ANNEX E

Methodology for Estimating CH_4 Emissions from Coal Mining

The methodology for estimating methane emissions from coal mining consists of two distinct steps. The first step addresses emissions from underground mines. For these mines, emissions are estimated on a mine-by-mine basis and then are summed to determine total emissions. The second step of the analysis involves estimating methane emissions for surface mines and post-mining activities. In contrast to the methodology for underground mines, which uses mine-specific data, the surface mine and post-mining activities analysis consists of multiplying basin-specific coal production by basin-specific emission factors.

Step 1: Estimate Methane Liberated and Methane Emitted from Underground Mines

Underground mines generate methane from ventilation systems and from degasification systems. Some mines recover and use methane generated from degasification systems, thereby reducing emissions to the atmosphere. Total methane emitted from underground mines equals the methane liberated from ventilation systems, plus the methane liberated from degasification systems, minus methane recovered and used.

Step 1.1: Estimate Methane Liberated from Ventilation Systems

All coal mines with detectable methane emissions[1] use ventilation systems to ensure that methane levels remain within safe concentrations. Many coal mines do not have detectable levels of methane, while others emit several million cubic feet per day (MMCFD) from their ventilation systems. On a quarterly basis, the U.S. Mine Safety and Health Administration (MSHA) measures methane emissions levels at underground mines. MSHA maintains a database of measurement data from all underground mines with detectable levels of methane in their ventilation air. Based on the four quarterly measurements, MSHA estimates average daily methane liberated at each of the underground mines with detectable emissions.

For the years 1990 through 1996 and 1998 through 2000, MSHA emissions data were obtained for a large but incomplete subset of all mines with detectable emissions. This subset includes mines emitting at least 0.1 MMCFD for some years and at least 0.5 MMCFD for other years, as shown in Table E-1. Well over 90 percent of all ventilation emissions were concentrated in these subsets. For 1997, the complete MSHA database for all 586 mines with detectable methane emissions was obtained. These mines were assumed to account for 100 percent of methane liberated from underground mines. Using the complete database from 1997, the proportion of total emissions accounted for by mines emitting less than 0.1 MMCFD or 0.5 MMCFD was estimated (see Table E-1). The proportion was then applied to the years 1990 through 2000 to account for the less than 10 percent of ventilation emissions coming from mines without MSHA data.

For 1990-1999, average daily methane emissions were multiplied by 365 to determine the annual emissions for each mine. For 2000, MSHA provided quarterly emissions. The average daily methane emissions were multiplied by the number of days corresponding to the number of quarters the mine vent was operating. For example, if the mine vent was operational in one out of the four quarters, the average daily methane emissions were multiplied by 92 days. Total ventilation emissions for a particular year were estimated by summing emissions from individual mines.

[1] MSHA records coal mine methane readings with concentrations of greater than 50 ppm (parts per million) methane. Readings below this threshold are considered non-detectable.

Table E-1: Mine-Specific Data Used to Estimate Ventilation Emissions

Year	Individual Mine Data Used
1990	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total)*
1991	1990 Emissions Factors Used Instead of Mine-Specific Data
1992	1990 Emissions Factors Used Instead of Mine-Specific Data
1993	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total)*
1994	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total)*
1995	All Mines Emitting at Least 0.5 MMCFD (Assumed to Account for 94.1% of Total)*
1996	All Mines Emitting at Least 0.5 MMCFD (Assumed to Account for 94.1% of Total)*
1997	All Mines with Detectable Emissions (Assumed to Account for 100% of Total)
1998	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total)*
1999	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total)*
2000	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total)*

* Factor derived from a complete set of individual mine data collected for 1997.

Step 1.2: Esti mate Methane Liberated from Degasification Systems

Coal mines use several different types of degasification systems to remove methane, including vertical wells and horizontal boreholes to recover methane prior to mining of the coal seam. Gob wells and cross-measure boreholes recover methane from the overburden (i.e., GOB area) after mining of the seam (primarily in longwall mines).

MSHA collects information about the presence and type of degasification systems in some mines, but does not collect quantitative data on the amount of methane liberated. Thus, the methodology estimated degasification emissions on a mine-by-mine basis based on other sources of available data. Many of the coal mines employing degasification systems have provided EPA with information regarding methane liberated from their degasification systems. For these mines, this reported information was used as the estimate. In other cases in which mines sell methane recovered from degasification systems to a pipeline, gas sales were used to estimate methane liberated from degasification systems (see Step 1.3). Finally, for those mines that do not sell methane to a pipeline and have not provided information to EPA, methane liberated from degasification systems was estimated based on the type of system employed. For example, for coal mines employing gob wells and horizontal boreholes, the methodology assumes that degasification emissions account for 40 percent of total methane liberated from the mine.

Step 1.3: Estimate Methane Recovered from Degasification Systems and Used (Emissions Avoided)

In 2000, ten active coal mines had methane recovery and use projects and sold the recovered methane to a pipeline. One coal mine also used some recovered methane in a thermal dryer in addition to selling gas to a pipeline. In order to calculate emissions avoided from pipeline sales, information was needed regarding the amount of gas recovered and the number of years in advance of mining that wells were drilled. Several state agencies provided gas sales data, which were used to estimate emissions avoided for these projects. Additionally, coal mine operators provided information on gas sales and/or the number of years in advance of mining. Emissions avoided were attributed to the year in which the coal seam was mined. For example, if a coal mine recovered and sold methane using a vertical well drilled five years in advance of mining, the emissions avoided associated with those gas sales (cumulative production) were attributed to the well up to the time it was mined through (e.g., five years of gas production). Where individual well data is not available, estimated percentages of the operator's annual gas sales within the field around the coal mine are attributed to emissions avoidance. For some mines, individual well data were used to assign gas sales to the appropriate emissions avoided year. In most cases, coal mine operators provided this information, which was then used to estimate emissions avoided for a particular year. Additionally, several state agencies provided production data for individual wells.

Step 2: Estimate Methane Emitted from Surface Mines and Post-Mining Activities

Mine-specific data were not available for estimating methane emissions from surface coal mines or for post-mining activities. For surface mines and post-mining activities, basin-specific coal production was multiplied by a basin-specific emission factor to determine methane emissions.

Step 2.1: Define the Geographic Resolution of the Analysis and Collect Coal Production Data

The first step in estimating methane emissions from surface mining and post-mining activities was to define the geographic resolution of the analysis and to collect coal production data at that level of resolution. The analysis was conducted by coal basin as defined in Table E-2, which presents coal basin definitions by basin and by state.

The Energy Information Agency's (EIA) Coal Industry Annual reports state- and county-specific underground and surface coal production by year. To calculate production by basin, the state level data were grouped into coal basins using the basin definitions listed in Table E-2. For two states—West Virginia and Kentucky—county-level production data was used for the basin assignments because coal production occurred from geologically distinct coal basins within these states. Table E-3 presents the coal production data aggregated by basin.

Step 2.2: Estimate Emissions Factors for Each Emissions Type

Emission factors for surface mined coal were developed from the *in situ* methane content of the surface coal in each basin. Based on an analysis presented in EPA (1993), surface mining emission factors were estimated to be from 1 to 3 times the average *in situ* methane content in the basin. For this analysis, the surface mining emission factor was determined to be twice the *in situ* methane content in the basin. Furthermore, the post-mining emission factors used were estimated to be 25 to 40 percent of the average *in situ* methane content in the basin. For this analysis, the post-mining emission factor was determined to be 32.5 percent of the *in situ* methane content in the basin. Table E-4 presents the average *in situ* content for each basin, along with the resulting emission factor estimates.

Step 2.3: Estimate Methane Emitted

The total amount of methane emitted was calculated by multiplying the coal production in each basin by the appropriate emission factors.

Total annual methane emissions is equal to the sum of underground mine emissions plus surface mine emissions plus post-mining emissions. Table E-5 and Table E-6 present estimates of methane liberated, used, and emitted for 1990 through 2000. Table E-7 provides emissions by state.

Table E-2: Coal Basin Definitions by Basin and by State

Basin	States
Northern Appalachian Basin	Maryland, Ohio, Pennsylvania, West Virginia North
Central Appalachian Basin	Kentucky East, Tennessee, Virginia, West Virginia South
Warrior Basin	Alabama, Mississippi
Illinois Basin	Illinois, Indiana, Kentucky West
South West and Rockies Basin	Arizona, California, Colorado, New Mexico, Utah
North Great Plains Basin	Montana, North Dakota, Wyoming
West Interior Basin	Arkansas, Iowa, Kansas, Louisiana, Missouri, Oklahoma, Texas
Northwest Basin	Alaska, Washington
State	**Basin**
Alabama	Warrior Basin
Alaska	Northwest Basin
Arizona	South West and Rockies Basin
Arkansas	West Interior Basin
California	South West and Rockies Basin
Colorado	South West and Rockies Basin
Illinois	Illinois Basin
Indiana	Illinois Basin
Iowa	West Interior Basin
Kansas	West Interior Basin
Kentucky East	Central Appalachian Basin
Kentucky West	Illinois Basin
Louisiana	West Interior Basin
Maryland	Northern Appalachian Basin
Mississippi	Warrior Basin
Missouri	West Interior Basin
Montana	North Great Plains Basin
New Mexico	South West and Rockies Basin
North Dakota	North Great Plains Basin
Ohio	Northern Appalachian Basin
Oklahoma	West Interior Basin
Pennsylvania.	Northern Appalachian Basin
Tennessee	Central Appalachian Basin
Texas	West Interior Basin
Utah	South West and Rockies Basin
Virginia	Central Appalachian Basin
Washington	Northwest Basin
West Virginia South	Central Appalachian Basin
West Virginia North	Northern Appalachian Basin
Wyoming	North Great Plains Basin

Table E-3: Annual Coal Production (Thousand Short Tons)

Underground Coal Production

Basin	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
N. Appalachia	103,865	103,450	105,220	77,032	100,122	98,103	106,729	112,135	116,718	107,575	105,374
Cent. Appalachia	198,412	181,873	177,777	164,845	170,893	166,495	171,845	177,720	171,279	157,058	150,584
Warrior	17,531	17,062	15,944	15,557	14,471	17,605	18,217	18,505	17,316	14,799	15,895
Illinois	69,167	69,947	73,154	55,967	69,050	69,009	67,046	64,728	64,463	63,529	53,720
S. West/Rockies	32,754	31,568	31,670	35,409	41,681	42,994	43,088	44,503	45,983	46,957	45,742
N. Great Plains	1,722	2,418	2,511	2,146	2,738	2,018	2,788	2,854	1,723	1,673	1,210
West Interior	105	26	59	100	147	25	137	212	247	200	241
Northwest	0	0	0	0	0	0	0	0	0	0	0
Total	**423,556**	**406,344**	**406,335**	**351,056**	**399,102**	**396,249**	**409,850**	**420,657**	**417,729**	**391,791**	**372,766**

Surface Coal Production

Basin	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
N. Appalachia	60,761	51,124	50,512	48,641	44,960	39,372	39,788	40,179	41,043	33,928	34,908
Cent. Appalachia	94,343	91,785	95,163	94,433	106,129	106,250	108,869	113,275	108,345	107,507	110,479
Warrior	11,413	10,104	9,775	9,211	8,795	7,036	6,420	5,963	5,697	4,723	4,252
Illinois	72,000	63,483	58,814	50,535	51,868	40,376	44,754	46,862	47,715	40,474	33,631
S. West/Rockies	43,863	42,985	46,052	48,765	49,119	46,643	43,814	48,374	49,635	50,349	49,587
N. Great Plains	249,356	259,194	258,281	275,873	308,279	331,367	343,404	349,612	385,438	407,683	407,670
West Interior	64,310	61,889	63,562	60,574	58,791	59,116	60,912	59,061	57,951	58,309	54,170
Northwest	6,707	6,579	6,785	6,340	6,460	6,566	6,046	5,945	5,982	5,666	5,911
Total	**602,753**	**587,143**	**588,944**	**594,372**	**634,401**	**636,726**	**654,007**	**669,271**	**699,608**	**708,639**	**700,608**

Total Coal Production

Basin	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
N. Appalachia	164,626	154,574	155,732	125,673	145,082	137,475	146,517	152,314	157,761	141,145	140,282
Cent. Appalachia	292,755	273,658	272,940	259,278	277,022	272,745	280,714	290,995	279,624	262,660	261,063
Warrior	28,944	27,166	25,719	24,768	23,266	24,641	24,637	24,468	23,013	19,499	20,147
Illinois	141,167	133,430	131,968	106,502	120,918	109,385	111,800	111,590	110,176	103,966	87,351
S. West/Rockies	76,617	74,553	77,722	84,174	90,800	89,637	86,902	92,877	95,618	96,207	95,239
N. Great Plains	251,078	261,612	260,792	278,019	311,017	333,385	346,192	352,466	387,161	406,324	408,880
West Interior	64,415	61,915	63,621	60,674	58,938	59,141	61,049	59,273	58,198	58,509	54,411
Northwest	6,707	6,579	6,785	6,340	6,460	6,566	6,046	5,945	5,982	5,665	5,911
Total	**1,026,309**	**993,487**	**995,279**	**945,428**	**1,033,503**	**1,032,975**	**1,063,857**	**1,089,928**	**1,118,132**	**1,093,975**	**1,073,374**

Source for 1990-99 data: EIA (1990-99), Coal Industry Annual. U.S.Department of Energy, Washington, DC, Table 3.
Source for 2000 data: EIA (2001) Personal Communication on August 29,2001, U.S. Department of Energy, Washington, DC.
Note: Totals may not sum due to independent rounding.

Table E-4: Coal Surface and Post-Mining Methane Emission Factors (ft^3 per Short Ton)

Basin	Surface Average *in situ* Content	Underground Average *In situ* Content	Surface Mine Factors	Post-Mining Surface Factors	Post Mining Underground
Northern Appalachia	49.3	171.7	98.6	16.0	55.8
Central Appalachia	49.3	330.7	98.6	16.0	107.5
Warrior	49.3	318.0	98.6	16.0	103.4
Illinois	39.0	57.20	78.0	12.7	18.6
S. West/Rockies	15.3	225.8	30.6	5.0	73.4
N. Great Plains	3.2	41.67	6.4	1.0	13.5
West Interior	3.2	41.67	6.4	1.0	13.5
Northwest	3.2	41.67	6.4	1.0	13.5

Source: EPA (1993), Anthropogenic Methane Emissions in the United States: Estimates for 1990, Report to Congress, U.S. Environmental Protection Agency, Air and Radiation, April.

Table E-5: Underground Coal Mining Methane Emissions (Billion Cubic Feet)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Ventilation Output	112	NA	NA	95	96	102	90	96	94	92	87
Adjustment Factor for Mine Data*	97.8%	NA	NA	97.8%	97.8%	91.4%	91.4%	100%	97.8%	97.8%	97.8%
Adjusted Ventilation Output	114	NA	NA	97	98	111	99	96	96	94	89
Degasification System Liberated	54	NA	NA	45	46	46	50	42	49	41	45
Total Underground Liberated	167	164	162	142	144	157	149	138	146	135	134
Recovered & Used	(14)	(15)	(17)	(23)	(27)	(30)	(36)	(28)	(35)	(32)	(36)
Total	**154**	**149**	**144**	**119**	**117**	**127**	**113**	**110**	**110**	**103**	**98**

* Refer to Table E-1.

Note: Totals may not sum due to independent rounding.

Table E-6: Total Coal Mining Methane Emissions (Billion Cubic Feet)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Underground Mining	154	149	144	119	117	127	113	110	110	103	98
Surface Mining	25	23	23	23	24	22	23	24	23	22	22
Post-Mining (Underground)	33	31	30	27	30	30	31	32	31	29	28
Post-Mining (Surface)	4	4	4	4	4	4	4	4	4	4	4
Total	**216**	**209**	**201**	**173**	**175**	**183**	**172**	**170**	**163**	**161**	**150**

Note: Totals may not sum due to independent rounding.

Table E-7: Total Coal Mining Methane Emissions by State (Million Cubic Feet)

State	1990	1993	1994	1995	1996	1997	1998	1999	2000
Alabama	33,175	26,694	30,283	39,334	29,928	26,440	27,058	26,209	23,997
Alaska	13	12	12	13	11	11	10	12	12
Arizona	402	433	464	425	371	417	403	419	466
Arkansas	0	0	0	0	0	0	0	0	0
California	2	-	-	-	-	-	0	0	0
Colorado	10,117	7,038	9,029	8,541	5,795	9,057	9,057	9,296	10,677
Illinois	10,643	8,737	10,624	11,106	10,890	8,571	7,859	7,812	8,531
Indiana	3,149	2,623	2,791	2,106	2,480	3,088	3,239	2,980	2,492
Iowa	3	1	0	-	-	-	0	0	0
Kansas	5	3	2	2	2	3	3	3	1
Kentucky	21,229	19,823	21,037	19,103	18,292	20,089	19,240	18,255	16,910
Louisiana	24	23	26	28	24	26	24	22	27
Maryland	510	245	256	259	287	296	282	260	345
Mississippi	-	-	-	-	-	-	0	2	92
Missouri	20	5	6	4	5	3	3	3	3
Montana	280	267	310	294	283	305	319	306	285
New Mexico	905	1,186	1,223	980	856	961	1,026	1,042	972
North Dakota	217	238	240	224	222	220	223	232	233
Ohio	4,710	4,110	4,377	3,900	3,992	4,313	4,244	3,820	3,443
Oklahoma	13	14	52	14	14	132	137	209	208
Pennsylvania	22,573	26,437	24,026	27,086	26,567	30,339	29,853	24,088	25,352
Tennessee	800	350	338	366	418	390	309	349	306
Texas	415	406	389	392	410	397	391	395	361
Utah	4,562	4,512	3,696	3,541	4,061	4,807	5,060	4,851	4,045
Virginia	45,883	30,457	26,765	19,893	19,847	16,972	14,087	13,539	12,179
Washington	37	35	36	36	34	33	35	31	32
West Virginia	55,280	37,803	36,854	42,992	42,870	40,197	43,511	41,500	37,490
Wyoming	1,382	1,578	1,782	1,977	2,090	2,122	2,351	2,520	2,533
Total	**216,350**	**173,029**	**174,622**	**182,616**	**169,750**	**169,190**	**168,725**	**158,153**	**151,397**

+ Does not exceed 0.5 Million Cubic Feet

Note: The emission estimates provided above are inclusive of emissions from underground mines, surface mines and post-mining activities. The following states have neither underground nor surface mining and thus report no emissions as a result of coal mining: Connecticut, Delaware, Florida, Georgia, Hawaii, Idaho, Maine, Massachusetts, Michigan, Minnesota, Nebraska, Nevada, New Hampshire, New Jersey, New York, North Carolina, Oregon, Rhode Island, South Carolina, South Dakota, Vermont, and Wisconsin. Emission estimates are not given for 1991 and 1992 because underground mine data was not available for those years.