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Agency

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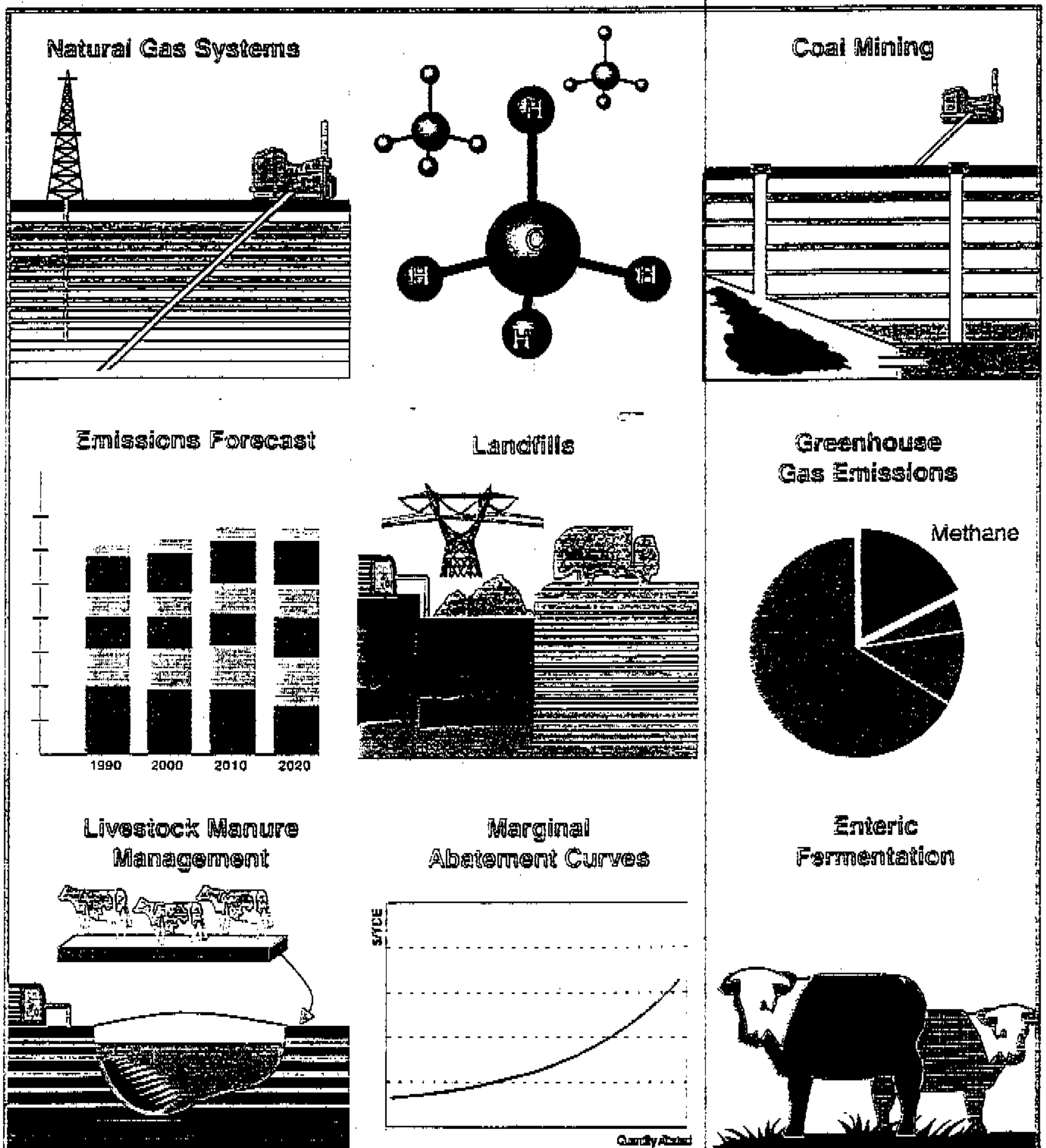
U.S. Methane Emissions 1990 – 2020: Inventories, Projections, and Opportunities for Reductions



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1. Introduction and Aggregate Results

Introduction

This report has two objectives. First, it presents the U.S. Environmental Protection Agency's (EPA's) baseline forecast of methane emissions from the major anthropogenic sources in the U.S., and EPA's cost estimates of reducing these emissions. Emission estimates are given for 1990 through 1997 with projections for 2000 to 2020. The cost analysis is for 2000, 2010, and 2020. Second, this report provides a transparent methodology for the calculation of emission estimates and reduction costs, thereby enabling analysts to replicate these results or use the approaches described herein to conduct similar analyses for other countries.

The information presented in this report can be used in several ways. The emission estimates and forecasts represent the most up-to-date estimates of methane emissions in the U.S.; thus, this report replaces and expands upon EPA's *Anthropogenic Methane Emissions in the United States, Estimates for 1990, Report to Congress* (1993a). As such, this report can be used where estimates of future emissions are required. The report also summarizes the state of knowledge on methane emissions from the major anthropogenic sources.

While the emission estimations are refinements of earlier approaches, the cost analyses presented in this report represent a major contribution to the literature on mitigating emissions. To date, most economic analyses of greenhouse gas (GHG) emission reductions have focused on the energy-related carbon emissions since carbon dioxide (CO_2) currently accounts for about 82 percent of the total U.S. emissions (weighted by 100-year global warming potentials) (EPA, 1999). The cost-estimates for reducing methane emissions presented in this report can be integrated into economic analyses to produce more comprehensive assessments of total GHG reductions. By including methane emission reductions, the overall cost of reducing GHG emissions in the U.S. is reduced. At increasing values for emission reductions, more costly CO_2 reductions can be substituted by lower cost methane reductions, when available, thereby lowering the marginal cost and the total cost of a particular GHG emission reduction level.

The marginal abatement curves (MACs) developed in this report can be used to estimate possible emission reductions at various prices for carbon equivalent emissions or conversely, the costs of achieving certain amounts of reductions. EPA recognizes that the cost analyses will change with the introduction of new technologies and additional research into methane emission abatement technologies. Other countries, nevertheless, can use the cost analyses presented in this report as the basis for estimating emission reduction costs.

1.0 Overview of Methane Emissions

Next to carbon dioxide, methane is the second largest contributor to global warming among anthropogenic greenhouse gases. Methane's overall contribution to global warming is significant because, over a 100-year time frame, it is estimated to be 21 times more effective at trapping heat in the atmosphere than carbon dioxide. As illustrated in Exhibit 1-1, methane accounts for 17 percent of the enhanced greenhouse effect (IPCC, 1996a).[1]

Over the last two centuries, methane's concentration in the atmosphere has more than doubled from about 700 parts per billion by volume (ppbv) in pre-industrial times to 1,730 ppbv in 1997 (IPCC, 1996a). Exhibit 1-1 illustrates this trend. Scientists believe these atmospheric increases are largely due to increasing

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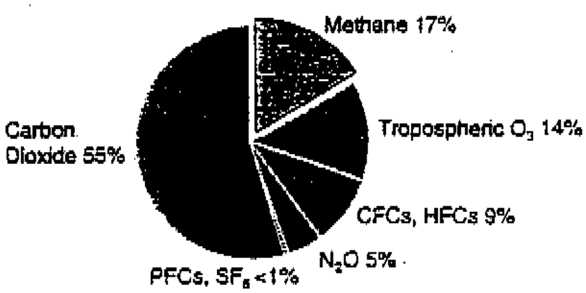
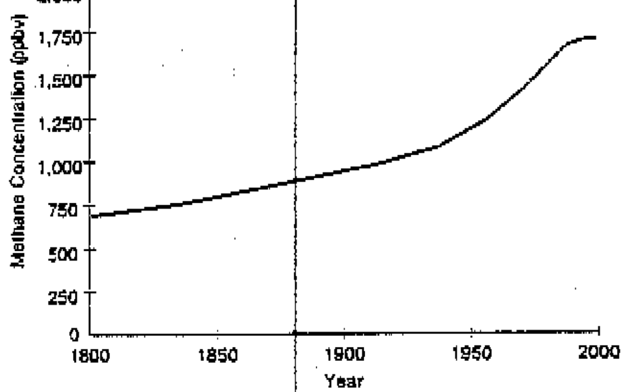
Exhibit 1-1: Global Enhanced Greenhouse Effect and Methane Concentrations

Contribution of Anthropogenic Gases to Enhanced Greenhouse Effect Since Pre-Industrial Times (measured in Watts/m^2)



Total = 2.85 Watts/m^2
Source: IPCC, 1996a.

Historical Global Atmospheric Methane Concentrations



Source: Boden, et al., 1994; Dlugokencky, et al., 1998.

emissions from anthropogenic sources. Although atmospheric methane concentrations continue to rise, the rate of increase appears to have slowed since the 1980s. If present trends continue, however, atmospheric methane concentrations will reach 1,800 ppbv by 2020 (Dlugokencky, et al., 1998).

Atmospheric methane is reduced naturally by sinks. Natural sinks are removal mechanisms and the greatest sink for atmospheric methane (CH_4) is through a reaction with naturally-occurring tropospheric hydroxyl (OH).[2] Methane combines with OH to form water vapor (H_2O) and carbon monoxide (CO), which in turn is converted into carbon dioxide (CO_2). Atmospheric methane, nevertheless, has a clearly defined chemical feedback that decreases the effectiveness of the hydroxyl sink. As methane concentrations rise, less hydroxyl is available to break down methane, producing longer atmospheric methane lifetimes and higher methane concentrations (IPCC, 1996a).

On average, the atmospheric lifetime for a methane molecule is 12.2 years (± 3 years) before a natural sink consumes it (IPCC, 1996a). This relatively short lifetime makes methane an excellent candidate for mitigating the impacts of global warming because emission reductions could lead to stabilization or reduction in methane concentrations within 10 to 20 years.

2.0 Sources of Methane Emissions

Methane is emitted into the atmosphere from both natural and anthropogenic sources. Natural sources include wetlands, tundra, bogs, swamps, termites, wildfires, methane hydrates, and oceans and freshwaters. Anthropogenic sources include landfills, natural gas and oil production and processing, coal mining, agriculture (livestock enteric fermentation and livestock manure management, and rice cultivation), and various other sources. By 1990, anthropogenic sources accounted for 70 percent of total global methane emissions (EPA, 1993a; IPCC, 1996a). This section summarizes the natural and anthropogenic sources of methane.

2.1 Natural Methane Emissions

In 1990, worldwide natural sources emitted 916 million metric tons of carbon equivalent (MMTCE) or 160 Teragrams (Tg) of methane into the atmosphere, or about 30 percent of the total methane emissions (IPCC, 1996a). The leading natural methane sources are described below in descending order of their contribution to emissions (see Exhibit 1-2).

Wetlands. Methane is generated by anaerobic (oxygen poor) bacterial decomposition of plant material in wetlands. Natural wetlands emit about 659 MMTCE

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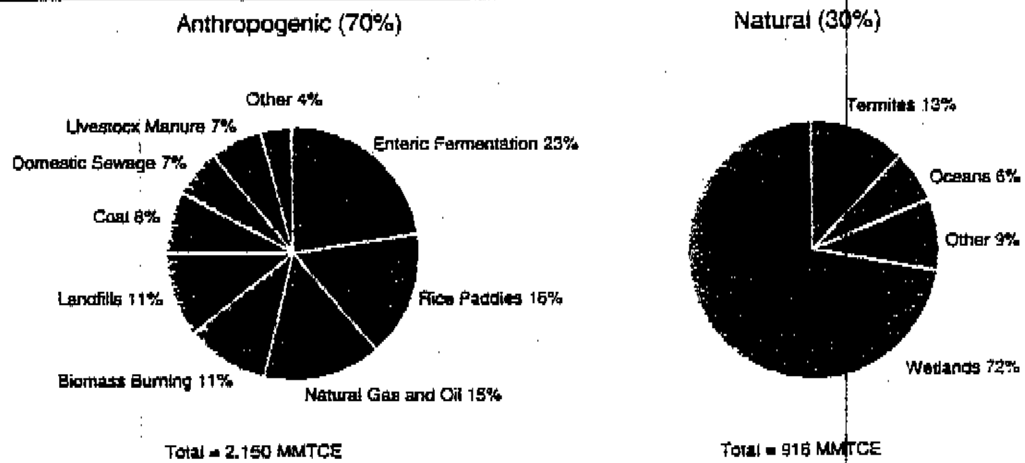
Exhibit 1-2: Worldwide Natural and Anthropogenic Methane Emissions in 1990



World Total = 3,066 MMTCE

Source: IPCC, 1995 and 1996a.

(115 Tg) of methane per year, which is 72 percent of natural emissions and 20 percent of total global methane emissions (IPCC, 1995). Methane emissions from wetlands will probably increase with global warming as a result of accelerated anaerobic microbial activity. In addition, climate change models predict increased precipitation as global temperatures rise, which could create more wetlands (EPA, 1993b). Tropical wetlands (between 20° N and 30° S) represent 17 percent of total wetland area and 60 percent of emissions from wetlands. These relatively high emissions are due to higher temperatures, more precipitation and more intense solar radiation, which encourage higher plant growth and decomposition rates (EPA, 1993b).

Northern Wetlands (those above 45° N) are usually underlain with near-surface permafrost that prevents soil drainage and creates wetland conditions. Northern wetlands represent nearly 80 percent of the wetland area and 35 percent of methane emissions from wetlands (EPA, 1993b).

Termites. Microbes within the digestive systems of termites break down cellulose, and this process produces methane. Emissions from this source depend on termite population, amounts of organic material consumed, species, and the activity of methane-oxidizing bacteria. While more research is needed, some experts believe that future trends in termite emissions are more influenced by anthropogenic changes in land use, i.e., deforestation for agriculture, than by climate change. Termites emit an estimated 115 MMTCE (20 Tg) of methane each year (IPCC, 1995).

Oceans and Freshwaters. The surface waters of the world's oceans and freshwaters are slightly supersaturated with methane relative to the atmosphere and therefore emit an estimated 57 MMTCE (10 Tg) of methane each year (IPCC, 1995). The origin of the dissolved methane is not known. In coastal regions it may come from sediments and drainage. It also has been suggested that methane is generated in the anaerobic gastrointestinal tracts of marine zooplankton and fish (EPA, 1993b). Methane in freshwaters can result from the decomposition of wetland plants. (In this report, methane emissions from freshwaters are included in the estimates for wetlands.) As atmospheric methane concentrations increase, the proportion of methane supersaturated in oceans and freshwaters will decline relative to the atmospheric concentrations of methane, assuming that the methane concentration in oceans and freshwaters remains constant.

Gas Hydrates. Methane is trapped in gas hydrates, which are dense combinations of methane and ice located deep underground and beneath the ocean floor. Recent estimates of hydrates suggest that around 44 billion MMTCE (7.7 billion Tg) of methane is trapped in both oceanic and continental gas hydrates (DOE, 1998). Scientists agree that increasing temperatures will eventually destabilize many gas hydrates, but are unsure about the timing and the amount of methane emissions that would be released from the deeply buried hydrates (EPA, 1993b).

Permafrost. Small amounts of methane are trapped in permafrost, which consists of permanently frozen soil and ice. (To be classified as permafrost, the ice and soil mixture must remain at or below 0° Celsius year-round for at least two consecutive years.) Due to the large amount of existing permafrost, the total amount of methane stored in this form could be quite high, possibly several thousand Tg (EPA, 1993b). This methane is released when permafrost melts. However, no estimates have been made for current emissions from this source.

Wildfires. Wildfires are primarily caused by lightning and release a number of greenhouse gases, including methane which is a product of incomplete combustion. However, no estimates are available for methane emissions from this source.

2.2 Anthropogenic Methane Emissions

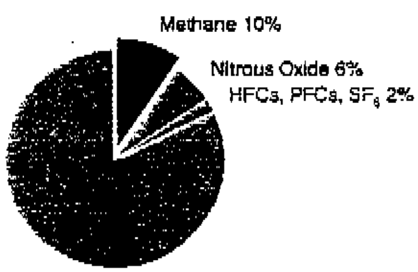
Methane emissions from anthropogenic sources account for 70 percent of all methane emissions and totaled 2,150 MMTCE (375 Tg) worldwide in 1990 (IPCC, 1996a). The leading global anthropogenic methane sources are described below in descending order of magnitude. The two leading sources of anthropogenic methane emissions worldwide are livestock enteric fermentation and rice production. By contrast, in the U.S., the two leading sources of methane emissions are landfills and natural gas and oil systems (see Exhibit 1-3). In 1997, the U.S. emitted 179.6 MMTCE (31.4 Tg) of methane, about 10 percent of global methane emissions for that year (EPA, 1999). The U.S. is the fourth-largest methane emitter after China, Russia, and India (EPA, 1994).

Enteric Fermentation. Ruminant livestock emit methane as part of their normal digestive process, during which microbes break down plant material consumed by the animal into material the animal can use. Methane is produced as a by-product of this digestive process, and is expelled by the animal. In the U.S., cattle emit about 96 percent of the methane from livestock enteric fermentation. In 1994, livestock enteric fermentation produced 490 MMTCE (85 Tg) of methane worldwide (IPCC, 1995), with the emissions coming from the former Soviet Union, Brazil, and India (EPA, 1994). EPA estimates that U.S. emissions from this source were 34.1 MMTCE (6.0 Tg) in 1997 (EPA, 1999). Under EPA's baseline forecast, livestock enteric fermentation emissions in the U.S. will increase to about 37.7 MMTCE (6.6 Tg) by 2020 (Exhibit 1-4). The projected increase is due to greater consumption of meat and dairy products.

Rice Paddies. Most of the world's rice, including rice in the United States, is grown on flooded fields where organic matter in the soil decomposes under anaerobic conditions and produces methane. The U.S. is not a

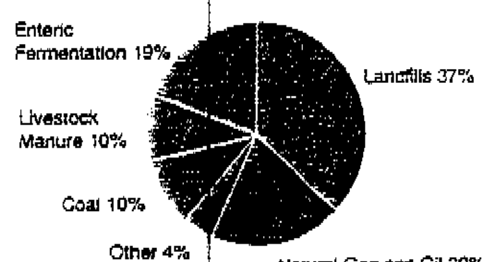
Exhibit 1-3: U.S. Methane Emissions

U.S. Greenhouse Gas Emissions in 1997
Weighted by Global Warming Potential



Total = 1,814 MMTCE
Source: EPA, 1999.

Source Breakdown of 1997 U.S. Methane Emissions



Total = 179.6 MMTCE
Source: EPA, 1999.

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Exhibit 1-4: Baseline Methane Emissions in the United States (MMTCE)

Source	1990[a]	1997[a]	2000	2010	2020
Landfills	56.2	66.7	51.4	52.0	41.1
Natural Gas Systems	32.9	33.5	35.6	37.9	38.8
Oil Systems	1.6	1.6	1.6	1.6	1.7
Coal Mining	24.0	18.8	23.9	28.0	30.4
Livestock Manure Management	14.9	17.0	18.4	22.3	26.4
Enteric Fermentation	32.7	34.1	35.2	36.6	37.7
Other[b]	7.3	7.4	7.8	7.6	7.6
Total	**169.9**	**179.6**	**173.9**	**186.0**	**183.7**

[a] Source: EPA, 1999.

[b] These estimates developed by EPA for the 1997 *Climate Action Report* (DOS, 1997).

Totals may not sum due to independent rounding.

major producer of rice and therefore emits little methane from this source. Worldwide emissions of methane from rice paddies were 345 MMTCE (60 Tg) in 1994 (IPCC, 1995), with the highest emissions coming from China, India, and Indonesia (EPA, 1994). EPA estimates U.S. emissions from this source at 2.7 MMTCE (0.5 Tg) in 1997 and expects emissions to remain stable in the future (EPA, 1999).

Natural Gas and Oil Systems. Methane is the major component (95 percent) of natural gas. During production, processing, transmission, and distribution of natural gas, methane is emitted from system leaks, deliberate venting, and system upsets (accidents). Since natural gas is often found in conjunction with petroleum, crude petroleum gathering and storage systems are also a source of methane emissions. In 1994, natural gas systems worldwide emitted 230 MMTCE (40 Tg) of methane and oil systems emitted 85 MMTCE (15 Tg) of methane (IPCC, 1995). EPA estimates that 1997 U.S. emissions were 33.5 MMTCE (5.8 Tg) from natural gas systems and 1.6 MMTCE (0.27 Tg) from oil systems (EPA, 1999). EPA expects emissions from oil systems to remain near 1997 levels through 2020. The baseline emission forecast is 38.8 MMTCE (6.8 Tg) from natural gas systems in 2020 (Exhibit 1-4). The increase results from higher consumption of natural gas and expansions of the natural gas system.

Biomass Burning. Biomass burning releases greenhouse gases, including methane, but is not a major source of U.S. methane emissions. In 1994, biomass burning produced 230 MMTCE (40 Tg) of methane worldwide (IPCC, 1995). EPA estimates that U.S. emissions from this source were 0.2 MMTCE (0.03 Tg) in 1997 and that emissions will remain stable through 2020 (EPA, 1999).

Landfills. Landfill methane is produced when organic materials are decomposed by bacteria under anaerobic conditions. In 1994, landfills produced 230 MMTCE (40 Tg) of methane worldwide (IPCC, 1995). EPA estimates that U.S. emissions from this source were 66.7 MMTCE (11.6 Tg) in 1997 (EPA, 1999). The baseline forecast is 41.1 MMTCE (7.2 Tg) from U.S. landfills in 2020 (Exhibit 1-4). Landfill methane is the only U.S. source that is expected to decline in the baseline over the forecast period. This decline is due to the implementation of the New Source Performance Standards and Emissions Guidelines (the Landfill Rule) under the Clean Air Act (March 1996). While the Landfill Rule controls greenhouse gas emissions that form tropospheric ozone (smog), it also will lead to lower methane emissions. The Landfill Rule requires large landfills to collect and combust or use landfill gas emissions.

Coal Mining. Methane is trapped within coal seams and the surrounding rock strata and is released during coal mining. Because methane is explosive in low concentrations, underground mines install ventilation systems to vent methane directly to the atmosphere. In 1994, coal mining produced 170 MMTCE (30 Tg) of methane worldwide (IPCC, 1995). EPA estimates that U.S. emissions from this source were 18.8 MMTCE