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Pre-Feasibility Study of Coal Mine Methane Recovery and Utilization at Zhdanovskaya Mine, Ukraine

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Global Methane Initiative

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1. Executive summary

This report presents the findings of a pre-feasibility study conducted at Zhdanovskaya Mine, Ukraine, as part of a larger initiative funded by the U.S. Environmental Protection Agency (EPA) under the auspices of the Global Methane Initiative (GMI), of which both the United States and Ukraine are founding partners.

The Project Team, headed by Ukraine's Agency for Rational Energy Use and Ecology (ARENA-Eco), examined whether a coal mine methane (CMM) recovery and utilization project is technically and economically feasible at Zhdanovskaya Mine based on preliminary factors. This report is intended to help make an initial assessment as to whether a full-scale feasibility study is warranted. Historically, the poor financial state of Ukrainian mines has been a strong impediment for the capture and utilization of methane in the country. However, a growing number of projects under development, usually in privatized or leased mines, are making use of captured methane in Ukraine. Two main reasons for selecting Zhdanovskaya Mine for this study were the interest that the mine management demonstrated on CMM recovery and utilization, and the fact that the mine is a privately operated enterprise, leased by the Ukrainian Government. Such mines are usually more productive and successful, thus, having greater potential to attract private investment. To determine whether it would be feasible to implement a CMM recovery and utilization project (herein referred to as a CMM project), the Project Team considered an array of initial factors, including gas emissions, historical and planned coal production, site and local infrastructure and availability of resources to develop appropriate infrastructure, and continued interest and engagement of mine management.

The Project Team found large potential to reduce methane emissions at Zhdanovskaya Mine. In 2010, the mine produced 901,000 tonnes of coal, resulting in estimated methane emissions of nearly 17 million m^3 that year. There are plans to increase production of coal at the mine. In particular, the mine company plans to mine two longwalls which, absent a CMM project, it is estimated would release about 30.9 m^3 of methane per minute.

The Project Team suspects that there are two main, technically-viable options for the optimal utilization of CMM at the mine: (1) electricity generation by installing a gas-engine generator to produce power for mine use or export to the public grid; and (2) on-site heat generation from existing mine boilers which presently consume coal, but can be switched to use CMM. To assess the value in continuing on to a full-scale feasibility study, the Project Team compared both options by taking into account geographical and geological conditions, plans for further mine activity, including implementation of a degasification system, and availability of CMM resources. A full-scale feasibility study could look at these options in more depth.

A cash flow projection shows that it is more cost-effective to invest in on-site heat-only production by using the mine's existing boilers. This is the case even when we consider benefits from recovering the waste heat from hot gases exhausted by the gas turbine or engine while producing electric power at no capital cost. The cash flow projection and related financial criteria of the second project option suggest that on-site heat generation would be financially attractive to investors as its net present value (NPV) is positive (194,000 USD) and its internal rate of return (IRR) of 17.3% exceeds the discount rate at 12%, a conservative estimate. However, using CMM for on-site electricity generation would result in greater CO_2-e emissions reductions, nearly twice the reductions achieved when using CMM for on-site heat production.

Table 1. Comparison of economic results

Evaluation scenario	Option 1: Electricity generation	Option 2: On-site heat generation
Methane utilized over project lifetime (million m^3)	60.5	34.8
Total CAPEX (million USD)	2.96	1.15
Tonnes of CO_2-e over project lifetime	948,800	419,200
CAPEX (USD)/tonnes of CO_2-e	3.12	2.74
NPV at 12% discount rate (USD)	-785,000	194,300
IRR (%)	5.0	17.3
Simple payback period (years)	11.6	5.7

The preliminary results from this assessment indicate that there is a business case for conducting a full-scale feasibility study of CMM utilization at Zhdanovskaya Mine. However, it is important to note that implementation of a CMM project at the mine is likely to be more successful if it is linked to carbon credits. Without carbon credits, the feasibility of implementing a CMM project at Zhdanovskaya Mine lies in the mine's ability to attract investment or its willingness to provide its own financing.

2. General overview

2.1. Pre-feasibility study background

This document serves as the final report for a pre-feasibility study that was conducted by a project team assembled and managed by the Agency for Rational Energy Use and Ecology (ARENA-Eco) in Ukraine (herein referred to as the Project Team). The study was developed for and funded by the USEPA Coalbed Methane Outreach Program, through the Global Methane Initiative, under an Interagency Agreement with Pacific Northwest National Laboratory.

To select the mine for this study, the Project Team began by reviewing ten mine profiles. The mine profiles were prepared by the Project Team prior to the pre-feasibility study in order to update information presented in the document "Coal Mine Methane in Ukraine: Opportunities for Production and Investment in the Donetsk Coal Basin" (Triplett et al., 2001), a guide for investors and other stakeholders interested in CMM project development in Ukraine. In the course of this process, the Project Team also considered a longer list of mines. Zhdanovskaya Mine was identified as a potential candidate based on the interest of the mine management to explore CMM capture and utilization, its willingness to share information, and the fact that it is a privately operated enterprise. A major barrier to CMM capture and utilization in Ukraine is the poor financial state of many Ukrainian mines. This has been slowly changing due to the government's initiative to privatize coal mines over the past decade. Today, most financially successful and productive Ukrainian coal mines are privatized or leased (Gagurin et al., 2010). Existing CMM projects in Ukraine suggest that these mines typically have a large CMM recovery potential.

2.2. Summary of mine characteristics

Zhdanovskaya Mine, located near the town of Zhdanovka, was created de jure in 1970 after the integration of two mines: Zhdanovskaya #4 and Zhdanovskaya #3. The Zhdanovskaya #4 and #3 mines became operational in 1957 and 1958, respectively. Both mines were based on a design developed by the institute *Dongyproshakht*[1], with planned capacities of 350,000 and 400,000 tonnes per year, respectively. Zhdanovskaya #3 reached its target capacity in 1964 and Zhdanovskaya #4 in 1965.

Initially, Zhdanovskaya Mine was part of the Oktyabrugol Coal Association. In 1997, the mine retired from Oktyabrugol Coal Association and became an independent state enterprise with a planned mining capacity of 780,000 tonnes of coal per year. In 2005, the mine was leased to the Closed Joint Stock Company “Zhdanovskaya Mine”.

The mine was issued a license for production of CMM in 1998 (#1499 of July 24, 1998). Currently, Zhdanovskaya Mine employs a total of 2,577 persons.

2.3. Geography and topography

The mining property is located in the Donetsk and Makeyevka geologic/industrial district in the central part of the Donetsk Coal Basin (Figure 1). The geographic coordinates of the mining area (center of Zhdanovskaya Mine) are: north latitude - 48°08′45″ and east longitude - 38°17′27″. The location is within a short distance of the region’s major industrial centers of Makeyevka, Khartsyzsk, and Yenakievo, which have large iron and steel works and other industries, including pipe and steel cable manufacturing.

[1] Dongyproshakht is a design institute in Donetsk, Ukraine, specialized in integrated design, reconstruction, and technical re-equipment of existing coal-fired plants, as well as coal mine development.

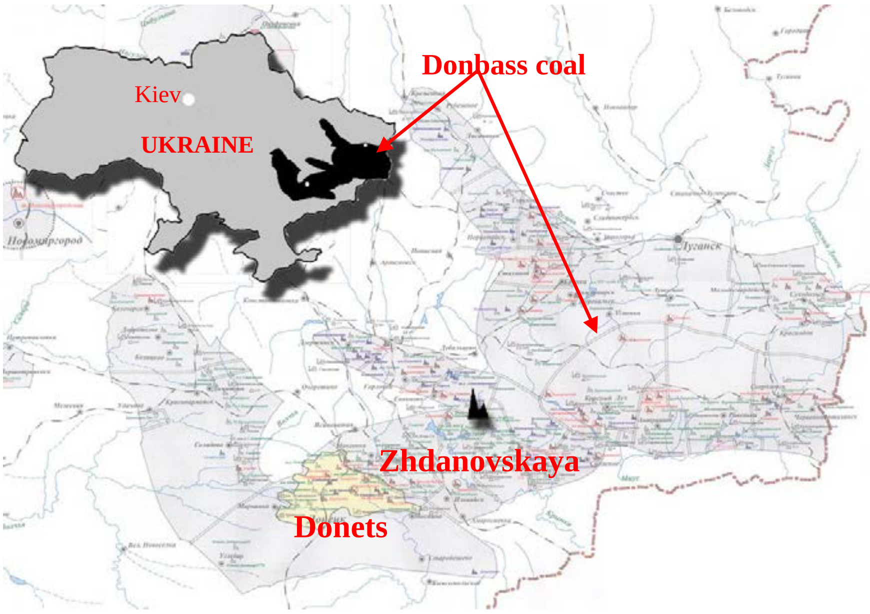

Figure 1. Location of Zhdanovskaya Mine

The surface terrain of the area in which the mine is located is an undulating plain that is crisscrossed by ravines. Elevation ranges from 260 meters above sea level in the southern part, to 200 meters in the northern section of the property. Most of the surface is farmed.

The total mining area of Zhdanovskaya Mine amounts to 27.2 km^2. The extension of the mining area is 4.3 km down the pitch and 6.3 km along the entire length of the strike.

In geological terms, the mining area is situated along the central portion of the south limb of the Chistiakovo-Snezhnyanskaya syncline.[2]

The north end of the Zhdanovskaya mining area lies adjacent to a spare block of Komsomolets Donbassa Mine. The eastern and southern ends of the mining area border the mining areas of Komsomolets Donbassa Mine and Rassvet Mine, respectively.

2.4. Coal reserves

According to Zhdanovskaya Mine's information, the mine holds 48.7 million tonnes of balance[3] coal reserves (coal-in-place), with corresponding total mineable reserves of about 35.2 million tonnes of primary low-volatile bituminous coal. This mine produces medium quality coal mostly used for raising steam for electricity generation.

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[2] A syncline refers to a geologic structure in which the rock strata are folded with stratigraphically younger rocks found in the center.

[3] In former Soviet Union countries, geologic reserves are classified into the categories of "balance" and "sub-balance" on the basis of economic factors, such as demand requirements of the planned economy for each grade of coal, geographic location and character of a specific coal deposit, cost of production for the specific deposit, including the cost to transport to industry, total amount of capital investment needed to develop the mine, and payback period for the required capital investment (Lawson, 2002).

Low-volatile bituminous coal reserves include a small amount of anthracite. Total amount of balance coal reserves by extent of exploration and total mineable reserves as of January 1, 2011, are shown in Table 2.

Table 2. Balance coal reserves by extent of exploration and total mineable reserves

Seam	Coal rank	Balance coal reserves (coal-in-place) by extent of exploration, thousand tonnes				Total mineable reserves, thousand tonnes
		A	B	C_1	$A+B+C_1$	
l_7	Low vol. bituminous coal	44	5,439	7,739	13,222	10,094
l_6	Low vol. bituminous coal	88	6,078	6,963	13,129	9,675
l_4	Low vol. bituminous coal	82	5,728	5,668	11,478	7,472
l_3	Low vol. bituminous coal	-	4,887	5979	10,866	7,924
Total	Low vol. bituminous coal	214	22,132	26,349	48,695	35,165

A: Detailed exploration work is completed with drill holes and measurements from mining having a spacing on the order of 600 to 800 meters for beds with lateral continuity and relatively uniform thickness: geological features which affect the beds have been identified and the quality of the beds has been determined, mining conditions have been established by actual mining, and preparation characteristics have been tested and are known.
B: Exploration not as detailed as **A**, with distances between drill holes, exploratory shafts, pits and drifts having a spacing ranging from 1,200 to 1,600 meters.
C_1: Widely spaced.

2.5. General characteristics of mining

Mining area of Zhdanovskaya Mine is developed by:

- One vertical cage shaft
- Four centrally located inclined shafts (one of them is utilized for coal and rock transportation, and the others are used for lifting miners, equipment, and material)
- Six end-on inclined air shafts laid over the seams l_3, l_4, and l_6 (Table 2).

The mining area is organized into mining levels. The upper levels are mined before the lower levels. Primary longwall mining is carried out by traveling along the course of the mining face and ventilation entries up to the border of the mining area.

The mine lease straddles the axis of an anticline[4] with dimensions of 1,500-3,000 meters and 1,900-2,250 meters.

The Zhdanovskaya Mine applies the advancing longwall method to develop panel mine sections at seam l_7. Combination system development of mine districts is applied at other worked seams. Zhdanovskaya Mine has reached per face outputs of 630-950 tonnes/day at seams l_3, 1_4, 1_6, and1_7.

The mine is ventilated using boundary ventilation layout. The mine uses a suction method for mine ventilation (Figure 2). There are four fans in the main ventilation system, which are installed on the east ventilation shafts of seams l_3 and l_7, on the central ventilation shaft of seam l_6, and on the west shaft of seam l_7.

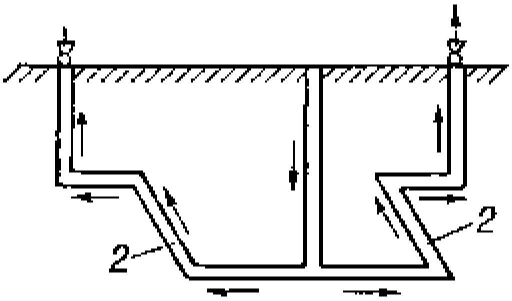

Figure 2. Mine ventilation scheme[5]

3. Geologic conditions

3.1. Tectonics

Structurally, the Chistiakovo-Snezhnianskaya syncline, where the mining area is located, is an asymmetric linear fold with a steep northern flank and a flat southern flank. Its synclinal axis plunges to the northwest at an angle of 5-8°, gradually merging into the vast Kalmyus-Toretskaya structural basin. The relatively flat-lying coal-bearing strata is broken by symmetrical anticlinal folds and faults at the intersect of the Chistiakovo-Snezhnianskaya syncline and the Kalmius-Toretskaya basin.[6]

The coal-bearing strata contained within the the Yasinovsko-Zhdanovskaya flexure lies alongside the Yunkomovsky thrust, which is a large regional upthrust separating the Chistiakovo-Snezhnianskaya syncline from the Kalmyus-Toretskaya basin, and is also a natural boundary of the mining area. It strikes northwest (at 26 to 45^o) and dips southeast (at 35 to 60^o). The results of exploration indicate that the center of the mining area is a stressed

[4] An anticline refers to a geologic structure in which the rock strata are folded with stratigraphically older rocks found in the center.

[5] From Russian Academic Dictionary, http://dic.academic.ru.

[6] A *structural basin*, is a depression formed in the earth's crust in which sediments accumulate.

zone containing failed rock features. The area's coal seams are also characterized by tectonic disturbances such as flexure bends (folds in the rock).

Actual mining is complicated by low-amplitude disturbances, which forms disjunctions in the rock. Nevertheless, the mining area at coal seam l_7 itself has no significant disjunctions. Eight minor disturbances with amplitude of 0.13 to 1.3 meters stretching from 150 to 450 meters were found while mining coal seam l_7. Key information regarding low-amplitude tectonic disturbances that had already been found at working seams is demonstrated in Table 3.

Table 3. Low-amplitude tectonic disturbances

Seam	Length of disturbances (meters) / Number of disturbances	Azimuth of fault plane (range, in degrees)	Amplitude of fault plane (range, in meters	Hade[7] of fault plane (range, in degrees)
l_7	150-425 / 8	128 - 320	0.13 -1.3	35 - 60
l_6	200-500 / 9	260 - 330	0.25 - 4.0	25 - 65
l_4	100-1,200 / 7	130 - 350	0.6 - 10.0	20 – 45
l_3	120-350 / 6	10 - 312	0.5 - 1.3	28 – 55

3.2. Characteristics of surrounding strata

The coal-bearing strata are formed out of clay shale, siltstone, sandstone, and limestone. The main physical and mechanical properties of these coal-bearing strata varieties are shown in Table 4.

The sandstones occupy insignificant areas in the roof and floor of the coal seams (from 4-15%). It is mainly small- and medium-grained sandstone. On rare occasions, layers of coarsely graded varieties can be found. One common configuration is to have aleurolite shale in the floor and a roof of coal seams (this configuration accounts for 21-81% of the coal-bearing area). The rocks are impermeable, but in tectonically disturbed zones, there are local methane concentrations.

[7] A *hade* refers to the inclination of a mineral fault from the vertical.

Table 4. Physical-mechanical properties of rock obtained from laboratory research and acoustic logging measurements

Name	Moisture content, %	Density, g/cm^3	Porosity, %	Breakdown point, g/cm^3	
				Under the compression force	Under the break force
Sandstone	0.83	2.69	3.37	1,266	114
Sandy shale	1.39	2.73	3.95	520	68
Clay shale	1.91	2.77	4.35	430	38
Limestone	0.27	2.72	1.89	1,161	79

3.3. Coal seams

Zhdanovskaya Mine works four coal seams of the Almaz suite formation: l_7, l_6, l_4, and l_3. Seams l_6, l_4, and l_3 are classified as dangerous with sudden outbursts of gas beginning at a depth of 230 meters; seam l_7 has similar characteristics beginning at a depth of 177 meters. However, the seams are not prone to coal-dust-related explosions and rock bumps nor spontaneous combustion.

Coal seam l_7 has a complex structure. On the western side, it consists of two coal layers with a thickness of 0.18-0.3 meters and 0.7-0.87 meters, respectively, which are separated by an interbed of clay shale with a thickness 0.2-0.5 meters. On the eastern side, the coal seam has a simple composition with a thickness of 1-1.2 meters.

The immediate top of the seam consists of sandy shale, which is thin-layered and unstable in stressed zones. The basic roof of the seam is made up of sandy shale and sandstone, which is hard quartz. The thickness of sandy shale and sandstones are 3.5-10.0 meters and 2.0 – 10.3 meters respectively.

The immediate bottom of the seam is made up of medium stable sandy shale with a thickness of up to 1.0 meter. The basic floor of the seam is sandy shale with a thickness of 2.8 to 5.6 meters.

Table 5 presents the main characteristics of the coal's quality, by seam.

Table 5. Major coal-quality characteristics of mineable coal seams

Seam	Ash content, %		Moisture content, %	Sulphur content, %	Volatile matter, %	Volatile matter volume yield, cm^3 /g
	Coal-in-place	Run of mine coal				
l_7	8.0	11.4	2.8	1.6	8.3	307
l_6	9.6	12.1	2.3	2.7	8.5	304
l_4	11.4	13.0	2.5	2.9	8.2	303
l_3	10.3	25.9	-	1.6	7.7	293

Below the zone of gas decay (150 m) down to seam l_7, there are 13 to 19 adjacent seams (17 on average).

The geological factors and mine technical conditions of seams subject to mining up to 2020 are presented in Table 6.

Table 6. Geological factors and mine technical conditions of seams mined up to year 2020

#	Name of indicator	Seam			
		l_7	l_6	l_4	l_3
1	Average seam thickness, m	1.17-2.03	1.22-1.36	1.0-1.15	1.32
2	Average thickness of coal in place, m	1.17-1.48	1.14-1.16	0.94-1.07	1.12
3	Length of longwall face, m	200	200	200-230	200
4	Mining-and-hauling machine	1K-101, 1GSh-68			
5	Length of the shaft, m	1,500-2,000	1,800-2,400	950-1,700	2,400
6	Depth of mining, m	685	642	630-700	640
7	Roof control method	Complete caving			

3.4. Natural coal seam gas content

The major factors that influence coal seam gas content are coal metamorphism, the depth of its bedding, and tectonic disturbances. CMM travels downward, northeast from a depth of 80 to 130 meters. The composition of the coal seam gas is high in methane; increasing with the depth of mining (Figure 3).

In the center of the seam l_7 mining area, the gas content ranges from 10 to 25 m^3 per tonne of dry and ash-free (daf) coal, with estimates of over 30 m^3 per tonne of daf coal nearby. At a depth level above 600 meters the gas content of coal reserves is greater than 30 m^3 per tonne of daf coal.

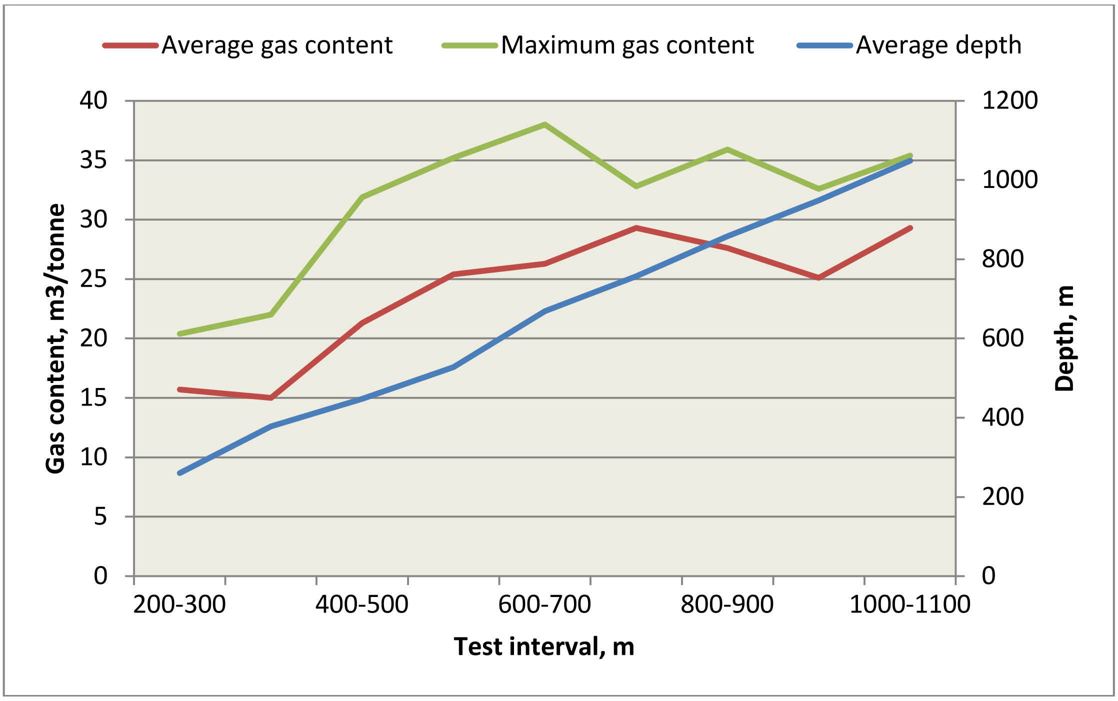

Figure 3. Horizon-oriented forecast of coal seams gas content

Table 7 shows the actual measurements of the longwalls' methane content. The maximum gas content was registered at seam l_7.

Table 7. Gas conditions of the mine

Seam	Maximum depth of mining, m	Maximum gas content, m^3 per tonne daf
l_7	520	31.4
l_6	450	18.8
l_4	385	5.3
l_3	350	10.0

On January 1 2011, the total methane resources of Zhdanovskaya mining area was estimated at 1465 million m^3, including 426.5 million m^3 at seam l_7. Figure 4 provides the historical volumes of total methane liberated from the mine, and coal production by years. Figure 5 shows methane emissions broken down by degasification and ventilation as well as specific emissions.

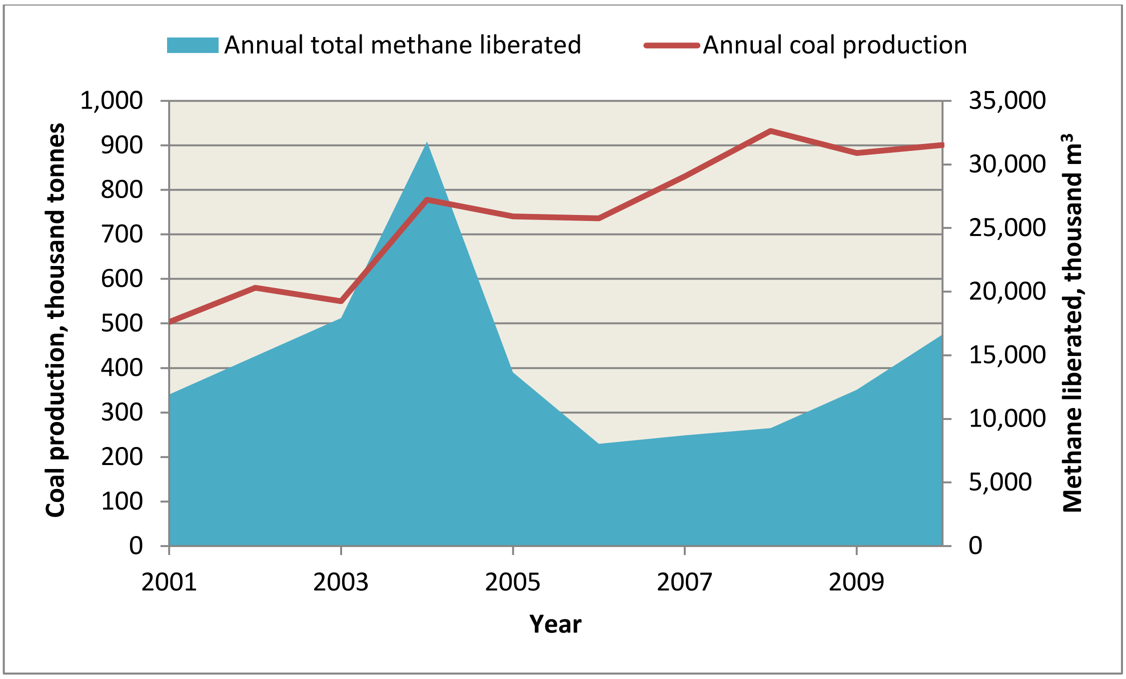

Figure 4. Historical total methane liberated and annual coal production

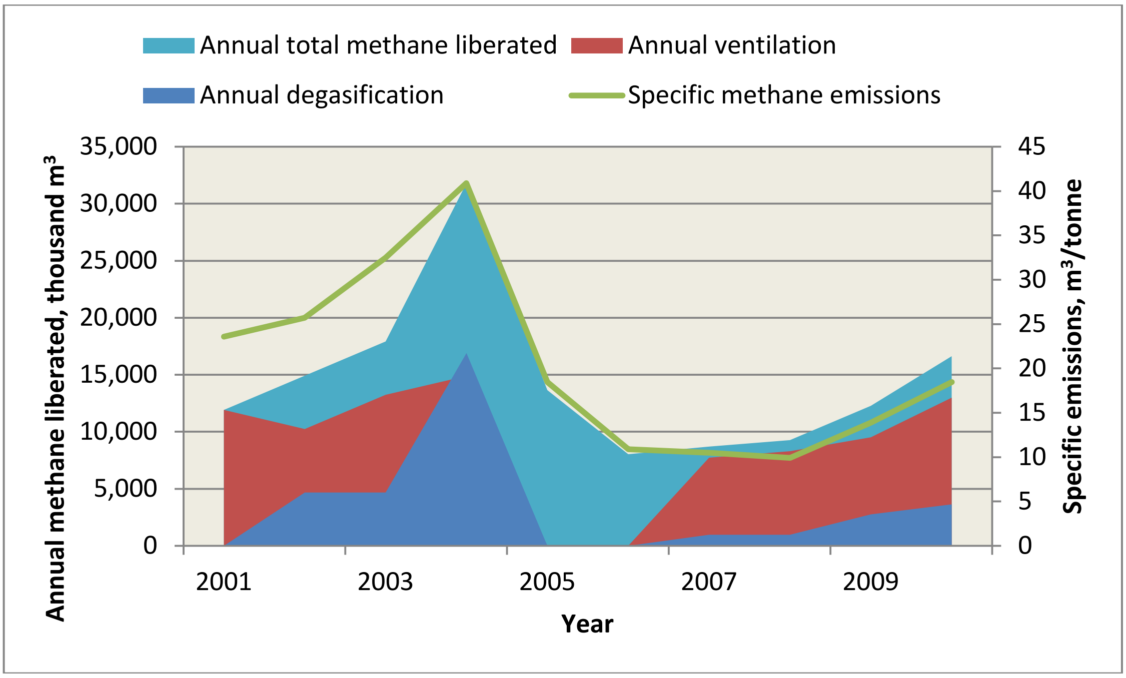

Figure 5. Historical methane emissions and specific emissions

4. Coal production and methane emissions projections

4.1. Planned coal mining activity

Zhdanovskaya Mine plans to develop the 8th East and 8th West longwalls of seam l_7 by 2018. 8th East longwall will be commissioned by the end of 2011. For the 8th East longwall, the length of the mining extracted area is 1,950 meters. The planned per face output is 600 tonnes per day. Mine operators will use the mining-and-hauling machine 1K-101 (model number) to extract the coal. The thickness of the seam that will be extracted is 1.18-1.34 meters. The longwall face is 200 meters long and its minimum cross-sectional area is 2.4 meters. The mine uses complete caving technology for roof control at both longwalls.

Table 8 lists the disposition of the contiguous seams relative to seam l_7 at the 8th East longwall face.

Table 8. Contiguous seams relative to seam l_7 at the 8th East longwall face

#	Seam	Distance from developed seam, m	Thickness of seam, m	#	Seam	Distance from developed seam, m	Thickness of seam, m
In the roof:				7	l_8^1	26.9	0.39
1	m_4	198.5	0.2	8	no syn.	22.7	0.05
2	m_3	154.1	1.03	9	no syn.	16.2	0.2
3	m_2	118.3	0.51	10	l_8	12.3	0.39
4	no symbol	70.3	0.2	11	l_7	0.0	1.13-1.34
5	no symbol	60.5	0.2		In the floor:		
6	l_8^2	36.7	0.2	12	l_6	83.3	1.13

After the 8th East longwall is mined at a depth of 670 meters, the 8th West longwall of seam l_7 will become operational in 2016. The mining extracted area is 1,500 meters long and the longwall face is 200 meters long. The planned per face output is 600 tonnes per day. Mine operators will use the mining-and-hauling machine 1-GSh-68 (model number) to extract coal. The thickness of the seam that will be extracted is about 2 meters. The minimum cross-sectional area of the longwall face is 4.7 meters. The mine uses complete caving technology for roof control.

The mine ventilation system of the worked zone will pass contaminated air back through the system along return airways to the gob (1,100 m^3/min).

The disposition of contiguous seams relative to seam l_7 at 8th East longwall face is listed in Table 9.

Table 9. Contiguous seams relative to seam l_7 at 8th West longwall face

Seam #	Seam	Distance from developed seam, m	Thickness of seam, m	Seam #	Seam	Distance from developed seam, m	Thickness of seam, m
In the roof:				9	m_1	51.4	0.2
1	m_4^0	184.5	31.8	10	l_8^2	31.8	0.2
2	m_4	170.3	29.0	11	no symbol	29.0	0.1
3	m_3	148.2	24.4	12	l_8^1	24.4	0.4
4	m_2^1	140.2	18.0	13	l_8	18.0	0.2
5	m_2	112.4	0.0	14	l_7	0.0	2.0
6	no symbol	83.7	0.24		In the floor:		
7	no symbol	68.3	0.15	15	$l_6^н$	81.2	1.2
8	m_1^1	65.0	0.24				

4.2. Evaluation of methane emissions and amount of methane captured

According to an official document approved by the State Committee of Ukraine for Labor Protection (1994), "Guidance on design of ventilation systems of coal mines," an evaluation of gas emissions for existing mines should be calculated based on actual data for exploiting a similar coal seam. Thus, to assess methane emissions for 8th East and 8th West of seam l_7, the Project Team used data from the similar 7th East and 7th West longwalls of this seam. Table 10 shows information related to gas emissions of the 7th East and 7th West longwalls.

Table 10. Data on similar longwall faces

Longwall face	Length, m	Productivity, tonne/ day	Methane flow in ventilation air of mining, thousand m^3/day	Methane flow in drainage system, thousand m^3/day	Total methane removed from the mine, thousand m^3/day
7th East longwall face of seam l_7	150	514	11.32	7.91	19.22
7th West longwall face of seam l_7	225	625	13.92	6.09	20.02

The Project Team used the following formula to assess the average methane emissions (MEas) at the mining area:

$$MEas = MEac \times (Las / Lac)^{0.4} \times (Ppl / Pac)^{0.6} \times Kmm \times Ked,$$

Where:

MEac – actual methane emissions at longwall face (based on 7th East and 7th West longwalls)
Las – the length of assessed longwall face, meters
Lac – the length of longwall face, meters
Ppl – planned coal production at assessed longwall face, tonne/day
Pac – average coal production at longwall face, tonne/day
Kmm – coefficient that takes into account change of mining method[8]
Ked – coefficient that relates dependence of methane emissions from depth of mining

Table 11 shows the initial data used to project CMM emissions at 8th longwalls of seam l_7. The results of the projection are shown in Table 12.

Table 11. Initial data for calculation of expected CMM recovery

Indicator	Comparable longwall face		Designed longwall face	
	7th East longwall face of seam l_7	7th West longwall face of seam l_7	7th East longwall face of seam l_7	7th West longwall face of seam l_7
Length, m	150	225	200	200
Average productivity, tonne/day	514	625	600	600
Methane flow, m^3/min	13.35	13.90	-	-
Mining method	gob-road system	panel system	gob-road system	gob-road system
Depth of mining, m	590	630	650	670

Table 12. Projection of CMM emissions of 8th East and West longwalls of seam l_7

Designed longwall face	Average expected methane release by sources, m^3/min				
	Mining seam	Coal seams in the roof	Coal seams in the floor	Rocks in the roof	Total
8th East longwall face of seam l_7	3.6	9.7	0.0	3.1	16.4
8th West longwall face of seam l_7	3.9	7.6	0.0	3.0	14.5

[8] The Project Team applied Kmm (equal to 1.124) because the 7th west longwall was worked out by using a panel system of mining, just as 8th west longwall will be worked out using a gob-road system of mining.

According to existing regulations, namely the regulation put forth by the Standards of Organizations of Ukraine (2004), drainage boreholes have to be drilled in the roof behind the longwall and with the U-turn on working face from the zone behind the seam being worked. Normally the degasification efficiency of the coal seam roof is no less than 70%.

With this assumption the drainage system will capture 0.7 x (9.7 + 3.1) = 8.96 m^3 methane per minute at the longwall district of the 8th East longwall face of seam l_7 and 0.7 x (7.6 + 3.0) = 7.42 m^3 methane per minute at the longwall district of the 8th West longwall face of this seam.

The mines' degasification experience in Donbas shows that boreholes drilled into the roof behind the longwall provide methane purity of at least 35%. Thus the mine has to ensure that the degasification system captures 8.96/0.35 = 25.6 m^3 of mine air per minute at longwall district of the 8th East longwall face and 7.42/0.35 = 21.2 m^3 mine air per minute at longwall district of the 8th West longwall face. Table 13 shows the drilling parameters of degasification wells that ensure that these amounts of mine air will be captured.

Table 13. Drilling parameters of degasification wells

Well number	Angle of turn from axis of coal heading, degrees	Borehole deviation from the horizon, degrees	Length, m	Depth of seal, m	Distance between wells, m	Diameter, mm
8th East longwall face of seam l_7						
1	47	28	59	10	-	93
2	58	21	63	10	-	93
3	50	31	55	11	22-25	93
4	90	38	46	11		93
8th West longwall face of seam l_7						
1	46	23	59	10	-	93
2	57	17	68	10	-	93
3	51	27	54	15	21-24	93
4	90	33	44	10		93

5. Options for CMM utilization at Zhdanovskaya Mine

5.1. Consideration of possible project options

While a full-scale feasibility study would explain all of the options for CMM utilization in detail, based on the pre-feasibility study at Zhdanovskaya Mine, there appears to be three potential options for the beneficial utilization of CMM. These three options are possible only if the methane captured in the mine's drainage system has concentration levels in the methane-air mixture that exceed 35%. This prefeasibility study mainly considers these options in the context of better understanding the usefulness of continuing on to a full-scale feasibility study. The options are as follows:

1. Electricity generation based on gas engine(s) (with or without recuperation of engine exhaust heat for heating mine facilities and other needs).

2. Heat generation in existing mine boilers, shifting fuel consumption from coal to CMM (with or without flaring of excessive methane).

3. Heat generation in the existing district heating system and separate boilers in neighboring residential areas (if these exist).

Zhdanovskaya Mine is located 3 km away from the town of Zhdanovka. All other things being equal, the third option requires additional expenses for laying up to 5 km of new gas pipelines, and non-payments in the district heating sector make project economics particularly difficult. For this reason, the Project Team assessed and compared the financial viability for options 1 and 2 only.

The common project conditions and basic technical assumptions for options 1 and 2 are the following:

- Underground degasification activities at the mine are implemented independently from both project options and do not interfere with methane extraction volumes to the surface.
- The considered project options include the same works and capital expenses with regards to improving the existing CMM drainage system at coal seam l_7.
- From 2012, when mining the 8th East longwall of coal seam l_7 will have begun, to 2016 (inclusive), the mine's improved degassing system will have extracted 8.96 m^3/min or 4.71 million m^3/year of CMM. From 2017-2019 while mining 8th West longwall of coal seam l_7, this degassing system will extract 7.42 m^3/min or 3.9 million m^3/year of CMM.
- Upon completion of mining the 8th longwall of coal seam l_7, coal mining will start on the 9th longwall of the same seam. Although the exact volume of methane to be extracted by the new degassing system is unknown at this stage, we can reasonably assume that the volume extracted will be similar to that of 8th East and West longwalls of coal seam l_7.
- Calorific capacity of 1 m^3 of methane is 8,280 kcal (at density 0.717 kg/m^3). The calorific capacity of bituminous coal is about 8,300 kcal/kg. Thus, one cubic meter of methane could replace approximately one kg of coal used in boilers for heat energy production.

The common methodological approaches and economic assumptions for both project options are the following:

- Degasification activities on the 8th and 9th longwalls of coal seam l_7 are excluded from capital costs, as they are not part of either project option and will be implemented irrespective of whether or not the considered project options will be implemented.
- The straight line depreciation method can be applied, i.e. a depreciating expense is incurred evenly over the lifetime of the fixed assets.

- For simplification, the salvage value of installed fixed assets is excluded.
- The income tax rates used to make a financial assessment reflects the Ukrainian government's decision to reduce corporate tax rates from 25% currently to 16% in 2014.
- The Project Team assumes that for the period 2015-2027, the tax rate will remain at the level of 16%.
- The price of bituminous coal produced by Zhdanovskaya Mine is 70 USD/tonne. This reflects the actual price of bituminous coal in Ukraine in January-February 2011 (UAENERGY, 2011). Moreover, the Project Team makes the assumption that the price of bituminous coal will be constant during the life of the project (see Table 14).[9]
- Cost of capital (discount rate) is real and equal to 12%.
- Inflation is not factored into the study's financial calculations.

Table 14. The trend and forecast of bituminous coal prices in Ukraine

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Price UAH/tonne	250	310	390	290	580	650	740	790	870	930	900
Exchange rate, UAH/USD	5.1	5.1	4.7	8	8	8	8	8	8	8	8
Price, USD/tonne	49	61	83	36	73	81	93	99	109	116	113

Source: Adopted from Altana Capital (www.altana-capital.com)

5.2. Option 1: Using CMM for on-site electricity generation

Under Option 1, using CMM for on-site electricity generation, the mine company would install a gas-fired generator. The projected volume of CMM produced from drainage of two mine longwalls would determine the potential size of the gas-fired generator. The power would be consumed by the mine itself and the mine's demand exceeds the potential power production from CMM in this project option, so demand is not a limiting factor. A full-scale feasibility study could help determine the cost-effectiveness by assessing potential future industrial power prices, and more precisely estimating potential CMM volumes as well as project costs.

Major financial assumptions for this project option are based on the "Best Practice Guidance for Effective Methane Drainage and Use in Coal Mines" developed by the United Nations Economic Commission for Europe and the Methane to Markets Partnership (now the Global Methane Initiative) (UNECE, 2010). The assumptions adopted from the Guidance are as follows:

[9] The U.S. Energy Information Administration estimates that the world coal consumption will recover, returning to its 2008 level by 2013 (EIA, 2011).

- Capital investments per 1 MW of installed power capacity of the electricity generation unit (gas engine and generator) are in the range 1-1.5 million USD. For the cash flow projection, the average estimated capital costs were used, i.e. 1.25 million USD.
- The operation and maintenance cost is in the range 0.02-0.025 USD per kWh of electricity produced; for the cash flow projection an average value was used, i.e. 0.025 USD/kWh.
- To produce 1 MW_e, the power generator would need to consume 2.5 million m^3 of pure methane per year.

The following preliminary work has to be done in order to allow use of CMM for power generation:

- Install a pipeline (length 3,200 m, diameter 325 mm) from the underground degasification facility along the bleeder shaft to the surface vacuum pump station, and then from the station to the gas engine module. Equip the pipe with valves and measuring devices. The diameter of the pipe is sized based on the most technically difficult segment of this system. This system segment is the piping used to degasify the 8th East longwall face;
- Acquire and install two vacuum pumps (VVN2-50) in containers on the surface (one for emergencies);
- Set container for instrumentation and control system and premise for operator on duty to control the work of vacuum pumps; and
- Install a modular gas engine and power generator.

Table 15 provides specific capital expenditure data used in the cash flow projection and cost-effectiveness calculations. The table looks at the costs associated with two different mine faces that would both supply CMM to the power generator. Cost effectiveness is calculated based on the total costs and return.

Table 15. Capital expenditure data for the project option related to electricity production using CMM (Option 1)

	Unit of measurement	Quantity	Cost per unit (without VAT), thousand USD	Capital costs for CMM utilization while mining longwall face 8 of seam I_7, thousand USD	Capital costs for CMM utilization while mining longwall face 9 of seam I_7, thousand USD	Depreciation, thousand USD/year
Laying main pipeline and equipping with valves and measuring devices	m	3,200	0.07	213.3	213.3	26.7
Portable vacuum pump	unit	2	156.3	312.5	0	19.5

Container for instrumentation and control system and operator on duty of vacuum pumps	unit	1	52.1	52.1	0	3.3
Capital investments of installed power capacity	1 MW	1.6	1.2	1,920	0	162.3
Avoided costs (associated with shorter degassing piping with the power generator compared to no generator)	thousand USD	-	-	-15	0	-1.9
Total (without contingency)	thousand USD	-	-	2,482.9	213.3	209.9
Contingency (10% of total capital expenditure)	thousand USD	-	-	248.3	21.3	20.1
Total cost	thousand USD	-	-	2,731.2	234.6	230

The power generation unit can be efficiently operated with a load factor of 74% or higher, and the load would most likely exceed this. Thus, for the cash flow projection, the Project Team assumed that the load factor will be 80%, i.e. the power generation unit will operate 7,000 hours per year. To ensure this operating regime, the nominal capacity of the power generation unit is chosen according to minimum yearly volume of CMM to be recovered during the project's life. Based on the projected volume of gas extracted while degassing the 8th West longwall of coal seam I_7 (3.9 million m^3/year), the nominal capacity of the unit could be 1.56 MW.

The Project Team also assumes that the operating life of the electricity generation unit is 16 years. This is the time needed to complete mining at longwall faces 8 and 9 of seam I_7.

Implementation would take six months, assuming that the power would be consumed by the mine itself. It is important to note that annual electricity consumption by Zhdanovskaya Mine is about 35,000 MWh, which exceeds the power generation capacity of the generator under consideration (about 11,000 MWh/year, on average). Despite this, it would be more beneficial for Zhdanovskaya Mine to use the electricity for its own purposes, displacing the purchase of electricity from the grid, rather than to sell it to the grid. This is because using the generated electricity for the mine's operation would significantly reduce the length of the investment period by avoiding the documentation and approval process required by the National Electricity Regulation Commission of Ukraine to get excess electricity to the public grid. This process is generally lengthy.

Table 16 provides a summary of input parameters used in cash flow projections and Table 17 provides the cash flow projection and financial criteria for the first project option.

The Project Team also analyzed the viability of this project option assuming waste heat recovery from hot gases exhausted by the gas engine. To make a simple and clear comparison of the project options, the Project Team made the following assumptions in this analysis:

- Hypothetically, waste heat recovery would reduce the coal consumed by the existing mine's boiler by 2,600 tonnes per year. The thermal energy content of this coal equals the quantity of energy in CMM to be recovered by the mine's drainage system and used for heat production by existing boilers.
- The heat recovery cost represents 10% of the total capital cost of a gas turbine (normally up to 30%).
- Other costs associated with heat recovery equal zero.

Table 16. Summary of input parameters and their values used to evaluate economic viability of on-site electricity generation option (Option 1).

Input parameters	Value
Planned project lifetime	16 years
Capacity of installed electricity generator	1.6 MW
Total capital investments required to install 1.6 MW in electricity generator capacity	2.731 million USD in 2012; 0.23 million USD in 2020 (see Table 15)
Hours per year generator is expected to operate	7,000 hrs/year
Sale price of electricity (tariff)	0.05 USD/kWh
Operating and maintenance expenses	0.025 million USD/kWh
Capital depreciation	0.23 million USD/year (see Table 15)
Corporate revenue tax rate	21% in 2012, 19% in 2013; 16% in 2014-2027
Discount rate	12%

To calculate economic performance of the measure in a given year, the following mathematical models were used:

Cumulative net cash inflow in year N = Net cash inflow in year N-1+After-tax revenue in year N+ Capital depreciation – Capital expenditure

After-tax revenue (savings) = % tax rate X (Income (savings) from displacing grid electricity – Operating and maintenance expenses – Capital depreciation)

Income (savings) from displacing grid electricity by using CMM-based generator = Generator capacity X Hours generator is expected to operate X Sale price of electricity (tariff).

Table 17. Cash flow projection for the project option related to electricity production using CMM (Option 1)

Year of project life	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Methane utilized from CMM recovery, million m^3	1.95	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
Annual average electricity production, MWh	5,460	10,920	10,920	10,920	10,920	10,920	10,920	10,920	10,920	10,920	10,920	10,920	10,920	10,920	10,920	10,920
Income (savings) from displacing grid electricity by using CMM-based generator, million USD	0.27	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
Capital expenditure, million USD	2.73	0	0	0	0	0	0	0	0.23	0	0	0	0	0	0	0
Capital depreciation, million USD	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Operating and maintenance expenses, million USD	0.14	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Pre-tax revenue, million USD	-0.09	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Tax rate, %	21	19	16	16	16	16	16	16	16	16	16	16	16	16	16	16
Tax amount, million USD	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
After-tax revenue, million USD	-0.09	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Net cash inflow, million USD	-2.60	0.26	0.27	0.27	0.27	0.27	0.27	0.27	0.03	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Cumulative net cash inflow, million USD	-2.60	-2.33	-2.06	-1.80	-1.53	-1.27	-1.00	-0.73	-0.70	-0.44	-0.17	0.10	0.36	0.63	0.89	1.16

IRR, %	**5.0**
NPV (at discount rate of 12%), million USD	**-0.785**
Simple payback period, years	**11.6**

The results of the financial assessment indicate that this project option would not be as financially attractive, as its NPV is negative (-0.785 million USD) and IRR (5%) is less than typical interest rates in Ukraine.

5.3. Option 2: Using CMM for on-site heat generation

Zhdanovskaya Mine could use CMM that is captured in its drainage system for on-site heat generation, thus replacing heat currently produced by coal. Under this project option, three of six existing coal boilers would be restructured in order for them to combust CMM instead of coal. The boilers would be upgraded with a CMM burner system.

Zhdanovskaya Mine has two heat-only boiler-houses (one for winter and the other for summer). The winter boiler-house is situated 600 meters from the site where the mine would install a vacuum pumping station, regardless of which project option is implemented. The winter boiler-house is equipped with four boilers: two DKVR 10/13 boilers, each with a heating capacity of 5.1 Gcal/hour, and two KE 10/14 boilers, each with a heating capacity of 5.0 Gcal/hour. The summer boiler-house is equipped with two Revokatova boilers with heating capacities of 5.0 Gcal/hour and 0.2 Gcal/hour. The mine's total heat demand in the winter is 44,500 Gcal. This demand is covered by two DKVR 10/13 boilers and one KE 10/14 boiler which consume 6,400 tonnes of bituminous coal in order to produce this amount of heat energy. Use of any of the boilers from the winter boiler-house at full capacity allows the mine to produce up to 22,400 Gcal of heat energy through the combustion of bituminous coal at 3,210 tonnes.

Over the winter period (182 days), the amount of recovered CMM would total 2.35 million m^3. This amount of gas is equivalent to the energy obtained from burning 2,570 tonnes of bituminous coal. Thus, Zhdanovskaya Mine could only switch one of the boilers at the winter boiler-house from coal to gas. The boiler's operation at full capacity would cover about 40% of the mine's heat demand during the winter season.

During the summer, the mine's heat demand is significantly lower than in the winter (0.37 Gcal/hour or 1.61 Gcal for the whole season). Both boilers in the summer boiler-house could be switched from coal to CMM. During the summer, the un-combusted methane would be released into the atmosphere.

In order to enable CMM utilization at the boiler-houses, the following has to be done:

- Install pipeline (with a length of 3,200 m and diameter of 325 mm) from the underground degasification facility along the bleeder shaft to the surface vacuum pumps station, and from the station to the boilerhouses. Equip the pipe with valves and measuring devices;
- Acquire and install two VVN2-50 vacuum pumps in containers on the surface;
- Build a small installation to house the instrumentation and control system, and a work space for the operator on duty to control the vacuum pumps;
- Re-equip the DKVR 10/13 or KE 10/14 boiler for CMM use and install a gas delivery pipe with measuring devices and protection equipment;
- Re-equip the Revokatova boilers for CMM use and install a gas delivery pipe with measuring devices and protection equipment.

At this stage, the purchase of a gas enrichment facility and controlling equipment system is not envisioned. It is assumed that CMM concentration in the gas will steadily exceed 35% and its fluctuation will not be significant, thus avoiding the danger of explosions.

Table 18 provides the specific initial cost data required for a cash flow projection as well for calculating the cost-effectiveness criteria of this project option.

Table 18. Capital expenditure data of the project option related to shifting fuel consumption on coal mine's boilers from coal to CMM (Option 2)

	Unit of measurement	Quantity	Cost per unit (without VAT), thousand USD	Capital costs for CMM utilization while mining longwall face 8 of seam I_7, thousand USD	Capital costs for CMM utilization while mining longwall face 9 of seam I_7, thousand USD	Depreciation, thousand USD/ year
Laying main pipeline and equipping it with valves and measuring devices	m	3,200	0.07	213.3	213.3	26.7
Vacuum pump	unit	2	156.3	312.5	0	19.5
Container for instrumentation and control system and operator on duty of vacuum pumps	unit	1	52.1	52.1	0	3.3
Re-equipping of a boiler in winter boilerhouse for using CMM and equipping delivery pipe with measuring devices and protection equipment	unit	1	208.3	208.3	0	13.0
Re-equipping of boiler Revokatova for using CMM	unit	2	31.3	62.5	0	3.9
Avoided costs (avoiding longer degassing piping)	thousand USD	-	-	-15	0	-1.9
Total (without contingency)	thousand USD	-	-	833.8	213.3	64.5
Contingency (10% of total capital expenditure)	thousand USD	-	-	83.4	21.3	5.2
Total	thousand USD	-	-	917.1	234.7	69.7

Table 19. Summary of input parameters and their values used to evaluate economic viability of on-site electricity generation option (Option 2)

Input parameters	Value
Planned project lifetime	16 years
Maximum volume of CMM the mine can utilize in winter and summer boilers	0.5 year (except in 2012) x the amount of methane extracted by the degassing system per year (see assumptions in Section 5.1. Consideration of possible project options)[10]
Total capital investments required to switch fuel in boilers from coal to gas	917,000 USD in 2012; 234,700 in 2020
Weight of bituminous coal equivalent in energy content to 1 million cubic meter of CMM	1,091.4 tonnes
Sale price of coal	70 USD/tonne
Operating expenses avoided from burning unit of coal at boiler houses	5 USD/tonne
Capital depreciation	69.7 thousand USD/year (see Table 18)
Corporate revenue tax rate	21% in 2012, 19% in 2013; 16% in 2014-2027
Discount rate	12%

To calculate economic performance of the measure in a given year, the following mathematical models were used:

Cumulative net cash inflow in year N = Net cash inflow in year N-1+After-tax revenue in year N+ Capital depreciation – Capital expenditure

After-tax revenue (savings) = % tax rate x (Income (savings) from selling saved coal +Avoided boiler operating expenses from switching to gas – Capital depreciation)

Income (savings) from selling saved coal = Maximum volume of CMM the mine can utilize in winter and summer boilers x Weight of bituminous coal equivalent in energy content to 1 million cubic meter of CMM x Sale price of coal

Table 20 provides the cash flow projection and financial criteria for the second project option.

[10] From 2012, when mining the 8th East longwall of coal seam l_7 will have begun, to 2016 (inclusive), the mine's improved degassing system will have extracted 8.96 m^3/min or 4.71 million m^3/year of CMM. From 2017-2019 while mining 8th West longwall of coal seam l_7, this degassing system will extract 7.42 m^3/min or 3.9 million m^3/year of CMM.

Table 20. Cash flow projection for the project option related to shifting fuel consumption on coal mine's boilers from coal to CMM (Option 2)

Year of project lifetime	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Methane utilized from CMM recovery, million m^3	1.8	2.4	2.4	2.4	2.4	1.9	1.9	1.9	2.4	2.4	2.4	2.4	2.4	1.9	1.9	1.9
Reduction in coal consumption, tonnes	1,927	2,570	2,570	2,570	2,570	2,128	2,128	2,128	2,570	2,570	2,570	2,570	2,570	2,128	2,128	2,128
Income from selling unconsumed coal, thousand USD	135	180	180	180	180	149	149	149	135	180	180	180	180	149	149	149
Avoided boiler operating expenses from switching to gas, thousand USD	10	13	13	13	13	11	11	11	13	13	13	13	13	11	11	11
Total income, thousand USD	145	193	193	193	193	160	160	160	148	193	193	193	193	160	160	160
Capital expenditure, thousand USD	917	0	0	0	0	0	0	0	234.7	0	0	0	0	0	0	0
Capital depreciation, thousand USD	69.7	69.7	69.7	69.7	69.7	69.7	69.7	69.7	69.7	69.7	69.7	69.7	69.7	69.7	69.7	69.7
Pre-tax revenue, thousand USD	75	123	123	123	123	90	90	90	78	123	123	123	123	90	90	90
Tax rate, %	21	19	16	16	16	16	16	16	16	16	16	16	16	16	16	16
Tax amount, thousand USD	15.7	23.4	19.7	19.7	19.7	14.4	14.4	14.4	12.5	19.7	19.7	19.7	19.7	14.4	14.4	14.4
After-tax revenue, thousand USD	59.1	99.7	103.3	103.3	103.3	75.5	75.5	75.5	65.7	103.3	103.3	103.3	103.3	75.5	75.5	75.5
Net cash inflow, thousand USD	-788.2	169.4	173.1	173.1	173.1	145.2	145.2	145.2	-99.3	173.1	173.1	173.1	173.1	145.2	145.2	145.2
Cumulative net cash inflow, thousand USD	-788.2	-618.8	-445.7	-272.7	-99.6	45.6	190.8	336.1	236.8	409.9	582.9	756.0	929.1	1,074.3	1,219.5	1,364.7

IRR, %	**17.3**
NPV (at discount rate of 12%), thousand USD	**194.3**
Simple payback period, years	**5.7**

5.4. Comparison of economic results for Options 1 and 2

Table 21. Comparison of economic results

Evaluation scenario	Option 1: Electricity generation	Option 2: On-site heat generation
Methane utilized over project lifetime (million m^3)	60.5	34.8
Total CAPEX (million USD)	2.96	1.15
Tonnes of CO_2-e over project lifetime	948,800	419,200
CAPEX (USD)/tonnes of CO_2-e	3.12	2.74
NPV at 12% discount rate (USD)	-785,000	194,300
IRR (%)	5.0	17.3
Simple payback period (years)	11.6	5.7

Overall, the cash flow projections show that even when benefits from exhaust heat recovery are considered, the first option, using CMM for on-site electricity generation, is not more cost-effective than using CMM in existing boilers for heat production instead of coal. The NPV of the first option (modified to include waste heat recovery) at a discount rate of 12% is negative, compared to a positive NPV under the second option (194,000 USD). Likewise, the IRR for the first option is 5.0% versus 17.3% under the second option (Table 21). The results of this assessment suggest that the second project option, using CMM for on-site heat generation, would be more financially attractive to investors.

6. Assessment of potential reduction in greenhouse gas emissions

6.1. Greenhouse gas emissions reductions under Project Option #1: Using CMM for on-site electricity generation

The greenhouse gas emissions reductions (in carbon dioxide equivalent) attributed to using CMM for on-site electricity generation at Zhdanovskaya Mine are two-fold: first, it is direct reduction in CMM emissions as a result of combustion of CMM (by the newly installed power generation unit); and second, it is indirect CO_2 emissions reduction from avoided offsite power production, which would be replaced by the power generation unit installed under the first project option.

The direct annual average emissions reduction for the lifetime of the first project option is 46,300 tonnes of CO_2-e (see Table 24).

To assess the indirect CO_2-e emissions reduction, the Project Team assumed that for the entire project lifetime, the specific indirect CO_2-e emissions from electricity consumed at the mine will remain at 2011 levels. We assume indirect CO_2-e emissions at 1.227 kg of CO_2-e per kWh. This figure is used in Ukraine's annual GHG inventories for the year 2011 according to the Order issued by the State Environmental Investment Agency of Ukraine (2011)[11], which specifies indirect CO_2-e emissions from electricity consumption by industrial consumers of Class 2 (voltage 5-35 kV) to which Zhdanovskaya Mine belongs.

The annual average electricity production under this project option is 10.58 million MWh (Table 16). Thus, the average CO_2-e emissions reduction will be approximately 13,000 tonnes of CO_2-e per year.

Therefore, the estimated total annual emission reduction attributed to the first project option is: 46,300 + 13,000 = 59,300 tonnes of CO_2-e per year. During the project's lifetime, the total amount of CO_2-e emissions reduction will be 948,800 tonnes.

6.2. Greenhouse gas emission reductions under Project Option #2: Using CMM for on-site heat generation

The generation of heat energy would lead to a reduction of CMM that would otherwise be emitted to the atmosphere. This project option is connected with direct emissions reduction only. The CO_2-e emission reductions generated by years are shown in Table 23.

The annual average emissions reduction for the life of the second project option is 26,200 tonnes of CO_2-e. The total amount of CO_2-e emissions reduction during the project's lifetime will amount to 419,200 tonnes.

[11] We believe this is a conservative estimate of CO_2 emissions reduction, as this figure is based on the current fuel balance of thermal power production. The expected sharp rise in natural gas prices would lead to a reduction in gas consumption, resulting in enhanced coal consumption by existing power plants. This is evidently linked to an increase in GHG emissions produced per kWh of electricity.

Table 22. Direct greenhouse gas emissions reductions generated by years for Project Option #1: Using CMM for on-site electricity generation

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	Total	Annual average
Baseline emissions of CH_4, million m^3	4.7	4.7	4.7	4.7	4.7	3.9	3.9	3.9	4.7	4.7	4.7	4.7	4.7	3.9	3.9	3.9	70.5	4.4
Baseline emissions of CH_4, thous. tonne	3.1	3.1	3.1	3.1	3.1	2.6	2.6	2.6	3.1	3.1	3.1	3.1	3.1	2.6	2.6	2.6	46.7	2.9
Baseline emissions of CH_4, thous. tonne CO_2-e	65.5	65.5	65.5	65.5	65.5	54.2	54.2	54.2	65.5	65.5	65.5	65.5	65.5	54.2	54.2	54.2	980.5	61.3
Volume of un-combusted CH_4, million m^3	2.0	0.8	0.8	0.8	0.8	0.0	0.0	0.0	0.8	0.8	0.8	0.8	0.8	0.0	0.0	0.0	9.2	0.6
Volume of un-combusted CH_4, thous. tonne	1.3	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	6.1	0.4
Project emissions from un-combusted CH_4 , thousand tonne CO_2-e	27.1	11.3	11.3	11.3	11.3	0.0	0.0	0.0	11.3	11.3	11.3	11.3	11.3	0.0	0.0	0.0	128.5	8.0
Volume of combusted CH4, million m^3	2.8	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	61.3	3.8
Volume of combusted CH_4, thousand tonne	1.8	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	40.6	2.5
Project emissions from combusted CH_4, thous. tonne CO_2-e	5.0	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	111.6	7.0
Emissions reduction of the project activity, thous. tonne CO_2-e	33.4	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	740.4	46.3

Source: Calculations made by Project Team

Table 23. Greenhouse gas emissions reduction generated by years for Project Option #2: Using CMM for on-site heat generation

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total	Annual average
Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027		
Baseline emissions of CH_4, million m^3	4.7	4.7	4.7	4.7	4.7	3.9	3.9	3.9	4.7	4.7	4.7	4.7	4.7	3.9	3.9	3.9	70.5	4.4
Baseline emissions of CH_4, thous. tonne	3.1	3.1	3.1	3.1	3.1	2.6	2.6	2.6	3.1	3.1	3.1	3.1	3.1	2.6	2.6	2.6	46.7	2.9
Baseline emissions of CH_4, thous. tonne CO_2-e	65.5	65.5	65.5	65.5	65.5	54.2	54.2	54.2	65.5	65.5	65.5	65.5	65.5	54.2	54.2	54.2	980.5	61.3
Volume of un-combusted CH_4, million m^3	2.9	2.4	2.4	2.4	2.4	2.0	2.0	2.0	2.4	2.4	2.4	2.4	2.4	2.0	2.0	2.0	35.8	2.2
Volume of un-combusted CH_4, thous. tonne	1.9	1.6	1.6	1.6	1.6	1.3	1.3	1.3	1.6	1.6	1.6	1.6	1.6	1.3	1.3	1.3	23.7	1.5
Project emissions from un-combusted CH_4, thous. tonne CO_2-e	40.9	32.7	32.7	32.7	32.7	27.1	27.1	27.1	32.7	32.7	32.7	32.7	32.7	27.1	27.1	27.1	497.7	31.1
Volume of combusted CH4, million m^3	1.8	2.4	2.4	2.4	2.4	2.0	2.0	2.0	2.4	2.4	2.4	2.4	2.4	2.0	2.0	2.0	34.7	2.2
Volume of combusted CH_4, thous. tonne	1.2	1.6	1.6	1.6	1.6	1.3	1.3	1.3	1.6	1.6	1.6	1.6	1.6	1.3	1.3	1.3	23.0	1.4
Project emissions from combusted CH_4, thous. tonne CO_2-e	3.2	4.3	4.3	4.3	4.3	3.6	3.6	3.6	4.3	4.3	4.3	4.3	4.3	3.6	3.6	3.6	63.2	4.0
Emissions reduction of the project activity, thous. tonne CO_2-e	21.4	28.5	28.5	28.5	28.5	23.6	23.6	23.6	28.5	28.5	28.5	28.5	28.5	23.6	23.6	23.6	419.5	26.2

Source: Calculations made by Project Team

6.3. Comparative summary of carbon dioxide emissions reductions

Table 24 compares estimated CO2-e emissions reductions for both assessed project options. For the purposes of this analysis, the Project Team assumes that CO_2 emissions associated with burning coal and CMM for heat production would be the same, hence there would be no indirect emission reductions. It should be noted however that emissions vary depending on the fuel type and coal accounts for a lot of emissions.

Table 24. Comparative summary of carbon dioxide emissions reductions, thousand tonnes

	Direct emissions reductions	Indirect emissions reductions	Total
Option 1: Using CMM for on-site electricity generation	46.3	13	59.3
Option 2: Using CMM for on-site heat generation	26.2	0	26.2
Ratio option 1 to option 2	177%	-	226%

7. Conclusions and recommendations

The preliminary results from this assessment indicate that there is a business case for conducting a full-scale feasibility study for a CMM project at Zhdanovskaya Mine. There is large potential to reduce methane emissions at Zhdanovskaya Mine. The mine holds mineable reserves of approximately 35.2 million tonnes of primary low-volatile bituminous coal. In 2010, the mine produced 901,000 tonnes of coal, which resulted in estimated methane emissions of nearly 17 million m^3 that year. As of 2011, it is estimated that the mine's total methane resources is 1,465 million m^3, including 426.5 million m^3 at seam l_7. The mine company has plans to mine two longwalls of seam l_7, and as such, there is an opportunity for the mine to implement a CMM project when working this seam. The Project Team estimates that a total of about 30.9 m^3 of methane per minute will be released into the atmosphere from the two longwalls. Although mining is complicated by low-amplitude disturbances, the mining area at coal seam l_7 has no significant disturbances.

To further assess the value in continuing on to a full-scale feasibility study of the mine, the Project Team considered three options for utilizing CMM captured at seam l_7. A full-scale feasibility could review these three options in greater detail.

Given the expense associated with laying new gas pipelines, it became clear from the beginning of the study that the option of generating heat in the existing district heating system using boilers in neighboring residential areas would be the least cost-effective. The first option, to install a gas-fired generator to produce electricity, also has a large disadvantage in that the electricity consumption of Zhdanovskaya Mine is higher than the electricity that the installed generator could produce. Selling the electricity to the grid is complicated by the documentation and time it takes to get approval by the National Electricity Regulation Commission of Ukraine. The analysis of this project option is also based on several assumptions which, if changed, could affect the results. For instance, the Project Team assumed that the CMM concentration in the gas will exceed 35% and that its fluctuation will not be significant. To ensure this, Zhdanovskaya Mine would need to install a gas-enrichment facility and controlling equipment system, which could significantly increase the cost of the project. The Project Team also assumes that the generator will operate efficiently and that it will have an operating life of 16 years, the time needed to complete mining at longwall faces 8 and 9 of seam l_7. However, if the generator operates less efficiently or stops operating sooner, then the total amount of CMM utilized will be lower.

The advantage of the second project option, using CMM for on-site heat generation, is that the mine already has most of the facilities and equipment needed. Although this option is more cost-effective, the Project Team estimates that during the winter season, the reconstructed boiler will only cover 40% of the mine's heat demand. Thus, the total reduction in methane emissions would be lower over a 16-year period than under Project Option #1—using CMM for electricity generation.

Ultimately, what is going to determine the successful implementation of a CMM project at this mine is whether the mine company will be able to attract investment. Most mines in Ukraine are state-owned and in poor financial state. This has been slowly changing since the government of Ukraine introduced an initiative to privatize its mines a decade ago. Through this process, the government has permitted several state mines to be privatized fully or partially leased. This opens the doors for investment.

The majority of recent CMM projects in Ukraine exist under the Joint Implementation (JI) [12]mechanism, though many small-scale projects were financed by mines themselves. Foreign project developers will invest in CMM projects that involve carbon credits or if there is direct investment. With carbon credits, investors do not have to get deeply involved into the mine's operations to simply purchase the credits, as long as the mine performs. Thus, implementation of a CMM project at Zhdanovskaya Mine is likely to be more successful if it is linked to carbon credits.

In the future, a number of recent policies and regulations that the Ukrainian Parliament has introduced could also provide incentives for CMM project development at Zhdanovskaya Mine. Despite the progress in the Ukrainian coal sector however, it may take some time before these initiatives are fully implemented and the associated benefits for CMM project development are realized. Before then, CMM project development will likely continue to depend on the joint implementation mechanism or other foreign investment.

[12] http://ji.unfccc.int/index.html

Appendix

Contact information

The mailing address of Zhdanovskaya Coal Mine is Zhdanovka, Donetsk Oblast, Lenina str., 86391.
The contact person at the coal mine is Mikhail Dronov, Director.

Telephone:

+38 (06252) 40726
+38 (06252) 50348
Fax: +38 (06252) 40726

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