

## **Coalbed Methane Recovery and Electric Power Generation at the Wesola Mine in Myslowice, Poland**

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### ABSTRACT

This paper presents the results of a prefeasibility assessment sponsored by the U.S. Environmental Protection Agency (EPA) Coalbed Methane Outreach Program to establish modern coal mine methane (CMM) recovery and use technologies at a gassy underground coal mine in Poland's Upper Silesian Coal Basin. The project is proposed at the Wesola Mine, a property of the Katowice Holding Company located near Myslowice, and is comprised of two components: (1) directional drilling and (2) power and heat generation.

The Wesola Mine, presently producing approximately 3.1 Mt of coal per year, searches for ways to reduce mining and degasification costs as it exploits deeper and gassier reserves. This multi-level longwall operation relies on a system of overlying galleries for stress relief, backfilling, and gob degasification. Ideally the mine operators make use of existing overlying mine entries for those purposes. However, for exploitation of the deeper reserves, they need to construct galleries in both uneconomic coal seams and rock. The proposed project introduces longhole directional drilling technology to implement horizontal gob gas drainage boreholes. These boreholes will serve to minimize overlying gallery development and will improve coal mine methane recovery.

The Wesola Mine presently sells 60 percent of the CMM it recovers to an affiliated boiler house for supply of mine and district heat. The proposed project introduces a CMM-fired turbine that uses all of the methane drained by the project, supplemented with fumigant methane contained in the mine's ventilation exhaust air. The cogeneration facility would sell 2.5 MWe to the mine and would supply steam to the heating facility.

The proposed project would provide benefits to the Wesola Mine and the affiliated heat company through improved safety, reduced mine degasification costs, and increased profit margins. The project would earn a rate of return of greater than 15 percent and would mitigate over 800,000 tonnes of carbon dioxide. This paper describes the proposed project, outlines the project's structure, presents the results of economic analyses, and identifies Polish financing sources including grant sources interested in participating in this project. The paper also summarizes the project's benefits.

### INTRODUCTION

Between 1995 and 1997 the U.S. EPA dispatched two missions to Poland to identify projects for transfer of modern coal mine methane technologies at gassy mines in the Upper Silesian Coal Basin (USB). Methane is a potent greenhouse gas, with approximately 21 times the radiative forcing of carbon dioxide over a 100 year period (IPCC, 1996). The U.S. EPA supports the introduction of methane recovery and use technologies at coal mines in the USB as an important part of an overall strategy to economically mitigate global greenhouse gas emissions. Mines of the USB account for 97 percent of Poland's hard coal production: approximately 120 Mt of coal per year. Many USB mines are gassy, and in total liberate an estimated 750 Mm<sup>3</sup> of methane (an equivalent of 10.7 Mt of CO<sub>2</sub>) into the atmosphere each year (EPA, 1995). Although many Polish mines recover and use methane (approximately 22

percent of methane liberated), coal operators encounter difficulty in reducing coal mine methane emissions, partly due to the lack of capital and partly due to uncertainty of the effectiveness of available modern technologies. Recent government coal sector restructuring efforts are pressuring coal companies to modernize and control costs to increase their probability of survival. These efforts, in addition to global environmental awareness, create economic opportunities for the introduction of the enhanced coal mine methane recovery and use methods described in this paper. Successful demonstration of directional drilling for enhanced coal mine methane recovery for power generation at the Wesola Mine will promote the replication of similar greenhouse gas mitigation projects in the USB.

## WESOLA MINE

Katowice Holding Company's Wesola Mine presently produces coal from six (6) sub-bituminous through high volatile, B, bituminous in rank, coal seams with an average heating value 23,545 kJ/kg. Immediate mine plans (next 5 years) focus on exploiting the Saddle Group comprised of two deep and very gassy coal seams: the 501 and 510 which have a combined thickness of 8.6 m. A binder that varies between one and 25 meters in thickness separates these two seams across the mine's property.

### Coal Reservoir Characteristics

Desorption measurements conducted on coals from the Wesola Mine indicate in-situ gas contents of up to 11.6 m<sup>3</sup>/t (EPA 1995). Polish Methane Hazard Classification information indicates that many of the coal seams presently mined at Wesola have in-situ gas contents greater than 8.0 m<sup>3</sup>/t.

Absolute permeabilities of coals in the USB typically range between 0.1 to 1.0 milli-darcy (md). Mining operations exploiting multiple gas-bearing strata with these characteristically low permeability values lend themselves to degasification techniques which focus on gob gas emissions.

The Wesola Mine recovers a methane and air mixture from gob areas: approximately 60 percent methane and 40 percent air on a volume basis.

### Methane Emissions and Use

Wesola personnel indicate that methane emissions during longwall mining of some of the gassier seams, longwall 1016a in the 501 seam for example, are in excess of 39 m<sup>3</sup> per minute. These emissions contribute to the present total mine methane liberation rate of between 105,000 and 140,000 m<sup>3</sup> per day (123,000 m<sup>3</sup> per day average for 1996). Mine methane emissions, by month for 1996, are illustrated on Figure 1. Wesola mining engineers anticipate that mine methane liberation will increase by approximately 10 percent by the year 2000.

As indicated on Figure 1, the Wesola Mine degasification system recovers between 12 and 21 percent of the methane liberated, or between 12,000 to 25,000 m<sup>3</sup> per day (17 percent average degasification system efficiency for 1996).

The Wesola Mine operates a surface methane drainage plant equipped with seven vacuum pumps, with a total production capacity of 86,400 m<sup>3</sup> of methane per day. The plant is situated at one of the mine's ventilation exhaust shafts. The plant presently operates at approximately 25 percent of capacity and processes gas of between 55 and 65 percent methane in air on a volume basis (61 percent 1996 average). As indicated on Figure 1, the mine uses most of the gas drained during the winter but less than 40 percent of the drained gas during summer months (65 percent 1996 overall average use). The gas is sold to a Katowice Holding Company subsidiary, Zaklad Energetyki Ciepłej (ZEC), which operates two boiler houses: a small facility capable of producing approximately 1.4 MW of thermal energy, and a larger, 30 MWth facility. As the boilers are fitted with over-stoke burners, ZEC has the option to fuel them with either gas or coal.

The Wesola Mine purchases more than 50 percent of the annual heat generated by ZEC for hot water heating and building heating (e.g., the mine purchased an average of 58 percent of ZEC heat in 1996). ZEC sells the balance to the local area district heating network.

## PROPOSED PROJECT

The proposed project comprises two components: (1) directional drilling and (2) a gas turbine cogeneration facility (power and heat generation).

### Directional Drilling Project

The Wesola Mine's near-term plans focus on exploitation of the Saddle Group in the northern part of the concession. In this region the two target seams remain relatively close to each other (1 m in some places), with the 501 seam at the higher elevation. The Mine exploits these seams using a retreat system of single entry longwall panels, each with the ability to produce up to 4,000 tonnes of coal per day.

In mining the Saddle Group the mine relies on a system of overlying galleries for stress relief, gob degasification, and for application of backfilling material. Wesola engineers indicate that because of their multi-level mining program, especially in areas where the mined seams are in close proximity to each other, extensive consolidation of the longwall gob is necessary to minimize roof control problems and stress conditions. For the initial longwalls in the Saddle Group, Wesola operators developed galleries in an uneconomic overlying coal seam (the 416), approximately 40 m above the 501. As operators developed subsequent panels they determined that this seam is not contiguous, and had to develop many overlying galleries in rock.

Wesola personnel indicate that new degasification techniques will need to be developed for continued exploitation of the Saddle Group, and that these techniques must consider stress relief conditions and gob consolidation requirements.

Degasification from Overlying Galleries in the Saddle Group. The Wesola mine utilizes galleries to develop angled gob boreholes into the strata overlying the 501 seam. Figure 2 shows methane emissions and the degasification effectiveness attained by Wesola with the overlying gallery system of degasification, as measured for one of the gassiest longwalls in the Saddle Group to date. The magnitude of these emissions, up to 39 m<sup>3</sup>/min at peak production for one of seven longwall faces, and lost time delays due to methane (up to 122 hours per month mine-wide for all working sections), demonstrate Wesola's degasification needs.

Wesola Mine engineers suggest that development of costly gallery infrastructure could be minimized by using in-mine horizontal gob boreholes. They indicate that this is particularly valid in the Saddle Group areas where the galleries need to be driven in rock. Table 1 presents an estimate of the costs incurred by Wesola to employ the overlying gallery degasification technique. Costs are presented on a per longwall panel basis for galleries developed in the 416 coal seam, as determined by information provided by the Wesola Mine.

The Horizontal Gob Borehole Approach. Horizontal gob boreholes are small diameter (76 - 90 mm), long (in excess of 1000 m) boreholes developed from the mining horizon up into strata overlying unmined panels as shown on Figure 3. Using directional drilling tools, these boreholes strategically intersect fractures that will generate over the rubble zone after undermining by longwall systems. The large surface area presented by the horizontal boreholes provides excellent connectivity with these mining-induced fractures.

This technique is applied in Japanese and Chinese coal operations, and has been field tested in the U.S. The Chinese demonstration resulted from the United Nations-administered Global Environmental Facility greenhouse gas reduction program. It is suitable for deployment in deeper, multi-seam operations, where the more common gob degasification techniques are cross-measure or overlying gallery methods. Miners have found that this technique provides high degasification efficiencies at lower implementation costs than either the overlying gallery or the cross-measure methods. This unique technique requires a reduced number of boreholes and applies to both advancing or retreating longwall systems.

Application at Wesola. Wesola engineers agree that horizontal gob boreholes are applicable for degasification of some longwall gobs in the Saddle Group. They indicate that, because of backfilling requirements and stress conditions, the horizontal gob boreholes will not replace all of the overlying gallery development but would certainly reduce the extent of this costly infrastructure. Although it is

difficult to assess without initial on-site trials of the technique, designers anticipate that between 25 to 30 percent of the gallery infrastructure could be negated by the horizontal gob boreholes in the Saddle Group. The estimated costs to develop three horizontal gob boreholes from one drill site at Wesola are presented in Table 2.

#### Benefits of Horizontal Gob Boreholes at the Wesola Mine.

The estimated cost of implementing a gob degasification system from overlying galleries constructed specifically for that purpose, on a per-longwall panel basis, is approximately US\$ 1.16 M. Assuming an average of three drill sites and three horizontal gob boreholes per drill site for two longwall panels, the development costs for an equivalent horizontal gob borehole system are US\$ 513,000 for two longwall panels, or US\$ 256,000 per panel. This represents a savings of US\$ 904,000 per longwall panel if all of the overlying galleries were avoided. The estimated savings per longwall panel if only 30 percent of these developments were avoided is US\$ 274,000 per longwall panel.

At the Wesola Mine, any improvements to system capture efficiency will reduce the frequent down times attributed to high methane concentrations at working faces. Wesola presently encounters mine-wide methane production delays of between 67 and 122 hours over a one month period. In gassy conditions average daily longwall production is approximately 1,875 tonnes per day, while under ideal conditions (no gas, geologic, or equipment delays), operators have achieved peak daily production rates of 3,500 to 4,000 tonnes per day.

Table 3 presents the potential total annual cost advantage of the horizontal gob boreholes relative to the gallery system for a range of district degasification efficiencies and avoided gallery development for a single longwall in the Saddle Group. The table assumes that Wesola could achieve, on average, 60 percent of ideal coal production rates (i.e., 2,400 tonnes per day per longwall) if gas delays were negated with a district degasification efficiency of 60 percent (current district efficiencies equal 40 percent).

#### Gas Turbine Cogeneration Facility

The project proposed at the Wesola Mine considers a gas turbine facility that will generate both power and heat using all of the methane drained by the mine. Methane in concentrations of less than one percent from the mine's ventilation exhaust shaft will be used as combustion intake air to supplement the fuel supply. The proposed project would use the drained methane gas more efficiently and provide cost benefits to both the Wesola Mine and ZEC.

Commercial turbines modified to operate on medium-quality gas as low as 35 percent methane in air are available and are applied at a few coal mining operations in Germany (Kowolik and Heimer, 1986). The introduction of mine ventilation exhaust air (with a methane concentration of approximately 0.7 percent) is presently supplementing fuel supplies at a large coal mine methane-fueled internal combustion engine power project at the Appin Colliery in Australia.

Methane from Wesola's Drainage Plant. In 1996 the Wesola Mine sold drained methane to ZEC for US\$ 0.022 per cubic meter of methane, which generated revenues to Wesola of approximately US\$ 106,000. The volume of methane drained per day by Wesola is sufficient to generate between 2.0 to 2.5 MWe, using a gas turbine, depending on efficiency. Mine management expects to produce coal at decreased rates from increasingly gassier seams. With improved methane drainage techniques and higher degasification system efficiencies, the mine potentially could supply sufficient gas to generate up to 4 MWe.

Wesola Mine Power / Heat Demands and Costs. The Wesola Mine uses over 150,000 MW-h and pays over US\$ 6 M per year for power. The Wesola Mine's time-weighted average cost of consumed power (not including demand) for 1996 is US\$ 0.031 per kW-hr. Accounting for demand charges, Wesola pays an average of US\$ 0.038 on a kW-hr consumed basis. Wesola management anticipates that the mine's power demand will gradually increase over the next 10 years as ventilation demands, haulage distances, etc., increase; they anticipate a 2.7 MW increase in 15 minute peak demand power between 1996 and 2005.

The Wesola Mine purchases heat from ZEC at an average price of US\$ 4.85 per GJ. In 1996, the mine purchased over 250,000 GJ (for US\$ 1.2 M). Peak mine heat demands in winter exceed 18 MWth while summer demands decrease to approximately 2 MWth.

Mine engineers estimate that the mine might consume an additional 2 to 6 MWth to operate absorption chillers that would satisfy future underground mine refrigeration requirements. Wesola engineers anticipate refrigerating the mine's ventilation air at deeper levels where they expect virgin rock temperatures exceeding 40 degrees C.

ZEC Costs and Revenues. The Wesola Mine and ZEC exchange the commodities listed in Table 4 at the (1996) rates indicated. ZEC revenues from heat sales generated by gas for 1996 are approximately US\$ 655,000. As indicated in Table 5, ZEC's 1996 net income from trade with the Wesola Mine was approximately US\$ 454,000.

ZEC and boiler houses operated by the local utility meet district heating demands in the Myslowice township. As Myslowice is a developed area, local planners do not anticipate increased heating demands over the next ten years.

Proposed Cogeneration Facility Configuration. The proposed project will generate power and heat using a gas turbine fueled by drained coal mine methane and combustion air from a ventilation exhaust shaft. The facility will be designed to accommodate additional modular power and heat generating units as the mine's methane liberation and drainage efficiencies increase.

The gas turbine proposed for this project will consume the maximum average daily volume of methane presently drained by the Wesola Mine and will initially operate at reduced capacity with lower available fuel volumes. Because the turbine will be fueled by gob gas, a methane/air mixture of approximately 60 percent methane, some of the combustion air will enter the turbine with the fuel (i.e., 0.200 m<sup>3</sup>/s, or 0.241 kg/s at standard conditions). Introducing combustion air from the mine's ventilation exhaust shaft with a methane concentration of approximately 0.2 percent in air by volume will provide approximately 0.025 m<sup>3</sup>/s, or 2,160 m<sup>3</sup>/day, of methane (0.016 kg/s at standard conditions). That increment corresponds to a little over 2 percent of the turbine's fuel requirement. Note that the air in the fuel and the methane in the combustion intake air represents a net increase in the air to fuel ratio (although minimal) and should not affect turbine performance.

Manufacturer specifications indicate that the turbine discharge gases will be at 446 Degrees C. The effluent will contain oxygen and nitrogen at concentrations of 15 and 76 percent by volume, respectively. Using a waste heat boiler from the gas turbine's manufacturer, the proposed installation will recover approximately 40 percent of the heat input, or 3.96 MWth at ISO conditions. The unfired boiler will provide 10,450 GJ per month of thermal energy.

Proposed Power and Heat Generation Rates. The proposed power and heat facility will operate so that a favorable price can be offered to the Wesola Mine and ZEC, respectively. The proposed project will offset between 2 and 2.5 MWe presently purchased by the Wesola Mine from the local utility. Because facility availability will be dependent to a large part on the recovery of gob gas from underground activities, the Wesola Mine must implement a system of load shedding when the unit is off-line to use the facility to its advantage. With load shedding the facility would allow the mine to reduce its demand power from 32 MW to at least 30 MW.

The most logical business arrangement with ZEC is to have the project: (1) compensate ZEC for the increased costs of generating heat with coal (US\$ 1.69 per GJ with coal versus US\$ 0.67 per GJ with gas), and (2) not compete with ZEC in heat sales. Table 6 summarizes the economic impact of the proposed power and heat project on ZEC based on 1996 information, assuming similar heat demand, and use of all of the methane drained. The data show that if the project sold all of its heat to ZEC at a favorable price of US\$ 3.61 per GJ (Wesola pays US\$ 4.85 per GJ) for resale to the mine or market, the project's impacts on ZEC are minimized.

## PROJECT FINANCING

The proposed drilling and power project will need to receive the majority of equity in the form of cash from an investor at financial closing. This is especially true of first-of-a-kind projects, as this project is for

the Polish mining industry. Debt suppliers need assurance that a major share of capital has been supplied by someone who assumes the risk of failure. Fortunately for the proposed project, two governmental agencies expressed interest in providing equity capital with favorable terms.

The project qualifies for Polish governmental assistance because of its strong environmental benefits. For these reasons part or all of the equity (including some in the form of a grant) and some debt will most likely come from national or bilateral agencies.

### ECOFUND

The ECOFUND which manages the "debt for environment swap" is able to grant funds for project investment at the closing (up to 30 percent) that will be considered as equity by debt suppliers. This capital is "free" in the sense that it need not earn a return (i.e. project earnings may be applied only to other equity suppliers, thus enhancing their rate of return).

### The National Fund for Environmental Protection and Water Management ("National Fund")

The National Fund and its local associate, the Voivodship Fund, lend capital (with loan remission provisions) and provide cash equity for investments in hard assets of commercially viable projects (National level only). To compensate for risk, the funds request strong equity positions (up to 40 percent) in projects developed by new companies or by coal mining operations. As these funds are supported by royalties on revenues from coal and methane sales and from environmental fees charged to mines, they may apply the earnings from their equity contribution in the project to offset fees charged to mine entities that are co-participants in the same project (Wesola Mine, Katowice Holding Co., or ZEC). Although possible, this arrangement will need further investigation.

### Financing Structure

As the proposed project is a first for Poland, economic models assumed a 60/40 debt to equity ratio. Later projects may be able to increase debt leveraging with 70/30 and 80/20 ratios. Typically, banks will only lend 80 percent of a project's capital if they have encountered similar, consistently successful projects.

Total Estimated Project Costs (US\$ 5.0 M). Table 7 presents the total estimated capital costs for the proposed project, including project development, procurement, and construction separated into two categories: hard costs, and potential sweat equity and in-kind contributions.

Equity Capital (US\$ 2 M). Potential sources for up to 40 percent cash equity are:

- 20 percent from ECOFUND in the form of a grant,
- 10 percent from National Fund, and
- 10 percent from project development and private sources.

Sweat and In-Kind Equity (US\$ 132,000). Potential sweat and in-kind sources could defer at a minimum, approximately 2 percent of total project costs. These include (1) project development efforts, by the developer, (2) engineering and permitting assistance, potentially including detailed engineering, by project participants such as the Wesola Mine, or ZEC, and (3) assistance with drilling equipment approval efforts and training by a project participant involved in methane drainage drilling.

Debt Capital (US\$ 3 M). The following are likely sources for the 60 percent debt capital:

- 30 percent from National Fund and/or Voivodship Fund, and
- 30 percent from commercial banks.

## ECONOMIC AND BENEFITS ANALYSIS

The EPA team conducted detailed financial evaluations of the proposed project in the context of Polish conditions, including inflation projections, energy price projections, interest rates, taxes, and allowances. The analyses varied the assumed prices the project would charge the Wesola Mine and ZEC for power and heat.

### Base Case and Sensitivity Analyses

First year base and sensitivity case prices charged by the project for drilling, heat, and power are presented in Tables 8 and 9, respectively. Table 10 presents a matrix of the commodity pricing and project finance permutations evaluated and the key economic indicators calculated for each scenario.

### Project Benefits

The proposed project will provide numerous benefits to the Katowice Holding Company and its subsidiaries, the USB coal mining industry, and to the global environment.

Power Cost Savings. The Wesola Mine will save US\$ 130,000 per year by purchasing power from the project at a favored cost of 20 percent less than avoided cost.

Increased Revenues from Gas Sales. As the proposed project will purchase all of the gas drained by the mine, gas sales will increase by 54 percent. Using 1996 drainage volumes, the Wesola Mine would gain additional revenue in excess of US\$ 57,000 per year.

Reduced Degasification Costs. The Wesola Mine potentially could reduce its degasification costs by US\$ 364,000 per longwall panel by avoiding up to 40 percent of overlying gallery infrastructure through the use of horizontal gob boreholes.

Increased Revenues from Increased Coal Production. Because the proposed horizontal borehole system can be readily controlled and optimized, the Wesola Mine can anticipate improvements in district methane drainage efficiencies and in recovered gas quality. Improved degasification efficiencies will reduce production delays due to methane gas and will increase longwall coal production. With a 25 percent increase in district drainage efficiency, the Wesola Mine could increase revenues from coal sales by over US\$ 1 M per longwall panel.

Benefits to ZEC. This investigation proposes that the project compensate ZEC for its increased heat generating costs resulting from firing its hot water boilers with coal rather than cofiring with coalbed methane. The project reimburses ZEC by selling its heat, up to 104,000 GJ per year, to ZEC for resale at below market prices. The margin earned by ZEC from resale is sufficient to offset ZEC's increased generating costs. Also, the volume of heat produced by the project is sufficient to supply ZEC's market heat demands during some of the summer months allowing ZEC to curtail summer costs and realize increased savings.

Environmental Benefits. Table 11 summarizes the estimated additional annual methane emissions mitigated by this project if it were implemented today and for the year 2000, assuming that (1) ZEC gas demands remain at 1996 levels, and (2) the mine's overall drainage efficiency increases by 5 percent per year. Cumulatively the project will mitigate in excess of 44 Mm<sup>3</sup> of methane and offset 90 kt of coal, or the equivalent of over 800,000 tonnes of CO<sub>2</sub> (based on a global warming potential of methane of 21 times that of CO<sub>2</sub> over a 100-year time frame (IPCC, 1996)).

## CONCLUSIONS

The proposed CMM drilling and cogeneration project would provide significant benefits to the project participants and coal mining industry in the USB. With favorable grant and loan financing from interested environmental funds, project developers can anticipate high internal rates return (IRR) with reasonable payback periods. Coupled with global environmental benefits and the potential value of mitigating carbon emissions, the proposed project has attracted interest among developers in Poland, including the World Bank.

Projected overall savings and revenue to the Wesola Mine, not including benefits of reduced ventilation demands and improved underground environmental conditions, are greater than US\$ 1.5 M per year. Structuring the proposed project so that ZEC, the affiliated heat generating plant, can benefit equitably from the cogeneration facility encourages ZEC to also participate. To capitalize the proposed drilling and cogeneration project would require approximately US\$4.95 M. Through grants and favorable loans from the ECOFUND and National and Voivodship Funds, project developers could earn an after-tax internal rates of return between 15 and 28 percent, depending on commodity pricing structures.

The Wesola drilling and cogeneration project would also introduce new technology to the USB mining region that would improve mine competitiveness, increase the market for CMM, and provide business opportunities. Directional drilling to off-set overlying gallery developments is also applicable at several mines in the region including, the Brezeszcze, Silesia, Staszic, Morcinek, and Krupinski mines.

Mitigating methane emissions and carbon dioxide emissions by displacing coal use would avoid approximately 800,000 tonnes of CO<sub>2</sub> during the 10 year project period. The local environment would also benefit from improved air quality.

## REFERENCES

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- Intergovernmental Panel on Climate Change (IPCC), 1996. *Radiative Forcing of Climate Change, The 1996 Report of the Scientific Assessment Working Group of IPCC, Summary for Policymakers*.
- Kowollik, G., and H. Heimer, 1986. "Transportable Gas Turbine Cogeneration Plant for German Coal Mine", Proceedings, Gas Turbine Conference, Dusseldorf, West Germany, June 2-8, 1986.

## TABLES

Component	Cost in US\$ (1000's)
1250 meters of gallery	900
60 Boreholes	224
Gathering Lines and Wellheads	21
System Maintenance	15
Total Per Longwall Panel	1,160

Table 1: Cost of Gob Degasification with Overlying Galleries Per Longwall.

Development Costs 3 X 1000 m Horizontal Gob Borehole	
Component	Cost (US\$)
Drill Site	\$10,250
Wellhead Equipment and Casing	\$10,800
Borehole Drilling @ US \$ 50 per m.	\$150,000
Total Estimated Costs	\$171,050

Table 2: Total Estimated Costs for 3 Horizontal Gob Boreholes.

Reduction in Gallery Development (%)					
Degas Efficiency (%)	30	40	50	60	70
40	\$161	\$228	\$302	\$390	\$477
45	\$785	\$852	\$926	\$1,014	\$1,101
50	\$1,409	\$1,476	\$1,550	\$1,638	\$1,725
55	\$2,033	\$2,100	\$2,174	\$2,262	\$2,349
60	\$2,681	\$2,748	\$2,822	\$2,910	\$2,997

Anticipated Gallery Reduction

Table 3: Projected Total Annual Cost Benefit (US\$ 1,000's) for Range of Avoided Gallery Development and Degasification Improvement in the Saddle Group on a per Longwall Basis.

Key Parameters of ZEC's Operations	Rate
Coalbed Methane Purchase Price (US\$/GJ)	\$.67
Coal Purchase Price (US\$/GJ)	\$1.69
Water Purchase Price (US\$/m <sup>3</sup> )	\$.04
Price of Heat to Wesola (US\$/GJ)	\$4.85

Table 4: Key Parameters of ZEC's Operations.

ZEC NET INCOME FROM TRADE WITH WESOLA	US\$1,000's
Heat Sold	\$1,218
Methane Purchased	(\$106)
Coal Purchased	(\$658)
Water Purchased	Negligible
NET	\$454

Table 5: 1996 ZEC Income from Commodities Traded with the Wesola Mine.

Heat Component	Value
Heat Demand for 1996 (GJ)	461,390
Heat to be Supplied by Project (GJ)	110,000*
Net Heat to be Supplied by ZEC (GJ)	351,390
ZEC's Cost to Supply (Fired by Gas and Coal)**	\$456,960
ZEC's Cost to Supply (Fired by Coal Only)	\$593,850
Net Increase in Cost to ZEC by Firing with Coal	\$136,890
Market Value of Heat Supplied by Project	\$533,500
Less Net Increase in Production Costs to ZEC	\$136,890
Favored Heat Purchase Value	\$396,610
Favored Heat Purchase Rate (per GJ)	\$3.61

\*Assumes turbine at full capacity and 95% availability.

\*\* Assumes cost of commodities only (gas, coal, etc.)

Table 6: Favorable Price for Heat to ZEC to Compensate for Project's Gas Use.

Components	Costs	Hard Costs	Sweat / In-Kind
<b>Project Development</b>			
Project Developer	\$ 50,000	\$ 20,000	\$ 30,000
Financial / Banking	\$ 20,000	\$ 20,000	
Legal, Environmental, Engineering	\$ 80,000	\$ 50,000	\$ 30,000
Permitting	\$ 15,000	\$ 15,000	
Transactions	\$ 25,000	\$ 25,000	
<b>Sub-Total</b>	\$ 190,000	\$ 130,000	\$ 60,000
<b>Project Construction</b>			
Capital/Interest During Construction	\$ 150,000	\$ 150,000	
Construction Management	\$ 20,000	\$ -	\$ 20,000
<b>Drilling Equipment</b>			
Procured Cost	\$ 992,000	\$ 992,000	
Approval by Higher Mining Authority	\$ 40,000	\$ 32,500	\$ 7,500
Directional Drilling Training	\$ 175,000	\$ 140,000	\$ 35,000
Shipping and Insurance	\$ 28,000	\$ 28,000	
Import Duties	\$ 204,000	\$ 204,000	
Taxes	\$ 85,680	\$ 85,680	
<b>Power and Heat Equipment</b>			
Procured Cost	\$ 2,278,240	\$ 2,278,240	
Shipping	\$ 25,000	\$ 25,000	
Import Duties	\$ 285,713	\$ 285,713	
Taxes	\$ 249,574	\$ 249,574	
<b>Subtotal</b>	\$ 4,533,206	\$ 4,470,706	\$ 62,500
<b>Total</b>	\$ 4,723,206	\$ 4,600,706	\$ 122,500
<b>7.5 % Contingency</b>	\$ 354,240	\$ 345,053	\$ 9,188
<b>Total Costs</b>	\$ 5,077,447	\$ 4,945,759	\$ 131,688

Table 7: Total Estimated Project Costs (US\$).

Commodity	Price (US\$)	Comments
Power (\$/kW-hr)	.032	10% less than avoided cost
Heat (\$/GJ)	3.61	75% of price paid by mine
Drilling (\$/m)	50.00	Rate for Polish contractor
Gas (\$/m <sup>3</sup> )	.022	Price presently paid by ZEC
Water (\$/m <sup>3</sup> )	.43	Price presently paid by ZEC

Table 8: First-Year Prices for Commodities Used in Analyses.

Commodity	Price (US\$)	Comments
Power (\$/kW-hr)	.029	20% less than avoided cost
Heat (\$/GJ)	3.15	65% of price paid by mine
Drilling (\$/m)	50.00	Rate for Polish contractor
Gas (\$/m <sup>3</sup> )	.022	Price presently paid by ZEC
Water (\$/m <sup>3</sup> )	.43	Price presently paid by ZEC

Table 9: First-Year Prices for Commodities Used in Sensitivity Analyses.

Without ECOFUND Grant	IRR (%)	NPV (10%) (\$1000's)	Pay Back Period (Yrs)
Debt to Equity 60/40, Base Case Prices	10.3	40	7.0
Debt to Equity 60/40, Sensitivity Prices	5.4	(541)	8.3
Debt to Equity 70/30, Base Case Prices	10.5	554	7.4
Debt to Equity 70/30, Sensitivity Prices	5.5	(507)	8.3
With ECOFUND Grant			
Debt to Equity 60/40, Base Case Prices	23.9	1,067	4.9
Debt to Equity 60/40, Sensitivity Prices	14.5	352	6.5
Debt to Equity 70/30, Base Case Prices	28.0	1,080	4.8
Debt to Equity 70/30, Sensitivity Prices	18.4	520	6.3

Table 10: Scenarios Simulated with Key Economic Indicators.

Year	Methane Liberated (m <sup>3</sup> )	Used by ZEC in 1996 (m <sup>3</sup> )	Additional CH <sub>4</sub> Emissions Mitigated by Project (m <sup>3</sup> )	Equivalent CO <sub>2</sub> Mitigated by Project (t)
1996	44,930,770	4,778,883	3,072,561	43,749
2000	49,879,440	4,778,883	4,781,361	68,080

Table 11: Additional Methane Emissions, and Equivalent CO<sub>2</sub> Mitigated by Proposed Project.

## FIGURES

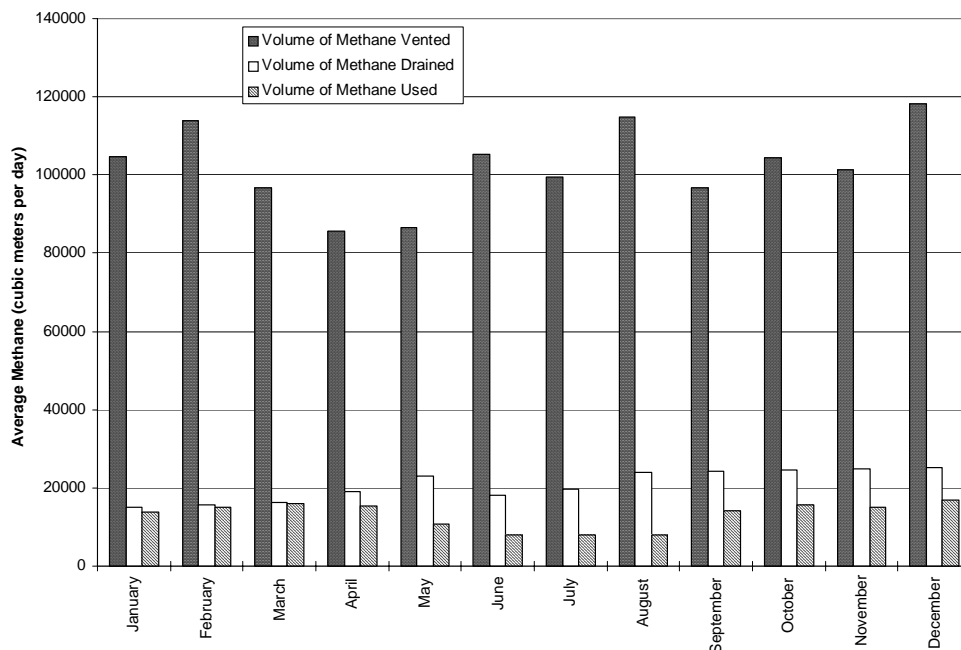


Figure 1: Wesola Mine 1996 Methane Vented, Drained, and Used.

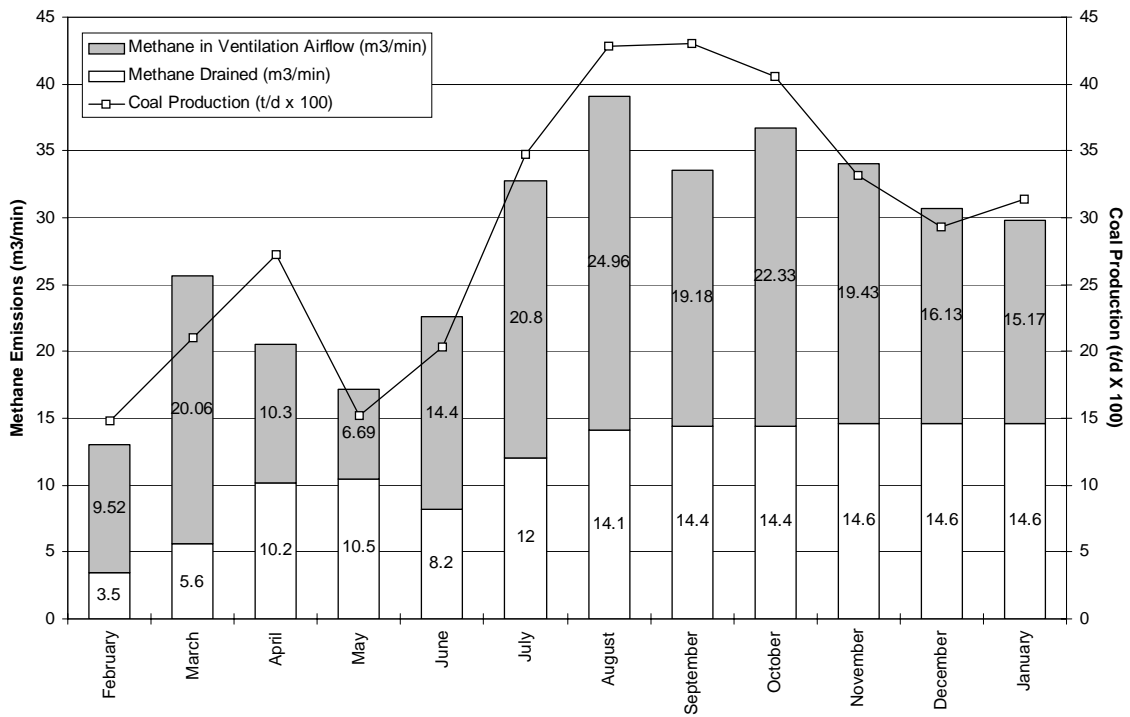


Figure 2: Coal Production and Methane Emissions from Longwall 1016a in the 501 Coal Seam.

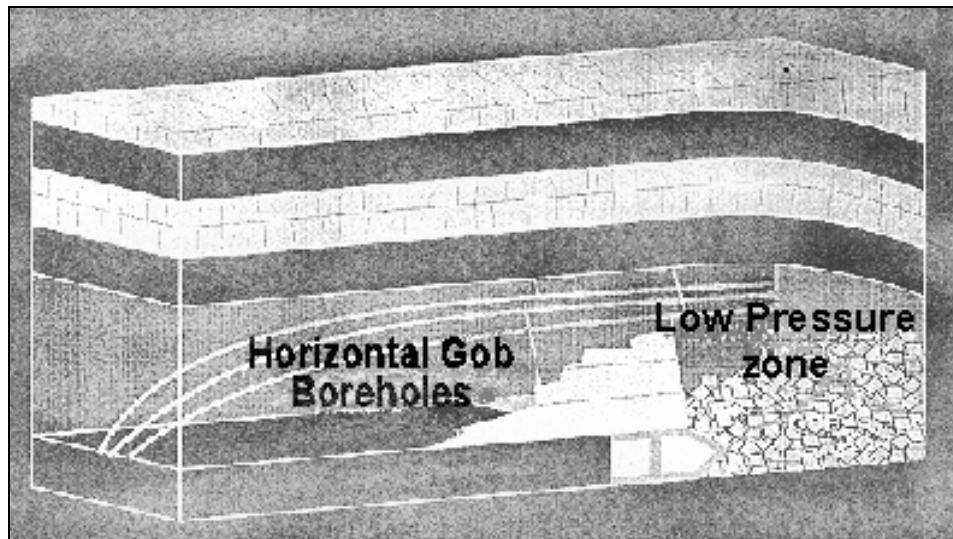


Figure 3: Horizontal Gob Boreholes.