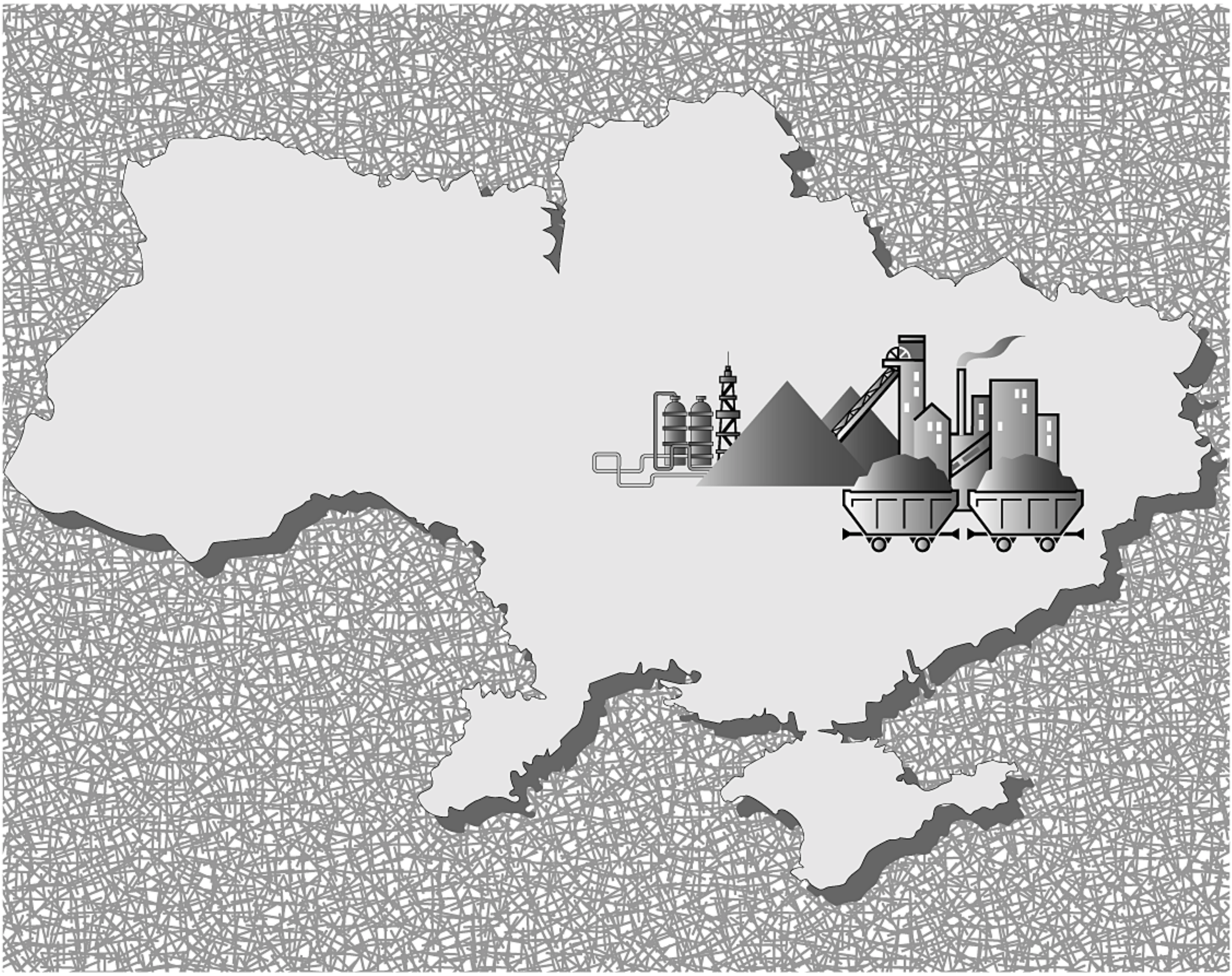
INVENTORY OF METHANE EMISSIONS FROM COAL MINES IN UKRAINE: 1990–2001



COAL MINE METHANE RECOVERY IN UKRAINE:

INVENTORY OF METHANE EMISSIONS FROM COAL MINES IN UKRAINE: 1990–2001

Prepared by:

Partnership for Energy and Environmental Reform

Sponsored by:

United States Environmental Protection Agency

August 2002

ACKNOWLEDGEMENTS

Partnership for Energy and Environmental Reform (PEER) gratefully acknowledges the efforts and assistance of the U.S. Environmental Protection Agency that inspired and financed preparation of this report.

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The important contribution to this report was done by A. Agafonov, E. Zakharov, A. Bobrov, and A. Lepikhov of the Donetsk Regional Expert Centre of the State Labor Safety Department.

PEER also acknowledges the following institutions for their assistance in preparation of this report:

Ministry of Fuel and Energy of Ukraine

Ministry of Labor and Social Policy of Ukraine

Ministry of Ecology and Natural Resources of Ukraine

Makeyevka State Mining Safety Research Institute

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EXECUTIVE SUMMARY

Ukraine has substantial reserves of methane resident in underground coal seams and surrounding rock strata. That methane, if captured, would constitute a valuable energy resource. Furthermore, capture and productive use of such methane, when associated with coal mining, would support the tenets of the United Nations Framework Convention on Climate Change by reducing the amount of methane that otherwise would be emitted to the atmosphere. This report is the result of a continued effort to annually update an inventory of coal mine methane (CMM) emissions from Ukrainian coal mines. Based on the CMM emissions inventories for the period between 1990 and 1999 [1], and between 1990 and 2000 [2], this inventory includes the results of emissions data for the year 2001.

To improve the accuracy of the CMM emissions inventory, an additional study of the emission factor for the post mining period was conducted for the year 2001. This study resulted in the development of the methodology for calculating the amount of methane released from coal after mining based on the mine-specific data (See Appendix1). Also, the report includes adjusted information about the CMM emissions from the surface mines for the year 2001.

During the study period, coal production in Ukraine declined by 50% resulting in a corresponding decrease in methane emissions; from 2,637.92 Gigagrams (Gg)[1] in 1990 to 1,282.21 Gg in 2001. However, capture and utilization of coal mine methane grew in 2001. For comparison, during 2001, the mines captured 182.15 Gg of methane (14.7% of the total liberated) and utilized 91.33 Gg (50.1% of the total captured or 7.4% of the total liberated). During 2000, Ukrainian coal mines captured 177.79 Gg of CMM (12.4% of the total liberated) and only 49.59 Gg was utilized (27.9% of the total captured). Substantial additional reductions in methane emissions can still be accomplished by further applying methane drainage and expanding methane utilization projects.

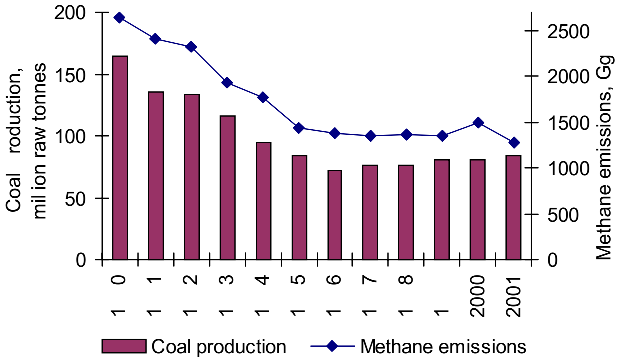

Figure 1. Coal production and CH_4 emissions trends in Ukraine for 1990–2001.

1.0 INTRODUCTION

This report quantifies methane emissions from coal mining activities in Ukraine. The inventory presented herein encompasses methane released from underground mining and surface mining and takes into account the extent to which such methane is captured and utilized. These data provide a benchmark against which future success in reducing methane releases from Ukrainian coal mines can be measured.

The methodology for the detailed CMM emissions inventory presented in the report is based on the international methodology recommended by the Intergovernmental Panel on Climate Change (IPCC) [3], and adjusted for Ukrainian conditions. It can be used for annual preparation of the CMM emission inventories from the Coal Industry of Ukraine to be included in the National greenhouse gas emission inventory.

1.1. METHANE AND GLOBAL WARMING

Methane is one of six gases that scientists believe contribute to the greenhouse effect, the trapping of heat in the Earth's atmosphere. The extent to which any given greenhouse gas (GHG) traps heat is measured relative to the heating effect of carbon dioxide. Methane is considered to be 21 times as potent as carbon dioxide in trapping atmospheric heat over a 100-year period [4]. Methane and other GHGs are released to the atmosphere through various natural processes. However, they also result from a host of human activities. With increasing concern over the potential consequences of rising average global temperatures, efforts are underway to identify options for reducing such antropogenic GHG releases. A first step in that process involves identifying GHG sources and sinks (processes that capture GHG and prevent their release to the atmosphere) and quantifying the magnitude of the global warming impact attributable to each source.

1.2. SPECIFIC FEATURES OF CMM AS A GREENHOUSE GAS

Methane occurs naturally in a number of geologic settings, including in association with coal deposits. The process of coal mining liberates the methane that is contained in the coal matrix and in the surrounding rock strata. This CMM can present underground coal mines with a serious safety problem, because it is explosive when mixed with air in concentrations ranging from 5 to 15 percent. Therefore, to ensure worker safety and

[1] Throughout this report, all references to Gg are Gg of methane. 1 million cubic meters (MCM) = 0.679Gg.

maintain productivity, underground coal mines must take precautions to keep in-mine methane concentrations low.

Ukraine currently produces approximately 99% of its coal from underground mines (See tables 2 and 3). Historically, mine operations have achieved methane control in underground mines by employing ventilation systems that flush large volumes of air into and through the active mine workings, thereby diluting methane concentrations and venting the methane out of the mine and into the atmosphere. Recent years have seen the introduction of drilling techniques that allow draining of the methane from the coal prior to mining, thereby reducing both the methane content of the air in the mine and the volume of methane that is released during the mining process. However, even at mines where methane drainage is employed, operators commonly release the captured CMM to the atmosphere rather than using it in some productive manner. This practice increases the atmospheric methane burden where it contributes to climate change and wastes a potentially valuable energy resource.

1.3. PURPOSE OF THIS INVENTORY

In 1998, the U.S. Environmental Protection Agency initiated a CMM assessment and project development program in Ukraine. One of the main tasks of the program was the development of a comprehensive CMM emissions inventory. During 2000 and 2001, the CMM inventories for the period 1990–1999 and 1990–2000, were developed and published. This report updates the previous inventory with the inclusion of the year 2001 data. The reports can be used to establish a baseline of Ukrainian CMM emissions in order to encourage commercial development projects, facilitate carbon credits trading, and to promote environmental stewardship in Ukraine.

In response to the growing concern over the possible consequences of global warming, in 1988, the United Nations (UN) established the Intergovernmental Panel on Climate Change (IPCC) to evaluate climate change processes, to analyze the potential extent of climate change effects on natural systems and human populations, and to identify options for mitigating such change. In 1992, representatives from 176 countries met at the Earth Summit in Rio de Janeiro, Brazil to consider cooperative approaches to climate change mitigation. An important result of the summit was that cooperating countries signed the UN Framework Convention on Climate Change (UNFCCC) wherein signatory countries (UNFCCC parties) agreed to pursue stabilization of GHG emissions at levels that would prevent negative anthropogenic influences on the global climate. UNFCCC parties meet periodically to develop a mechanism that will encourage GHG emission reductions.

Therefore, in addition to presenting in this report a set of recent and historic CMM emission data in a format recommended by the IPCC [3], the investigators have made an attempt to analyze the data in the broader context of reducing GHG emissions. This study considers practices to increase the amount of CMM that can be captured and productively utilized, or at least combusted, thereby reducing the contribution of CMM emissions from Ukrainian coal mines.

2.0 DATA SOURCES

Given the fact that underground coal mining in Ukraine accounts for 99% of coal production, where possible, measurements of actual emissions from underground mines were chosen as the basis for this inventory. All Ukraine underground coal mines are required to monitor the methane concentrations in the air at various locations in the mine workings. They are also required to measure the methane content of the coal being mined. If these data, combined with other factors, exceed Ukrainian mine safety standards [5], the mines are required to report this information to various governmental organizations (such mines are often referred to as “gassy”). The set of standards for the determination of reporting include methane content in the coal, concentration levels of methane in the mine areas, historical frequency of methane outbursts, concentration levels of dust particles in the air of the mine areas, and various other factors. For these gassy mines, the data were collected directly from the mines for the period 1990 through 2001. The methodologies and equipment used for these measurements in Ukraine are discussed in Section 4.

It was determined for the study period of 1990 through 2001 that mines producing approximately 30% (annually weighted average) of the annual underground coal production in Ukraine did not exceed Ukrainian mine safety standards and the mines were not required to report the emissions data. To verify this percentage, each year of the study period was analyzed by subtracting the annual production for those mines that did report their methane emissions data from the total annual underground coal production. On an annual basis, this analysis resulted in a range of between 18% (year 2000) to 32% (year 1990) of the total coal production that did not report emissions during the study period. Precise verification of the data was not possible due to changes in mine names, particular mines stopping and re-starting production, coal production shifting between different seams, and other minor inconsistencies. There were 150 mines that reported their methane emissions in the year 2001. This number also includes the mines in the different phases of closure process, which continue reporting their methane emissions until physical closure. Assuming that the coal produced by non-gassy mines still contains some amount of methane, the emissions from corresponding underground coal production were estimated using an emission factor (see Section 4.5).

Surface coal mining accounts for a very small portion of the coal production (and methane emissions) in Ukraine. For the years 1990–2000 CMM emissions from surface mining were estimated using an emission factor (see Section 4.6). In addition, this same approach also was applied in estimating post-mining CMM emissions for the years 1990–2000 (see Section 4.7).

For the year 2001, the CMM emissions for the post-mining period were calculated based on a methodology developed by the Donetsk Regional Expert Center of the Ministry of Labor and Social Policy of Ukraine. Using this methodology improves the accuracy of the inventory. Additional information was obtained regarding the emissions from the surface mines.

The information sources and collaborators in this effort included the Ministry of Fuel and Energy of Ukraine[1], The Ministry of Labor Safety and Social Policy of Ukraine, Makeyevka Mine Safety Institute, coal mine associations, and independent coal mines.

3.0 COAL MINES AND PRODUCTION IN UKRAINE

3.1. TYPES AND LOCATION OF UKRAINIAN COAL MINES

Ukraine has two major coal basins: the Donetsk Basin and the Lviv-Volyn Basin. These basins contain both bituminous and subbituminous coal resources. The Donetsk Basin, commonly referred to as the Donbass, is located in the eastern and southeastern parts of the country and is Ukraine's largest coal basin both in terms of reserves and the number of mines. Depending on coal rank, the coal produced in the Donetsk Basin either is used for electric power generation or is processed into coke for the iron and steel industry. The Lviv-Volyn Basin, located in the western part of Ukraine, currently has only 14 active mines, all of which are underground workings, and the coal is primarily used by local electric power generating plants.

There are currently only three active surface mines in Ukraine and all of them are located in the western part of the Donetsk Basin. These surface mines produce peat, lignite, and sub-bituminous coals that have low methane content.

3.2. PRODUCTION TRENDS

From 1990 through 2000, Ukraine experienced a precipitous decline in its coal production; from 165 million raw tonnes in 1990 to 80.3 million raw tonnes in 2000 (see Fig. 1). The coal production stabilized during 1995–2000 at the level of approximately 80 million raw tonnes per year. In 2001, the Ukrainian coal mines produced 83.4 million raw tonnes of coal. In the progress of the Coal Industry restructuring, the number of underground and surface mines dropped from a total of 284 in 1990 to 184 in 2001. The decline of coal production was accompanied by a relatively linear decrease in methane emissions (see Figure 1).

The Cabinet of Ministers of Ukraine approved the «Ukrainian Coal» Program [6] in September, 2001. This is a complex program of Ukrainian coal industry development for the period 2001–2010. According to the program, the coal production should increase to over 110 million tonnes per year by 2010, while the number of mines will reduce to 162, including closure of inefficient mines and building the new ones. The list of the mines planned for closure is also a part of this program.

At present, the total installed capacity of active Ukrainian mines is estimated at 104 million tonnes of run-of-mine coal per year. However, this capacity does not reflect actual production due to the lack of capital to replace antiquated and worn-out equipment.

4.0 METHODOLOGY FOR UKRAINIAN INVENTORY (1990–2001)

The general methodology for calculating CMM emissions is based on the following formula, as recommended by the IPCC guidelines [3]:

Total emissions = Emissions from underground mining
+ Emissions from surface mines
+ Post-mining emissions
- Utilized and flared methane

The total methane emissions in 2001 were estimated to be 1,282.21 Gg, a decline from 2,637.92 Gg in 1990 (see Table 1).

For the purpose of this inventory, the difference between coal bed methane (CBM) and CMM is important. Coal bed methane represents total methane deposits contained in coal seams and surrounding rock strata in the country. CMM represents only methane reserves of the currently active coal mines or mine fields planned for future production. In accordance with the IPCC guidelines, only CMM emissions are to be considered for inventory purposes since they result from antropogenic (man made) activity. It is for the same reason that natural CBM emissions occurring due to erosion and/or natural rock fracturing, and CBM extraction and use from virgin coal seams were not included in this inventory.

[1]Until early 2000, a separate Ministry of Coal Industry existed in Ukraine; these responsibilities are now a part of the Ministry of Fuel and Energy.

The inventory accounts for the methane emissions only from the working coal mines. The closed and abandoned mines also contribute to the overall methane emissions. But the measurement data from such mines are not available since methane emissions at these mines don't influence mining safety. At present, experts are devising methods to reliably quantify and verify methane emissions from the abandoned mines.

The general emissions theory, specific types of coal mine emissions, and methods of their monitoring and calculation are discussed in the following sections.

4.1. FORMATION OF METHANE

Methane is formed during coalification (the process of plant material transformation into coal). Following coalification, the gas remains trapped under high pressure in coal seams and surrounding rock strata. One of the main geological characteristics of a CBM deposit is the amount of gas it can store. The amount of methane formed at the time of coalification may exceed the adsorptive capacity of the coal. In this situation, large quantities of methane permeate into the rock surrounding the coal seam. The methane is stored there and released during coal mining or natural erosion when the coal and rock is fractured, which releases the gas into the mine working area from which it eventually finds its way to the atmosphere.

4.2. FACTORS INFLUENCING METHANE EMISSIONS

Not all the methane stored within the coal and surrounding strata can be released. The quantity of methane emitted per tonne of mined coal depends upon such factors as gas content, the permeability of coal and gas diffusion rate, and the mining method employed.

4.2.1. Coal Ranks

The gas content of coal depends on its rank and geological history. Coal rank is a measure of the degree of coalification with more methane being present in higher rank coals. Higher rank coals tend to have greater adsorptive capacities and therefore contain more gas. Deeper coal seams generally have higher methane content than do shallow coal seams of similar rank. Thus, the deeper mines typically contain larger quantities of methane.

4.2.2. Mining Methods

There are two main underground mining methods: room and pillar and longwall mining. The longwall process causes more caving and fracturing in the roof strata above the coal seam that was mined than the room and pillar method. Correspondingly, greater volumes of methane are released per tonne of coal. All underground coal mines in Ukraine utilize the longwall system.

4.2.3. Permeability and Diffusion Rate

Permeability of coal and diffusion rate influence how quickly the gas can migrate through the coal and into mine workings. After the coal is mined utilizing the longwall method of extraction, the strata overlying the mined coal caves in, causing a formation of highly fractured area. This fracturing increases the permeability of the methane containing strata and facilitates the release of methane.

4.3. NEED TO REMOVE METHANE FROM COAL MINES

Methane represents a serious problem for coal mining because of its influence on the safety of miners working underground. Methane is highly explosive when its mixture with air yields a concentration of five to fifteen percent of methane. To maintain proper safety conditions in an underground coal mine, it is necessary to reduce methane concentration to less than two percent. This is accomplished in two principal ways: ventilating the mine workings with large quantities of air and draining methane using special techniques utilizing both surface and underground drilling. When selecting a methane

Table 1. CH_4 Emissions from Ukrainian Coal Mines (Gg) for 1990–2001.

Activity	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*
Liberated (underground mining)	2,518.04	2,321.96	2,209.90	1,825.93	1,706.43	1,383.74	1,312.60	1,289.41	1,316.86	1,290.89	1,436.68	1,237.14
Recovered (utilized) (underground mining)	98.46	93.84	60.00*	47.19	64.54	60.55	32.69	38.59	56.63	53.68	49.59	91.33
Total emitted (underground mining)	2,419.58	2,228.12	2,149.90	1,778.74	1,641.89	1,323.19	1,279.91	1,250.82	1,260.23	1,237.21	1,387.09	1,145.81
Surface mining, emitted	8.70	6.74	5.42	3.89	2.50	2.15	1.49	1.34	1.31	1.11	1.00	0
Post mining (underground), emitted	208.40	172.12	171.27	149.55	122.99	108.96	93.90	99.79	100.19	107.03	106.14	136.40
Post mining (surface), emitted	1.24	0.96	0.77	0.56	0.36	0.31	0.21	0.19	0.19	0.16	0.14	0
Total emitted	2,637.92	2,407.94	2,327.36	1,932.74	1,767.74	1,434.61	1,375.51	1,352.14	1,361.92	1,345.51	1,494.37	1,282.21

* *The number is an estimate, because the reported data of 1992 methane recovery is not complete*

recovery technique, several important factors should be considered, such as:

- thickness and depth of the targeted coal seam,
- amount of methane contained in the coal,
- number of seams being mined,
- the efficiency of ventilation systems,
- mining method,
- permeability of coal, and
- potential gas quality and utilization options.

4.4. METHANE UTILIZATION OPTIONS

Instead of emitting vented and drained methane into the atmosphere, it can be utilized as an environmentally clean fuel for different purposes. The main methane utilization options are:

- pipeline injection – requires pipeline quality gas (~95% or more CH_4);
- power generation — typically can be accomplished with lower quality gas (~30% or more methane). In this case, CMM captured by degasification systems is used as fuel for electricity and heat production at combined heating and power plants, heat boilers, gas turbine generators, or internal combustion engines. Ventilation air methane (less than 1%) can also be used to generate power through oxidation process;
- local use — different on-site application options exist for methane, such as fueling on-site boilers for preparation plants, heating the air in shafts, or hot water generation. It can also be used to heat greenhouses or as fuel for cars and trucks.

4.5. UNDERGROUND MINING

4.5.1. Monitoring and Calculating Methane Emissions

There are several different technological processes that cause methane to be released into the atmosphere from an underground coal mine. Coal mines emit methane from their ventilation systems and from the following degasification techniques: vertical surface bore holes, horizontal bore holes, and cross-measure bore holes.

Methane measurements are performed in both degasification and ventilation systems. Direct measurements are applied to monitor two factors: methane concentration and gas mixture flow rate. On the basis of these measurements, the total amount of emissions is calculated. In the Ukrainian reporting system, the mines provide data on methane emissions in 100 percent methane equivalent units. Mines categorized as gassy report methane-related data to the regional departments of the Ministry of Labor Safety and Social Policy of Ukraine. For different purposes, methane data are also reported to their mining associations and the regional inspectorates of the Ministry of Ecology and Natural Resources. The main sources of the ventilation and degasification data used for this inventory were the Ministry of Labor and Social Policy of Ukraine, and the Mine Safety Institute, Makeyevka.

The two components of the reported methane emissions from an underground mine are the methane contained in the exhaust ventilation air and the methane liberated by the mine degasification systems. The mines also report the amount of utilized methane. Post-mining activities such as processing, storage, and transportation also produce methane emissions; however, these emissions are not reported. As shown in Table 2, methane emissions represent the difference between the total liberated volume and the amount of methane that is recovered and used.

Methane emissions from Ukrainian underground coal mines for the period of 1990 through 2001 are presented in Table 2 and they are categorized by actual methane emissions and calculated methane emissions. The first category is a tabulation of actual methane emissions data that are collected and reported for those mines that have been determined to exceed a set of Ukrainian safety standards and are therefore categorized as gassy. For the study period, approximately 70% on average of the underground coal production in Ukraine was produced from gassy mines, and these mines reported their actual methane emission. For the year 2001, the coal production from mines classified as gassy represented 79.4% of the total underground coal production as compared to 82.4% in 2000.

The second category is a calculation of methane emissions for the coal production from the mines that have been determined not to be gassy. For the purposes of this inventory, the total annual underground coal production from non-gassy mines was multiplied by an emissions factor of 3.4 kg of CH_4 per tonne of mined coal. This emissions factor corresponds to 5 cubic meters of CH_4 per tonne of coal. The methane content of 5 cubic meters of CH_4 per tonne of coal is the maximum allowed by the Ukrainian safety standard for coal mines that do not report their CMM data. Therefore, the utilization of this factor is the most conservative estimate for CMM emissions for mines that are not required to report their methane emissions.

4.5.2. Ventilation System

Underground mine ventilation systems are necessary for safety reasons. Large fans blow fresh air from the surface through the working areas of a mine to dilute the gas content and remove the methane. The capital and operating costs of installing and running these fans are extremely high and even more so for gassy mines. When methane concentration is in the range of 5 to 15 percent, the methane and air mixture becomes highly explosive. Safety regulations require that the concentration of methane in underground mine workings be less than 2 percent, and less than 0.5 percent in the mine shaft air stream.

4.5.2.1. Metering Methane Emissions from Ventilation System

Metering emissions from a mine ventilation system is more complex as compared to the degasification system. To calculate the air mixture flow rate, air velocity is multiplied by the cross-section area of a given mine working. Special metering stations are installed in the underground workings. Airflow velocity and direction meters provide continuous measurement and data is transmitted to a dispatching center for monitoring and recording. The range of velocity metering is 0.25 to 8.0 m/sec, and the absolute error limit is $\Delta V = \pm(0.15 + 0.05 \cdot V)$ m/sec, where velocity (V) is the metered flow rate in meters per second.

The meter features a converter that can account for cross-section area and air velocity fluctuation in the cross-section of a working. The index plate of the meter is scaled to indicate the volumetric flow rate of the air in m^3/min. The meter has an analog output and can be connected to a plotter.

The device used to measure methane content in the ventilation air of Ukrainian mines is a model AMT-3 automatic metering system. The device includes a methane sensor, an alarm unit, a signal transmission system, and plotters. Should methane content exceed the allowed limit, the alarm unit, which is installed in mine workings, emits an electric impulse, cutting power supply to the mine working area. The plotters continuously indicate volumetric percentage of methane in the air. The methane sensor is based on the thermocatalytic principle. The metering range is 0 to 25 percent, with a margin of error of 0.2 percent and a time lag of 60 seconds.

Additional methane content analyses are performed by taking mine air samples and measuring the methane concentration of those samples in a laboratory.

Methane emissions from ventilation systems of Ukrainian underground coal mines for the period of 1990 through 2001 are presented in Table 2.

4.5.3. Degasification Systems

Mine degasification or drainage systems drain the gas from coal-bearing strata before, during, and after mining, depending on the particular needs of the

Table 2. CH_4 Emissions from Ukrainian Underground Coal Mines (Gg) for 1990–2001

	Activity	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*
Methane emissions measured and reported by mines													
Donetsk coal basin	Ventilation	1,855.64	1,769.34	1,698.48	1,386.14	1,348.05	1,072.36	1,053.28	1,019.74	1,004.23	993.97	1,155.71	943.00
	Degasification	403.73	344.52	302.75	252.21	207.29	183.68	129.60	142.45	190.27	174.31	177.62	182.15
	Total liberated	2,259.37	2,113.86	2,001.23	1,638.35	1,555.34	1,256.04	1,182.88	1,162.19	1,194.50	1,168.28	1,333.33	1,125.14
	Total recovered (utilized)	98.46	93.84	60.00*	47.19	64.54	60.55	32.69	38.59	56.63	53.68	49.59	91.33
	Coal production, million raw tonnes	95.63	79.71	79.39	68.86	57.13	51.34	44.74	48.11	48.30	51.71	62.19	61.83
Lviv–Volyn coal basin	Ventilation	90.82	69.96	72.61	69.69	54.90	42.55	56.73	49.92	44.79	40.06	55.89	54.28
	Degasification	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00
	Total recovered (utilized)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total liberated	90.82	69.96	72.61	69.69	54.90	42.55	56.73	49.92	44.79	40.06	56.06	54.28
	Coal production, million raw tonnes	10.45	8.05	8.35	8.02	6.32	4.89	3.84	3.59	3.62	3.85	3.11	3.65
Calculated methane emissions from mines that did not report their emissions													
Coal production , million raw tonnes		49.44	40.69	40.08	34.73	28.33	25.08	21.50	22.77	22.85	24.32	13.91	17.00
Methane emitted (emissions factor 3.4kg CH_4/tonne of coal)		167.85	138.14	136.06	117.89	96.19	85.15	72.99	77.30	77.57	82.55	47.29	57.72
Total underground mines coal production and methane emissions													
Total coal production (underground mines), million raw tonnes		**155.52**	**128.45**	**127.81**	**111.60**	**91.78**	**81.31**	**70.07**	**74.47**	**74.77**	**79.87**	**79.21**	**82.49**
Total methane emitted (underground mines)		**2,419.58**	**2,228.12**	**2,149.90**	**1,778.74**	**1,641.89**	**1,323.19**	**1,279.91**	**1,250.82**	**1,260.23**	**1,237.21**	**1,387.09**	**1,145.81**

* *The number is an estimate, because the reported data of 1992 methane recovery is not complete.*

mine. Degasification allows mines to minimize ventilation costs, reduce mining delays, and enhance mine safety. It is accomplished by three major types of wells: vertical wells drilled from the surface, underground horizontal boreholes drilled along the mined coal seam, and cross-measure boreholes drilled through the coal seam and surrounding rock. Each degasification technique has specific features in terms of methane extraction.

Vertical wells are drilled in advance of mining to recover gas with high content of methane, often over 95 percent. Vertical wells can be drilled from the surface into actively mined coal seams and surrounding rock strata. Often, if the area is very gassy, these wells are used to remove methane from the coal and surrounding rock strata five to ten years in advance of mining. Vertical wells drilled in advance of coal mining can recover up to 70% of the methane contained in coal seams. Vertical wells remaining in or drilled into the collapsed strata zone are called *gob wells*. Usually such wells are drilled from the surface to a point 3 to 20 meters above the target seam and the gas is extracted from the fracture zone caused by the collapsed strata after mining passes. Gob wells often produce gas with methane content of 20 to 80 percent.

Horizontal boreholes are drilled inside the mine to drain methane from unmined areas of blocked-out longwall panels. In Ukraine they are typically 30 to 50 meters long. Generally, these wells recover gas that contains over 95 percent methane. However, their drainage efficiency is lower compared to vertical wells and is typically within the range of 10 to 50 percent.

Cross-measure boreholes are most common in Ukrainian mines. They are used to degasify the overlying and underlying strata of the coal seam being mined. Cross-measure boreholes often produce gas with methane content between 30 and 80 percent and their drainage efficiency averages 20 percent.

Degasification wells and boreholes are linked to a centralized vacuum pump or a compressor station by a system of connected pipelines. Since mines operate at very deep levels in Ukraine and have little funds to properly maintain their facilities, the drainage system often has multiple leakage points, resulting in lower methane content in the gas stream.

The awareness of the need to use degasification is growing. Currently there are several domestic and international programs that study and test the application of surface degasification in advance of mining and upgraded underground degasification systems at Ukrainian mines.

4.5.3.1. Metering Methane Emissions from Degasification System

The gas flow rate is calculated on the basis of the pressure difference on diaphragms installed in the degasification system pipelines. Differential manometers are calibrated to indicate the flow rate in cubic meters per hour, while other flow meters are used to measure the pressure difference. The gas flow rate is calculated using the following equation:

$$Q = 0.209 \cdot 10^{-3} \cdot LE \cdot d^2 \cdot \sqrt{\frac{\Delta P}{\rho}}$$

Where:

L is a factor dependent on diaphragm characteristics;
E is a gas expansion equation factor;
d is diameter of the diaphragm orifice in mm;
P is pressure difference in kg/m^2; and
ρ is gas mixture density in kg/m^2.

To measure methane concentration in gas/air mixture captured by the degasification system, Ukrainian underground mines employ model TP-2301 or GIAM-14 automatic gas analyzers at the vacuum pump stations. The first analyzer meters the thermal conductivity variation, and the second analyzer meters the optical density of the gas. Continuous readings are plotted in the range of 0 to 100 percent. If methane concentration drops below a set limit (typically 35%), an alarm signal is initiated to automatically shut off the gas supply to the consumer. The metering error is less than ±5 percent for a TP-2301 analyzer, and ±2 percent for a GIAM-14 analyzer.

In Ukraine, ShI-12 portable interferometers are also used to measure methane content in mine workings by taking air samples by hand.

Methane emissions from degasification systems of Ukrainian underground coal mines for the period of 1990 through 2001 are presented in Table 2.

4.6. SURFACE MINING

There are currently three active surface mines in the western portion of the Donbass Basin (this region is known as Dnieper Basin). The surface mines produce low rank peat and lignite coal, often referred to as brown coal. The product is used locally for home heating and small boilers.

The measurement data on methane emissions from the surface mines are not available. Previously in order to determine the amount of methane liberated from the surface mines during the period 1990–2000 their total coal production was multiplied by the emission factor 0.938 kg of CH_4 per tonne of mined coal. This factor was used based on the IPCC guidelines and previous Ukrainian GHG emission inventories.

Additional research of emission factor for the surface mines was undertaken for the year 2001. According to the information provided by the geological and drilling enterprise Ukruglegeologia of the Ministry of Fuel and Energy of Ukraine, due to the low rank of coal and the small depth the coal of the Ukrainian surface mines has zero in-situ gas content. However, the mines emit significant amount of carbon dioxide. These mines produced only 930 thousand tonnes of coal altogether in 2001. Based on this information, the methane emissions from the surface mines in 2001 are considered zero. The estimates of methane emissions from the surface mines activities are presented in Table 3.

4.7. POST-MINING EMISSIONS

Methane cannot be completely removed from the coal during the mining process. While degasification and ventilation systems significantly reduce the amount of methane in the coal seam and mine workings, once extracted to the surface, coal still contains a certain amount of the gas. Depending on its desorption capacity, coal can release methane for many years if the coal is not consumed. During the post-mining period, methane is released from coal primarily due to the increase of the surface area during transloading or by further processing prior to utilization. Before being used, coal is usually subjected to certain treatment at a coal preparation plant, where it is crushed, washed, dried, and loaded into transportation vehicles. For most industrial processes, coal is unloaded from the transportation vehicles, put into and out of storage areas, and then crushed to a size under 5 mm. At each point where coal is handled, additional methane can be released into the atmosphere.

Methane-specific data are not available in Ukraine for post-mining activities. In accordance with the IPCC guidelines, in order to determine the post-mining methane emissions for the previous inventories (1990–2000), the underground coal production was multiplied by the emission factor, which was taken from previous Ukrainian GHG reports [7, 8]. With the purpose to improve the accuracy of the CMM emission inventory the additional study of the post-mining emission factors was conducted for the year 2001 (See Appendix 1). A methodology was developed that allows for calculating the amount of methane released from coal after mining based on the mine-specific data. These data include the mine-specific information about amount of coal delivered to the surface, natural gas content of the coal seams, remaining gas content of the coal after mining, storage time of coal, coal moisture, ash content, and other relevant factors. The updated post-mining emission factor for Ukraine was calculated to be 2.4 m^3 per tonne, which is higher than the previously used factor of 2.0 m^3 per tonne. It is possible to use the above methodology for calculating a new emission factor for the future inventories in case of significant changes in the coal seams mined, old mine closures, and new mines openings.

The estimates of methane emissions during post-mining activities are presented in Table 4.

4.8. UTILIZATION OF CMM: CURRENT STATUS AND OPPORTUNITIES

Of all CMM liberated by Ukrainian coal mines, approximately 14.7% is currently extracted through degasification systems, and only 7.4% is utilized. Fifty mines in Ukraine used degasification systems in 2001, as compared to forty-five mines in 2000, and 16 mines utilized methane for their needs, as compared to 12 mines in 2000. The amount of utilized methane increased by 84 percent compared to the year 2000. The number of mines that use degasification and utilize methane varies from year to year. The main reasons for that is the continuing mine closure process (48 mines stopped production in the year 2001), administrative mine merger, growing

Table 3. CH_4 Emissions from Ukrainian Surface Coal Mines (Gg) for 1990–2001

Activity	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*
Total emitted, emissions factor 0.938 kg CH_4/tonne of coal	8.70	6.74	5.42	3.89	2.50	2.15	1.49	1.34	1.31	1.11	1.00	0.00
Coal production, million raw tonnes	9.28	7.18	5.78	4.15	2.66	2.29	1.59	1.43	1.39	1.18	1.06	0.93

Table 4. CH_4 Emissions in Ukraine from Post-Mining Activities (Gg) for 1990–2001

Activity	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*
Post-mining (Underground) Emissions factor 1.34 kg CH_4/tonne of coal	208.40	172.12	171.27	149.55	122.99	108.96	93.90	99.79	100.19	107.03	106.14	136.40*
Post-mining (Surface) Emissions factor 0.134 kg CH_4/tonne of coal	1.24	0.96	0.77	0.56	0.36	0.31	0.21	0.19	0.19	0.16	0.14	0.00*

* *The emissions from post-mining in 2001 were calculated based on the improved methodology (See Attachment 1).*

or decreasing coal production at particular mines, and starting new long walls. At the mine level, the principal application of methane is as a substitute for coal in mine boilers.

In addition to the traditional use of high-concentration methane recovered through degasification systems, there is an option to use ventilation air methane (VAM). Typically VAM concentration in the ventilation air is less than 1%. Through the oxidation process, this gas can be used to generate thermal energy to provide heat for applications such as coal drying, centralized heating systems or to generate electricity in turbine engines. Pilot projects to use VAM are currently being developed and tested; however, none of the pilot projects are located in Ukraine as of the date of publication of this Inventory.

While this is the situation today, reasons exist to believe that CMM could be used for many other productive purposes. Since Ukraine is heavily dependent on imported natural gas, any additional domestic source of this fuel could make the country's economy more self-sustaining. New legislative enactments, such as the Law on Alternative Fuels, the Production Sharing Agreement, and the establishment of Free Economic Zones, can stimulate the implementation of CMM utilization. The government of Ukraine has put forth several initiatives, namely the National Energy Conservation Program [9] and the Program of Reducing Natural Gas Consumption, that include several methane projects. A program of complex degasification of the coal seams was prepared by the Ministry of Fuel and Energy and submitted to the Cabinet of Ministers consideration in 2002. However, only a few selected efforts have been implemented so far, due to the lack of funding. Among them, of particular mention could be:

- utilization of methane in boilers at sixteen mines of the Donbass,
- using CMM as fuel for cars and trucks at one mine, and
- using methane for power generation at diesel electric generators.

For inventory purposes, the amount of recovered (utilized) methane was subtracted from methane liberated from degasification and ventilation systems. The results are presented in Table 1 and 2.

5.0 RESULTS OF THE INVENTORY

Accumulated data of methane emissions from Ukrainian coal mines are presented in Table 1 (in Gg of CH_4).

As it is shown in the table, the methane emissions from the coal mines were 2,637.92 Gg in 1990 and reduced to 1,282.21 Gg in 2001. For the year 2001, one hundred and fifty mines, which produced 65.5 million raw tonnes of coal (79.4% of the total underground production), reported their methane emissions as compared to 185 mines that produced 65.3 million raw tonnes of coal (82.4% of the total underground production) and reported their emissions in 2000.

This inventory has been supplemented with the adjusted estimation of the emissions from surface mines and post-mining activities. The obtained methodology shown in the Appendix 1 allows to perform such calculation in the future, as well as to update the post-mining emission factor when it is necessary.

Previously there have been attempts to estimate the total methane emissions from Ukrainian coal mines using either regional calculations or IPCC guidelines. For example, during 1995, the company Arena-Eco conducted a study that later became the basis for the first Ukrainian National Communication on Climate Change [8]. The results of their study indicated that total methane emissions from Ukrainian coal mines were 2,784.87 Gg during the year 1990. The method of calculation to arrive at their conclusion was based on the IPCC guidelines utilizing the procedures outlined under Tier 1 and Tier 2[1]. In accordance with the IPCC methodology, methane emissions were calculated by multiplying annual coal production by regional specific emissions factors. During the year 1999, Arena-Eco, at the request of the Ministry of Ecology, updated the GHG inventory of Ukraine for 1998 and calculated CMM emissions from Ukraine at a total of 1,478.74 Gg.

In this study, the total methane emissions from Ukrainian coal mines for 1990 as shown in Table 1 were 2,637.92 Gg, approximately 5% less than that calculated by Arena-Eco. Correspondingly in this study, the total methane emissions from Ukraine coal mines for 1998 as shown in Table 1 were 1,361.92 Gg, approximately 8% less than that calculated by Arena-Eco. These minor differences in emissions estimates can be primarily attributed to the two different methods of arriving at the total. Whereas

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[1]Countries with a significant amount of underground mining should focus efforts on improving this part of the overall coal estimate, due to the higher emissions potential of underground mined coal. The decision tree provides guidance in choosing the appropriate method for all sources of coal mine methane. The *Revised 1996 IPCC Guidelines* recommend the following general equation for estimating emissions:

Emissions = Coal Production (Surface or Underground) x Emission Factor

The Tier 2 approach is to use country or basin-specific emission factors that reflect the average methane content of coal actually mined. The Tier 1 default approach requires that countries choose from a global average range of emission factors, and is more uncertain as a consequence. For underground mines, actual measurement data may be available. Although not specified explicitly as Tier 3 in the coal chapter of the IPCC Guidelines, the use of measurement data is generally regarded as a Tier 3 approach.

the Arena-Eco study arrived at their total utilizing an emissions factor, the results shown in Table 1 are a combination of actual and calculated data. Actual methane emissions are gathered at the coal mines and then reported to the State Department for Labor Safety of the Ministry of Labor Safety and Social Policy of Ukraine, Makeyevka Mining Safety Institute and other governmental organizations. As indicated in IPCC guidelines Tier 3[1], actual data should always be utilized first if available. The total methane emissions presented in this Inventory are based on over 86% actual data. However, actual data were not always available and the following exceptions are noted:

- surface mines do not collect actual methane emissions data and calculations prescribed under IPCC guidelines Tier 1 and Tier 2 were used;
- methane emissions created by post mining activities were calculated by utilizing IPCC Tier 1 and Tier 2 guidelines;
- between 20% and 30% of the annual underground coal production is produced from mines that have been determined by Ukrainian experts to not contain sufficient levels of methane to be reported, and therefore actual measured data are not available. This determination is required for safety reasons, and is based on many mine specific geological and technological factors that include gas content in coal, average methane emissions, coal production, frequency of gas outbursts, etc. The coals of these mines have significantly lower methane content than regional averages. It was determined to apply a conservative emissions factor to the coal production from these mines; and
- with Ukraine declaring independence in 1991 from the USSR and the significant changes of the Ukrainian coal industry structure, there is the possibility of data error for the early years of this study. In analyzing the results of the study, it appears that the general trend of the methane emissions is in balance with the general trend of the coal production and that the magnitude of any error is minimal.

While the current inventory provides a solid basis for the future development of the national GHG emissions inventory for the coal industry, there is a potential for its improvement. There are uncertainties associated with the emission data and estimates. Major uncertainties are caused by the metering errors, both instrumental and procedural. Also, there are possible uncertainties associated with the different calculation methodologies used by different mines. Additional efforts are needed to improve such methodologies and data collection procedures. The coal mine methane emission inventory can be further improved by including the methane emission from the abandoned mines.

This inventory was prepared with the assistance of the United States Environmental Protection Agency, and will be transferred to the Ministry of Ecology and Natural Resources of Ukraine under the technical assistance program.

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EMISSION FACTORS ANALYSIS FOR METHANE RELAEASED FROM THE COAL PRODUCED BY UKRAINIAN COAL MINES IN 2001

Appendix 1

1. INTRODUCTION.

The current research was conducted by the Donetsk Expert and Technical Center of the Gosnadzorohrantruda. The authors of the research are A.V. Agafonov, Doctor of Science; A.I. Bobrov, Professor Doctor of Science; E.P. Zakharov, Professor Ph.D., and A.G. Lepikhov, Senior Researcher Ph.D.

2. OBJECTIVE OF THE RESEARCH.

Statistical information about methane released from coal after mining is not available in Ukraine. According to the IPCC recommendations the emissions during the post-mining period are calculated based on an emission factor for a particular coal basin.

The objective of this research is to quantify methane emissions from the coal during post-mining period for each mine that produced coal in 2001 based on scientific research results and engineering calculations.

3. STATUS OF THE COAL MINES OF UKRAINE ON JANUARY 01, 2002.

The industrial coal reserves of the working underground and surface mines of Ukraine during the past ten years are over 10 billion tonnes. The reduction of the industrial reserves is compensated by the addition of new coal fields.

Over 93.4% of the industrial coal reserves are located above 1,200 m depth, and 57% are located above 600 m depth. The average depth of mining in Ukraine is currently 585 m. Approximately 44% of the mines are working at the depth over 600 m which produces about 40% of the overall coal production. More than 21% of the mines are deeper than 900 m, and some mines are deeper than 1,200 m.

Of all mines producing coal in Ukraine 77% are categorized as gassy. At some mines, the natural gas content of the coal seams can exceed 35 cubic meters per one tonne of dry ash free coal.

The temperature at the mine operating level can reach 42–52°C. Every year the temperature of the rock strata is growing by 0.1–1.0°C due to the increasing depth of mining.

The raw coal ash content of the produced coal is 37.2% on average through the coal industry. It varies from 20% to 54% at particular mines. The moisture content of the run-of mine coal is from 4% to 8%.

The coal industry on January 1, 2002, comprised 174 administrative units that include 286 technical units (mines). Only 184 mines have industrial capacity. All the mines are organized into 48 structural units including 18 state holding companies, 7 production associations, and 22 independent mines. The are two state enterprises responsible for the mine closure in the coal industry.

177 underground and surface mines produced coal in 2001. The total coal production in 2001 was 83.4 million tonnes of run-of-mine coal, or 45.887 million tonnes of dry ash free coal. This includes 9.2 million tonnes of coal produced from the zones of natural gas weathering and metamorphic demethanization.

4. METHODOLOGY FOR DETERMINING THE AMOUNT OF RELEASED METHANE.

The amount of methane released from the coal after mining can be determined based on the data about each mine and the coal characteristics. The statistic methods were used to average this information for each individual mine and coal seam. The initial data gathered from the mines consisted of 1,300 factors.

The authors of the research developed a methodology to calculate time dependence of methane emissions from coal after mining. Additional analysis and research was conducted to improve some previously identified dependencies. It was taken into account that the sorptive capacity of coal, which characterizes the natural gas content of the coal seam, depends on coal metamorphism, i.e. on its volatility. The utilization of coal in a particular industry of Ukraine also depends on its metamorphism (or coal rank).

Thousands of tests have been performed in Donetsk and Lviv-Volyn coal basins during past 20–25 years to determine the natural methane content of the industrial coal seams. Based on the results of these tests, the maps of natural methane content were developed. These maps were used as a basis for the current research.

The mines that operate in the zones of natural gas weathering and metamorphic demethanization were also taken into account. There are 37 such mines in Ukraine and they emit no methane.

The information about industrial coal seams volatility was obtained from the technical tests of coal. Most of the data was double-checked with the mines.

Statistic analysis of the time of coal transportation from a mine to a consumer, and of the storage period of coal after mining, indicated that this period, as a rule, does not exceed 5 days. It was proved that the major amount of methane is released during this period. In addition, crushing of coal does not significantly impact the methane emissions.

The methodology for calculating methane emissions from coal after mining by each particular mine takes in account the following factors:

$$\mathbf{I_e=f\ (A_m,\ X_n,\ X_{or};\ T_s,\ T_u,\ W,\ A^c,\ H,\ H_o,\ V^{daf}\ ),}$$

where

I_e – methane emissions, m^3;

A_m – amount of coal delivered to the surface, t;

X_n – natural gas content of the coal seam, m^3/t daf;

X_r – remaining gas content of the coal, m^3/t daf;

T_s – storage time of coal on the surface after mining, days (minutes);

T_u – storage time of coal underground after mining, hours;

W – coal moisture, before cleaning, %;

A^c – coal ash content, before cleaning, %;

H – depth of mining, m;

H_0 – depth of the upper level of methane gas zone, m;

V^{daf} – volatility, %.

Based on 3,700 calculations, the methane emissions from coal produced by each individual mine were determined for the period between coal delivery to the surface and its utilization by power plants, coke and chemical plants, and municipal organizations.

The total methane emissions from coal mining during post-mining period in Ukraine in 2001 amounted to 200.89 million cubic meters, or 136.4 Gg.