine and is planning for a ventilation air methane (VAM) project at the Brzeszcze Mine.

2.2.1 CMM Emissions from Active Mines

In 2010, coal mining was the source of 22.6 percent of the country's overall methane emissions (USEPA, 2012), with total emissions equaling 2,364 million cubic meters (Mm^3). Table 3 summarizes Poland's CMM emissions by mining category.

Emission Category	1990	1995	2000	2005	2008	2009	2010	2011
Underground coal mines – mining activities	817.49	789.10	690.26	600.71	503.72	455.35	446.87	436.86
Underground coal mines – post-mining activities	65.84	58.97	49.38	45.43	38.89	35.64	35.08	34.39

Surface coal mines – mining activities	1.22	1.15	1.08	1.11	1.08	1.04	1.02	1.14
Solid fuel transformation	9.59	8.22	6.37	5.96	7.15	5.04	6.91	6.65
Emission from coke oven gas subsystem	6.41	4.75	4.43	3.92	5.73	4.71	6.14	6.29
Total emitted	884	849.22	740.73	647.25	543.69	492.02	482.97	472.39

Source: UNFCCC (2013)

Table 3: Poland's CMM Emissions (Mm^3)

As of 1997, about 300 Mm^3 was being drained from Polish coal mines annually, with 65 percent to 70 percent of drainage being used at the mine sites or sold to outside consumers, and the rest vented (Schwochow, 1997). Methane recovery, however, has declined over the years, mainly due to the closure of numerous mines. Of an estimated 870 Mm^3 of methane emissions in 2006, less than 30 percent was removed through degasification (IEA, 2008). In 2008, 269 Mm^3 was removed through degasification, with about 166 Mm^3 utilized and 103 Mm^3 released into the atmosphere (Skiba, 2009). In 2011, about 268.97 Mm^3 was removed through degasification systems, which comprised approximately 13 percent of methane emissions for 2011 (UNFCCC, 2013).

Although the number of gassy mines has decreased in Poland by 48 percent from 1989 to 2005, absolute gassiness has dropped by only 19 percent over the period, indicating an increasing share of gassy coal mines in the country. This scenario represents an opportunity for CMM recovery and utilization projects (IEA, 2008). CMM capture is forecasted to increase to 320.5 Mm^3 by 2015, with an estimated utilization potential of 1,068 gigawatt-hours (GWh) (Skiba & Wojciechowski, 2009). Poland has an open, emerging market economy that should be conducive to CMM project implementation, and Polish mining authorities are supportive of CMM development initiatives (IRG, 2003). Actions similar to the World Bank's industry restructuring loan should also constitute positive factors favoring project development.

The GMI awarded a grant in 2008 to the Central Mining Institute of Katowice, Poland to provide "Detailed Characteristics of the Ventilation Air Methane Emissions from Ten Gassy Underground Coal Mines in Poland," and another in 2009 to perform a "Pre-feasibility Study for Degasification and Methane Capture Before Mining at the Pawlowice I Coal Field." A third grant was awarded to the Institute for Ecology of Industrial Areas in 2008 to perform an "Abandoned Mine Feasibility Study and Coal Mine Methane to Liquefied Natural Gas Assessment" at the Zory Coal Mine in the Silesian region [M2M Agreements (2008); M2M Agreements (2009)].

2.2.2 CMM Emissions from Abandoned Coal Mines

No data quantifying emissions from abandoned Polish mines are currently available, though the methane volume in abandoned coal mines in the Upper Silesian Basin was estimated in 2006 to range from 150 billion cubic meters (Bm^3) to 200 Bm^3 (Nagy, Awrychlicki, & Siemek, 2006).

2.2.3 CBM from Virgin Coal Seams

Estimated in-place coal seam gas resources in Poland are summarized in Table 4. One estimate of resources in actively mined and undeveloped coals in the Upper Silesian Basin yields 1,300 Bm3 of coalbed methane (CBM) to a depth of 1,500 m. A different method used by the Polish Geological Institute yields a more conservative estimate of 350 Bm3, of which 210 Bm3 exists in virgin coal. Including the Lower Silesian and Lublin basins, total in-place CBM resources range from 425 Bm3 to 1,450 Bm^3 (Schwochow, 1997).

Coal Basin	**Gas Content**		**Gas in Place**	
	m^3/Mg	**m^3/t**	**billion m^3**	**Tcf**
Upper Silesian, first estimate*				
Active mines to 1,000 m (3,280 ft)	—	—	370	13.1
Undeveloped coal to 1,000 m (3,280 ft)	—	—	340	12.0
Coal at 1,000–1,5000 m (3,280–4,920 ft)	—	—	590	20.8
Subtotal	***≤ 22***	***≤ 20***	***1,300***	***45.9***
Upper Silesian, second estimate† Coal to 1,500 m (4,920 ft)	≤ 20	≤ 18.1	350	12.4
Lower Silesian‡	≤ 30	≤ 27.2	25-50	0.9-1.8
Lublin‡	25	22.7	50-100	1.8-3.5
Total	**≤ 97**	**≤ 88**	**425-1,450**	**15-51**

Source: *Hoffman and Weil (1993); †Surówka (1993); ‡Grzybek (1996), as presented in Schwochow (1997)

Table 4: Poland’s In-Place CBM Resources

The Upper Silesian Basin first attracted CBM developers in the early 1990s. Several CBM concessions were granted from 1991 to 1997, but none of these could establish commercial production of CBM. CBM production in Poland is contingent on the availability of highly specialized equipment and expertise (Hadro, 2008).

2.3 KWK “Pniówek” Coal Project

KWK “Pniówek” began mining in 1974 with the current concession area (O.G Krzyżowice III) covering 28.5 km² at a depth of 1,100 m below the surface (Figure 3 and Figure 4). The coal deposit is split into seven sections (B, C, K, N, P, S, and W) with five operating shafts covering the area. Shafts 1 and 2 and the Ludwik shaft are located within the center of the concession. Shaft 4 is located in the north-west and shaft 5 is located in the far east of the concession.

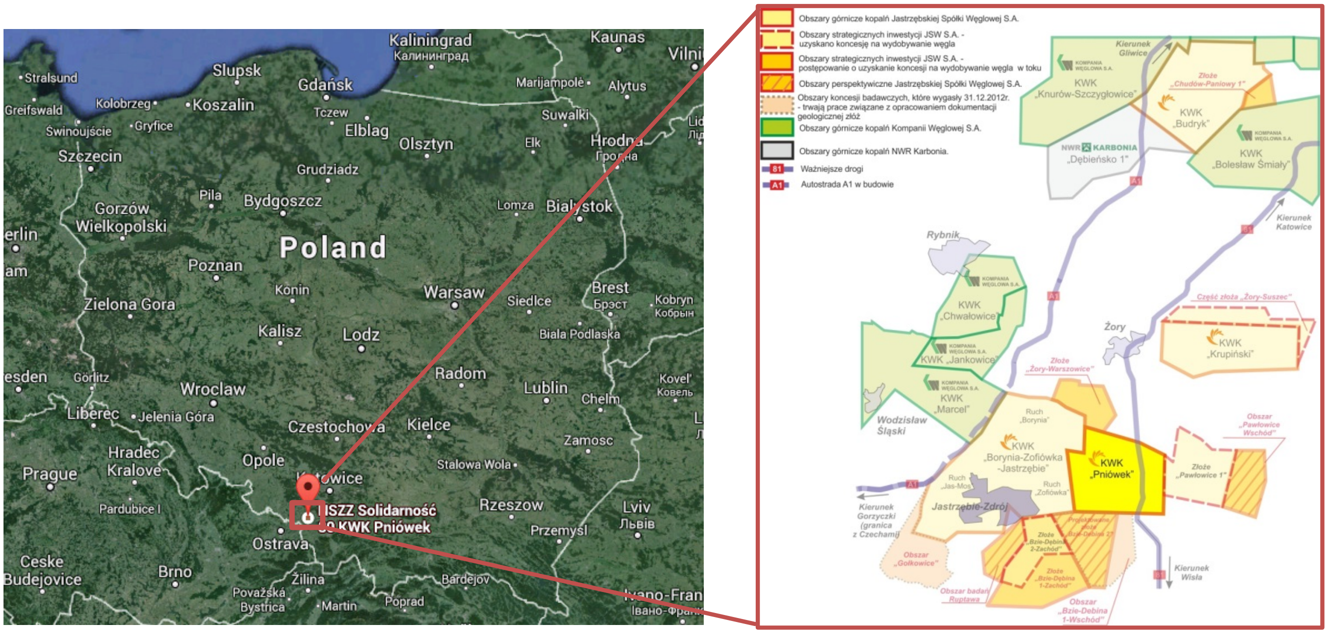


Figure 3: Location of the KWK “Pniówek” Coal Project (JSW SA, 2014)

Concession Details	O.G Krzyżowice III	Pawłowice I	Deepening	Exploration of Pawłowice-Wschód Deposit
Concession Received (Planned)	1993	2012	-	2012
Concession End	2020	2051	-	2015
Concession Area	28,55 km²	15,83 km²	28,55 km²	13,18 km²

Concession Depth	1 100 m	1 300 m	1 230 m	Floor of Carboniferous

Table 5: Concessions of the KWK "Pniówek" Coal Project (JSW SA, 2014)

There are currently 23 industrial seams within the Krzyżowice III concession area, from seam 355/1 to seam 409/4 while in Pawłowice I there are 10 industrial seams, from 356/1 to 401/1. The coal deposits of "Pniówek" are situated within the south-western part of the Upper Silesian Coal Basin, to the east of the Jastrzębie anticline.

2.4 JSW SA

Jastrzębska Spółka Węglowa SA was established on April 1, 1993 when seven independently operating mining enterprises transformed into a wholly owned company of the State Treasury. JSW SA is the largest producer of high-quality coking coal in the European Union at 9.8 Mt in 2013. JSW SA is composed of five mines producing coking coal and steam coal: Borynia-Zofiówka-Jastrzębie, Budryk, Knurów-Szczygłowice, Krupiński, "Pniówek", and the Material Logistics Center. In addition to steam and coke coal mines, the JSW SA group also has coking plants that process approximately 50 percent of the coking coal that the company produces; JSW SA coking plants produced 3.9 Mt of coke in 2013.

3 Summary of Mine Characteristics

3.1 Coal Production

The Upper Silesia Coal Basin is the major coal producing region of Poland where coal deposits have been mined since the seventeenth century (Smakowski, 2011). Currently the mine plan shows six faces being worked at the same time. However, production is constrained by a number of factors:

- Methane levels are high on certain faces and restrict output in order to maintain gas levels in the return below the statutory limit.
- The transfer time of the faces is planned to be 2.5 to 3 months indicating a considerable gap in production as faces are changed.

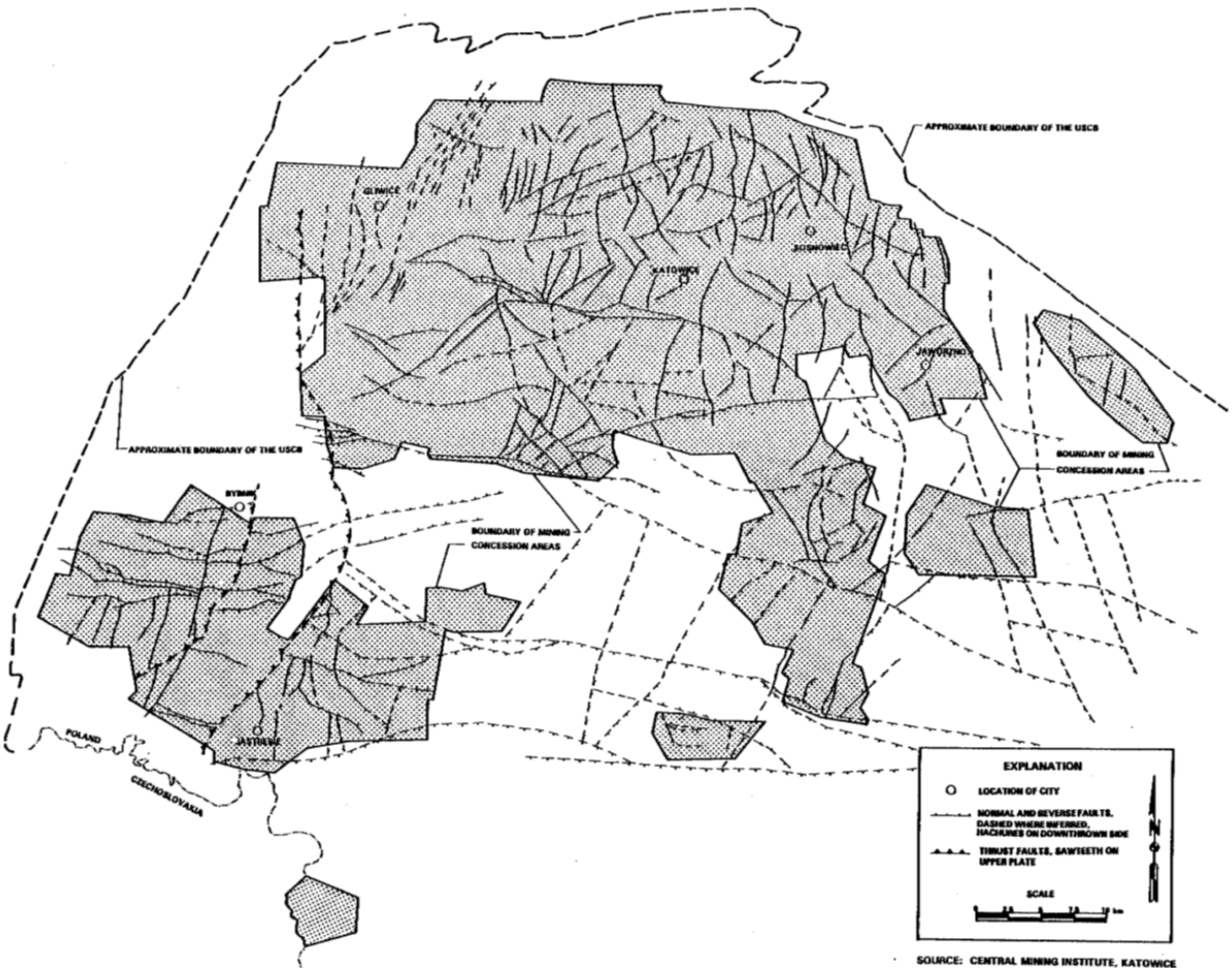
Typically the face tonnage from a 245 m wide face is planned to be approximately 2,500 tonnes (t) per day from a face 1.8 m in height. KWK "Pniówek" produced 2,558,695 saleable tonnes from 5,650,517 run-of-mine (ROM) tonnes in 2012, producing from an average of 4.8 faces at any one time. This would indicate an average face performance of 1,984 t/day. The mine produced 2,875,000 saleable tonnes from 6,250,000 ROM tonnes in 2013, producing an average of 11,500 t/day. Production is planned to increase to more than 12,000 t/day on average over the next four years, then increasing again to 12,600 t/day in 2016 and 2017.

3.2 Geological Characteristics

3.2.1 Regional Geology and Tectonics

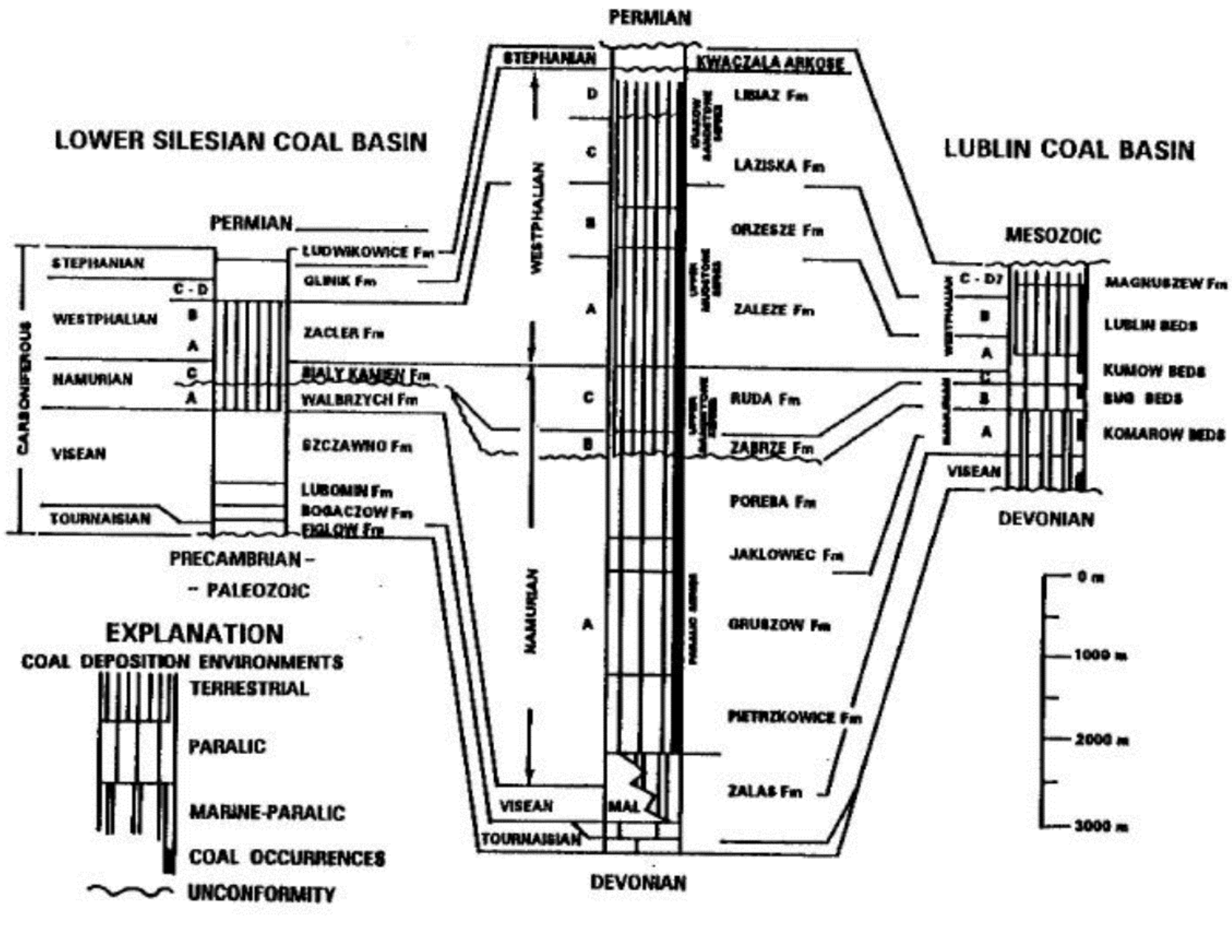
The Upper Silesian Coal Basin is bordered on the west by the Moravo-Silesian Fold Zone, on the south by the Brunnia-Upper Silesia Massif, and on the east by the Krakow Fold Belt. The Upper Silesian Coal Basin extends southward from the Rybnik area into the Ostrava-Karvina coal mining district of the Czech Republic. Predominant tectonic characteristics (Figure 4) are south-southwest to north-northeast trending folds and thrusts in the west; faults are superimposed on dome and basin structures in the center and east of the basin while half horsts cut across the entire basin.

Generally dipping south-southeast, the coal bearing formations are divided into an upper part consisting of continental sediments deposited in limnic-fluvial environments and a lower part comprised of siliciclastic, molasse sediments deposited in marine, deltaic, fluvial, and limnic environments. The general stratigraphy of the basin is depicted in Figure 5. Formations of Carboniferous age contain the 4,500 m thick productive series, which includes 234 coal seams, of which 200 are considered economic (Kotas & Stenzel, 1986). The total thickness of the coal seams is 339 m. The upper part of the Namurian section includes the Zabrze and Ruda formations, totaling a coal bearing thickness of about 80 m. Also known as the Upper Sandstone Series, the Zabrze and Ruda formations comprise the principal economic section within the basin and pinch out to the east.



SOURCE: CENTRAL MINING INSTITUTE, KATOWICE

Figure 4: Tectonic Map of the Upper Silesian Coal Basin, Poland



(AFTER KOTAS AND PORZYCKI)

Figure 5: Stratigraphic Correlation of the Coal Bearing Formations in Poland

On average, Upper Silesian Coal Basin coals contain 0.86 percent to 1.99 percent sulfur (average 1.3 percent) and 11.05 percent to 16.21 percent ash (average 13.7 percent). Heating value ranges from 28.7 megajoules per kilogram (MJ/kg) to 32.1 MJ/kg. Coal rank ranges from subbituminous to anthracite; only subbituminous and bituminous coal is being mined at present. Mining depth ranges from 235 m to 1,160 m.

3.2.2 “Pniówek” Geology

The “Pniówek” concession is bounded on the south by east-west trending normal faults. Strata south of this boundary are downthrown as much as 300 m relative to those north of the boundary. A zone of east-west trending normal faults is also present in the northernmost part of the concession. These faults displace strata to the south as much as 250 m. Just outside the north-east boundary of the concession, a normal fault displaces strata to the south by up to 500 m. Faults in the southern part of the concession do not reach the surface. Carboniferous formations are unconformably overlain by Miocene strata in the southern part of the concession, and presumably in the northern part as well. The average geothermal gradient is 4.0° C per 100 m (USEPA, 1995).

3.3 Mining and Geologic Conditions of Operations

3.3.1 Mine Specifics

The mine is accessed from the surface by five shafts called Ludwik, II, III, IV, and V. Shafts III, VI, and V are upcast shafts with ventilation equipment exhausting air from the mine. Shaft III is additionally used for transport of men and materials. Shaft Ludwik is a downcast shaft and the main hoisting shaft, while shaft II is upcast and used for transport of men and materials. The basic shaft details are presented below in Table 6.

Shaft Details	Shaft I "Ludwik"	Shaft II	Shaft III	Shaft IV	Shaft V
Ventilation	Intake	Intake	Return	Return	Return
Use	Main Coal Winding shaft	Men and Materials, Rock hoisting	Ventilation Men and materials	Ventilation	Ventilation
Diameter (m)	8	8	7.5	7.5	7.5
Shaft depth (m)	921	1038	865	709	1018
Winding depth (m)	830	1000	830	705	1000
Skip or cage size, capacity	Side 1 - 2X25t Side 2 – 2x25t	2 x two 4-storey cages, each with capacity of 3.5 Mg	Material skip, Single 2-storey cage with capacity of 16 Mg		

Table 6: Basic Shaft Details

The seams are only slightly dipping over most of the take with maximum dip of 12 degrees to the north-east adjacent to the Pawłowice I field. All the underground roadways are formed using standard "V" arches, those observed were mainly four piece arches, which is typical for all the mines. Construction of the roadways uses conventional mining methods with heading machines matched with the strata conditions. The heading machines cut out 1 m to 2 m of ground and then arches at 0.7 m width setting are set. The whole arch setting method is used where the arch is constructed on the ground and then lifted into position as a whole. Linking steel mesh is used around the arch to prevent small pieces from falling (USEPA, 1995). The heading machines are mainly manufactured by Polish manufactures: AM50, AM75, R130, KTW 200, and MR 340X-Ex. There is a mix of ownership of the machines with some being leased and some owned outright by the mine.

The mine uses the longwall retreat method of mining and works six faces on average to achieve its production targets involving up to six face transfers a year. In 2012, the typical face width was 223 m, face lengths were typically 500 m to 1500 m, with face heights of 2.53 m producing 1,984 t/day, although there is variation between individual faces. The mining method is conventional with the coal being cut in strips of 0.8 m and the roof caving behind the powered supports as the face retreats.

The drives are in the roadways, and the arches in the top and bottom roadways must have the face side leg removed to allow the face to move out. Generally, conditions in the roadways in advance of the face appeared to be good with little or no floor lift or roof convergence, which is typical of many such installations. On some faces, the waste is sealed using a hydraulic fill of fly ash or anti-pyrogenic agent and saline water. This does not give support to protect against surface subsidence but it does reduce air leakage through the gob preventing methane from building up in the gob area and also limiting spontaneous combustion through that air leakage.

3.3.2 Coal Seam Characteristics

Almost two-thirds of the documented coal resources of the Upper Silesian Coal Basin are subbituminous or high volatile C and B bituminous. Most of the remaining coal resources are classified as medium and low-volatile bituminous coal. Coals at “Pniówek” are predominantly of Type 35, a coking coal, and are low to moderate in ash content, low in sulfur content and are of medium volatile content. Table 7 and Table 8 summarize the coal types in the “Pniówek” and Pawłowice I deposits, respectively.

Coal Type	Percentage of Coal Types within “Pniówek”
34.1	0.6%
34.2	2.7%
35.1	38.1%
35.2A	45.7%
35.2B	12.9%

Table 7: Summary of Coal Types in Industrial Reserves in “Pniówek” deposit

Coal Type	Percentage of Coal Types within Pawłowice 1
34.2	21.4 %
35.1	78.6 %

Table 8: Summary of Coal Types in Industrial Reserves in Pawłowice 1 deposit

3.4 Proximate Analysis

Average coal characteristics are shown in Figure 6, Table 9, and Table 10 below. For reference, coking coals usually have a calorific value of 29.3 MJ/kg to 35.1 MJ/kg, an ash value of less than or equal to 6.9 percent, a total sulfur value of less than or equal to 0.7 percent, a moisture value of less than or equal to 8.0 percent, and a volatile matter value of less than or equal to 8.0 percent (UNECE, 2010). The average coal quality data are stated for net coal, excluding waste bands found within the mined seams greater than 5 centimeters (cm) thick. Higher ash content values are likely to be associated with the presence of in-seam waste bands less than 5 cm thick.

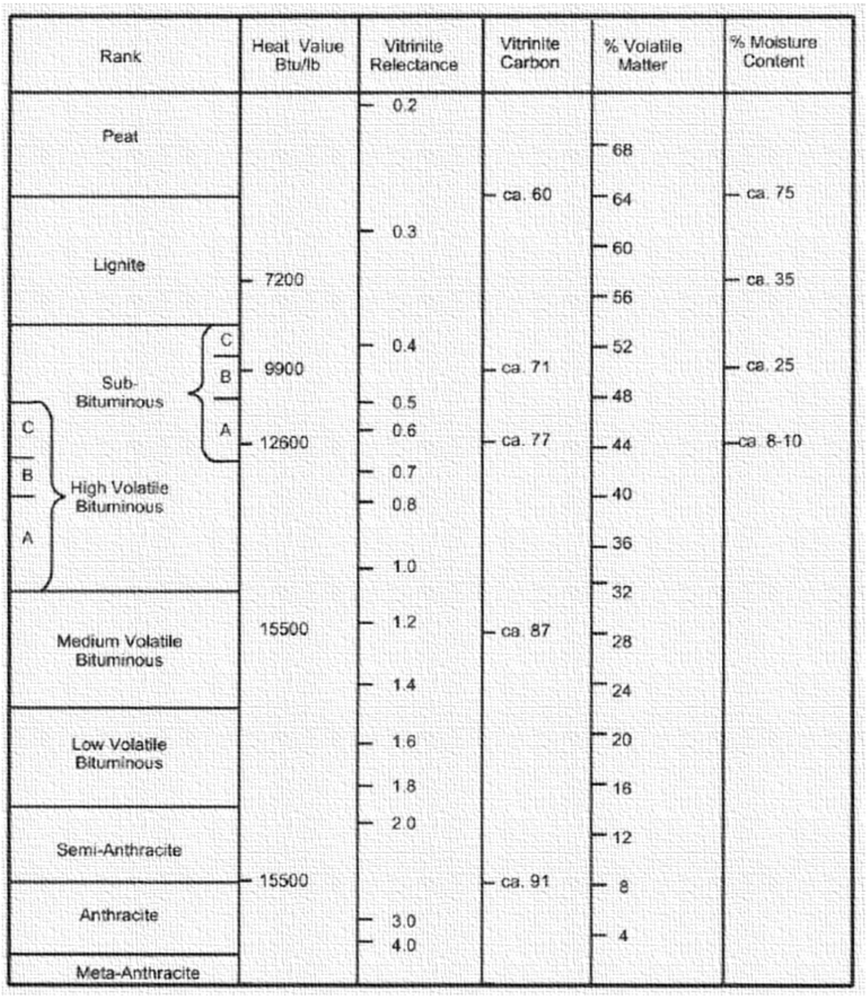


Figure 6: Relationship between Coal Type and Parameters of Heat Value, Vitrinite Reflectance, Vitrinite Carbon, Volatile Matter, and Moisture content (McCune, 2002)

Seam	Moisture	Ash	Volatile Matter	Calorific Value	Sulfur	Phosphorus	Coal Type
355/1	1.63	15	27.57	28094	0.88	0.09	34.2
356/1	1.36	11	28.21	30289	0.63	0.06	34.2 i 35.1
357/1	1.26	23	29.01	25501	0.62	0.05	34.2 i 35.1
358/2	1.25	11	27.61	30077	0.69	0.16	35.1
360/1	1.19	9	27.81	30871	0.60	0.06	35.1
361	1.09	9	27.21	31300	0.66	0.07	34.2 i 35.1
362/1	1.08	18	25.50	27965	0.68	0.15	35.1 i 35.2A
362/3	1.16	20	25.25	27931	0.73	0.10	35.1 i 35.2A
363	0.99	12	26.08	29826	0.63	0.10	35.1 i 35.2A
401/1	0.97	13	26.03	29726	0.60	0.07	35.1 i 35.2A
403/1	0.95	11	24.86	30789	0.75	0.08	35.1
404/1	0.87	15	24.84	29517	0.56	0.06	35.1 i 35.2A
404/2	0.94	10	24.87	30927	0.50	0.06	35.1 i 35.2A
404/3	0.99	12	23.75	30282	0.98	0.07	35.2A
404/4	1.10	8	22.92	31344	0.43	0.05	34.1. 35.2A i 35.2B
404/4+405/1	1.15	8	26.36	31410	0.42	0.05	35.2A i 35.2B
405/1	1.19	14	29.80	29025	0.50	0.04	34.1. 35.1. 35.2A i 35.2B
405/2	0.90	17	22.84	24542	0.52	0.06	35.2A
406/2	0.86	17	22.17	28847	0.56	0.20	35.1 i 35.2A
407/2	0.99	24	22.38	25675	0.65	0.01	35.1 i 35.2A
407/4	1.20	11	21.66	31588	0.52	0.04	35.2A
408/2	0.87	20	22.21	23537	0.54	0.01	35.2A
409/4	0.70	22	18.76	26856	0.67	0.02	35.2A

Table 9: Average Coal Quality per Seam (Air-Dried Basis) in "Pniówek" Deposit

Seam	Moisture	Ash	Volatile Matter	Calorific Value	Sulfur	Phosphorus	Coal Type
356/1	1.24	13.30	28.78	27823	0.52	n/a	34.2 i 35.1
357/1	1.20	13.65	29.34	29100	0.43	n/a	34.2 i 35.1
358/1	1.15	11.13	29.34	28327	0.45	n/a	34.2 i 35.1
359/1	1.14	10.68	29.26	30044	0.60	n/a	34.2 i 35.1
359/3	1.16	11.40	28.40	29977	0.48	n/a	35.1
360/1	1.06	16.97	27.94	28074	0.60	n/a	35.1
361	1.13	14.62	27.72	28951	0.58	n/a	35.1
362/1	0.94	12.44	27.39	29742	0.58	n/a	35.1
363	0.91	21.18	26.39	26425	0.44	n/a	35.1
401/1	0.85	15.66	25.84	28693	0.49	n/a	35.1

Table 10: Average Coal Quality per Seam (Air-Dried Basis) in Pawłowice 1 Deposit

4 Gas Resources

4.1 Overview of Gas Resources

The “Pniówek” Coal Mine is the gassiest mine in Poland; the Carboniferous deposits where the coal is mined are covered by an overburden of thick, non-permeable Miocene layers, which prevent methane from escaping the coal seams (Patyńska, 2013). The “Pniówek” Coal Mine practices multi-level longwall mining (with six longwall faces) and exploits moderately gassy coal seams that are likely lower in permeability. Longwall panels are generally 200 m to 240 m wide by 500 m to 1500 m long and are developed with single entry gateroads. The longwall panels are mined in retreat with the gob ventilated in some cases (bleeder type system), or sealed using hydraulic fill. Methane is emitted primarily from longwall gob areas when adjacent overlying and underlying coal seams are disturbed (stress relaxation) during mining.

Mine methane emissions are over 225 cubic meters per minute (m^3/min) with methane capture efficiencies of approximately 30 percent using only cross-measure boreholes for gob gas recovery. These may be implemented from both gateroads (headgate and tailgate) depending on conditions (typically only from tailgate). In-seam drilling in advance of mining (rotary probe holes, for example) is likely not implemented except perhaps for the 404 seams that are prone to gas outbursts.

Figure 7: Methane Drainage Station at the “Pniówek” Coal Mine (JSW SA)

In 2012, the methane drainage installations collected 40.6 Mm^3 of pure methane, out of which 33.7 Mm^3 (83 percent) was utilized in energy installations, including 18.8 Mm^3 (56 percent) in four gas engines operated by “Pniówek” Coal Mine (Table 11). In 2013, the methane drainage installations collected 37.1 Mm^3 of pure methane, out of which 34.2 Mm^3 (92 percent) was utilized in energy installations, including 19.1 Mm^3 (56 percent) in four gas engines operated by “Pniówek” Coal Mine. In 2012, the drained methane was used to produce 97,367 megawatt-hours (MWh) of electricity, 248,546 gigajoules (GJ) of heat, and 33,621 MWh of cooling.

Methane capacity m^3/min	**Year**				
	2009	**2010**	**2011**	**2012**	**2013**
Ventilation	148.29	139.65	144.67	144.62	155.77
Drainage	85.39	83.45	93.44	77.13	70.67
Total	233.68	223.10	238.11	221.75	226.44
Efficiency of Drainage	36.5%	37.4%	39.2%	34.7%	31.2%

Table 11: Methane Emissions in "Pniówek" Mine

4.2 Proposed Gas Drainage Approach

Based on a detailed review of the mine data provided by JSW SA, the following directional drilling approaches are recommended for gas drainage at the "Pniówek" Coal Mine. Depending on the local mining conditions present at each longwall panel, one or more of the drainage concepts presented below could be applicable:

- In-seam boreholes in advance of single entry developments for geologic exploration (fault detection and characterization), de-pressurization of any gas charged faults, and to reduce in-situ gas contents as feasible depending on time available for drainage.
- Overlying horizontal gob boreholes along the up-dip and tailgate side of panels drilled from within the mine (most panels are less than 1,000 m long so this should be feasible). These would displace cross-measure boreholes and improve recovered gas quality, gob gas recovery management, and methane drainage efficiency.
- Strategically placed dual purpose overlying horizontal gob boreholes drilled in advance of mining to (a) reduce gas contents of source seams, especially those that have been affected by mining induced fractures, and (b) subsequently recover gob gas during longwall mining depending on elevation.
- Dual purpose or horizontal gob boreholes developed from overlying active mine entries down to appropriate elevations in the interburden above planned lower elevation longwall panels.

To illustrate the application of the above drainage concepts at the "Pniówek" Coal Mine, drainage approaches designed specifically for longwall panels in two mine sections (designated hereafter as PW and W) are recommended as outlined below.

4.2.1 Gas Drainage of PW Panels

Figure 8 and Figure 9 illustrate the conceptual gas drainage approach proposed for the PW panels. In this example, gas drainage is accomplished through a combination of one in-seam flanking borehole (HDH1 as designated in green in Figure 8) and four horizontal gob boreholes (HGH1-4 as designated in blue in Figure 8). The in-seam flanking borehole will reduce gas content in advance of PW-3 gate development and define the extent of mineable reserves along bounding geologic features (e.g., faults). The horizontal gob boreholes will be placed along the up-dip tailgate side of the PW-2 panel on 20 m centers and be drilled from separate collars for gas management, each capable of producing up to 10 m^3/min under high vacuum.

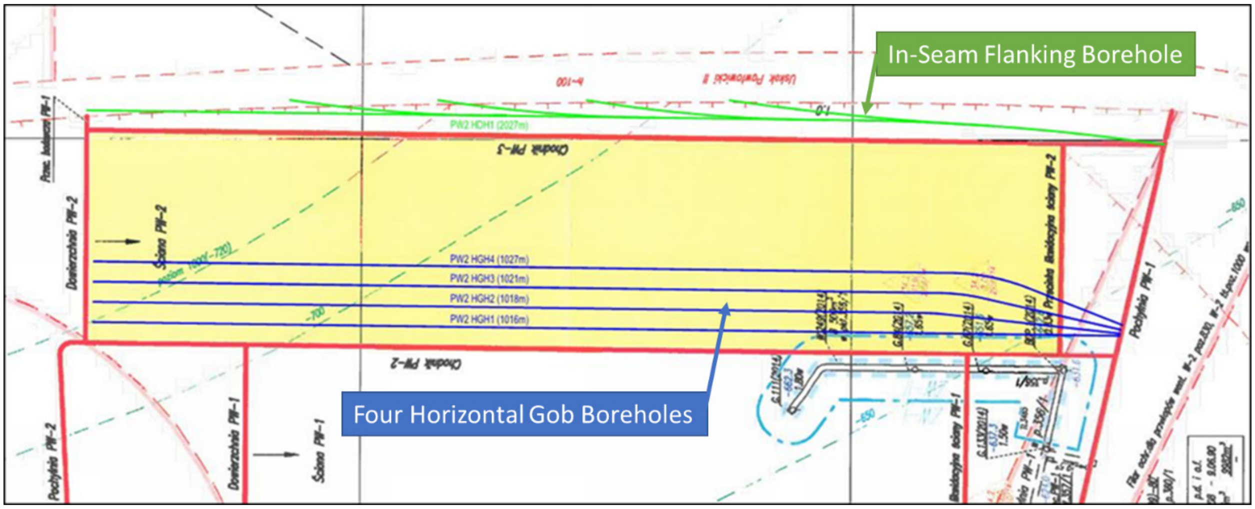


Figure 8: Conceptual Gas Drainage Approach PW Panels (Top View)

As shown in Figure 9, the horizontal gob boreholes will be placed at varying elevations to target relaxed strata (the tension zones along the sides and ends of the panel and in the fracture zone above the rubble zone in the gob) resulting from under-mining. Placement should be varied and each borehole developed from an independent collar to optimize vertical placement through field testing (production monitoring). Ideally boreholes should be placed below the lowest gob gas source seam and at sufficient elevation to remain intact to produce gob gas over the entire length of the borehole as the longwall advances. Boreholes need to be placed on high vacuum and monitored for gas make and volume flow rate.

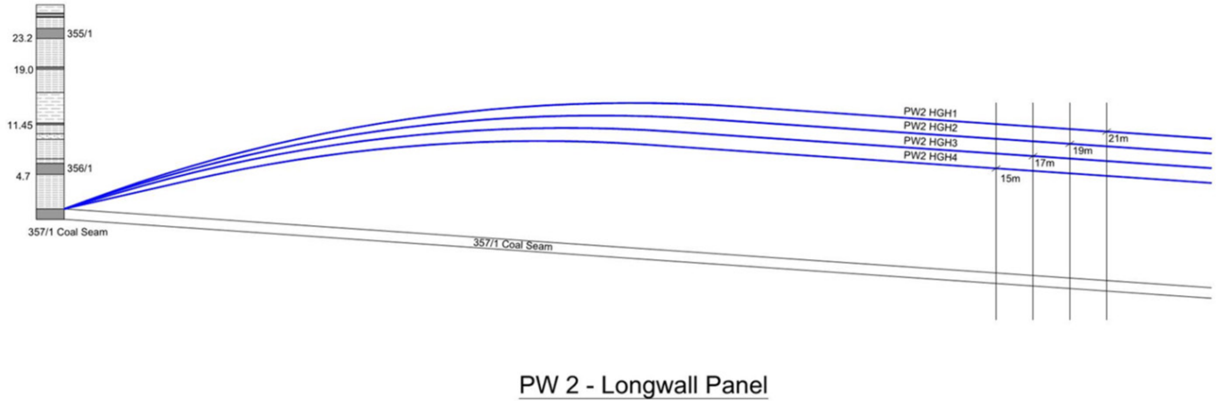


Figure 9: Conceptual Gas Drainage Approach PW Panels (Side View)

4.2.2 Gas Drainage of W Panels

Figure 10 and Figure 11 illustrate the conceptual gas drainage approach proposed for the W panels. In this example, gas drainage is accomplished through the application of three dual purpose horizontal gob boreholes (DPHGH1-3). The dual purpose horizontal gob boreholes, which will be drilled in advance of longwall mining, serve to reduce the gas content of the gob gas contributing source seam, Seam 360/3 (fractured due to over-mining), and serve as horizontal gob boreholes during subsequent longwall mining.

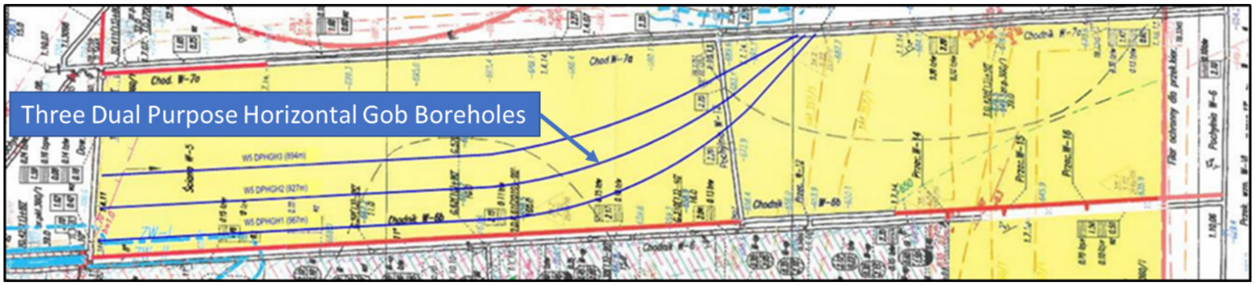


Figure 10: Conceptual Gas Drainage Approach W Panels (Top View)

Overlying mining at the 360/1 Seam level (24-35 m above) has likely induced fractures in gob gas source seams in the interburden (between 361 and 360/1), increasing their permeability. As depicted in Figure 11, the dual purpose horizontal boreholes can be drilled from two different locations:

- Option A: Dual purpose boreholes drilled from the 361 seam mining level from a drill site developed off of the gateroad inby entry W-12 to reduce the gas content of the fractured 360-3 gob gas contributing source seam in advance of mining and to subsequently serve as horizontal gob boreholes during longwall mining.
- Option B: Dual purpose boreholes drilled from workings in the overlying 360/1 seam to reduce the gas content of the fractured 360-3 gob gas contributing source seam in advance of mining and to subsequently serve as horizontal gob boreholes during longwall mining.

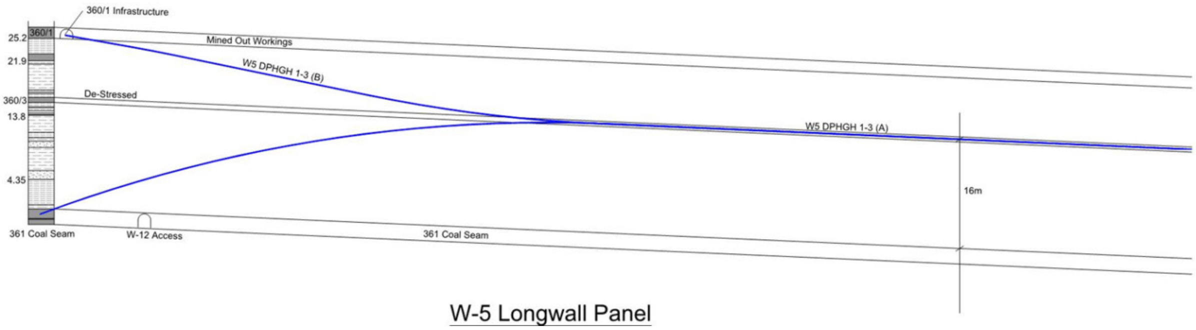


Figure 11: Conceptual Gas Drainage Approach W Panels (Side View)

4.3 Estimating Gas Production from PW Panels

Two reservoir models designed to simulate gas production volumes from in-seam flanking and horizontal gob 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

For the degasification of PW panels, a single-layer model was constructed in order to calculate gas production for the in-seam flanking borehole, and a multi-layer model was used to simulate gas production from the four horizontal gob boreholes within the panel. The in-seam flanking borehole model was run for five years in order to simulate gas production rates and cumulative production volumes from a PW panel within the project area. The horizontal gob borehole model was run for 130 days in order to simulate gas production rates and cumulative production volumes during longwall mining, assuming a face advance rate of 7.7 meters per day (m/d).

A typical PW panel at the mine is estimated to have a face width of 220 m and a panel length of 1000 m covering an aerial extent of 22 hectares (ha). The grid for the in-seam flanking borehole model consisted of 65 grid-blocks in the x-direction, 43 grid-blocks in the y-direction, and one grid-block in the z-direction (Figure 12). The grid for the horizontal gob borehole model consisted of 65 grid-blocks in the x-direction, 43 grid-blocks in the y-direction, and 12 grid-block in the z-direction (Figure 13).

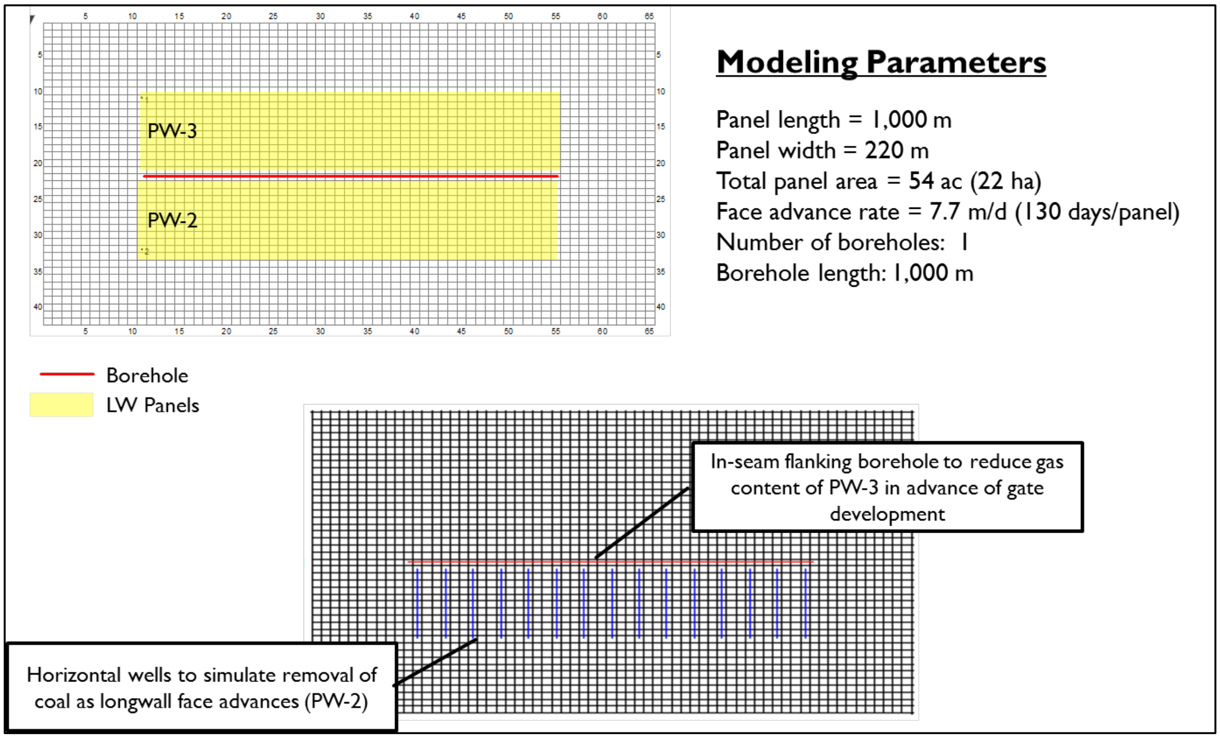
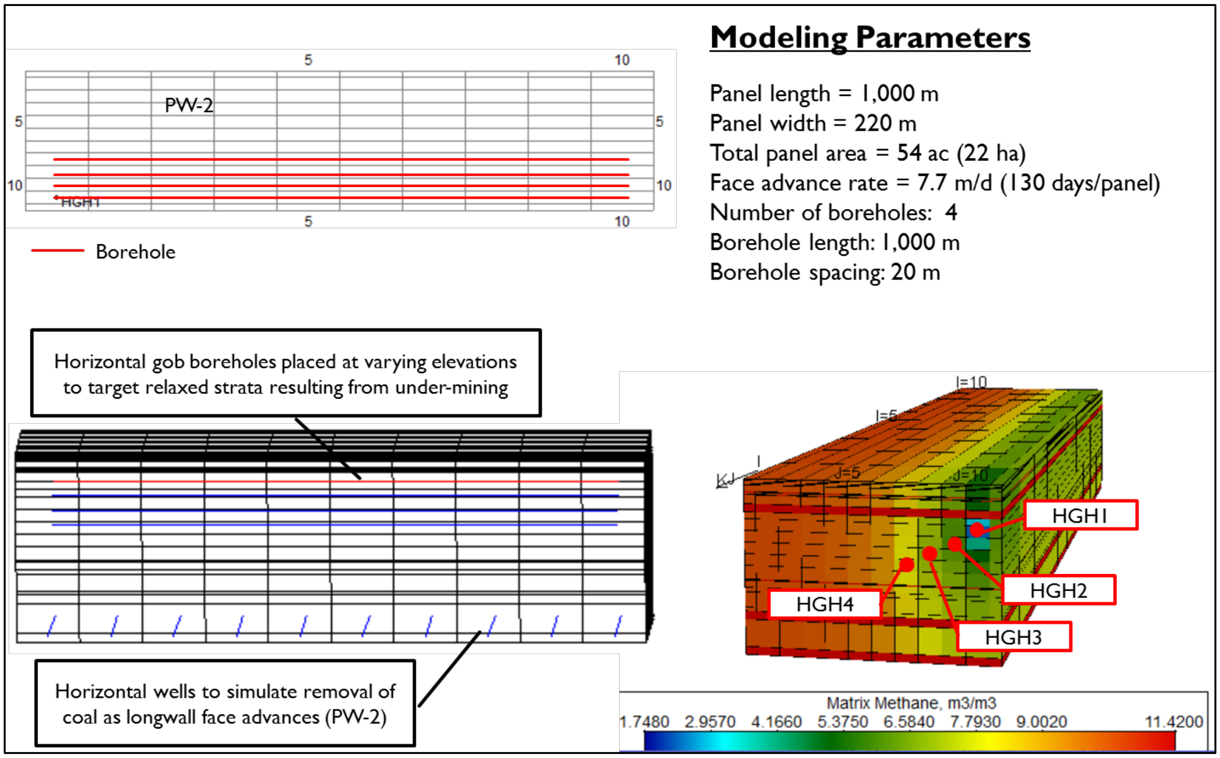


Figure 12: Model Layout for In-Seam Flanking Borehole



Modeling Parameters

Panel length = 1,000 m
Panel width = 220 m
Total panel area = 54 ac (22 ha)
Face advance rate = 7.7 m/d (130 days/panel)
Number of boreholes: 4
Borehole length: 1,000 m
Borehole spacing: 20 m

Horizontal gob boreholes placed at varying elevations to target relaxed strata resulting from under-mining

Horizontal wells to simulate removal of coal as longwall face advances (PW-2)

Figure 13: Model Layout for Horizontal Gob Boreholes

4.3.2 Model Preparation & Runs

The input data used to populate the reservoir model were obtained primarily from the geologic and reservoir data provided by JSW SA. Any unknown reservoir parameters were obtained from analogs within the Upper Silesian Coal Basin. The input parameters used in the reservoir simulation study for the in-seam flanking borehole and the horizontal gob boreholes are presented in Table 12 and Table 13, respectively, followed by a brief discussion of the most important reservoir parameters.

Reservoir Parameter	**Value(s)**	**Source / Notes**
Avg. Coal Depth, m	950	Based on mine data for Seam 357/1
Avg. Coal Thickness, m	1.6	Based on mine data for Seam 357/1
Coal density, g/cc	1.68	Assumption
Pressure Gradient, kPa/m	10.65	RECOPOL analog
Initial Reservoir Pressure, kPa	10114	Calculated from Avg. depth and pressure gradient
Initial Water Saturation, %	60	Assumption
Langmuir Volume, m^3/tonne	17.00	RECOPOL isotherm analysis
Langmuir Pressure, kPa	2490	RECOPOL isotherm analysis
In Situ Gas Content, m^3/tonne	6.80	Based on mine data
Desorption Pressure, kPa	1660	Calculated from gas content and isotherm
Sorption Times, days	20	Assumption
Fracture Spacing, cm	2.5	RECOPOL analog
Absolute Cleat Permeability, md	0.5	RECOPOL analog
Cleat Porosity, %	0.5	RECOPOL analog
Relative Permeability	Curve	Texaco analog; See Figure 16
Pore Volume Compressibility, kPa^{-1}	2.9 x 10^{-5}	RECOPOL analog
Matrix Shrinkage Compressibility, kPa^{-1}	1.5 x 10^{-7}	RECOPOL analog
Gas Gravity	0.6121	RECOPOL analog
Water Viscosity, (mPa·s)	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 based on RECOPOL analog	
Pressure Control	In-mine pipeline with surface vacuum station providing vacuum pressure of 35 kPa	
Borehole Placement	In-seam flanking borehole to reduce gas content in advance of gate development (assumes 80 mm borehole diameter)	

Table 12: Reservoir Parameters for In-Seam Flanking Borehole Simulation

Reservoir Parameter	Value(s)	Source / Notes
Midpoint Depth, m	932	Based on depth of HGH boreholes
Total Coal Thickness, m	3.9	Based on seams present within model area
Coal density, g/cc	1.68	Assumption
Pressure Gradient, kPa/m	10.65	RECOPOL analog
Initial Reservoir Pressure, kPa	9923	Calculated from Avg. depth and pressure gradient
Initial Water Saturation, %	100	Assumption
Langmuir Volume, m^3/tonne	17.00	RECOPOL isotherm analysis
Langmuir Pressure, kPa	2490	RECOPOL isotherm analysis
In Situ Gas Content, m^3/tonne	10.87	Calculated from isotherm assuming 80% gas saturation
Desorption Pressure, kPa	4418	Calculated from gas content and isotherm
Sorption Times, days	20	Assumption
Fracture Spacing, cm	2.5	RECOPOL analog
Absolute Cleat Permeability, md	5	Based on RECOPOL analog; assumes 10-fold increase in k due to under-mining
Cleat Porosity, %	0.5	RECOPOL analog
Relative Permeability	Curve	Texaco analog; See Figure 16
Pore Volume Compressibility, kPa^{-1}	2.9×10^{-5}	RECOPOL analog
Matrix Shrinkage Compressibility, kPa^{-1}	1.5×10^{-7}	RECOPOL analog
Gas Gravity	0.6121	RECOPOL analog
Water Viscosity, (mPa·s)	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 based on RECOPOL analog	
Pressure Control	In-mine pipeline with surface vacuum station providing vacuum pressure of 35 kPa	
Borehole Placement	Horizontal gob boreholes placed at varying elevations to target relaxed strata (assumes 80 mm borehole diameter)	

Table 13: Reservoir Parameters for Horizontal Gob 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 it is a critical input parameter for reservoir simulation studies. Absolute permeability data for the coal seams in the study area were not provided. However, permeability values determined in association with the RECOPOL project, located in the west central Upper Silesian Basin in the south of Poland near the Czech border, ranged between 0.5 millidarcy (md) and 2 md (Van Wageningen & Maas, 2007). For the current study, permeability values were assumed to be 0.5 md and 5 md for the in-seam flanking borehole and horizontal gob borehole models, respectively. The increase in permeability associated with the horizontal gob borehole model assumes a 10-fold increase in permeability due to under-mining of the 357/1 seam.

4.3.2.2 Langmuir Volume and Pressure

The Langmuir volume and pressure values were taken from the lab-derived methane adsorption isotherms obtained from the RECOPOL project (Van Wageningen & Maas, 2007). The corresponding Langmuir volume used in the reservoir simulation models for the longwall area is 17 cubic meters per tonne (m^3/t) and the Langmuir pressure is 2,490 kilopascal (kPa). Figure 14 and Figure 15 depict the methane isotherms utilized in the in-seam flanking borehole and horizontal gob borehole simulations, respectively.

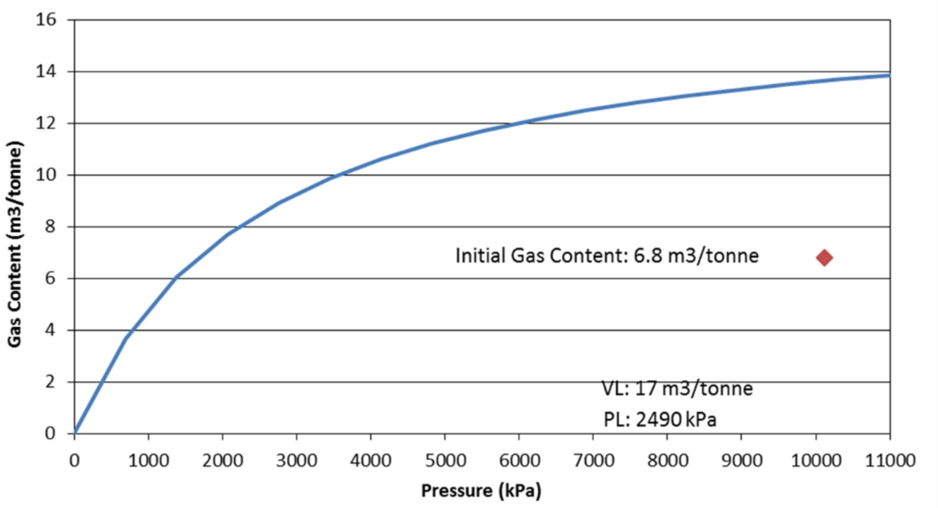


Figure 14: Methane Isotherm Used in In-Seam Flanking Borehole Simulation

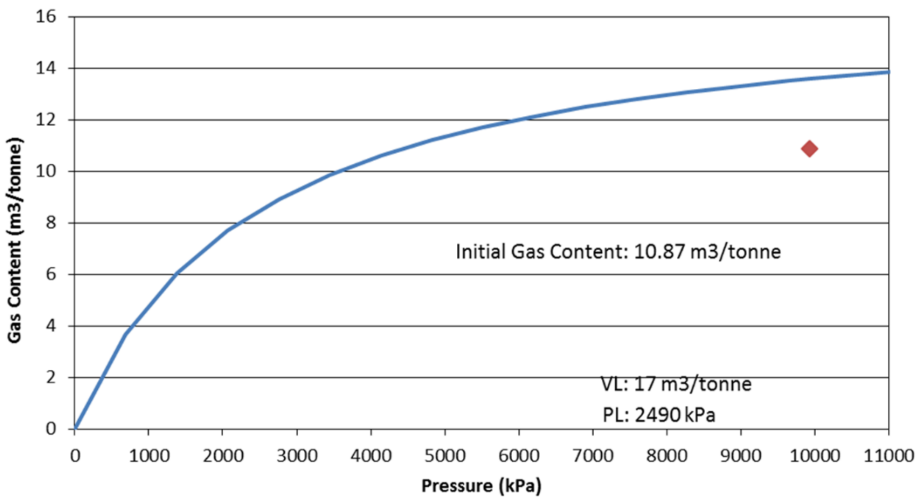


Figure 15: Methane Isotherm Used in Horizontal Gob Borehole Simulation

4.3.2.3 Gas Content

Based on data provided by the mine, the methane gas content of Seam 357/1 is 6.8 m^3/t (Figure 14). Gas desorption analyses performed during the coring program indicate a high level of dispersion. All other coal seams were assumed to be 80 percent gas saturated with respect to the isotherm (Figure 15). This assumption is based off of work conducted by Texaco in the 1990s during a field test of its CBM license in the southern part of Poland's Upper Silesian Coal Basin. Texaco's work showed significant variations in gas content and saturation state (McCants, Spafford, & Stevens, 2001). At depths of greater than 600 m the coals were shown to be moderately undersaturated (i.e., 35 to 80 percent gas saturated).

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 in the study 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 Texaco's pilot project in the Upper Silesian Coal Basin. Figure 16 is a graph of the relative permeability curves used in the reservoir simulation of the study area, which are based on the modeling study of the Texaco pilot project (Reeves & Taillefert, 2002). The relative permeability appears consistent with that commonly used to history match coalbed methane production from Carboniferous coal reservoirs in the Black Warrior Basin, Alabama (McCants, Spafford, & Stevens, 2001).

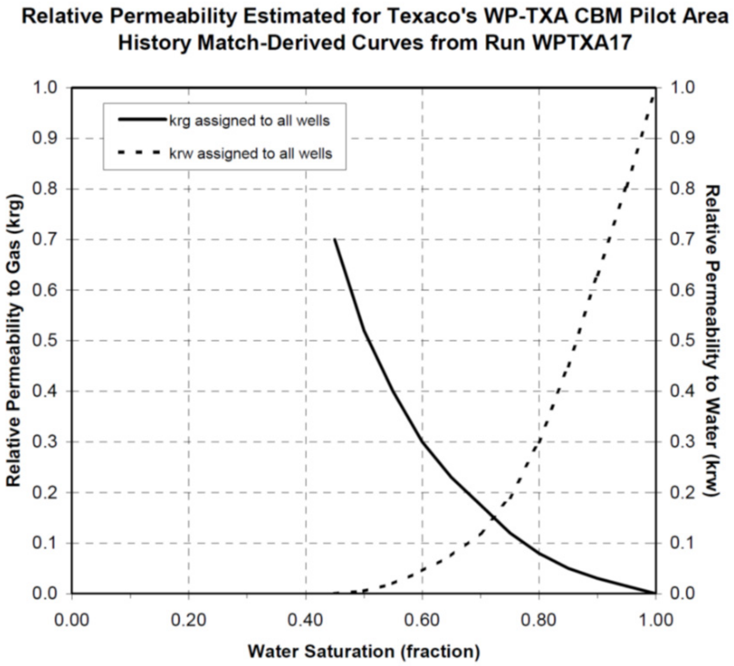


Figure 16: Relative Permeability Curve Used in Simulation

4.3.2.5 Coal Seam Depth and Thickness

Based on mine data, the coal seams of the PW panel range in depth from 895 m to 1,010 m below sea-level with coal seams ranging between 1.35 m and 1.60 m in thickness. For modeling of the longwall panel and the in-seam flanking borehole, the depth to the top of the coal reservoir is assumed to be 950 m, and the coal thickness is taken to be 1.60 m. Included in the model for the horizontal gob boreholes are five additional coal seams ranging in depth from 11.65 m to 26.63 m above Seam 357/1, which range in thickness between 0.18 m and 2.00 m.

4.3.2.6 Reservoir and Desorption Pressure

Using a hydrostatic pressure gradient of 10.65 kPa/m^3 and the midpoint depth of the coal seams, initial average reservoir pressures of 10,114 kPa and 9,923 kPa were computed for the in-seam flanking borehole and horizontal gob gas borehole models, respectively. Because the coal seams are assumed to be undersaturated with respect to gas, desorption pressures are calculated using the methane isotherms. The resulting desorption pressures used in the models are 1,660 kPa and 4,418 kPa for the in-seam flanking borehole model and horizontal gob gas borehole model, respectively.

4.3.2.7 Porosity and Initial Water Saturation

Porosity is a measure of the void spaces in a material. In this case, the material is coal, and the void space is the cleat fracture system. Since porosity values for the coal seams in the longwall 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 RECOPOL project (Van Wageningen & Maas, 2007). The cleat and natural fracture system in the reservoir was assumed to be 60 percent water saturated in the in-seam flanking borehole model and 100 percent water saturated in the horizontal gob gas model.

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 20 day sorption time was used. Production rate and cumulative production forecasts are typically relatively insensitive to sorption time.

4.3.2.9 Fracture Spacing

A fracture spacing of 2.5 cm was assumed in the simulations, which is consistent with simulations performed for the RECOPOL project (Van Wageningen & Maas, 2007). In the reservoir simulation 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

As shown previously in Figure 12, a single borehole to reduce gas content in advance of gate development is utilized in the in-seam flanking borehole model. Four horizontal gob boreholes placed at varying elevations (Figure 13) to target relaxed strata are utilized in the horizontal gob borehole model. All boreholes are assumed to have borehole diameters of 80 millimeters (mm).

4.3.2.11 Completion

Long in-seam and gob boreholes with lateral lengths of 1,000 m are proposed to be drilled and completed in the longwall panel. For modeling purposes, a skin factor of +3 based on the RECOPOL analog is assumed (Reeves & Taillefert, 2002).

4.3.2.12 Pressure Control

For the purposes of this study, an in-mine pipeline with a surface vacuum station providing a vacuum pressure of 35 kPa was assumed. In coal mine methane operations, low well pressure is required to achieve maximum gas content reduction. The in-seam flanking boreholes were allowed to produce for a total of five years, and the horizontal gob gas boreholes were allowed to produce for a total of 130 days.

4.3.3 PW Panel Modeling Results

As noted previously, two reservoir models were created to simulate gas production for a representative PW panel located at the “Pniówek” Coal Mine. Simulated gas production rate and cumulative gas production for an average in-seam flanking borehole and horizontal gob gas borehole within the longwall panel are shown in Figure 17 and Figure 18, respectively.

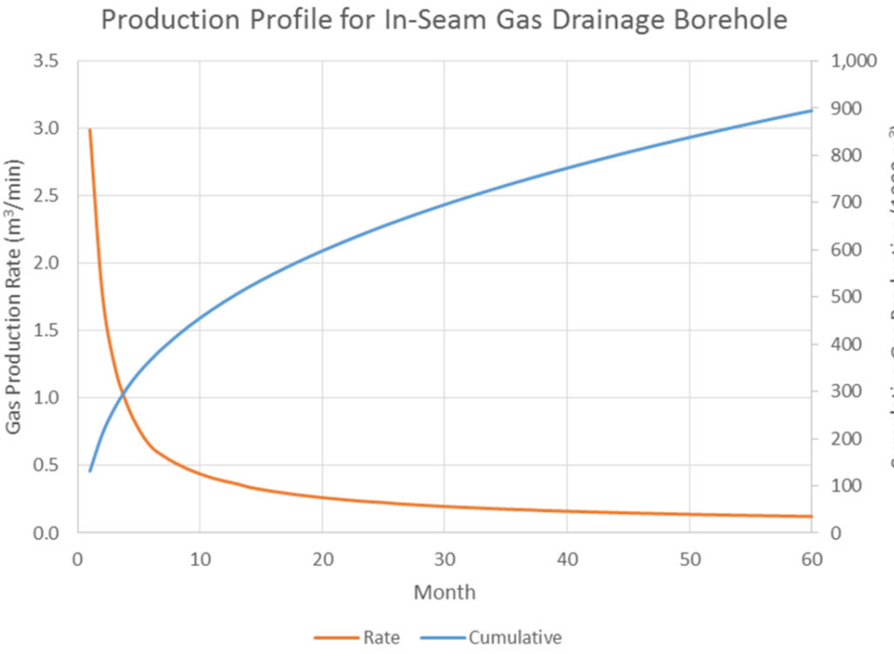


Figure 17: Production Profile for In-Seam Flanking Borehole

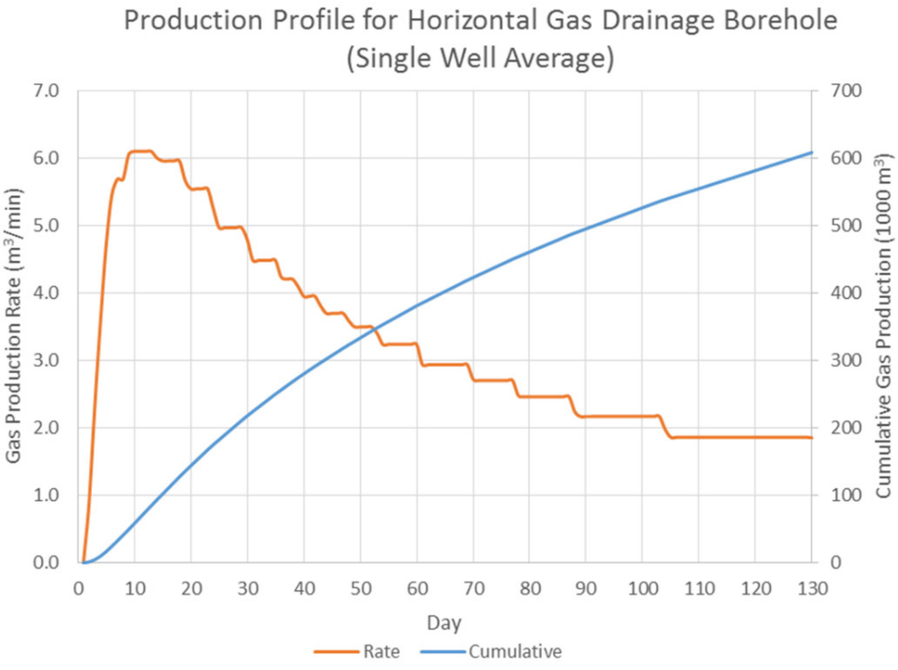
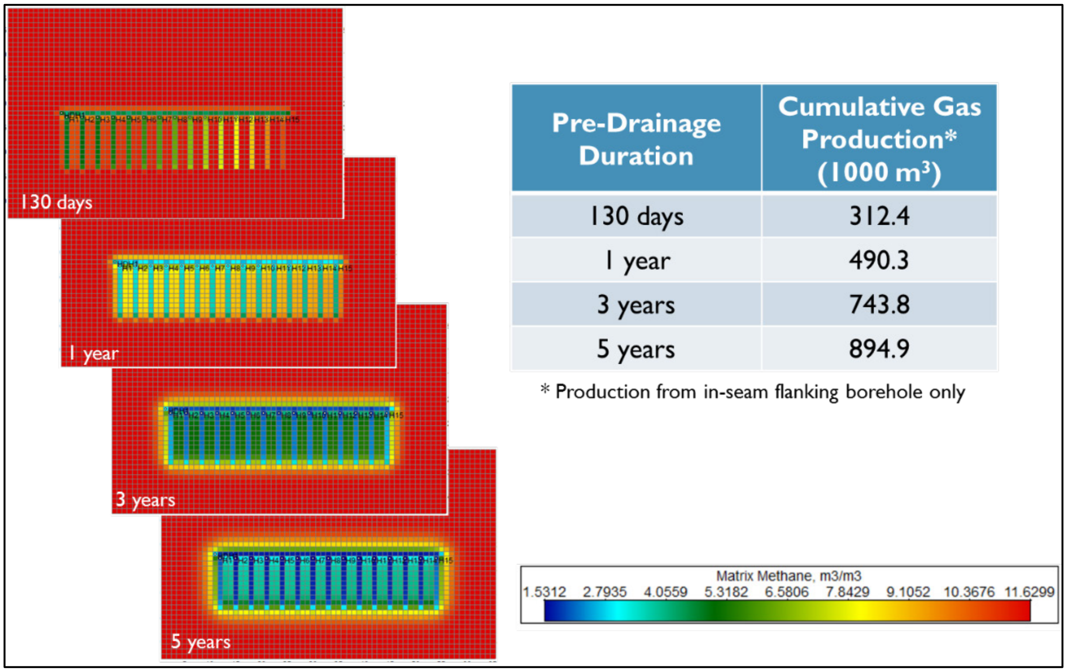


Figure 18: Production Profile for Horizontal Gas Borehole (Single Well Average)

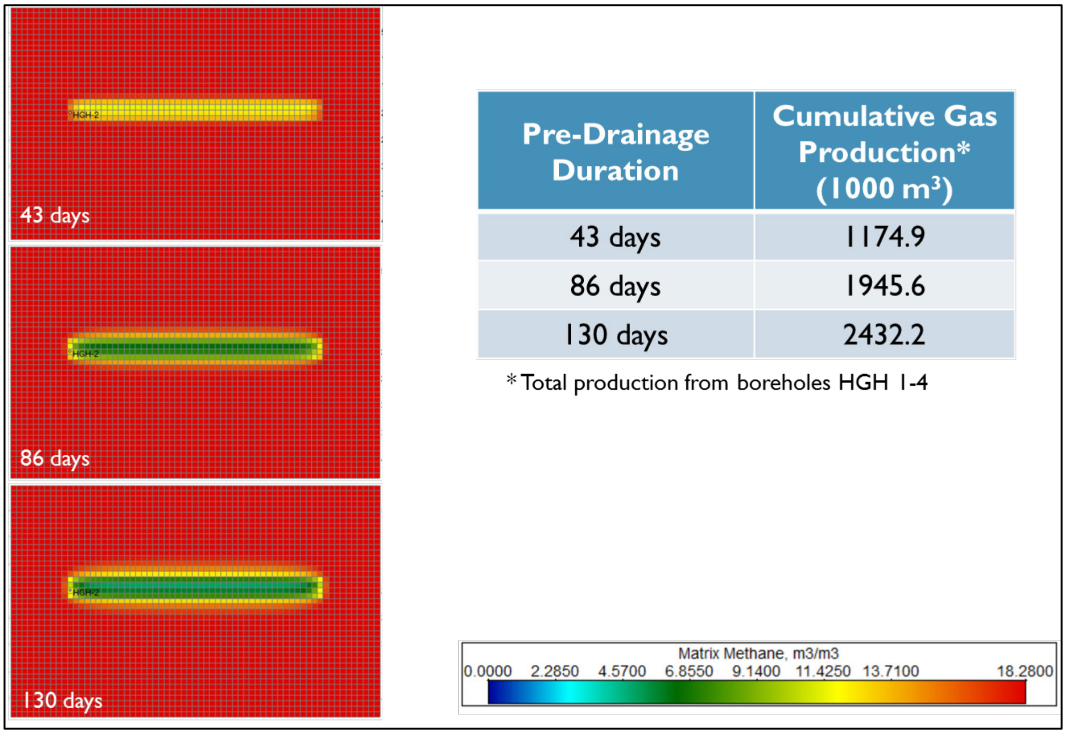
One of the benefits of pre-drainage is the reduction of methane content in the coal seams prior to mining. Figure 19 shows cumulative gas production and illustrates the reduction in in-situ gas content in the coal seam over time utilizing the in-seam horizontal borehole. Figure 20 shows cumulative gas production and illustrates the reduction in in-situ gas content over time utilizing horizontal gob boreholes during the mining of the longwall panel.



Pre-Drainage Duration	Cumulative Gas Production* (1000 m^3)
130 days	312.4
1 year	490.3
3 years	743.8
5 years	894.9

* Production from in-seam flanking borehole only

Figure 19: Illustration of Reduction in Gas Content over Time from In-Seam Flanking Borehole



Pre-Drainage Duration	Cumulative Gas Production* (1000 m³)
43 days	1174.9
86 days	1945.6
130 days	2432.2

* Total production from boreholes HGH 1-4

Figure 20: Illustration of Reduction in Gas Content over Time from Horizontal Gob Boreholes

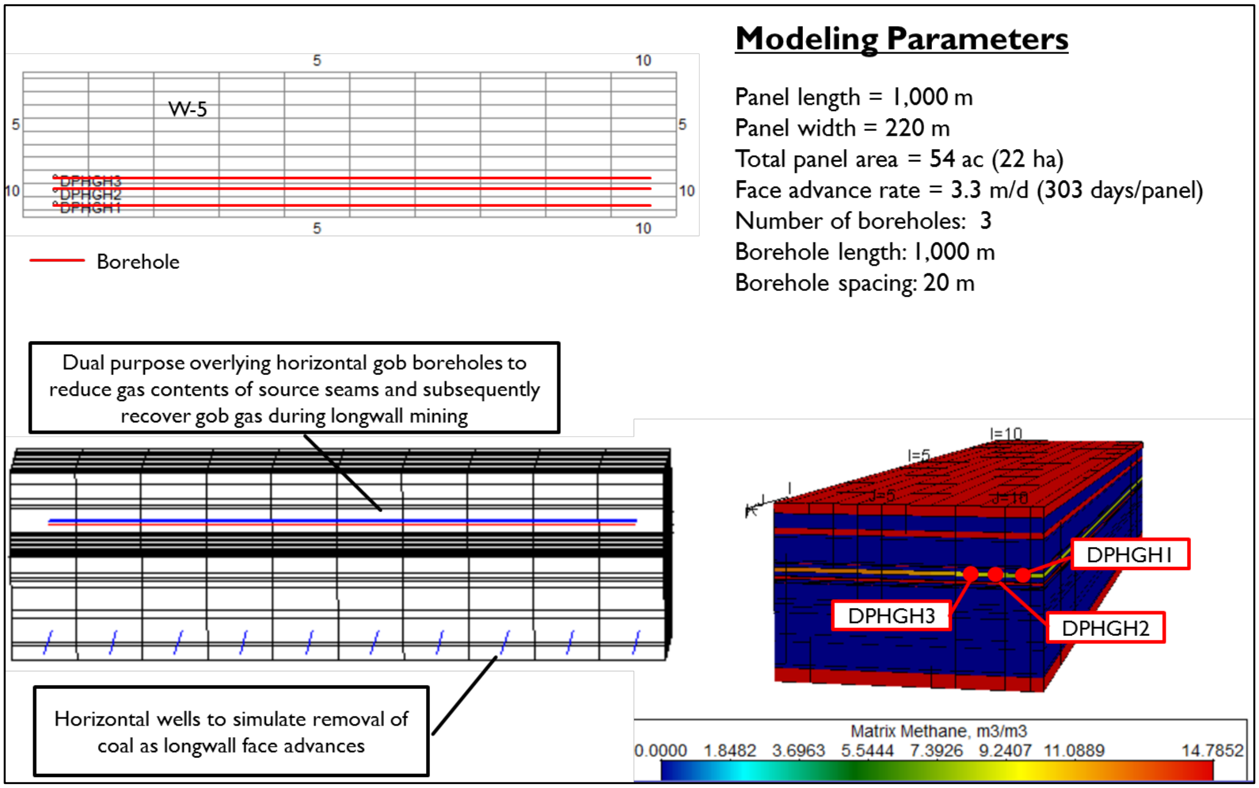
4.4 Estimating Gas Production from W Panels

A reservoir model designed to simulate five-year gas production volumes from dual purpose horizontal gob boreholes was constructed. The following sections of this report discuss the construction of the dual purpose gob borehole model, the input parameters used to populate the reservoir simulation model, and the simulation results. It should be noted that this model, and the reservoir parameters used in the model, are very similar to the model created for the horizontal gob boreholes as discussed above.

4.4.1 Simulation Model

To model degasification of W panels, a multi-layer model was used to simulate gas production from the three dual purpose horizontal gob boreholes within the panel. The model was run for five years in order to simulate gas production rates and cumulative production volumes from a W panel within the project area.

A typical W panel at the mine is estimated to have a face width of 220 m and a panel length of 1000 m covering an aerial extent of 22 ha. The grid for the horizontal gob borehole model consisted of 65 grid-blocks in the x-direction, 43 grid-blocks in the y-direction, and 12 grid-block in the z-direction (Figure 21).



Modeling Parameters

Panel length = 1,000 m
Panel width = 220 m
Total panel area = 54 ac (22 ha)
Face advance rate = 3.3 m/d (303 days/panel)
Number of boreholes: 3
Borehole length: 1,000 m
Borehole spacing: 20 m

Dual purpose overlying horizontal gob boreholes to reduce gas contents of source seams and subsequently recover gob gas during longwall mining

Horizontal wells to simulate removal of coal as longwall face advances

Figure 21: Model Layout for Dual Purpose Horizontal Gob Boreholes

4.4.2 Model Preparation & Runs

The input data used to populate the reservoir model were obtained primarily from the geologic and reservoir data provided by JSW. Any unknown reservoir parameters were obtained from analogs within the Upper Silesian Coal Basin. The input parameters used in the reservoir simulation study for the dual purpose horizontal gob boreholes are presented in Table 14. The input parameters and assumptions used for the dual purpose horizontal gob model are similar to those used for the horizontal gob model simulation (Table 13). The only major difference is the number of wells modeled (three per panel for the dual purpose horizontal gob boreholes versus four per panel for the horizontal gob boreholes), the position of the boreholes (all boreholes are located within the same seam in the dual purpose horizontal gob borehole model, whereas the boreholes within the horizontal gob borehole model are located at varying elevations), the total number of coal seams, and coal seam depths and thicknesses.

Reservoir Parameter	Value(s)	Source / Notes
Avg. Coal Depth, m	933	Based on mine data
Avg. Coal Thickness, m	1.53	Based on mine data; includes overlying (1) and underlying (2) seams
Coal density, g/cc	1.68	Assumption
Pressure Gradient, kPa/m	10.65	RECOPOL analog
Initial Reservoir Pressure, kPa	9940	Calculated from Avg. depth and pressure gradient
Initial Water Saturation, %	100	Assumption
Langmuir Volume, m^3/tonne	17.00	RECOPOL isotherm analysis
Langmuir Pressure, kPa	2490	RECOPOL isotherm analysis
In Situ Gas Content, m^3/tonne	10.88	Calculated from isotherm assuming 80% gas saturation
Desorption Pressure, kPa	4427	Calculated from gas content and isotherm
Sorption Times, days	20	Assumption
Fracture Spacing, cm	2.5	RECOPOL analog
Absolute Cleat Permeability, md	5	Based on RECOPOL analog; assumes 10-fold increase in k due to overlying mining
Cleat Porosity, %	0.5	RECOPOL analog
Relative Permeability	Curve	Texaco analog; See Figure 16
Pore Volume Compressibility, kPa^{-1}	2.9×10^{-5}	RECOPOL analog
Matrix Shrinkage Compressibility, kPa^{-1}	1.5×10^{-7}	RECOPOL analog
Gas Gravity	0.6121	RECOPOL analog
Water Viscosity, (mPa·s)	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 based on RECOPOL analog	
Pressure Control	In-mine pipeline with surface vacuum station providing vacuum pressure of 35 kPa	
Borehole Placement	Dual purpose horizontal gob boreholes drilled in advance of longwall mining (assumes 80 mm borehole diameter)	

Table 14: Reservoir Parameters for Dual Purpose Horizontal Gob Borehole Simulation

4.4.3 W Panel Modeling Results

As noted previously, a reservoir model was created to simulate gas production for a representative W panel located at the “Pniówek” Coal Mine. Simulated gas production rate and cumulative gas production for an average dual purpose horizontal gob borehole within the longwall panel is shown in Figure 22.

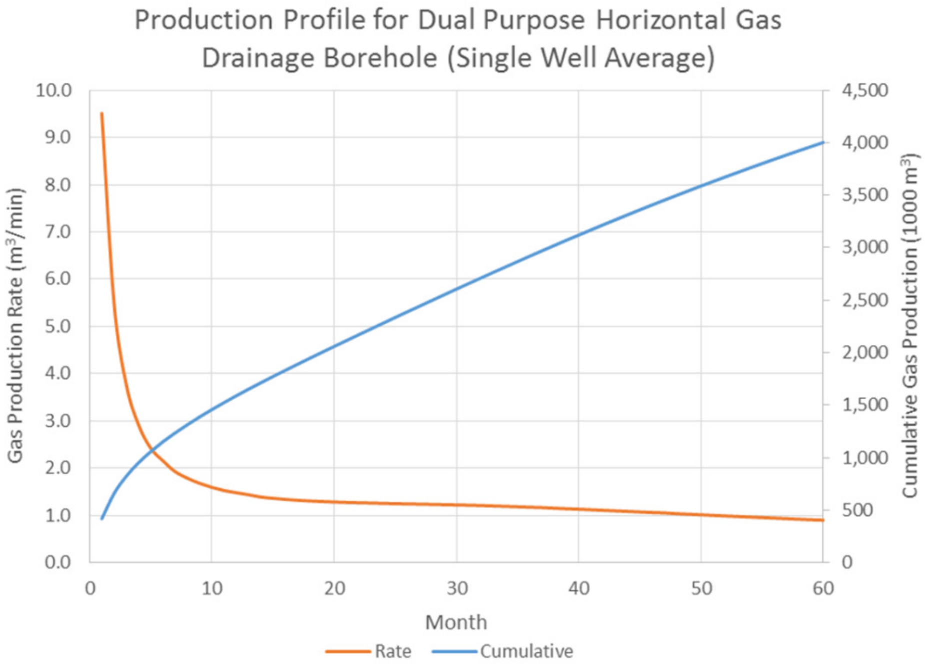
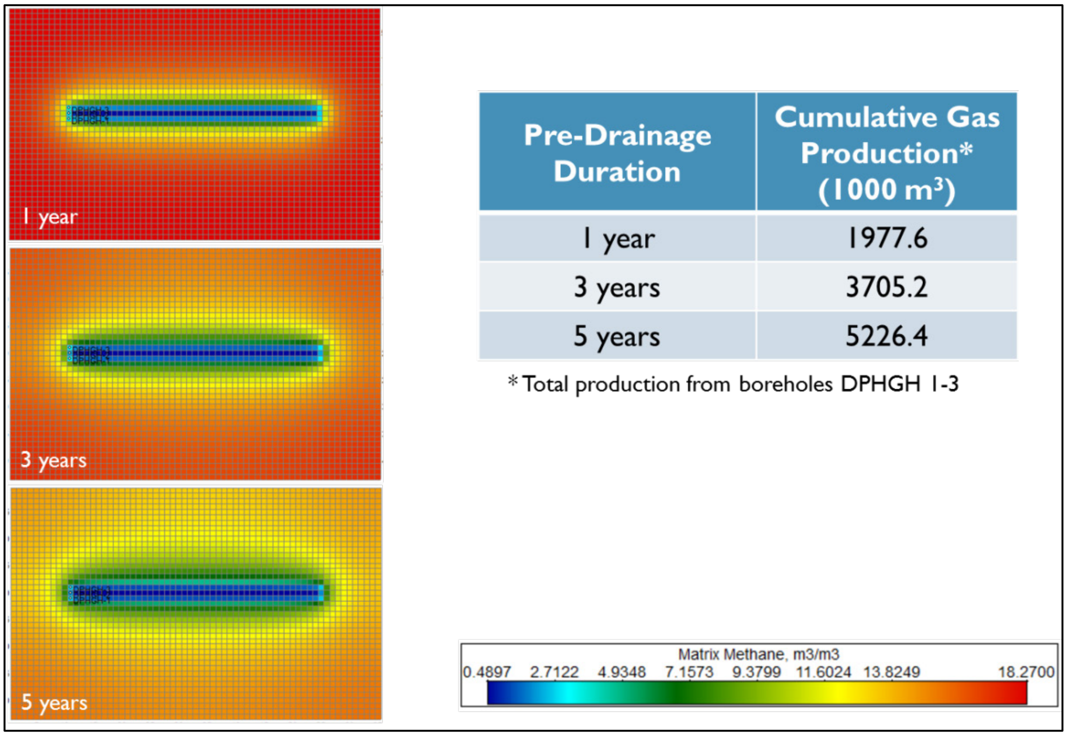


Figure 22: Production Profile for Dual Purpose Horizontal Gob Borehole (Single Well Average)

One of the benefits of pre-drainage is the reduction of methane content in the coal seams prior to mining. Figure 23 shows cumulative gas production and illustrates the reduction in in-situ gas content in the coal seam over time utilizing the dual purpose horizontal gob boreholes.



Pre-Drainage Duration	Cumulative Gas Production* (1000 m^3)
1 year	1977.6
3 years	3705.2
5 years	5226.4

* Total production from boreholes DPHGH 1-3

Figure 23: Illustration of Reduction in Gas Content over Time from Dual Purpose Horizontal Gob Boreholes

5 Market Information

The “Pniówek” Coal Mine is located in the historic region known as Upper Silesia within Silesia Province, which occupies most of the Upper Silesian Coal Basin. As highlighted by Pilcher et al. (1991), Katowice, the central city of the province, is about 70 km northwest of Krakow, and a similar distance northeast from the Czechoslovakia border. The population of Katowice was just over 300,000 in 2014 and the total population of the province is 4.6 million as of 2012, the most recent data available.

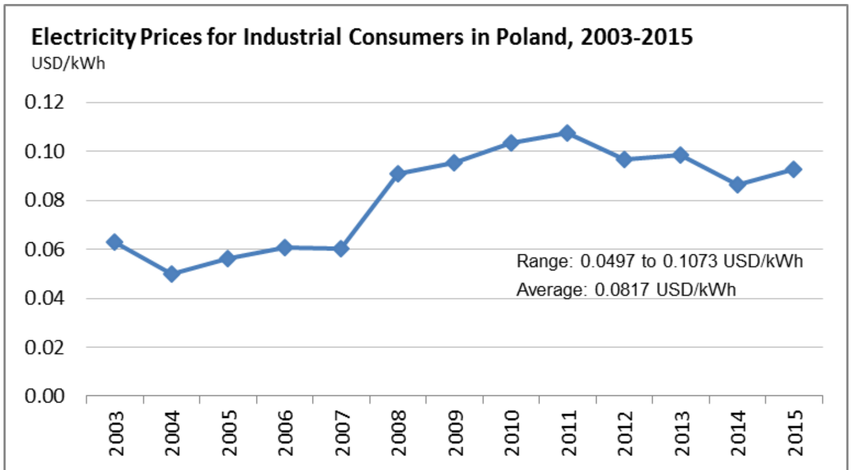
In the 1960's and 1970’s, the Upper Silesia region was a major focus of Poland's efforts to develop its industrial base. Today, the Upper Silesian Coal Basin area is the most heavily industrialized region in Poland. Present energy utilization is largely dependent on coal for steam and electrical generation. Natural gas, coke oven gas, small amounts of coalbed methane and oil are also used throughout this region for industrial, commercial, and residential purposes (Pilcher, et al., 1991). There are numerous coal-fired generating plants in the Upper Silesian Coal Basin that are connected to the national power grid, and many industrial facilities such as coal mines and steel works generate their own electrical and thermal power using coal (Pilcher, et al., 1991).

Due to the heavy industrialization of the basin and the fact that industry accounts for more than one-third of the final energy consumption in Poland, the Upper Silesia area is the largest energy consuming region of Poland. The industrial consumers of energy produce such items as machinery, transport equipment, and other iron and steel goods. Additional industrial consumers are the food processing industry and the coal industry, since Upper Silesia is the largest producer and consumer of coal in Poland (Pilcher, et al., 1991).

As stated by Pilcher et al. (1991), coalbed and coal mine methane (CBM/CMM) utilization would benefit the region by helping it to meet its energy needs with a less polluting energy source. Generation of electricity and steam at mine power plants is an attractive option for CMB/CMM in the region. Electrical power is used by all coal mines and thermal heat is supplied to mining communities for district heating. Most mines in Upper Silesia generate electricity using coal, while allowing large amounts of methane to be emitted to the atmosphere. Power and steam generation is an ideal use for this otherwise wasted methane, with the added benefit of displacing coal.

5.1 Energy Markets

The primary market available for a CMM utilization project at the "Pniówek" Coal Mine is power generation using internal combustion engines. At this time, sales to natural gas pipelines or use as vehicle fuel (e.g., compressed natural gas) are neither technically nor economically viable. With respect to electricity markets, as of mid-2015 the average rate of electricity for medium size industrial customers is EUR 0.0833/kWh, equivalent to USD 0.0928/kWh at current exchange rates (see Figure 24) (Eurostat, 2015).



Source: Eurostat (converted from EUR/kWh using 1.1143 USD/EUR exchange rate); Electricity prices for industrial consumers are defined as average national price per kWh without taxes applicable for the first semester of each year for medium size industrial consumers (Consumption Band Ic with annual consumption between 500 and 2000 MWh)

Figure 24: Electricity Prices for Industrial Consumers in Poland, 2003-2015

There is a strong case to use the incremental gas production for power generation at "Pniówek" Coal Mine. JSW SA already has experience with power generation at the mine. Its success with the existing projects provides confidence that it has the technical and financial capacity to deliver a power project. The experience of developing, building, and operating power projects provided an important learning experience, and future efforts should be able to capitalize on that experience to reduce overhead associated with design and build of the projects.

Generating electricity on site is attractive, because the input CMM gas stream can be used as is, with minimal processing and transportation. Additional generating sets can be installed relatively cheaply and infrastructure for the power plant and distribution system is already in place. Coal mines are major power consumers with substations and transmission lines near large mining operations and accessible to CMM-based power projects.

5.2 Environmental Markets

Markets for environmental attributes include carbon markets such as the European Union Emissions Trading Scheme (EU ETS) and the project-based emissions trading under the Kyoto Protocol, renewable energy markets, green energy markets, and feed-in-tariffs and other subsidies.

Poland has signed and ratified the UNFCCC and Kyoto Protocol and is eligible to host Joint Implementation (JI) projects that can acquire revenue from the sale of carbon credits. However, due to the lack of a post-2012 agreement to succeed the Kyoto Protocol and oversupply of emission allowances in the EU ETS, carbon markets today are generally not viable. Although Poland has 11 CMM projects registered as JI projects, the Kyoto markets have effectively crashed with offsets selling for under US$1 per metric tonne of CO_2 equivalent, well below transaction and other administrative costs (Fenhann, 2015). At this time, there is no indication that prices in the Kyoto markets will shift significantly; therefore, a value for the carbon is unlikely to drive project development.

5.3 Regulatory Environment

As noted in USEPA's CMM Country Profile for Poland, the *Geological and Mining Law* of February 4, 1994 regulates the ownership of natural resources, including the right to explore for and extract them. The Energy Law requires energy enterprises to supply and connect customers, meet demands, and initiate actions for reducing consumption. There are 27 licenses for exploration fields reported in the Upper Silesian Basin and 68 licenses for coal mines (USEPA, 2015).

Poland is currently providing support for methane use by promoting the use of Combined Heat and Power (CHP) systems through the "CHP Certificates" mechanism and is also providing excise tax exemptions for electricity generation (Skiba & Wojciechowski, 2009).

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.

As noted in the Market Information section, the primary market available for a CMM utilization project at the "Pniówek" Coal Mine is power generation using internal combustion engines. Given the relatively small CMM production volume, as well as the requirement for gas upgrading, 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 6.9 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 and distribution system is already planned.

7 Economic Analysis

7.1 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 be drilled and begin production three to five years prior to the initiation of mining activities at each panel. CMM gas production profiles were generated for a total of four project development cases:

- Case 1: PW panels with 3 years of pre-drainage
- Case 2: PW panels with 5 years of pre-drainage
- Case 3: W panels with 3 years of pre-drainage
- Case 4: W panels with 5 years of pre-drainage

Under all four development cases it is assumed a total of 12 longwall panels will be mined. Production at one longwall panel will be initiated every four months until a maximum of six panels are in operation. Once a longwall panel has been mined through, production at another panel begins (assuming a face transfer time of three months) until a total of 12 longwall panels have been mined.

For the development of the PW panels, an in-seam flanking borehole is drilled and put on production either 3 years (Case 1) or 5 years (Case 2) prior to the commencement of longwall mining at each panel. After pre-drainage is completed, longwall mining operations begin along with gob production from the four horizontal gob boreholes drilled above each panel. For PW panels, mining of each panel is completed in 130 days based on a longwall face advance rate of 7.7 m/d. As a result, the total project life for development of PW panels is 9 and 13 years for Case 1 and Case 2, respectively.

For the development of the W panels, dual purpose horizontal gob boreholes are drilled and put on production either 3 years (Case 3) or 5 years (Case 4) prior to the commencement of longwall mining at each panel. After pre-drainage is completed, longwall mining operations begin along with gob production from the three dual purpose horizontal gob boreholes drilled above each panel. For W panels, mining of each panel is completed in 303 days based on a longwall face advance rate of 3.3 m/d. As a result, the total project life for development of W panels is 10 and 14 years for Case 3 and Case 4, respectively.

7.2 Gas Production Forecast

Gas production forecasts were developed using the simulation results (Figure 17, Figure 18, and Figure 22) and the development cases discussed above. The CMM production forecast for each project development case is shown in Figure 24, and the estimated methane concentration of the CMM is presented in Figure 25.

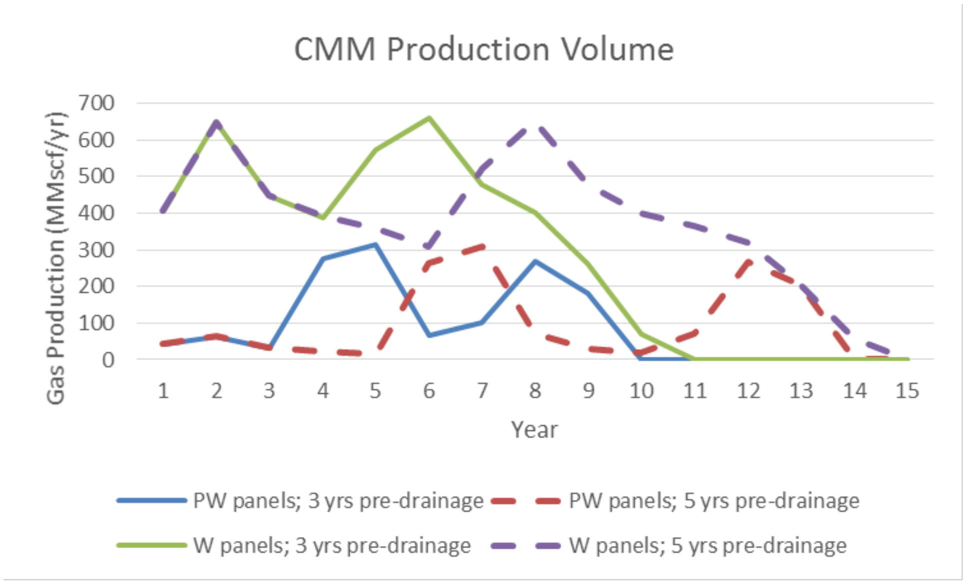


Figure 25: CMM Production Volume

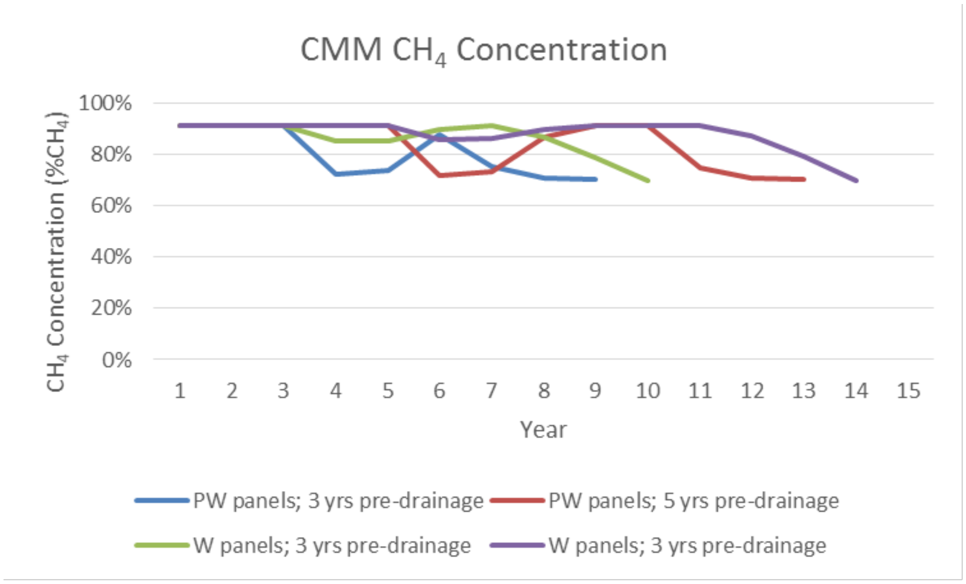


Figure 26: CMM CH_4 Concentration

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 at the "Pniówek" Coal Mine 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). The capital and operating costs used in the economic analysis are based on per well costs from oil and gas projects rather than on an underground mining analysis, which would most likely lower the costs. A more detailed analysis should be conducted if this project advances to the full-scale feasibility study level. The major cost components for the CMM project include the in-seam and horizontal gob boreholes, gathering system, surface vacuum station, compressor, and pipeline to the sales system or utilization project. The capital cost assumptions, operating cost assumptions, and physical and financial factors used in the evaluation of upstream economics are provided in Table 15. A more detailed discussion of each input parameter is provided below.

Physical & Financial Factors	**Units**	**Value**
Royalty	%	1.5%
Price Escalation	%	3.0%
Cost Escalation	%	3.0%
Calorific Value of Drained Gas	MJ/m^3	34.58
Calorific Value of Gob Gas	MJ/m^3	26.60
Capital Expenditures	**Units**	**Value**
Drainage System		
Well Cost	\$/m	131
Surface Vacuum Station	\$/W	1.34
Vacuum Pump Efficiency	W/1000m^3/d	922
Gathering & Delivery System		
Gathering Pipe Cost	\$/m	131
Gathering Pipe Length	m/well	444 (PW); 740 (W)
Satellite Compressor Cost	\$/W	1.34
Compressor Efficiency	W/1000m^3/d	922
Pipeline Cost	\$/m	180
Pipeline Length	M	1,000
Operating Expenses	**Units**	**Value**
Field Fuel Use (gas)	%	10%
O&M	\$/1000m^3	17.66

Table 15: Summary of Input Parameters for the Evaluation of Upstream Economics (CMM Project)

7.3.2.1 Physical and Financial Factors

Royalty: A royalty rate of 1.5 percent was assumed.

Price and Cost Escalation: All prices and costs are assumed to increase by 3 percent per annum.

Calorific Value of Gas: The drained gas is assumed to have a calorific value of 34.58 megajoules per cubic meter (MJ/m^3) and the gob gas is assumed to have a calorific vale of 26.60 MJ/m^3. These numbers are based on a calorific value of 38.00 MJ/m^3 for pure methane adjusted to account for lower methane concentration of the CMM gas, which is assumed to be 91 percent and 70 percent methane for drained and gob gas, respectively.

7.3.2.2 Capital Expenditures

The drainage system includes the in-seam and horizontal gob drainage boreholes and vacuum pumps used to bring the drainage gas to the surface. The major input parameters and assumptions associated with the drainage system are as follows:

Well Cost: A borehole with a lateral length of 1,000 m is assumed to cost \$129,000 per well. This is based on preliminary cost estimates provided for contract drilling. This estimate is based on 10,000 m of drilling and represents a cost of \$129 per meter. Should the CMM project advance beyond the pre-feasibility stage, the implementation of an in-house drilling program by the mine operator should be considered as a way to reduce development costs. As the mine assumes this responsibility, drilling costs will be reduced over the project life.

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 pump station, a pump cost of $1.34 per Watt (W) and a pump efficiency of 922 watts per thousand cubic meters per day (W/1000m^3/d) 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., $/W x W/1000m^3/d x 1000m^3/d).

Gathering & Delivery System Cost: 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, and the delivery system consists of the satellite compressor and the pipeline that connects the compressor to the sales system leading to the utilization project. The gathering system cost is a function of the piping length and cost per meter. For the proposed project, we assume a piping cost of $131/m and roughly 2,220 m of gathering lines.

Satellite compressors are used to move gas through the pipeline connected to the end-use project. Similar to vacuum pump costs, compression costs are a function of the gas flow rate and efficiency of the compressor. To estimate the capital costs for the compressor, we assume a compressor cost of $1.34/W and an efficiency of 922 W/1000m^3/d. As with the vacuum pump costs, total capital cost for the compressor is estimated as the product of compressor cost, compressor efficiency, and peak gas flow (i.e., $/W x W/1000m^3/d x 1000m^3/d). The cost of the pipeline to the end-use project is a function of the pipeline length and cost per meter. For the proposed project, we assume a pipeline cost of $180/m and length of 1,000 m.

7.3.2.3 Operating Expenses

Field 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 10 percent, which is deducted from the gas delivered to the end use.

Normal Operating and Maintenance Cost: The normal operating and maintenance cost associated with the vacuum pumps and compressors is assumed to be $17.66/1000m^3.

7.3.2.4 Upstream (CMM Project) Economics

The economic results for the CMM project are summarized in Table 16. Based on the forecasted gas production, the breakeven cost of producing gas through in-seam drainage boreholes is estimated to be between $105 and $614/1000m^3 ($3.21 and $18.73 per million British thermal units, MMBtu). The results of the economic assessment indicate the lowest CMM production costs are associated with the W panels, with 3 years of pre-drainage (Case 3) preferred over 5 years (Case 4).

Case	Panel	Years of Pre-Drainage	Breakeven Gas Price $/1000m^3
1	PW	3	405.06
2	PW	5	614.11
3	W	3	105.11
4	W	5	117.36

Table 16: 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 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 assumptions used to assess the economic viability of the power project are presented in Table 17. A more detailed discussion of each input parameter is provided below.

Physical & Financial Factors	Units	Value
Generator Efficiency	%	35%
Run Time	%	90%
Capital Expenditures	**Units**	**Value**
Power Plant	$/kW	1,300
Operating Expenses	**Units**	**Value**
Power Plant O&M	$/kWh	0.02

Table 17: Summary of Input Parameters for the Evaluation of Downstream Economics (Power Project)

7.3.3.1 Physical and Financial Factors

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

7.3.3.2 Capital Expenditures

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

7.3.3.3 Operating Expenses

Power Plant Operating and Maintenance Cost: The operating and maintenance costs for the power plant are assumed to be $0.02 per kilowatt-hour (kWh).

7.3.3.4 Downstream (Power Project) Economics

The economic results for the power project are summarized in Table 18. The breakeven power sales price, inclusive of the cost of methane drainage, is estimated to be between $0.059 and $0.172/kWh. Based on a breakeven CMM price of $117/1000m^3 ($3.58/MMBtu) (Case 4), the mine could generate power at a price equivalent to $0.059/kWh. A CMM-to-power utilization project at the mine would be economically feasible if the mine currently pays a higher price for electricity. Although power combined with CMM drainage appears to be economic, removing the cost of mine degasification from downstream economics as a sunk cost would significantly reduce the marginal cost of power.

Case	Panel	Years of Pre-Drainage	Breakeven Power Price $/kWh
1	PW	3	0.172
2	PW	5	0.157
3	W	3	0.070
4	W	5	0.059

Table 18: 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 a CMM project at the “Pniówek” Coal Mine. The analysis performed reveals that methane drainage using long, in-seam directional drilling in association with the development mine 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 in-seam drainage boreholes is estimated to be between USD $405 and $614/1000m^3 ($12.36 and $18.73/MMBtu) for PW panels, and between $105 and $117/1000m^3 ($3.21 and $3.58/MMBtu) for W panels. The results of the economic assessment indicate the lowest CMM production costs are associated with the W panels with three years of pre-drainage (Case 3).

In terms of utilization, the power production option appears to be economically feasible. 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 price is estimated to be between $0.157 and $0.172/kWh for PW panels, and between $0.059 and $0.070/kWh for W panels. The results of the economic assessment indicate the lowest power price is associated with the W panels with five years of pre-drainage (Case 4). As of mid-2015 the average rate of electricity for medium size industrial customers was $0.0928/kWh. When compared to the breakeven power sales price for Case 4 of $0.059/kWh, utilizing drained methane to produce electricity would generate profits of more than $33 per MWh of electricity produced.

The power production option appears to be 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 110,000 tonnes of carbon dioxide equivalent (tCO_2e) per year. Should JSW SA wish to continue with the proposed drainage plan, a phased project approach is recommended. The first phase would be to demonstrate the benefits of the proposed approach, and would likely include the following steps:

- Conduct on-site scoping mission and meetings with mine technical personnel.
- Develop methane drainage approach and scope of work for demonstration project including estimated costs.
- Obtain budget approval for demonstration program.
- Meet to discuss and finalize project approach.
- Evaluate and approve drill room location and configuration and required utilities (water supply/discharge and electricity).
- Evaluate, design and install gas collection and safety system.

Once the first phase is completed and the results are evaluated, a corporate decision should be made on whether or not to proceed with Phase II. The second phase would include equipment purchase and training to implement the proposed modern methane drainage technologies in house.

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