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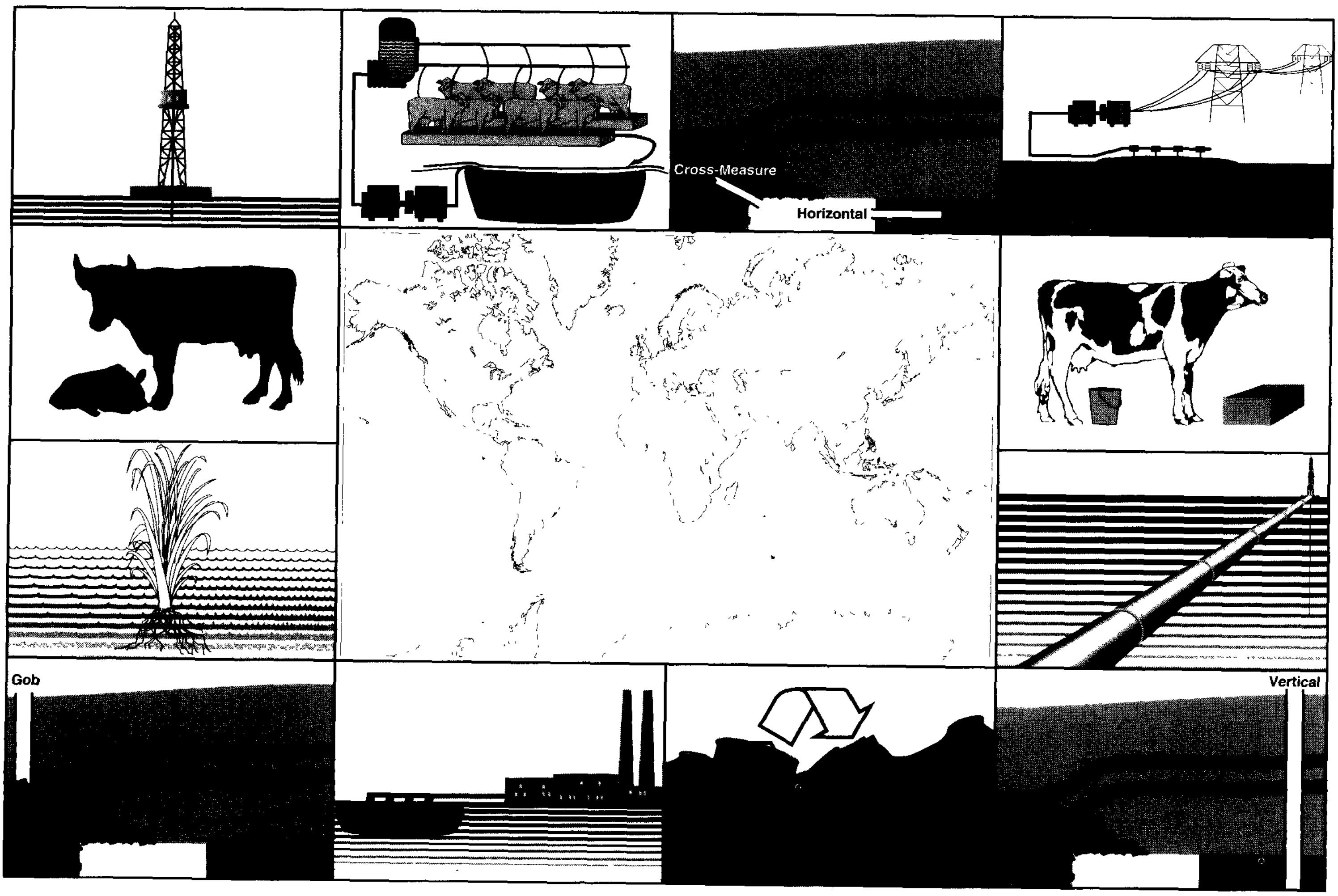
Options for Reducing Methane Emissions Internationally

Volume II: International Opportunities for Reducing Methane Emissions

Report to Congress



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Options for Reducing Methane Emissions Internationally

Volume II:

International Opportunities for Reducing Methane Emissions

Report to Congress

Editor: Kathleen B. Hogan

U.S. Environmental Protection Agency
Office of Air and Radiation

October 1993

Disclaimer

Table of Contents

VOLUME II

List of Exhibits

EXECUTIVE SUMMARY

CHAPTER ONE

CHAPTER TWO

Foreword

I am pleased to transmit the attached report, Options for Reducing Methane Emissions Internationally, Volume II: International Opportunities for Reducing Methane Emissions, in partial fulfillment of the Congressional request in the Clean Air Act Amendments of 1990 for a series of methane-related reports. This report builds on a companion report (Volume I) which describes an array of technologies and practices which are currently available and well understood and which can profitably reduce methane emissions into the atmosphere.

This report presents a number of key case studies and investigates how methane-reducing technologies and practices could be employed in a more widespread manner around the globe. The report assesses the most appropriate technologies for use in different settings and the types of programs which may be most effective in accelerating their adoption. The report shows how methane emissions can be reduced as part of the efforts of many countries to stabilize their emissions of greenhouse gases.

The report will make a large international contribution in addition to providing up-to-date information to Congress. The report will be presented to Working Group II of the Intergovernmental Panel on Climate Change (IPCC) for their consideration in furthering the international understanding of options for reducing greenhouse gas emissions.

Paul M. Stolpman
Acting Director
Office of Atmospheric Programs
Office of Air and Radiation

Acknowledgements

This report was made possible through the intensive efforts of a number of people.

As a direct result of prefeasibility studies conducted in countries around the world, the chapters of this report were developed by Global Change Division staff as follows:

Natural Gas Systems	Kathleen Hogan
Landfills	Cindy Jacobs
Coal Mining	Dina Kruger
Ruminant Livestock	Mark Orlic
Livestock Manure (Other Sources)	Kurt Roos

The staff specially designed these prefeasibility efforts to identify the most appropriate methane reducing technologies for particular situations, any barriers that might hamper the more widespread adoption of these technologies, and the potential solutions for overcoming these barriers.

A number of other experts participated in gathering key information for this report. This includes Carol Bibler (Raven Ridge Resources), Richard Bowman (AT International), Michael Gibbs (ICF), Ron Leng (Australia), James Marshall (Raven Ridge Resources), Ray Pilcher (Raven Ridge Resources), Al Sollod (Tufts University) and Gordon Weynand (USAID). Substantial efforts were made by Jeff Fiedler, Jeff Ross, Eric Taylor, and Laura Van Wie to synthesize the available information into the final chapters. Valuable comments on the report were received from Bill Breed (DOE), A.D. Bhide (India), David Gardiner (USEPA), Bill Hohenstein (USEPA), Susan Thorneloe (USEPA), Bill White (USEPA), and Ted Williams (DOE).

VOLUME II
EXECUTIVE SUMMARY

Introduction

Methane currently accounts for over 15 percent of expected future warming from climate change. While methane's concentration in the earth's atmosphere is small, it has a sizable contribution to potential future warming because it is a potent greenhouse gas and because methane's concentration in the atmosphere has been increasing rapidly. Its global atmospheric concentration, which continues to rise, has more than doubled over the last two centuries after remaining fairly constant for the preceding 2,000 years.

Methane's rising concentration is largely correlated with increasing human populations, and currently about 70 percent of global methane emissions are associated with human activities such as energy production and use (coal mining, oil and natural gas systems, and fossil fuel combustion); waste management (landfills and wastewater treatment); livestock management (ruminants and wastes); biomass burning; and rice cultivation.

Reductions in methane emissions of 30 to 40 million metric tons per year, or about 10 percent of annual anthropogenic (human-related) emissions, would halt the annual rise in methane concentrations. This report identifies technologies and practices which are currently available for profitably reducing methane emissions from the major human-related sources of methane and which are appropriate for many countries around the world. It also examines the potential for reducing methane emissions from some key countries through further adoption and use of these available technologies. This report has two volumes:

- **Volume I:** Technological Options for Reducing Methane Emissions. This volume was prepared in part for the Response Strategies Working Group of the Intergovernmental Panel on Climate Change (IPCC) by the U.S./Japan Working Group on Methane. The technology assessments were compiled from information and comments submitted by IPCC participating countries and have been reviewed by government officials and technical experts in these countries.

- **Volume II:** International Opportunities for Reducing Methane Emissions. This volume investigates the potential for applying or expanding the use of available technologies in key countries around the world, for the major methane sources. Key barriers inhibiting the further use of these technologies and practices are identified, and possible solutions, such as targeted technology transfer programs, are suggested.

The report has been prepared in response to a Congressional request under Section 603 of the Clean Air Act Amendments of 1990:

> **Preventing Increases in Methane Concentrations:** Not later than two years after the enactment of this Act, the Administrator shall prepare and submit to the Congress a report that analyzes the potential for preventing an increase in atmospheric concentrations of methane from activities and sources in other countries. Such report shall identify and evaluate the technical options for reducing methane emissions from each of the activities listed in subsection (b),

> as well as other activities or sources that are deemed by the Administrator in consultation with other relevant Federal agencies and departments to be significant and shall include an evaluation of the costs. The report shall identify the emission reductions that would need to be achieved to prevent increasing atmospheric concentrations of methane. The report shall also identify technology transfer programs that could promote methane emission reductions in lesser developed countries.[1]

Another report, Options for Reducing Methane Emissions from Anthropogenic Sources in the United States, was requested by Congress and is being prepared to examine the applicability of available options in the United States.

Volume II. International Opportunities For Reducing Methane Emissions

Many technologies and practices are currently available which can profitably reduce methane emissions from the major human-related sources including landfills, coal mining, natural gas production and distribution, and animal husbandry. These technologies and practices can profitably reduce methane emissions because methane (the major component of natural gas) emissions are often wasted energy which can be cost-effectively captured and used. The available technologies and practices are economically viable under a range of conditions and have already been implemented to some extent (as discussed in Volume I).

Furthermore, these technologies are generally attractive due to the many other benefits that they provide. These benefits include reduced risk of explosion and fire, improved air quality, better protection of surface and groundwater, enhanced animal productivity, and increased utilization of energy resources. These benefits are consistent with the development goals of many countries.

There are large opportunities to expand the use of these technologies and practices in different regions of the world. This volume summarizes the potential for expanding the use of the available technologies and practices in some key countries, in terms of:

Promising Technologies and Practices: Although there are a range of technologies and practices that are currently available, there are important country specific factors that may limit the applicability of some of them. This volume identifies which among the available technologies and practices are the most promising options for many of the countries which currently emit substantial quantities of methane. The technologies and practices which are identified in this volume are promising candidates for commercially viable projects and for forming the basis of programs which could substantially enhance the productivity of existing industries.

Possible Emission Reductions: Estimating the potential reductions in methane emissions which may result from the implementation of these technologies and practices is a very uncertain process. The uncertainty results both from uncertainty in the initial estimates of methane emissions from particular facilities and practices and from uncertainty in the effectiveness of technologies and alternative practices in reducing methane emissions

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1 Section 603(c)(2) of the Clean Air Act Amendments of 1990.

when applied at particular sites. However, the general understanding of the effectiveness of various technologies and practices has advanced substantially over the last several years. This volume uses up-to-date information to provide estimates of the reductions in methane emissions that may be achieved through the more widespread use of available technologies and practices. These estimates are provided for reductions in methane emissions that may be achieved in the near term and the reductions that may be achieved over the longer term. The near term reductions are those achievable over the next five to ten years, as technologies and practices which are currently available, economically viable in certain conditions, and generally consistent with country objectives and markets, are employed to a greater extent at appropriate sites. The longer term reductions are those which could be achieved profitably with available technologies but may require changes in institutional, market, or technological conditions.

Activities Likely to Promote Technologies and Practices: While the available technologies and practices may be profitable at particular sites and facilities and will help meet the energy and/or agricultural development goals of a country, there are often a range of barriers which are hindering their more widespread use. This volume identifies many of these barriers and suggests activities which may be effective in overcoming them, based on recent program development experience. Possible activities include the development of targeted technology transfer programs for demonstrating economically viable technologies and practices, the design of training programs necessary to support the technologies and practices, and the development of institutional support, among others. This volume also presents preliminary cost estimates for these types of technology transfer activities. Many of the initial activities would also lead to better estimates of methane emissions and potential reductions in emissions as prefeasibility studies are begun for individual projects.

This volume examines the opportunities to expand the use of available technologies and practices in different regions of the world for the following methane sources:

- Landfills;
- Oil and Natural Gas Systems;
- Coal Mining; and
- Ruminant Livestock.

These sources represent about 60 percent of methane emissions from anthropogenic sources world-wide. The general findings of this report for these sources are summarized below.

Landfills

Landfills worldwide are estimated to produce 20 to 60 teragrams (Tg)[2] of methane per year, as a direct result of the natural decomposition of the organic component of waste streams. About two-thirds of these emissions are estimated to come from the more developed

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2 1 teragram (Tg) is equivalent to 10^{12} grams or 1 million metric tons.

countries of the world, with eleven countries currently representing about 70 percent of global emissions. The United States is by far the largest emitter, followed by the People's Republic of China, Canada, Germany, the United Kingdom, and the Commonwealth of Independent States (CIS). The relative contribution of the developing countries is rapidly changing, however. With continuing trends in population growth and urbanization, developing countries could account for 30 to 40 percent of methane emissions from this source by 2000. In addition, economic growth may increase emissions from non-OECD countries.

Landfilling of wastes presents an opportunity for large reductions in methane emissions in many countries around the world while also presenting opportunities for (1) the generation of inexpensive domestic energy through energy recovery projects or (2) for the production of useful products such as fertilizer through composting and recycling efforts. For example, between 50 and 85 percent of landfill gas (generally about 50 percent methane) can typically be recovered from covered landfills, with well-designed projects achieving almost complete gas recovery (see Volume I). This gas can be profitably used as a medium quality fuel in many applications, including electricity generation and co-generation, industrial uses, and residential and commercial cooking and heating.

Although these options are already in use, to some extent, in both developed and developing countries, there are substantial opportunities to expand their use worldwide. For example, there are large opportunities for expanding existing methane recovery programs in countries such as the United States and the United Kingdom. Emissions in these two countries could be reduced by 50 percent or more over the next decades through efforts justified by the economics of the energy recovery and reductions in emissions of air pollutants.

There is also potential to expand the existing methane recovery program in Brazil and to promote appropriate technologies and practices in regions such as the CIS and Eastern Europe, and in developing countries such as India and China where limited quantities of methane are currently recovered. Recycling of organic materials, composting, and incineration may also be large components of waste management programs over the coming decades and will result in less landfilled waste and lower methane emissions. In general, many countries are interested in the further expansion of these waste management practices because of their associated benefits, which include: potential for significant energy recovery; reduced public health hazards; reduced surface and groundwater pollution and air emissions; and the production of compost material for use as fertilizer or soil amendments.

Based on currently available technologies, it is technically feasible to reduce annual methane emissions from landfills globally by about 50 percent of current emissions or by more than 10 to 25 Tg per year. Not all of these reductions in methane emissions will be economically viable, however. Estimates of the potential for economically viable emission reductions are uncertain, and they depend upon the country and site-specific conditions of particular projects. In general, economically attractive emission reductions are most common at larger waste disposal sites located close to large urbanized areas, where the potential for recovering and using large quantities of methane are most likely. Fortunately, in many countries these types of sites represent the majority of methane emissions.

The portion of the technically achievable methane reductions that may be economically viable has been estimated by examining waste management practices in several key countries, such as Brazil, India, Poland, the United Kingdom and the United States. The estimated potential economically viable reductions for these countries are presented in Exhibit ES-1. This exhibit also presents estimates for potential reductions that may be achieved in countries that were not examined explicitly; these estimates were derived by generally assuming that their waste management practices are similar to other countries in their regions. Exhibit ES-1 shows that global reductions in methane emissions of 9 to 14 Tg per year could be economically viable in the near term. In the United States, an impending landfill rule is expected to reduce emissions from landfills on the order of 50 percent, or 4 to 6 Tg per year.[3] Global emission reductions of 10 to 25 Tg per year may be feasible in the longer term, with even larger

Exhibit ES-1
Estimates of Economically Viable Reductions in Methane Emissions from Landfilling Waste

Country	Estimated Emissions (Tg/yr)[1]	Near Term Reductions		Longer Term Reductions	
		Tg/yr	%	Tg/yr	%
United States[2]	8 - 12	4 - 6	~ 50	4 - 6	~ 50
United Kingdom	1.0 - 3.0	0.2 - 0.5	15 - 20	0.5 - 1.4	40 - 50
Brazil	0.7 - 2.2	0.2 - 0.6	25 - 30	0.2 - 0.6	25 - 30
India	0.2 - 0.8	0.1 - 0.2	25 - 40	0.1 - 0.4	25 - 50
Poland	0.1 - 0.4	0.1	~ 20	0.1 - 0.3	20 - 60
Others	11 - 39	4 - 7	15 - 35	4 - 15	15 - 40
TOTAL[3]	21 - 57	9 - 14	25 - 35	9 - 24	40 - 50

1 These emissions estimates are based on recent drafts of the report to Congress *Global Anthropogenic Emissions of Methane* (USEPA, 1993b), currently in preparation, and will likely change as this report is finalized.
2 USEPA, 1993a
3 Totals may not add up due to rounding.

potential for methane reductions over the next several decades as lower cost technologies are developed.

A number of barriers to the expanded use of improved waste management practices and methane recovery and utilization technologies must be overcome if the economically viable emissions reductions are to be achieved in many countries. The general types of barriers are summarized in Exhibit ES-2, and they include technical, financial, management and informational barriers, among others. In addition, Exhibit ES-2 summarizes some of the possible responses to these barriers.

3 This rule will be promulgated to reduce emissions of air pollutants such as toxics and non-methane organic compounds from landfills. Methane will be reduced as a side-benefit.

Exhibit ES-2
Key Barriers and Possible Responses for Landfills

Key Barriers	Possible Responses
Policy & Management Issues · Unclear legal and regulatory framework · Many different groups responsible for different parts of waste management · Different groups responsible for waste management, energy generation, and fertilizer supply	· Policy reform assistance · Organize management groups overseeing all elements of waste management · Organize joint management groups for waste management and energy development · Organize joint management groups for waste management and fertilizer supply
Information Issues · Lack of awareness on part of government and others about value of fuel and fertilizer from managed wastes · Lack of awareness on part of potential project developers about potential in various countries	· Provide information on potential near-term value of resource and available technologies. · Provide information to potential project developers and lending agencies regarding role waste management projects can play in meeting country goals
Technical Issues · Lack of access by waste managers to technologies such as drills, composters, and sorters · Lack of familiarity with methane recovery and source reduction techniques · Lack of familiarity with power generation technologies · Technical problems related to the corrosiveness of landfill gas	· Encourage joint ventures and the introduction of new technologies · Establish technology demonstration projects to act as training centers · Establish technology centers to provide information on appropriate technologies and techniques · Disseminate available information on best technologies and maintenance practices for addressing corrosion
Financial Issues · Lack of capital for investment · Subsidized energy prices for other energy sources reduce attractiveness	· Raise awareness on profitability of landfill projects with development agencies · Raise awareness on appropriateness of landfill projects for international loans · Assess financial needs for providing more efficient waste management overall

Effectively encouraging economically viable methane reductions in individual countries will require examination of a country's specific conditions and unique barriers. Using such assessment information, specific programs and projects can be developed to overcome the barriers. Some preliminary analyses of country-specific barriers and most appropriate responses to them have been conducted for selected countries, as summarized in Exhibit ES-3. This exhibit includes information about the actions that may be taken in countries such as the United States as well as outlining possible technology transfer programs for developing countries and countries with economies in transition. Importantly, as efforts continue in this area a better understanding will develop for the potential for reducing methane emissions from landfilling of wastes worldwide and the types of technology transfer programs that will be most effective in response to specific country conditions.

Exhibit ES-3
Projects/Programs for Reducing Methane Emissions from Landfills

Country	Estimated Emissions (Tg/yr)[1]	Promising Technologies & Practices	Possible Activities
United States	8 - 12	· Energy recovery where economically viable · Landfill gas recovery and flaring where appropriate to control air pollutant emissions · Recycling programs	· Regulation to control air pollutant emissions from landfills · Technology/Information Outreach Program
United Kingdom	1.0 - 3.0	· Energy recovery where economically viable · Recycling programs	· Regulatory framework to encourage gas recovery/utilization, alternative practices · Research and development
Brazil	0.7 - 2.2	· Energy recovery where economically viable · Recycling programs	· Technology demonstration · Technical assistance and training
India	0.2 - 0.8	· Energy recovery where economically viable · Recycling programs	· Technology demonstration · Technical assistance and training
Poland	0.1 - 0.4	· Energy recovery where economically viable · Recycling programs	· Technology demonstration · Technical assistance and training
Others	11 - 39	To be determined	To be determined
Near-term Global Reductions	10 - 15		
Longer-term Global Reductions	10 - 25		

1 These emissions estimates are based on recent drafts of the report to Congress *Global Anthropogenic Emissions of Methane* (USEPA, 1993b), currently in preparation, and will likely change as this report is finalized.

Oil and Natural Gas Systems

Significant methane emissions are associated with the various components of oil and natural gas systems, such as production wells, processing and storage facilities, and transmission and distribution systems. Emissions generally include fugitive emissions (leakage) and emissions during routine operations and maintenance of the systems, as well as emissions from unplanned events or system upsets. Estimates for worldwide methane emissions from this source range from about 30 to 65 Tg per year.[4] The countries that are the largest contributors of these emissions are the countries with the largest production and use of natural gas, the Commonwealth of Independent States (CIS) and the United States. These two countries represent over two-thirds of global emissions from this source.

Technological solutions are available to reduce methane emissions from different components of oil and natural gas systems. These technological solutions include reduced venting and flaring during production, improved compressor operation, enhanced leak detection and pipeline repair, and greater use of low emission technologies and practices. They can be accomplished through the replacement of existing equipment with equipment of newer design, improved rehabilitation and repair, enhanced inspection and maintenance, and other changes in routine operations. Use of these technologies and practices can reduce methane emissions at particular sites by up to 20 to 80 percent (see Volume I). These efforts can also result in other important benefits to natural gas systems such as enhanced overall efficiency and economics, improved safety of the system, and improved local air quality.

While these technologies and practices are already in use to varying degrees throughout the world, there is substantial opportunity to expand the use of these options. In the United States, for example, methane emissions can be profitably reduced by about 20 percent or more through the use of recently available technologies and practices.[5] However, there are much larger opportunities in other regions of the world such as the CIS, where lack of equipment and capital has hindered the introduction of newer technologies. In addition, the venting and flaring of natural gas during production can be reduced in many regions as countries continue to expand their gas infrastructures which will allow more vented and flared gas to be utilized.

Based on currently available technologies, it is technically feasible to reduce annual methane emissions from oil and natural gas systems by about 60 percent of current emissions or by roughly 15 to 40 Tg per year. Estimating the portion of these reductions that may be economically viable is highly uncertain and requires assessment of country and site-specific conditions for numerous individual projects. In general, however, economically attractive emission reductions will be most common where old, out-dated, or difficult to maintain equipment is being utilized to handle large quantities of natural gas. The largest opportunity is likely to be in Russia which is the largest gas producer in the world and which has

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4 It is estimated that 70 to 80 percent of this total is emitted from natural gas systems worldwide, and 20 to 30 percent from oil systems (including associated gas production).

5 See Report to Congress, *Opportunities to Reduce Methane Emissions in the United States* (USEPA, 1993a).

developed much of its natural gas system under adverse environmental conditions and with equipment shortages.

The portion of the technically achievable methane reductions that may be economically viable has been estimated by examining the natural gas systems in the United States and CIS. The estimated potential economically viable reductions for these countries are presented in Exhibit ES-4. This exhibit also presents estimates for potential reductions that may be achieved in countries that were not examined explicitly; these estimates were derived by assuming, conservatively, that technologies and practices in their natural gas systems are similar to the system in the United States. Exhibit ES-4 shows that global reductions in methane emissions of 5 to 15 Tg per year could be economically viable in the near term. A large portion of these reductions would be achieved in the CIS through high-impact projects such as pipeline leak prevention and rehabilitation. Other reductions would be achieved through continuing technological improvements in the West. Economically viable emissions reductions of 10 to 35 Tg per year may be achieved in the longer term as a wider range of more efficient technologies and practices are introduced, including drilling and well maintenance practices, gas processing technologies, metering, and end use equipment, as well as increased use of associated gas.

Exhibit ES-4
Estimates of Economically Viable Reductions in Methane Emissions from Oil and Natural Gas Systems

Country	Estimated Emissions in 1990 (Tg/yr)[a]	Near Term Reductions		Longer Term Reductions	
		Tg/yr	%	Tg/yr	%
CIS	16 - 36	3 - 10	20 - 30	5 - 25	30 - 70
US	2.4 - 5.3	0.3 - 1.2[b]	13 - 23[b]	0.3 - 1.3[b]	13 - 25[b]
Others	14.5 - 27.0	1 - 5	10 - 20	2 - 8	20 - 30
TOTAL	33 - 68	4 - 16	12 - 24	7 - 34	21 - 50

Sources:
a USEPA (1993b)
b USEPA (1993a)

A number of barriers to the expanded use of low emission technologies and practices for natural gas systems must be overcome if the economically viable emissions reductions are to be achieved. The general types of barriers hindering technological improvements in these systems are summarized in Exhibit ES-5, and they include legal, regulatory, technical, financial, and informational barriers, among others. In addition, Exhibit ES-5 summarizes some of the possible responses to these barriers.

Effectively encouraging economically viable methane reductions in individual countries will require examination of a country's specific conditions and unique barriers. Using such assessment information, specific programs and projects can be developed to overcome these barriers. Preliminary analyses of country-specific barriers and appropriate responses to them have been conducted for the United States and Russia, as shown in Exhibit ES-6. Currently there are a number of efforts through the World Bank, International Monetary Fund, and others to assist in rehabilitating the Russian natural gas system and improve venting and flaring practices. These efforts combined with key demonstration programs should greatly increase the understanding of the potential for profitably reducing methane emissions. The U.S. EPA is also working with the U.S. gas industry to encourage economically viable reductions domestically.

Exhibit ES-5
Key Barriers and Possible Responses for Oil and Natural Gas Systems

Key Barriers	Possible Responses
Legal & Regulatory Issues · Uncertain gas ownership · Unclear mechanisms for joint venture project development · Project approval process unclear	· Resolve ownership legally or legislatively · Develop system for foreign investment, repatriation of profits, etc. · Streamline and clarify project approval process
Information Issues · Lack of awareness on part of government and gas industry personnel about magnitude and value of emissions reductions · Lack of awareness on part of potential project developers about project opportunities in various countries	· Provide information to countries on emissions, reduction options, and appropriate policies · Provide information to oil and gas companies and lending agencies, regarding potential for profitable projects
Technical Issues · Lack of access to existing technologies such as low bleed valves, measurement techniques, and processing technologies · Lack of familiarity with maintenance procedures, such as wellhead work-overs · Lack of familiarity with pipeline repair and control technologies, such as polyethylene pipe replacement	· Fund demonstration projects in key technical areas · Organize study tours and training trips for key gas industry personnel · Establish technology centers to disseminate information on state-of-the-art technologies and techniques
Financial Issues · Lack of capital for investment in methane recovery projects · Dependence of gas organizations on subsidies · Low subsidized energy prices reduce economic attractiveness · Absence of economic incentives to become efficient	· Encourage the development of joint ventures to introduce new approaches · Foster free market pricing of gas at all stages of the system · Introduce cost accounting of lost gas; economic incentives for recovery

Exhibit ES-6
Projects/Programs for Reducing Methane Emissions from Oil and Natural Gas Systems

Country	Estimated Emissions (Tg/yr)	Promising Technologies & Practices	Possible Activities
United States	2.4 - 5.3	· Low-bleed pneumatic devices · Recovery of dehydrator emissions · Directed inspection/maintenance programs · Continued replacement/rehabilitation of "leaky" pipeline systems · Encourage use of turbines, where feasible · New technology demonstrations	· Voluntary emission reduction program with industry -- Natural Gas STAR
CIS	16 - 36	· Improved drilling and well maintenance practices · Increased gas processing capacity/capability · Improved system maintenance · Improved end-user and system energy efficiency · Improved gas metering/measurement	· Assess gas system -- technical and financial audit · Demonstrate new technologies and practices · Develop sources of domestic and foreign investment capital
Others	15 - 27	To be determined	To be determined
Near-term Global Reductions	4 - 16		
Longer-term Global Reductions	7 - 34		

Coal Mining

Coal mining activities are estimated to produce about 22 to 36 Tg per year of methane per year globally. This methane was trapped millions of years ago in the coal formations and surrounding strata during the process of coalification and is emitted as mining reduces the pressure on the trapped gas. Most of the methane emissions result from the mining of underground coal in the major coal-producing countries. The People's Republic of China, the United States, and the Commonwealth of Independent States (the former Soviet Union) account for an estimated 70 percent of the emissions from this source.

Coal mining represents a promising opportunity to reduce methane emissions worldwide, because of the availability of technologies to recover and use the methane emitted during mining and because of the many benefits associated with such projects. Available technologies for increasing methane recovery include enhanced gob well recovery and degasification of coal seams in advance of mining using vertical or in-mine recovery methods. When vertical pre-drainage is combined with in-mine recovery or the use of surface gob wells, potential methane recovery efficiencies can reach 75 percent (see Volume I). The recovered gas can then be used for power generation or for industrial and residential uses. In many countries, this coalbed methane could make a large contribution to the primary energy supply. In addition to the benefits of increasing the supply of a clean burning fuel and reducing methane emissions, such projects may also improve coal mine productivity and safety.

Recovery of coal mine methane is already performed, to some extent, in the major coal-producing countries. The degasification technologies have been employed by gassy underground coal mines to maintain safe mining conditions. However, much of the gas recovered at these operations is currently vented to the atmosphere, so there remain large opportunities to collect and use the gas. In addition, there are large opportunities for expanded methane recovery in many countries with large emissions from coal mining, such as the United States, the People's Republic of China, Russia, Ukraine, Poland and Czechoslovakia.

Based on currently available technologies, it is technically feasible to reduce annual methane emissions from coal mining globally by about 40 percent of current emissions (i.e., 50 percent of the emissions from gassy underground mines) or by about 10 to 16 Tg per year. While estimates of the potential for economically viable emission reductions are uncertain, and they depend upon the country and site-specific conditions of particular projects, a large portion of these reductions in methane emissions may be economically viable due to the large quantity of gas that can be produced from the gassy mining areas.

Economically viable reductions in methane emissions from coal mining were estimated by examining current mining and degasification practices in the major coal producing countries. As summarized in Exhibit ES-7, this examination indicates that economically viable reductions of up to 7.2 Tg per year may be potentially achievable in the near term by developing uses for currently recovered gas from coal mines, such as local heating or nearby industrial uses (contributing about 1.5 - 2.6 Tg per year of the reductions) and by expanding methane recovery and use, using existing technologies. Reductions of 7 to 11 Tg per year could be achieved in the longer term through more aggressive gas drainage practices, perhaps supplemented with the development of new technologies.

Exhibit ES-7
Estimates of Potential Economically Viable Reductions in Methane Emissions from Coal Mining

Country	Estimated Emissions (Tg/yr)	Near Term Reductions		Longer Term Reductions (Tg/yr)	
		Tg/yr[1]	%	Tg/yr	%
China	8.5 -13.0	1.2 - 1.6 (0.1)	10 - 15	2.8 - 3.4	25 - 35
United States	3.6 - 5.7	1.0 - 2.2 (0.4 - 1.5)	35 - 40	1.7 - 3.1	45 - 55
CIS[2]	4.3 - 5.8	0.7 - 1.1 (0.6)	10 - 20	1.0 - 1.4	20 - 25
Poland	0.6 - 1.5	0.1 - 0.3 (0.1)	15 - 20	0.2 - 0.4	25 - 35
Czechoslovakia	0.3 - 0.5	0.1 - 0.2	30 - 40	0.2 - 0.3	60 - 65
Others[3]	3.7 - 6.9	0.9 - 1.8 (0.2)	20 - 30	1.5 - 2.8	35 - 45
TOTAL	21.5 - 33.5	4.0 - 7.2 (1.5 - 2.6)	15 - 25	7.4 - 11.4	30 - 40

1 Emission reduction estimates in parentheses can be achieved by utilizing gas currently recovered and vented to the atmosphere.
2 Emissions estimates are for entire CIS; reductions estimates include Russia and Ukraine.
3 Emissions estimates include several important coal-producers, such as Australia, Germany, India, South Africa, and the United Kingdom.

A number of barriers to the expansion of methane recovery and utilization technologies must be overcome if the economically viable emissions reductions are to be achieved in many countries. The general types barriers are summarized in Exhibit ES-8, and they include technical, financial, management and informational barriers, among others. In addition, Exhibit ES-8 summarizes some of the possible responses to these barriers.

Effectively encouraging economically viable methane reductions in individual countries will require examination of a country's specific conditions and unique barriers. Using such assessment information, specific programs and projects can be developed to overcome these barriers. Some preliminary analyses of country-specific barriers and most appropriate responses to them have been conducted for the major coal-producing countries. The results of these analyses are summarized in Exhibit ES-9. This exhibit includes information about the actions that may be taken in countries such as the United States as well as outlining possible technology transfer programs for developing countries and countries with economies in transition. Many of these activities are well underway through a variety of U.S. programs, so better information on achievable methane reductions and the components of the most successful technology transfer programs can be expected over the next several years.

Ruminant Livestock

Domestic ruminant livestock, especially large ruminants (cattle and buffalo), produce methane emissions as part of their normal digestive processes. Global emissions from ruminant livestock are estimated to be 65 to 100 Tg per year, with about 80 percent of these emissions from the larger ruminants (i.e., cattle and buffalo). Roughly 20 percent of these emissions are from animals raised under highly managed conditions in the U.S. and Western Europe. As much as 30 percent of these emissions may come from developing countries in Asia. An estimated 15 percent of emissions are from Eastern Europe and the Commonwealth of Independent States (CIS) and about 30 to 35 percent from South America and Africa.

Exhibit ES-8
Key Barriers and Possible Responses for Coal Mining

Key Barriers	Possible Responses
Legal Systems: • Unclear gas ownership • Undeveloped concession system • Unclear mechanisms for joint venture project development	• Resolve ownership legally or legislatively • Develop resource leasing mechanisms • Develop system for foreign investment, repatriation of profits, etc.
Regulatory Issues: • Project approval process unclear • Appropriateness of mine safety regulations for gas recovery • No produced water regulations for CBM development • No specialized "field rules" for CBM development	• Streamline and clarify project approval/permit requirements • Determine how to incorporate gas recovery with mine safety regulations • Develop produced water regulations and industry "field rules" specific to CBM development
Information Issues: • Lack of awareness on part of government, mining personnel and others about magnitude and value of resource • Lack of awareness on part of potential project developers regarding project opportunities in various countries	• Provide information to countries on resource, appropriate policies, technologies, etc. • Provide information to development companies and lending agencies regarding potential attractiveness of projects
Technical Issues: • Lack of access to new technologies, such as advanced drill rigs, reservoir simulators, etc. • Lack of familiarity with new methane recovery approaches, such as vertical pre-mine drainage or in-mine fracturing of longholes • Lack of familiarity with new methane utilization technologies, such as power generation • Need to demonstrate utilization options for low-concentration methane in ventilation air	• Encourage the development of joint ventures to introduce new approaches • Fund demonstration projects in key technical areas • Organize study tours and training trips for key personnel to advanced CBM projects • Establish technology centers to disseminate information on appropriate technologies and techniques
Financial Issues: • Lack of capital for investment in methane recovery projects • Poor financial condition of coal mines and historic dependence on heavy subsidies • Low subsidized energy prices reduce economic attractiveness	• Foster joint ventures • Raise awareness on part of international development agencies about coalbed methane potential • Encourage development of methane recovery and use projects that can improve coal productivity and mining economics

Exhibit ES-9
Projects/Programs for Reducing Methane Emissions from Coal Mining

Country	Estimated Emissions (Tg/yr)	Promising Technologies & Practices	Possible Activities
China	8.5 - 13.0	· Improved pre-mining degasification and gobwell recovery · Expanded utilization through pipeline injection, power generation, and direct use	· Development of appropriate policies and comprehensive plans · Demonstration and technology transfer · Training and technical assistance · Information dissemination through in-country coalbed methane clearinghouse
CIS	4.3 - 5.8	· Expanded degasification using vertical or gob methods · Improved utilization through power generation, direct use, or pipeline injection	· Development of appropriate policy framework · Technology transfer and demonstration · Technical assistance and training · Information dissemination through in-country coalbed methane clearinghouse
United States	3.6 - 5.7	· Expanded degasification using vertical pre-drainage · Improved utilization through pipeline injection, or power generation	· Removal of legal and regulatory barriers · Information dissemination · Demonstration of key technologies such as gas enrichment
Poland	0.6 - 1.5	· Introduction of vertical degasification technologies and possibly surface gob recovery · Expanded gas utilization technologies of all types, including ventilation air use	· Technology transfer and joint venture project development · Technical assistance and training · Information dissemination through in-country coalbed methane clearinghouse
Czechoslovakia	0.3 - 0.5	· Introduction of vertical pre-drainage and possibly surface gob recovery · Expanded gas utilization technologies of all types, including ventilation air use	· Technology transfer and joint venture project development · Technical assistance and training · Demonstration of ventilation air use and gas enrichment
Others	5.5 - 9.5	To be determined	To be determined
Near-term Global Reductions	4 - 7		
Longer-term Global Reductions	7 - 11		

A number of proven technologies and practices exist for reducing methane emissions from ruminant animals. These technologies and practices improve animal productivity and thus reduce methane emissions per unit of product (e.g., milk produced), or per unit of feed that is consumed. Available options include: improving animal nutrition through enhanced feed processing; improving nutrition by strategically supplementing current diets to address known deficiencies; improving genetic characteristics; and improving animal reproduction. These techniques have resulted in reductions in methane production per unit product of up to 60 percent, as well as significant increases in productivity, especially milk production (see Volume I). Other benefits related to increased productivity include improved human diets, increased animal health, increased farmer security, and reduced need for the importation of animal products.

Increasing the productivity of large ruminant animals is economically and technically feasible in many countries. For example, there continue to be opportunities to increase animal productivity in the advanced animal production systems in North America and Western Europe. While these systems have generally achieved low methane emissions per unit product through management techniques developed over the last fifty years, a number of practices remain to be implemented on a more widespread basis.

The largest opportunities for reducing methane emissions from large ruminant animals, however, may be found in developing countries. In these countries, animals have not experienced large changes in productivity over the preceding decades and increased demand for animal products has been met by increasing the number of managed animals. Currently, dairy herds present a large opportunity for productivity improvement programs in these countries because the increased production of milk is a quickly and easily seen improvement and the additional milk may be sold in cash markets. Furthermore, many of these countries are striving to increase milk production to increase in turn the amount of protein in their people's diets. Simultaneously, land is becoming more scarce and the past approach of increasing the number of managed animals is becoming less feasible.

Opportunities for the expansion of projects and programs which enhance animal productivity cost-effectively appear to exist throughout the developing world. This report examines Bangladesh, China, and India to assess the opportunities in southeast Asia; examines Tanzania to assess the opportunities in Africa; and takes a regional look at Eastern Europe and the Commonwealth of Independent States (CIS).

Through efforts focused first on improving the productivity of dairy animals and then expanded to include programs focussing on draft animals, it is estimated that currently available technologies and management practices can cost-effectively reduce overall methane emissions by about 4 to 10 Tg per year in the near term. These estimates of possible reductions assume that animal populations will continue to grow to some extent over the next decades to meet country development goals. However, more and more of the increased production of animal products will result from increased animal productivity as opposed to increased number of animals. Global methane reductions of 10 to 19 Tg per year may be possible over the longer term through aggressive programs to increase animal productivity and animal health in general. Exhibit ES-10 summarizes the estimated emissions and potential emission reductions for large ruminants (i.e., cattle and buffalo).

Exhibit ES-10
Estimates of Potential Economically viable Reductions in Methane Emissions from Cattle and Buffalo

Country	Estimated Emissions (Tg/yr)[1]	Near Term Reductions (Tg/yr)		Longer Term Reductions (Tg/yr)	
		Tg/yr	%	Tg/yr	%
CIS/E.Europe	7.5 - 12.5	up to 1	5 - 10	over 1	5 - 15
India	7.2 - 12.0	0.8 - 1.2	5 - 10	1.2 - 2.5	15 - 20
United States[2]	4.4 - 6.6	up to 1	~ 25	over 1	~ 25
China	3.5 - 5.9	0.5 - 0.7	10 - 15	0.7 - 1.5	20 - 25
Bangladesh	0.6 - 1.2	0.1	10 - 15	0.2 - 0.3	25 - 30
Tanzania	0.4 - 0.6	0.1	15 - 20	0.1 - 0.2	25 - 35
Others	38 - 62	2 - 6	5 - 10	6 - 12	15 - 20
TOTAL	50 - 82	4 - 10	~ 10	10 - 19	20 - 25

1 These estimates are for cattle and buffalo only.
2 Estimates being developed in USEPA (1993a), "Options for Reducing Methane Emissions in the United States."

Recent efforts to investigate animal management practices in countries with large animal populations indicate that various barriers may exist in different countries which hinder the full implementation of efforts to improve animal productivity. These barriers, including informational, technical, sociocultural and financial issues, are summarized in a general manner in Exhibit ES-11 along with possible responses which may promote methane reductions.

Examination of the unique barriers within a country as well as other country specific conditions will be necessary to effectively encourage economically viable methane reductions. Using such assessment information, specific programs and projects can be developed to overcome the critical barriers. Preliminary analyses of some country-specific barriers and most appropriate responses to them have been conducted for selected countries. The results of these analyses are summarized in Exhibit ES-12. This exhibit includes information on the actions that may be taken in the United States as well as on technology transfer programs for developing countries and countries with economies in transition. Some of this information will be expanded and refined over the next several years as the success of activities which have recently been initiated is monitored.

Other Sources

In many countries, potential may exist to reduce methane emissions from additional sources of methane, including livestock manure, wastewater management, rice cultivation, biomass burning, and fossil fuel combustion. Current estimates of methane emissions from these sources worldwide range from about 70 to 200 Tg per year. A number of technically and economically feasible options have been identified to reduce emissions from some of these sources. Options for the other sources are being researched, developed, and demonstrated, and should be available in the future.

Exhibit ES-11
Key Barriers and Possible Responses for Ruminant Livestock

Key Barriers	Possible Responses
Information Issues • Lack of knowledge about ruminant methane and animal productivity on part of government officials, extension personnel, and producers • Institutional capabilities are weak at the extension level • Appropriate literature is lacking for farmers with varying levels of literacy • Lack of awareness of potential production benefits on part of funding agencies	• Provide information to countries on potential benefits, resources, appropriate policies, technologies, etc. • Provide information to international development and lending agencies about benefits of ruminant methane reduction efforts • Conduct training of extension personnel • Develop range of texts for farmers
Technical Issues • Access to remote, small-scale farms is difficult • Limited infrastructure for development, production, and dissemination of technologies • Limited availability of land for production of improved forages and feed supplement inputs • Inadequate field-testing of technologies; past problems of improper application • Supplement formulation often does not address specific deficiencies • Genetic improvement of production is hampered by poor nutrition	• Improve extension services through training, increased mobility, and closer contact with producers • Match technologies to existing infrastructure and level of development within region • Maximize efficient use of existing resources, including agro-industrial byproducts, crop residues, and marginal land cultivation • Ensure field testing, and proper use of technologies • Conduct forage analyses as part of project assessments to determine nutritional imbalances
Sociocultural Issues • In many cultures, numbers of animals are more important than liveweight • Religious and cultural factors may prohibit slaughter of animals • Extension programs may facilitate communication with men, but overlook women's important roles in livestock management	• The role of women should be addressed directly in project development • Maintain an awareness of sociocultural factors and their impact on project development
Financial Issues • Lack of capital for investment in feed processing facilities and other infrastructure and resource improvements • Livestock traditionally kept for savings and security, not production; reduced incentive for increasing productivity • Direct economic incentives lacking for draft animals • Artificially low milk prices	• Raise awareness on part of international development agencies and other sources of capital • Encourage development of economically feasible projects; emphasize economic sustainability • Use multi-purpose animals to increase value of animals • Inform farmers of benefits of managing animals for increased production; develop markets

Exhibit ES-12
Projects/Programs for Reducing Methane Emissions from Ruminant Livestock

Country	Estimated Emissions (Tg/yr)	Promising Technologies & Practices	Possible Activities
CIS/Eastern Europe	7.5 - 12.5	· Nutrient supplements · Productivity enhancing Agents · Improved reproductive methods	· Further study to identify appropriate technologies
India	7.2 - 12.0	· MUBs · Feed Processing	· Policy support · Project planning and evaluation · Technology transfer and demonstration · Enhanced training and extension services
United States	4.4 - 6.6	· Continued efficiency gains	· Beef and milk marketing · Improved reproduction/genetics · *Production enhancing agents* · Targetted mineral/protein supplements
China	3.5 - 5.9	· Urea treated straws · Cultivation of improved forages	· Policy support · Project planning and evaluation · Technology transfer and demonstration · Enhanced training and extension services · Development of markets for ruminant livestock products
Bangladesh	0.6 - 1.2	· MUBs · Cultivation of improved forages	· Promote dissemination of appropriate methods · Initiate demonstration projects
Tanzania	0.4 - 0.6	· Increase efficiency of food utilization	· Enhanced training and extension services
Others	38 - 62	To be determined	To be determined
Near-term Global Reductions	4 - 10 Tg/yr		
Longer-term Global Reductions	10 - 19 Tg/yr		

Summary

While substantial uncertainty exists in estimates of methane emissions from the major sources and the potential for reducing these emissions through economically viable projects and programs, it is clear that there are a number of economically viable opportunities to reduce methane emissions from these sources in countries around the world. In addition, there are important accompanying benefits which often make options attractive for reasons other than the reductions in methane emissions that may be achieved.

Based on a variety of analyses discussed in this report, it may be possible to employ existing technologies and practices and cost-effectively reduce methane emissions from landfills, oil and natural gas systems, coal mining, and ruminant livestock by about 23 to 47 Tg per year over the next 5 to 10 years. These reductions represent about 5 to 15 percent of current anthropogenic emissions, or 4 to 10 percent of total global methane emissions. Emissions reductions of about 37 to 90 Tg per year (10 to 25 percent of current anthropogenic emissions) may be possible in the longer term. Estimates of potential methane reductions from these emission sources worldwide are summarized in Exhibit ES-13. Estimated potential reductions from other methane sources require further investigation and are not included in this report.

Exhibit ES-13
Estimates of Potential Global Methane Emission Reductions

Source	Near-term Reductions (Tg/yr)	Longer term Reductions (Tg/yr)
Landfills	10 to 15	10 to 25
Oil and Natural Gas Systems	5 to 15	10 to 35
Coal Mining	4 to 7	7 to 11
Ruminant Livestock	4 to 10	10 to 19
Other Sources[1]	?	?
TOTAL	23 to 47	37 to 90

[1] Includes livestock manure, wastewater management, rice cultivation, biomass burning, and fossil fuel combustion.

The possible near term reductions in annual emissions of 23 to 47 Tg per year are a large part of the 30 to 40 Tg per year reduction required to stabilize atmospheric methane concentrations. The possible longer term reduction could provide all of this amount, as well as largely compensate for any emissions growth expected from these methane sources.

Importantly, the existence of economically viable technologies and practices alone will not necessarily lead to the implementation of projects to reduce methane emissions. There are numerous barriers that have been identified which can greatly inhibit the adoption of economically viable technologies and practices. Assessment of the key barriers within a particular country and the development of projects and programs to overcome these barriers will require well designed efforts performed in cooperation with appropriate country officials and experts to compile site specific project information. These efforts will include

- screening and scoping studies to identify the best opportunities for economically viable projects and to highlight the means for overcoming the most important barriers;
- prefeasibility and feasibility analyses for individual projects;
- technology demonstration and pilot projects; and
- institution building in the form of information clearinghouses and training programs;

These efforts will lead to commercialization of economically viable technologies and practices as well as provide a large amount of information useful to U.S. industries. In addition, these efforts will greatly refine our understanding of methane emissions and opportunities for economically viable reductions.

The costs for carrying out these activities will vary greatly from country to country depending upon the area of work, the current state of development, interest by potential investors, etc. These costs have been generally estimated for some of the key countries and are presented in Exhibit ES-14. This exhibit shows that for a cost of about $500,000 to $3,000,000 per country, major progress would be made toward achieving the potential economically viable methane reductions.

There are a variety of funding sources available to finance projects that result in economically attractive methane emissions reductions. International sources include the World Bank., the United Nations Development Program and regional development banks. In addition, the Global Environmental Facility Fund, which is implemented by the World Bank and the UNDP, is dedicated to funding global environmental projects including the reduction of greenhouse gases. U.S. Government sources include programs implemented by the U.S. Agency for International Development, the State Department, and other agencies. These programs support economic development and U.S. business opportunities abroad. The U.S. government also offers technical and financial assistance to developing countries through its Country Studies program, with the aim of improving greenhouse gas inventories and identifying feasible emission reduction options. There are also a variety of private foundations and groups that support global environmental projects.

Exhibit ES-14
Project/Program Costs for Promoting Economically Viable Reductions in Methane Emissions

Methane Source	Costs of Major Technology Transfer Activities				Key Countries
	Scoping Assessments ($K/Country)	Feasibility Analyses ($K/project)	Demonstration/ Pilot Projects ($K/project)	Institution Building ($K/yr/country)	
Coal Mining	100 - 1,000	75 - 500	1,000 - 15,000+	75 - 100	China CIS Poland/Czech.
Waste Management	100 - 1,000	75 - 500	500 - 15,000+	25 - 100	China India Brazil CIS/E.Europe
Natural Gas Systems	100 - 2,000	100 - 500	500 - 10,000+	75 -100	CIS
Ruminant Livestock	50-75	50 -75	50 - 500	25 -75	CIS/E.Europe China India Tanzania Bangladesh

References

USEPA (United States Environmental Protection Agency) (1993a), Opportunities to Reduce Methane Emissions in the United States, Report to Congress, USEPA/OAR (Office of Air and Radiation), Washington, D.C.

USEPA (1993b), Global Anthropogenic Emissions of Methane, Report to Congress (in progress), USEPA/OPPE (Office of Policy, Planning and Evaluation), Washington, D.C.

CHAPTER ONE
INTRODUCTION

This report evaluates international options for reducing methane emissions from anthropogenic (human related) sources through the use of technologies that are either currently in use or under development. This report has been prepared in partial fulfillment of Section 603 of the Clean Air Act Amendments of 1990, which requires that the EPA prepare and submit to Congress a series of reports on domestic and international issues concerning methane. As one of this series of reports, EPA has been requested to evaluate opportunities to reduce methane emissions in countries other than the United States:

> **Preventing Increases in Methane Concentrations:** Not later than two years after the enactment of this Act, the Administrator shall prepare and submit to the Congress a report that analyzes the potential for preventing an increase in atmospheric concentrations of methane from activities and sources in other countries. Such report shall identify and evaluate the technical options for reducing methane emissions from each of the activities listed in subsection (b), as well as other activities or sources that are deemed by the Administrator in consultation with other relevant Federal agencies and departments to be significant and shall include an evaluation of the costs. The report shall identify the emission reductions that would need to be achieved to prevent increasing atmospheric concentrations of methane. The report shall also identify technology transfer programs that could promote methane emission reductions in lesser developed countries.[1]

This report has two volumes. The first presents technical assessments of the key technological options for reducing methane emissions, and the second focuses on opportunities to reduce emissions in some of the key emitting countries.

The first volume, Technological Options for Reducing Methane Emissions, was prepared in part for the Intergovernmental Panel on Climate Change (IPCC) Response Strategies Working Group (RSWG), by the U.S./Japan Working Group on Methane. The technology assessments were compiled from information and comments submitted by IPCC participating countries. The findings presented in this report indicate that technological options exist for reducing emissions from most of the major methane sources, including oil and natural gas systems, coal mines, landfills, ruminant livestock, and livestock manure.

The second volume, International Opportunities for Reducing Methane Emissions, investigates the potential for applying or expanding the use of available technologies in key emitting countries around the world,[2] for the major methane sources. The key barriers in various countries which are hampering the expansion of methane recovery projects are identified and

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1 Section 603(c)(2) of the Clean Air Act Amendments of 1990.

2 These are countries other than the United States. Options for reducing methane emissions in the U.S. are examined separately in US EPA (1993a), "Options for Reducing Methane Emissions from Anthropogenic Sources in the United States," Report to Congress (in progress), U.S. EPA/OAR.

types of technology transfer programs which may address these barriers and achieve emission reductions are discussed.

1.1 Background: The Importance of Methane

Methane is an important greenhouse gas and a major environmental pollutant. Methane is also the primary component of natural gas and a valuable energy source. Methane emission reduction strategies offer one of the most effective means of mitigating global warming in the near term for the following reasons:

- **Methane is one of the principal greenhouse gases,** second only to carbon dioxide (CO_2) in its contribution to potential global warming. In fact, methane is responsible for roughly 18 percent of the total contribution in 1990 of all greenhouse gases to "radiative forcing," the measure used to determine the extent to which the atmosphere is trapping heat due to emissions of greenhouse gases (IPCC, 1992a).[3]

- **Methane concentrations continue to rise rapidly.** The atmospheric concentration of methane is currently increasing at a rate of about 0.6 percent per year (Steele et al., 1992) (in contrast to CO_2 concentrations, which are increasing by about 0.4 percent per year),[4] and has more than doubled over the last two centuries (IPCC, 1992a). While methane concentrations continue to rise rapidly, the rate of increase has slowed since the early 1980s when concentrations increased at a rate of about 1.0 percent per year

- **Methane is a potent contributor to global warming.** On a kilogram for kilogram basis, methane is a more potent greenhouse gas than CO_2 (about 60 times greater over a period of 20 years, 21 times greater over a period of 100 years, and 9 times greater over a period of 500 years).[5]

- **Reductions in methane emissions will produce substantial benefits in the short run.** Methane has a shorter atmospheric lifetime than other greenhouse gases -- methane lasts around 10 years in the atmosphere, whereas CO_2 lasts about 120 years (IPCC, 1992a). Due to methane's high potency and short lifespan, stabilization of methane emissions will have a rapid impact on mitigating potential climate change.

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3 Global contribution to radiative forcing by gas is estimated on a carbon dioxide equivalent basis using IPCC (1990) global warming potentials for a 100-year time horizon, including direct and indirect effects of methane.

4 Based on measurements taken at Mauna Loa from 1970 to 1990 (Oak Ridge National Laboratory, 1992).

5 Methane is reported to have a direct Global Warming Potential (GWP) of 11 over a one hundred year timeframe, and to have indirect effects that could be equal in magnitude to its direct effect (IPCC, 1992). Over a fifty year timeframe, the direct GWP would be on the order of 25 to 30. The GWP reflects the effect that releasing a kilogram of methane would have over a specified time horizon, relative to releasing a kilogram of carbon dioxide. While the GWP of methane continues to be uncertain, efforts by the IPCC, EPA's Office of Research and Development, and others, should begin to resolve these uncertainties over the next few years.

- **Methane stabilization is nearly as effective as stabilizing CO_2 emissions at 1990 levels.** In order to stabilize methane concentrations at current levels, total anthropogenic methane emissions would need to be reduced by about 10 percent. This methane concentration stabilization would have roughly the same effect on actual warming as maintaining CO_2 emissions at 1990 levels (Hogan et al., 1991).

- **In contrast to the numerous sources of other greenhouse gasses, a few large and gassy facilities often account for a large portion of methane emissions.** Therefore, applying emission reductions strategies to these gassiest facilities would result in a substantial decrease in estimated current and future methane emissions levels.

- **Because methane is a source of energy as well as a greenhouse gas, many emissions control options have additional economic benefits.** Methane emissions are usually an indication of inefficiency in a system. In many cases, methane that would otherwise be emitted to the atmosphere can be recovered and utilized, or the quantity of methane produced can be significantly reduced through the use of economically viable management methods. Therefore, emission reduction strategies have the potential to be low-cost, or even profitable. For example, methane recovered from coal mines, landfills, and livestock manure systems can be used as an energy source, and options for reducing methane emissions from livestock can also improve the productivity of each animal.

- **Well-demonstrated technologies are commercially available for profitably reducing methane emissions.** For the major sources of anthropogenic methane emissions (except rice cultivation and biomass burning), economically viable methane reduction technologies are already commercially available. Additionally, a number of other technologies are under development. While offering substantial emission reductions and economic benefits, these technologies have not been implemented on a wide scale in the U.S. or globally because of financial, informational, and institutional barriers.

The unique characteristics of methane emissions demonstrate the importance of promoting strategies to reduce the amount of methane discharged into the atmosphere. Understanding the sources of methane emissions, and in particular the emissions from systems that are partially controllable, is the first step in identifying economically viable options for reducing emissions.

What is Methane?

Methane (CH_4) is a radiatively and chemically active trace greenhouse gas.[6] Being radiatively active, methane traps infrared radiation (IR or heat) and helps warm the earth. It is currently second only to carbon dioxide in contributing to potential future warming. Being chemically active, methane enters into chemical reactions in the atmosphere that increase not only the

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[6] A trace gas is a gas that is a minor constituent of the atmosphere. The most important trace gases contributing to the greenhouse effect include water vapor, carbon dioxide, ozone, methane, ammonia, nitrous oxide, and sulfur dioxide.

abundance of methane, but also atmospheric concentrations of ozone[7] and stratospheric concentrations of water vapor, which are both greenhouse gases.

Methane is emitted into the atmosphere largely by anthropogenic sources, which currently account for approximately 70 percent of the estimated 500 teragrams (Tg) of annual global methane emissions.[8] Anthropogenic sources of methane emissions include: natural gas and oil systems; coal mining; landfills; domesticated ruminant livestock; liquid and solid wastes; rice cultivation; and biomass burning. Natural sources of methane, which currently account for the remaining 30 percent of global emissions, include natural wetlands (e.g., tundra, bogs, swamps), termites, wildfires, methane hydrates, oceans and freshwaters.

The concentration of methane in the atmosphere is determined by the balance of the input rate, which is increasing due to human activity, and the removal rate. The primary sink (removal mechanism) for atmospheric methane is its reaction with hydroxyl (OH) radicals in the troposphere. In this reaction, methane is converted into water vapor and carbon monoxide, which is in turn converted into carbon dioxide (CO_2). The atmospheric concentration of OH radicals is determined by complex reactions involving methane, carbon monoxide, non-methane hydrocarbons (NMHC), nitrogen oxides, and tropospheric ozone. The size of an OH sink can vary and may actually decrease in response to increasing levels of methane (IPCC, 1992a). A small amount of methane is also removed from the atmosphere through oxidation in dry soils. Compared to removal by reaction with OH, this oxidation mechanism is believed to be relatively small. There are no significant anthropogenic activities that remove methane from the atmosphere. Methane's atmospheric lifetime is presently estimated to be about 10 years (IPCC, 1992a).

Atmospheric Levels of Methane Are Rising

The concentration of methane in the atmosphere has been steadily increasing. The rise in methane concentrations has been well-documented in recent studies and corroborated by measurements from different locations and several monitoring groups. The principal methods for estimating methane concentrations over time have been analysis of ice core data and direct atmospheric measurements.

Analyses of ice cores in Antarctica and Greenland have yielded estimates of atmospheric methane concentrations of approximately 0.35 parts per million by volume (ppmv) to 0.65 ppmv for the period between 10,000 and 160,000 years ago. Similar analyses of air in ice cores have placed atmospheric methane concentrations at approximately 0.8 ppmv for the period between 200 and 2,000 years ago. The level of methane rose to about 0.9 ppmv at the beginning of this century (IPCC, 1990a).

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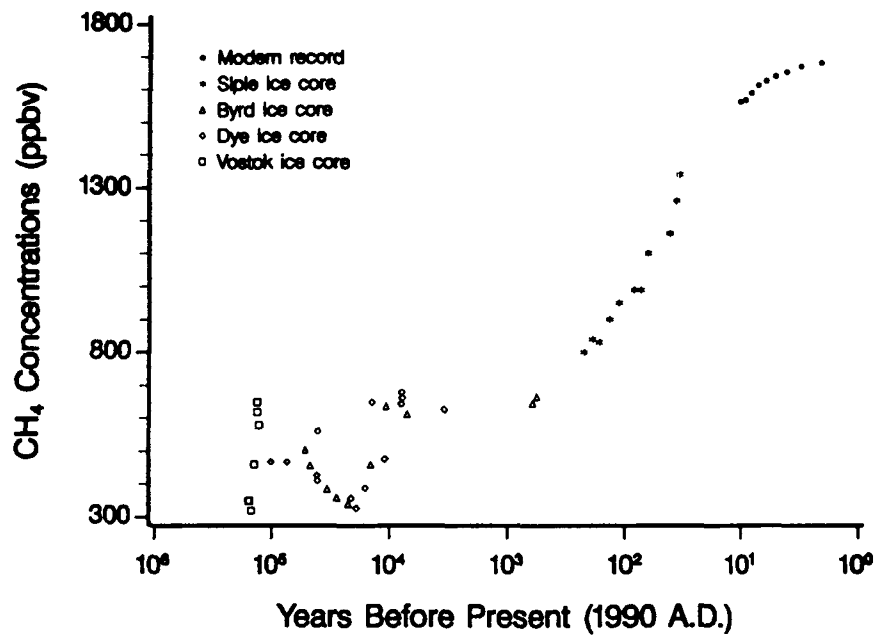
7 While methane does not contribute significantly to the formation of urban smog, methane is a major concern in the formation of ozone in the free troposphere.

8 The portion of total methane emissions from anthropogenic sources is based on IPCC (1992a). Total annual methane emissions is based on Crutzen (1991).

Direct measurement of the global atmospheric methane concentration was begun in 1978. At that time, the global atmospheric methane concentration was calculated to be 1.51 ppmv. In 1990, the level was approximately 1.72 ppmv -- nearly double the concentration level estimated for the beginning of this century (IPCC, 1990a). A summary of the ice core data and direct measurement data showing the increase in atmospheric methane concentrations is provided in Exhibit 1-1. In addition to ice core data and direct atmospheric measurements, analysis of infrared solar spectra has shown that the atmospheric concentration of methane increased by about 30 percent over the last 40 years (Rinsland et al., 1985).

Exhibit 1-1
Global Methane Concentrations



Annual atmospheric CH_4 concentrations during the past 160,000 years (derived from ice cores and the NOAA/CMDL flask sampling network).

Source: Oak Ridge National Laboratory/Carbon Dioxide Information Analysis Center, August 1990

At present, the atmospheric level of methane of 1.72 ppmv is approximately 4,900 Tg (IPCC, 1990a). This amount is thought to be increasing by about 30 to 40 Tg per year (Steele et al., 1992). Atmospheric methane concentrations are expected to continue to increase, although global measurement programs indicate that the rate of increase appears to have slowed in the last several years (WMO, 1990; Steele et al., 1992). The reason for this is currently not well understood. Given a continuation of the current annual rate of increase of atmospheric methane of about 0.0095 to 0.0133 ppmv, the atmospheric concentration of methane would exceed 2.0 ppmv by the year 2020. Recent models of expected future emissions and atmospheric processes indicate that without controls, atmospheric concentrations could range from 3.0 ppmv to over 4.0 ppmv by the year 2100 (USEPA, 1989; IPCC, 1992a), although these scenarios should be reinvestigated using the most recent information on methane concentration trends.

Methane and Global Climate Change

Methane's increasing concentration in the atmosphere has important implications for global climate change. Methane is very effective at absorbing infrared radiation (IR) reflected by the earth's surface. By absorbing IR and inhibiting its release into space, methane in the atmosphere contributes to increased atmospheric and surface temperatures. This process is commonly referred to as the "greenhouse effect."

A gram of methane is about 35 times more effective at warming the surface of the earth than a gram of CO_2 over a 20 year timeframe (IPCC, 1992a). In addition to this direct radiative forcing, methane's participation in chemical reactions in the atmosphere indirectly contributes to global warming by influencing the amount of ozone in the troposphere and stratosphere, the amount of hydroxyl in the troposphere, and the amount of water vapor in the stratsophere; these reactions are discussed in more detail below. Methane's indirect effect on global warming resulting from these chemical reactions could be equal in magnitude to its direct effect, although considerable uncertainty remains (IPCC, 1992a).[9]

When compared to CO_2, methane's greater direct and indirect impacts per gram of emissions is mitigated somewhat by its shorter atmospheric lifetime of around 10 years, compared with approximately 120 years for CO_2 (IPCC, 1992a). Considering methane's atmospheric lifetime and its effect on tropospheric ozone, a gram of methane has a global warming potential (GWP) 21 times greater than a gram of CO_2 over a 100 year time period (IPCC, 1992a). It has been estimated that approximately 18 percent of the greenhouse effect is due to increasing atmostpheric methane concentrations. The total contribution to radiative forcing of all greenhouse gases in 1990 is shown in Exhibit 1-2.

Models of atmospheric chemical processes have indicated that increasing methane concentrations result in net ozone production in the troposphere and lower stratosphere, and net ozone destruction in the upper stratosphere. It has been calculated that methane's net effect in these processes is to cause an increase in ozone (Wuebbles and Tamaresis, 1992).[10]

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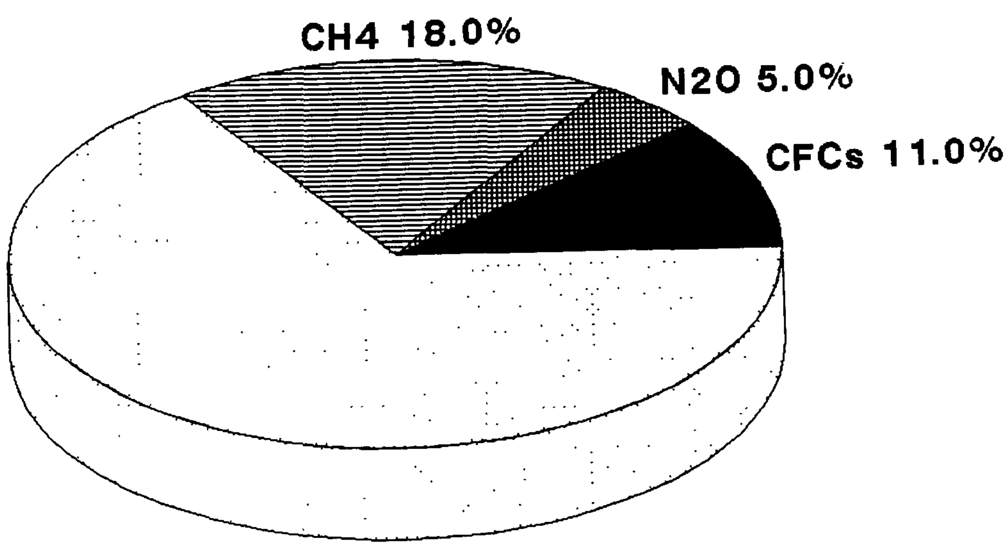
9 The uncertainty in the GWPs for methane result largely from the indirect effects of methane in the atmosphere, which have not been fully characterized. Some of these uncertainties will be reduced over the next several years through the efforts of the Intergovernmental Panel on Climate Change as well as others, including EPA's Office of Research and Development.

10 As described in IPCC (1990), "Ozone plays an important dual role in affecting climate. While CO_2 and other greenhouse gases are relatively well-mixed in the atmosphere, the climatic effect of ozone depends on its distribution in the troposphere and stratosphere, as well as on its total amount in the atmosphere. Ozone is a primary absorber of solar radiation in the stratosphere, where it is directly responsible for the increase in temperature with altitude. Ozone is also an important absorber of infrared radiation. The balance between these radiative processes determines the net effect of ozone on climate."

As the most abundant organic species in the atmosphere, methane also plays an influential role in determining the oxidizing capacity of the troposphere. Through reactions with hydroxyl, 80 to 90 percent of methane destruction occurs in the troposphere (Cicerone and Oremland, 1988). Increasing methane levels could reduce hydroxyl, which would result in a further increase in the methane concentration. A decrease in the oxidizing capacity of the troposphere would increase not only the atmospheric lifetime of methane, but also the lifetime of other important greenhouse gases, and would permit transport of pollutants over long distances, resulting in atmospheric changes even in remote regions (Wuebbles and Tamaresis, 1992). For example, the atmospheric lifetimes of hydrogenated-CFCs (HCFCs) may be increased, thereby reducing their desirability as substitutes for CFCs.

Exhibit 1-2
Global Contribution to Integrated Radiative Forcing by Gas for 1990[1]
CO_2-Equivalent Basis Using IPCC 1990 GWPs for a 100-Year Time Horizon



Note: Estimated on a carbon dioxide equivalent basis using IPCC (1990a) global warming potentials (GWPs) for a 100-year time horizon. Anthropogenic emissions only.

1 This chart is used to present a general understanding of methane's contribution to future warming based on the GWPs presented in IPCC (1990a). However, these GWPs are constantly being revised due to a variety of scientific and methodological issues. It is likely that the contribution of CFCs presented will decrease and that the contribution of other gases will be about the same or greater upon further investigation.

Source: IPCC 1990a

Finally, concentrations of stratospheric water vapor (one of the most important greenhouse gases) should increase as concentrations of methane increase; methane oxidation reactions roughly produce two moles of water vapor for each mole of methane that is destroyed (Wuebbles and Tamaresis, 1992). In addition to the impact on global warming, increases in stratospheric water vapor concentrations as a result of increased methane concentrations could contribute to the formation of polar stratospheric clouds (PSCs), which have been identified as one factor that enables the chlorine and bromine from chlorofluorocarbons (CFCs) and halon compounds to cause the severe seasonal loss of stratospheric ozone over Antarctica (WMO, 1990).

Stabilization of Global Methane Levels and Further Reductions

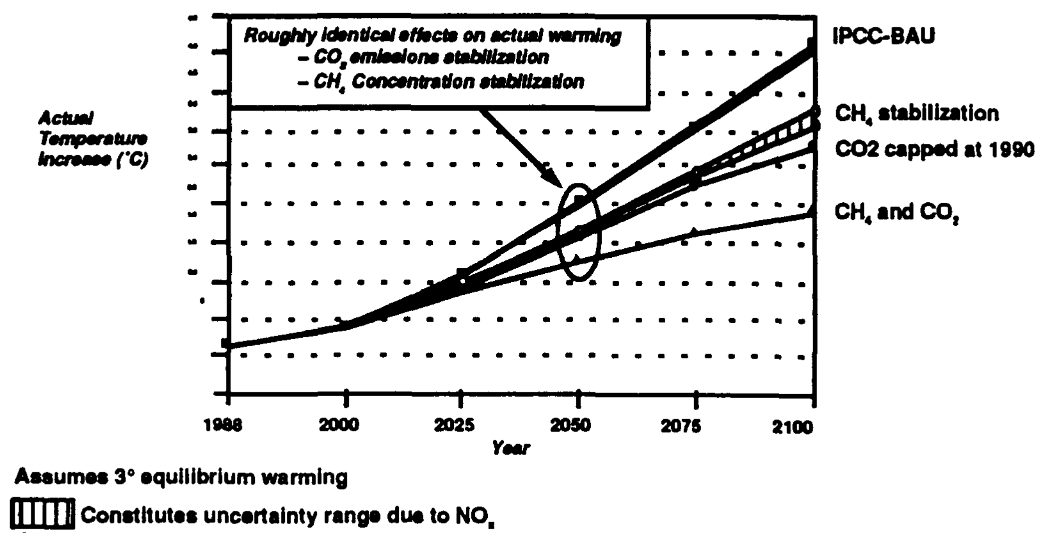
Since atmospheric methane has been increasing at a rate of about 30 to 40 Tg per year, stabilizing global methane concentrations at current levels would require reductions in methane emissions of approximately this same amount. Such a reduction represents about 10 percent of current anthropogenic emissions. This percentage reduction is much less than the percentage reduction necessary to stabilize the other major greenhouse gases: CO_2 requires a greater than 60 percent reduction; nitrous oxide requires a 70 to 80 percent reduction; and chlorofluorocarbons require a 70 to 85 percent reduction (IPCC, 1990b).

Because methane has a relatively short atmospheric lifetime as compared to the other major greenhouse gases, reductions in methane emissions will help to ameliorate global warming relatively quickly. Therefore, methane reduction strategies offer an effective means of slowing global warming in the near term. Exhibit 1-3 compares the effects on future temperature increases of stabilizing methane concentrations versus maintaining CO_2 emissions at 1990 levels. This exhibit illustrates that stabilizing atmospheric concentrations of methane will have a virtually identical effect on actual warming as capping CO2 emissions at 1990 levels. The recent evidence that the rate of annual increase in methane emissions is slowing (Steele et al., 1992) may mean that reductions on the order of 30 to 40 Tg per year could reduce concentrations to the extent that they fall below the level of stabilization. This result would also have large benefits for the global atmosphere.

1.2 Technological Options for Reducing Methane Emissions

Because methane released by anthropogenic activities is generally a wasted resource, opportunities may exist for low cost, if not profitable, emission reductions. Estimates of global emissions from these sources are listed in Exhibit 1-4, and an overview of these emissions is provided below. Depending on the source, it is possible to reduce a significant portion of the methane currently emitted to the atmosphere through the use of economically viable technologies. In Volume I: Technological Options for Reducing Methane Emissions, the key options for reducing methane emissions from the major sources are identified and characterized. These options are summarized in Exhibit 1-5 and described below.

Exhibit 1-3
CO_2 and Methane Reduction Comparison



Benefits of methane stabilization where methane emissions are capped at 540 Tg/yr as compared to capping CO2 emissions at 1990 levels (and concentrations grow to over 500 ppm by 2100).

Source: Hogan et al. (1991)

Exhibit 1-4
Global Methane Emissions from Major Sources

Source	Estimated Emissions - 1990 (Tg)
Coal Mining, Natural Gas & Petroleum Industry	70 - 120
Ruminant Livestock	65 - 100
Livestock Manure	10 - 20[a]
Landfills	20 - 70
Wastewater	20 - 25
Biomass Burning	20 - 80
Rice Cultivation	20 - 150

Source: IPCC 1992a
a. Emissions from Livestock Manure reflect revised estimates. Emissions for all other sources are currently being updated by USEPA (1993b).

Exhibit 1-5
Summary of Technologies for Reducing Methane Emissions

Source/Technologies	Availability	Applicability	Benefits
Oil & Natural Gas		Applicable for: - Harsh Conditions - Older Systems - System Expansion	- Improved Safety - Reduced Gas Loss - Improved Air Quality
Venting & Flaring	Now		
Compressor Operations	Now		
Detection/Repair	Now		
Low Emission Technologies	Now		
Coal Mining		Dependent upon: - Gassy Mines - Nearby Gas Use - Available Technology - Available Capital	- Improved Mine Safety - Increased Productivity - Clean Energy Source
Enhanced Gob Recovery	Now		
Pre-mining Degasification	Now		
Ventilation Air Use	Needs Demonstration		
Integrated Recovery	Now		
Landfills		Dependent Upon: - Landfill Design - Nearby Gas Use - Available Technology - Available Capital	- Improved Safety - Improved Air & Water Quality - Clean Energy Source
Recovery and Utilization	Now		
Aerobic Landfills	Now		
Source Reduction	Now		
Ruminant Livestock		Dependent upon: - Current Management System - Available Technology - Available Capital - Available Markets	- Improved Productivity - Improved Health of Animals - Reduced Food Imports
Feed Processing	Now		
Strategic Supplementation	Now		
Production Enhancers	Now		
Improved Genetics	Now		
Improved Reproduction	Now		
Animal Wastes		Dependent upon: - Waste Management System - Temperature - Available Technology - Available Capital	- Improved Water Quality - Reduced Health Risk - Improved Productivity - Clean Energy Source
Covered Lagoons	Now		
Advanced Digesters	Now		
Low-Technology Digesters	Now		

Source: IPCC, 1992b

Oil and Natural Gas Systems

Methane is the primary component of natural gas, and significant methane emissions can result during all the major phases of the natural gas systems operations: production, processing, storage, transmission and distribution. Emissions result from normal operations (including compressor exhaust emissions, emissions from pneumatic devices and fugitive emissions); during routine maintenance (including equipment blowdown and venting, well workovers and scraper operations); and during system upsets when methane is emitted due to sudden, unplanned pressure changes or mishaps. Because natural gas is often found in conjunction with oil, gas leakage during oil exploration and production is also a source of emissions. Current global emissions from oil and gas systems are estimated to be 30 to 65 Tg per year (USEPA, 1993b).[11]

The technical nature of emissions from natural gas systems is well understood and emissions are largely amenable to technological solutions, including reduced venting and flaring during production, improved compressor operation, leak detection and pipeline repair, and installation of pipeline control devices that reduce or eliminate venting. These technologies can lead to large reductions in methane, some of which are economical and can also result in improved safety, increased productivity (sales) through reduced losses, and improved air quality.

Coal Mining

Methane and coal are formed together during coalification, a process in which vegetation is converted into coal by biological and geological forces. Methane is stored within coal seams and surrounding rock strata and is released to the atmosphere during mining or through natural erosion. In underground mines, methane is hazardous because it is explosive in low concentrations (5 to 15 percent) when mixed with air. Therefore, underground mines use ventilation and degasification systems to remove methane from mine workings; this methane is usually vented to the atmosphere. In surface mines, methane is emitted directly to the atmosphere as the rock strata overlying the coal seam are removed. The amount of methane released from a mine depends mainly upon the type of coal and the depth of the coal seam. For example, deeper coal can hold more methane. This means that emissions from coal mining are likely to increase in the future as shallower reserves are depleted, and deeper coal is mined. Current global coal mine emissions are estimated to be 24 to 40 Tg per year (USEPA, 1993b).

Several technologies are available for recovering and utilizing methane that would otherwise be released to the atmosphere during coal mining. Methane can be recovered before, during and after mining using in-mine or surface recovery techniques. Where surface recovery methods are used, methane recovery can begin ten or more years before mining occurs. The recovered gas can vary in quality, depending on whether it has been contaminated with mine air during the recovery process. Depending on its quality, quantity and local market conditions, it can be used for power generation or injected into a pipeline system and used directly by residential or industrial customers. Among the additional benefits of expanded

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[11] It is estimated that 70 to 80 percent of this total is emitted from natural gas systems worldwide, and 20 to 30 percent from oil systems.

recovery and use of methane at coal mines are improved mine safety and productivity (because methane is explosive in low concentrations in air) and a larger domestic supply of clean-burning natural gas.

Landfills

Methane is generated in landfills as a direct result of the natural decomposition of solid waste primarily under anaerobic conditions (in the absence of oxygen). The organic component of landfilled waste is broken down by bacteria in a complex biological process that produces methane, carbon dioxide, and other trace gases. Global emissions are estimated to be 20 to 60 Tg per year (USEPA, 1993b).

Several options exist for recovering or reducing the methane produced from landfills. One option is to recover and utilize the methane for electricity generation, for direct use as a fuel, or for sale as natural gas. An emission reduction strategy of much greater technical complexity is to design aerobic landfills so that less methane is produced. Aerobic designs increase the rate of decomposition and reduce emissions of harmful and odorous trace gases. Finally, emission reductions can be achieved through reducing the quantity of waste that is landfilled by recycling material, incinerating solid waste and composting organic material. Additional benefits that result from these emission reduction strategies include improved air and water quality and reduced risk of fire and explosion.

Ruminant Livestock

Ruminant animals (cattle, sheep, buffalo, goats, and camels) produce significant quantities of methane as part of their normal digestive processes. Ruminant animals are characterized by a large "fore-stomach" or rumen, in which microbial fermentation converts feed into products that can be digested and utilized by the animal. The microbial fermentation enables ruminant animals to utilize coarse forages that monogastric animals, including humans, cannot digest. Methane is produced by rumen methanogenic bacteria as a byproduct of normal rumen fermentation, and then is exhaled or eructated by the animal. The amount of methane produced is dependent upon both animal type and management practices. Global emissions are estimated to be 65 to 100 Tg per year (USEPA, 1993b).

Many opportunities exist for reducing methane emissions from ruminant animals. The most beneficial emission reduction option for any given livestock system will depend on a number of factors including: feeding practices; climate; economic and physical infrastructure; and traditions and customs. In nearly all cases, however, methane emissions per unit of product (e.g., methane emissions per kg of milk produced) can be reduced by improving animal productivity. Options for reducing methane emissions from ruminant livestock include: improved nutrition through mechanical and chemical feed processing; improved nutrition through strategic supplementation; production enhancing agents; improved production through improved genetic characteristics; and improved production efficiency through improved reproduction.

Livestock Manure and Other Sources

In many countries, potential may exist to reduce methane emissions from additional sources, including livestock manure, wastewater management, rice cultivation, biomass burning, and fossil fuel combustion. Current estimates of methane emissions from these sources worldwide range from about 70 to 200 Tg per year or more (USEPA, 1993b).

A number of technically and economically feasible options have been identified to reduce emissions from livestock manure. Many developed countries manage the wastes from large numbers of cattle, swine, and poultry using liquid waste management systems that are conducive to anaerobic fermentation of the wastes and methane production. Global emissions from livestock manure are estimated to be 10 to 18 Tg per year (USEPA, 1993b). The most promising option for reducing methane emissions from livestock manure is to recover methane for use as an on-farm energy source to generate electricity, to provide heating, or to produce cooling.

Technically and economically feasible options have also been identified to reduce emissions from wastewater and fossil fuel combustion. Options for the other sources are being researched, developed, and demonstrated, and should be available in the future. Some types of actions to promote methane reduction from these sources worldwide may include technology and information transfer programs, funding assistance, country planning studies, and policy assistance. In addition to reducing methane emissions, controlling and recovering methane from these sources can provide benefits such as: reduced ground and surface water pollution; improved public health; odor reduction; and reliable renewable energy resources.

1.3 Financing of International Projects with Methane Reduction Potential

An important factor in the implementation of international options for reducing methane emissions is financing. Lesser developed countries and countries with economies in transition present uncertain business environments to potential investors. Political instability, lack of hard currency, uncertain legal and regulatory systems, poor infrastructure, and inadequate information are some of the factors that increase the risks of investing in methane emissions reductions overseas. Therefore, obtaining adequate financing often involves relying on various combinations of private financing, donor assistance, or governmental support for exports.

Several potential sources of financing exist for international projects to reduce methane emissions, though each has its specific focus. Major potential sources of direct project financing include:

- World Bank;
- Regional Multilateral Development Banks;
- Global Environmental Facility (GEF);
- U.S. Government Agencies;
- Private Foundations; and
- Commercial Banks, Investment Firms, and Private Companies.

Other potential U.S. sources of support for international projects to reduce methane emissions, though more indirect, are:

- U.S. Export-Import Bank (ExIm Bank);
- Overseas Private Investment Corporation (OPIC);
- U.S. Country Studies Program; and
- U.S. Trade and Development Program.

World Bank

The World Bank supports projects by lending to governments, which in turn distribute funds to organizations that undertake projects. To benefit from this funding, U.S. investors must collaborate with governments and local counterparts in the host country. World Bank funds support general development of agriculture and energy systems, both important sectors for methane reduction options. It is thus likely that general development projects will overlap with methane reduction opportunities.

Regional Multilateral Development Banks

The Asian Development Bank, African Development Bank, Inter-American Development Bank, European Bank for Reconstruction and Development, and others, though smaller than the World Bank, also fund development projects in their regions. In some regions and countries, such as Central America, regional banks provide greater financial assistance than the World Bank.

Multilateral development banks (including the World Bank) tend to fund projects that have substantial local benefits for the country or region in question. Therefore, methane mitigation projects most likely to be funded by these sources are those that will generate significant local benefits in addition to the global environmental benefits of combating climate change.

Global Environmental Facility (GEF)

GEF was created in 1990 to provide incremental resources for projects that generate global environmental benefits in four specific areas; greenhouse gases, biological diversity, international waters, and (to a limited extent) ozone depletion. GEF is managed by the World Bank, United Nations Environmental Programme (UNEP) and the United Nations Development Programme (UNDP). In 1992, GEF was made the interim financial mechanism for implementation of the Framework Convention on Climate Change.

GEF is the source of financing most directly aligned with the objectives of methane emissions reduction projects. GEF has funded a technical assistance project to demonstrate methane reduction opportunities at coal mines in China. GEF is currently initiating projects to reduce methane leakage from natural gas pipelines in Russia and China and is considering additional coal mine methane projects. In addition, GEF recently approved technical assistance to a biogas facility in Tanzania. While GEF is an attractive funding source, it is intended to demonstrate technologies and overcome implementation obstacles in new areas. Thus it will likely not be able to fund all economically feasible methane reduction projects. GEF projects will probably be most useful as demonstrations for technologies in specific regions (as in the case of Tanzania biogas), and as sources of information on implementation obstacles.

U.S. Government Agencies

Many U.S. Government agencies finance international projects as part of their programs. Among the most relevant for methane reductions are U.S. Agency for International Development, Environmental Protection Agency, Department of Agriculture, Department of Commerce, Department of Energy, Department of State, and Department of Treasury. Of the multitude of programs housed in these agencies that are potential sources of support for methane reduction projects, most have primary objectives unrelated or indirectly related to climate change, such as promotion of U.S. exports, improvement of local environmental conditions and creation of new energy sources. To the extent methane reduction projects can meet these other objectives, they could be eligible for funding.

Private Foundations and Non-Profit Organizations

Many private foundations and non-profit organizations provide support for international environmental protection and development projects, including W. Alton Jones Foundation, the Ford Foundation, and the Rockefeller Foundation. The pool of money available through these sources is relatively small and distributed among a wide variety of environmental and non-environmental projects. Non-profit organizations, such as the Environmental Defense Fund, the Natural Resources Defense Council, and the World Wildlife Fund, though directly concerned and active on climate change, usually do not have sufficient resources to undertake projects without foundation, government, or private sector support.

Commercial Banks, Investment Firms, and Private Companies

Commercial financing (banks, investment firms) for methane reduction projects or other projects producing environmental benefits (e.g., energy efficiency) may be difficult to obtain, especially when these projects demonstrate new technologies or when they are being developed in countries with unstable economies. Debt or equity capital is often difficult to attract, so companies are left to their own resources to finance projects. Smaller companies manufacturing new technologies and providing new services may not have the resources to absorb setbacks which can easily occur under changing economic conditions of developing countries.

Demonstration projects funded by the GEF can provide important information on the probability of success of some types of projects, and lending by multilateral development banks and governments can directly support projects. Indirect support of private sector initiatives is also supplied by ExIm Bank, OPIC, the U.S. Country Studies Program and the U.S. Trade and Development Program.

U.S. Export-Import Bank (ExIm Bank)

The ExIm Bank is an independent government agency that facilitates exports of U.S. goods and services, particularly in developing countries. Its main programs include direct loans to foreign borrowers, export credit guarantees and insurance, and discount loans. Since it is not a development assistance agency, it must have reasonable assurance of repayment.

Overseas Private Investment Corporation

OPIC is a public-private corporation created by Congress that directly oversees projects sponsored by U.S. private investors in developing countries and provides insurance against political risks for U.S. private investments in those countries. More than 90 percent of OPIC's money goes to loan guarantees, with a small amount going to direct project financing, including the funding of market assessments and pre-feasibility studies.

U.S. Country Studies Program

In February 1992, the United States announced an initiative to provide $25 million over 2 years to help countries prepare studies to address climate change. Under this new initiative, the U.S. Government will provide financial and technical support to developing countries and countries with economies in transition. These studies will enable countries to develop inventories of their anthropogenic emissions of greenhouse gases, assess their vulnerabilities to climate change, and evaluate response strategies for mitigating and adapting to climate change.

Preliminary work indicates that methane emissions reductions will be an important element of the reduction strategies in several countries. By working with host governments and helping them focus on the most promising areas for reductions, the Country Studies Program will ease investments in all greenhouse gas mitigation projects in host countries.

U.S. Trade and Development Agency

U.S. Trade and Development Agency (TDA) is an independent agency that funds feasibility and planning studies for projects involving export markets for U.S. goods and services. Its focus is primarily on large public sector projects, and it must be confident that project development will result in the procurement of U.S. goods and services before it commits funds. TDA is currently funding a feasibility study of a methane reduction project at coal mines in Poland. It has also funded a variety of natural gas projects in Russia.

1.4 Methane Reduction Options in Countries of Interest

This report examines how currently existing technologies for reducing methane emissions could be employed in some of the key emitting countries for the various methane sources. In many cases, several key countries account for most of the emissions from the major methane sources. For example, three countries contribute over 70 percent of emissions from global coal mining activities. Four countries contribute over 80 percent of global emissions from the production and transportation of natural gas. In some cases, however, such as with ruminant livestock, methane emissions are fairly evenly distributed worldwide. No individual country is responsible for more than 10 to 15 percent of global emissions from this source. In cases such as this, countries discussed in this volume were selected primarily according to the feasibility of achieving reductions, or because they are representative of regions of interest. The key countries of interest and their respective methane emissions from each of the major sources are presented in Exhibit 1-6. This exhibit also shows the percentage of methane emissions (excluding the emissions from the U.S.) that are contributed by these key countries.

Exhibit 1-6
Methane Emissions from Key Countries, by Source

Source/Country(or Region)	Emissions (Tg/yr)	Percentage of Non-U.S. Emissions[2]
Natural Gas		60%
CIS	16 - 36	
Coal Mining		70%
China	9.5 - 16.3	
CIS	4.8 - 6.0	
Poland	0.6 - 1.5	
Former Czechoslovakia	0.3 - 0.5	
Ruminants[1]		60%
Asia	14 - 24	
Eastern Europe/CIS	7 - 12	
Africa	5 - 8	
Landfills		25%
China	1.0 - 4.0	
United Kingdom	1.0 - 3.0	
Brazil	0.7 - 2.2	
India	0.2 - 0.8	
Poland	0.1 - 0.4	

1 Emissions from large ruminants only (i.e., cattle and buffalo).
2 Non-U.S. emissions are represented here because U.S. Emissions are addressed separately in USEPA (1993a), "Opportunities to Reduce Methane in the United States," Report to Congress (review draft), USEPA/OAR

While a variety of emission reduction technologies are available for each major anthropogenic methane source -- oil and gas systems, coal mining, landfills, domesticated animals and livestock manure -- these technologies have not yet been fully implemented in many countries. In many cases, existing financial, political, and informational barriers constrain the wider application of these technologies. This volume, Volume II: International Opportunities for Reducing Methane Emissions, focuses on the most important barriers which may constrain the development of methane reduction programs and outlines possible actions that could be undertaken to encourage greater profitable methane recovery and utilization.

1.5 Overview of Report

This report is organized as follows:

Volume I: Technological Options for Reducing Methane Emissions: Volume I presents technical assessments of the principal methane recovery and utilization technologies available for each of the major sources. The report has separate chapters dealing with technologies to reduce methane from the following sources:

- Landfills;
- Oil and Natural Gas Systems;
- Coal Mining;
- Combustion: Mobile and Stationary Sources;
- Ruminant Livestock;
- Livestock Manure;
- Wastewater Management;
- Biomass Burning; and,
- Rice Cultivation.

For each methane source, the available technologies for reducing emissions are described, including technical characteristics, costs, availability, applicability, barriers to implementation, and additional benefits of implementation. These categories were created by the IPCC Response Strategies Working Group, and the information contained in this volume is a compilation of submissions by IPCC member countries. These technical assessments have been reviewed by government officials and experts in these countries.

Volume II: International Opportunities for Reducing Methane Emissions: This report summarizes the particular conditions of key emitting countries, in terms of the most promising options for reducing emissions, the possible emission reductions, and the types of technology transfer programs which may increase the implementation of the economically viable emission reduction technologies. This report has chapters on:

- Landfills;
- Oil and Natural Gas Systems;
- Coal Mining;
- Ruminant Livestock; and,

Other Sources (including Livestock Manure, Wastewater Management, Biomass Burning, Fossil Fuel Combustion, and Rice Cultivation).

For each of these sources, the overall emission reduction potential is discussed and case studies of the key international sources are presented.

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CHAPTER TWO

LANDFILLS

2.1 Introduction

There are two primary options for reducing methane emissions from landfills:

> **1) Capture and use the methane to produce energy.** The landfilling of organic wastes presents an opportunity for energy recovery and substantial reductions in methane emissions in many countries around the world. Landfill gas can be put to a number of cost-effective uses, including electricity generation, industrial use, and residential cooking and heating.
>
> **2) Reduce the quantity of waste that enters landfills.** Waste management programs that prevent or reduce the generation of methane, such as recycling programs for paper and composting of other organic wastes, can reduce methane emissions and yield useful products such as sanitized fertilizer for use in agricultural areas.

These options are in use, to some extent, in both developed and developing countries. There are over 200 landfill gas recovery projects worldwide (providing roughly 50 million MBTU of energy) and many source reduction and recycling projects (Richards, 1989; USEPA, 1993b). There is substantial opportunity to expand the use of these options, however. For example, there are thought to be more than 1000 potential new sites for landfill gas recovery in developed countries alone (Richards, 1989).

Based on currently available technologies, it is technically feasible to reduce methane emissions from landfills globally by over 50 percent (USEPA, 1990; Richards, 1989). If global methane emissions from this source are 20 to 60 Tg per year (USEPA, 1993b), then potential reductions could be 10 to 25 Tg CH_4 per year or more. A large portion of the potential reductions is in the United States, which contributes about 20 to 35 percent of global methane emissions from landfills (USEPA, 1993a). Furthermore, these reductions are likely to be achieved by the end of the decade since the United States has recently proposed regulations to limit air emissions (i.e., air toxics and volatile organic compounds) from landfills which, when implemented, will reduce methane emissions significantly, while affecting just a portion of existing landfills (Federal Register, 1992). The landfills affected by the rule will tend to be larger landfills with substantial methane generation, which are the best candidates for profitable energy recovery projects (USEPA, 1993c).

The potential for methane reductions will increase in the coming decades as more organic wastes are generated and disposed of in landfills, particularly in landfills surrounding rapidly growing urban centers in many developing countries. Furthermore, there is a trend toward larger, more regionalized sanitary landfills, which tend to have higher methane emissions. Thus, emissions in many countries may increase and additional opportunities for energy recovery will be created.

This chapter describes the opportunities for reducing methane emissions to the atmosphere from the disposal of municipal wastes. Importantly, such operations provide a range of benefits in addition to reducing methane emissions, such as increased safety (reduced risk of fire) at landfills, economic production of a useful fuel, reduced emissions of air pollutants, and improved water quality. The chapter first presents background information on global emissions of methane from landfills and the available technologies for profitably reducing these emissions. The use of these technologies in specific countries is then examined, with an emphasis on the types of programs that could be designed and implemented to promote the recovery of valuable materials and products. Although such programs are underway in several countries, there are many opportunities to enhance these efforts through technology exchange and assistance programs. This chapter examines the opportunities for reducing methane emissions from landfills in Brazil, India, and Poland. Landfill gas recovery in the United Kingdom is also discussed. Emissions reduction opportunities in the United States are addressed in EPA's "Options for Reducing Methane Emissions in the United States" (USEPA, 1993c).

2.2 Methane Emissions

Until the early 1970s the majority of refuse generated was deposited and burnt in "dumps" which were typically holes in the ground. This disposal method created numerous problems, including: the lack of cover attracted flies; the burning led to uncontrolled fires and air quality problems; and the lack of liners led to groundwater contamination. Although sanitary landfills eliminated many of these problems, other problems persist. Landfills produce large quantities of methane gas as the organic matter in the refuse decomposes in the anaerobic environment of the landfill. Unless strict engineering principles are applied, groundwater contamination can also result.

Emissions from the anaerobic decomposition of wastes disposed in landfills are a major global source of methane, contributing between 20 and 60 Tg of methane annually (USEPA, 1993b). The range of estimated emissions is based on a number of studies employing different methodologies (Bingemer and Crutzen, 1987; Orlich, 1990; OECD, 1991; and USEPA, 1993b). The major uncertainties in these estimates include the amount of organic material actually disposed of annually in landfills by different countries, the portion of the organic wastes that decompose anaerobically, and the extent to which these wastes will ultimately decompose.

About two-thirds of methane emissions from landfills come from the more developed countries of the world, another 15 percent from countries with transitional economies, and 20 percent from lesser developed countries (USEPA, 1993b). Ten countries represent about 60 to 70 percent of methane emissions from landfills. The country with the largest emissions, by far, is the United States. The next largest emitters are China, Canada, Germany, the United Kingdom, and the Commonwealth of Independent States (Exhibit 2-1).

The differences in emissions result primarily from the larger quantities of waste generated in developed countries (1 to 2 kg/capita/day versus 0.4 to 0.9 kg/capita/day in developing countries), as well as from a higher component of degradable organic matter in the waste of developed countries (Orlich, 1990; Bingemer and Crutzen, 1987). Differences in waste management practices between developed and developing countries also contribute to the differences in the quantity of methane emitted. For example, while most generated waste in developed countries is disposed of in landfills, wastes in many developing countries are

Exhibit 2-1
Key Emitters of Methane Emissions from Landfills

Country	Waste Landfilled Annually[1] (Tg/yr)	Estimated Emissions[2] (Tg/yr)	
		Low	High
United States[a]	189.0	8.0	12.0
United Kingdom[b,c]	25.0	1.0	3.0
China[b]	166.3	1.2	3.9
Germany[b]	159.3	0.9	2.0
Canada[b,d]	21.3	0.8	2.0
Italy[b,e]	18.3	0.7	1.5
Brazil[b]	22.0	0.7	2.2
C.I.S.[b]	53.7	0.7	2.5
Japan[b]	11.4	0.5	1.0
Australia[b,f]	12.3	0.3	1.5
France[b]	6.7	0.4	0.9
Spain[b]	8.7	0.4	0.9
India[b]	124.6	0.2	0.8
Poland[b,g]	11.5	0.1	0.4
Other	-	5.1	22.4
TOTAL[b]	-	21.0	57.0

a: USEPA, 1993a
b: USEPA, 1993b
c: Personal Communication, Liz Aitchison, ETSU, Harwell Laboratory, 1993
d: Jacques, 1992
e: Gaudioso et al., 1993
f: Australian Draft Inventory Preparation Group, 1991
g: Personal Communication, Mike Pyka, Polish Foundation for Energy Efficiency, 1993

1 Based on per capita waste generation estimates and an estimated percentage of waste landfilled, as in OECD, 1991, except where indicated. These estimates for landfilled waste typically are highly uncertain. Developing country estimates are particularly uncertain as they typically use per capita generation estimates from urban studies. In estimating emissions, this and other factors have been taken into account.

2 Estimated upper and lower bounds are based primarily on recent drafts of the Report to Congress, *Global Anthropogenic Emissions of Methane* (USEPA, 1993b), as well as country specific data. These estimates will likely change as the Report to Congress is finalized.

extensively recovered and recycled on an informal basis. For example, it is estimated that scavengers in Mexico City recover at least 25 percent of the mixed waste and about 70 percent of the industrial solid waste (Elkington and Shopley, 1989). In some cities in India, 50 to 100 percent of the waste may be recovered and diverted for use as animal fodder or sent directly to agricultural farms outside the city for use as fertilizer (Rajabapaiah, 1989).

In the 1960s and 1970s, waste generation, and therefore methane emissions, increased dramatically in the United States and other industrialized countries. While these emissions are now leveling off, waste generation in lesser developed countries is expected to double by the year 2000 (IPCC, 1990). In the near future, the developing countries will likely be the fastest growing source of methane emissions from landfills, as urban populations grow and industrialization continues. Based on projections of future emissions (Kresse and Ringeltaube, 1982), lesser developed countries may contribute 30 to 40 percent of global emissions from landfills in 2000.

2.3 Emission Reduction Opportunities

There are two approaches to reducing methane emissions from landfills. First, the methane generated in landfills can be recovered and used to produce energy. Landfill gas, which is generally 50 percent methane, is a relatively inexpensive fuel. Furthermore, landfills are often located near urban centers that need energy. Second, the quantity of landfilled waste can be reduced through source reduction, recycling, and other waste management practices. These approaches are discussed below in greater detail.

Recovery and Use of Landfill Gas: A number of options exist for cost-effectively recovering methane from landfills. Recovery technologies have been demonstrated and are in use, already reducing methane emissions in several countries. There is great potential for expanding these technologies in developed countries, and there are many opportunities to adapt technologies and practices to the conditions existing in developing countries. The available technical options are summarized in Exhibit 2-2 and more fully described in Volume I of this report.

The recovery and utilization of methane generated in landfills involves practices that can be expanded throughout the world. Anaerobic conditions can be maintained in almost any landfill, including landfills covered with thin layers of soil or clay as well as uncovered landfills which are sufficiently dense or deep (Bhide et al., 1990). Between 50 and 85 percent of the landfill gas can typically be recovered from covered landfills, with well-designed projects achieving almost complete gas recovery. Options for using the recovered gas are discussed below.

Electricity Generation and Co-Generation. The recovered methane can be used to power an electricity generator, with the generated electricity used on-site or sold to others for use. The waste heat energy produced during electrical generation can also be recovered and used for local heating needs. Electricity generation requires relatively large amounts of landfill gas, and is therefore suitable for larger landfills. Economic viability depends primarily upon the price at which the electricity can be sold. Historically, over 50 percent of landfill projects worldwide have been for electricity generation (Richards, 1989), including projects in the United States, United Kingdom,

Exhibit 2-2
Summary of the Technical Options for Reducing Methane Emissions from Landfills

Considerations	Methane Recovery and Utilization	Aerobic Landfill Management	Reduced Landfilling of Waste
Recovery/Reduction Techniques	· Recovery Wells · Collection Systems	· Semi-Aerobic Landfills · Recirculatory Semi-Aerobic · Aerobic Landfills	· Source Reduction · Incineration · Composting
Gas Use/Combustion Options	· Electricity Generation · Natural Gas Supply · Flaring	-	-
Availability[1]	· Currently Available	· Currently Available · Under Development	· Currently Available
Capital Requirements	· Medium	· Medium/High	· Low/Medium
Technical Complexity	· Medium/High	· High	· Low/Medium
Applicability	· Existing and New Landfills · Landfill Design · Nearby Gas Use · Capital and Technology Dependent	· Smaller Landfills · New Landfills · Capital and Technology Dependent	· Widely Applicable
Methane Reductions[2]	· 50-90%	· Semi-aerobic: 50% · Others: 80% in tests	· Up to 100%

Source: USEPA, 1993d
[1] All three options are currently available. Continued improvements over the next decades will improve their efficiency and economic attractiveness.
[2] These are reductions that may be achieved at individual landfills.

Germany, Brazil, India, and the Netherlands. The Global Environment Facility (GEF) Fund is planning to undertake a project in Lahore, Pakistan that will recover over 14 million cubic meters (m^3) per year of landfill gas (over a period of five years) from a large sanitary landfill designed to handle 730,000 tons of waste disposed of annually by the city's 5 million inhabitants.

Medium BTU gas. Landfill gas can be used directly as a medium BTU fuel to provide heating, cooling, or steam for industrial processes, or for other industrial purposes. Recovered landfill gas is already profitably used as a boiler fuel and for other industrial and residential applications in a variety of countries, including the United States, Brazil, South Africa and Chile. For example, in a very low cost and low technology gas recovery project operating in Manaus, Brazil, landfill gas is recovered with garden hoses from hand drilled wells, compressed, and used without cleaning as a gas burner fuel in a nearby communal kitchen (Monteiro, 1992).

Natural Gas Supply. Landfill gas can be processed to produce "pipeline quality" gas (over 95 percent methane[1]) with minimal impurities by removing moisture, carbon dioxide and hydrogen sulfide. The gas must also be compressed at a certain minimum pressure to be injected into a pipeline or distribution system. There are several such projects in the United States that provide gas to local gas distribution systems. In Brazil, landfill gas has been recovered and purified using local technology, and used as a vehicle fuel for a fleet of natural gas powered garbage trucks and taxicabs (Monteiro, 1992).

Existing methane recovery projects represent only a small portion of the potential projects worldwide. The United States, the United Kingdom, Germany, and the Netherlands have an estimated 1000 additional potential sites for profitable landfill gas recovery, and about 100 new project sites are already planned in these countries (Richards, 1989) (Exhibit 2-3). Moreover, there are vast opportunities in Eastern Europe and the Commonwealth of Independent States (CIS), where most waste has been disposed of in sanitary landfills and open dumps. For example, electricity generation from landfills may play a large role in the Ukraine where landfilled waste is reportedly over 90 percent paper (Rowland, pers. comm.), and where there is a need to develop domestic sources of gas (the Ukraine produces only 25 percent of its gas demand). In addition, there are many opportunities for many developing countries, including India, Pakistan, China, and Brazil, to expand their current programs.

Alternative Waste Management Strategies: Other technical options applicable in the near and longer term can reduce the landfilling of wastes through source reduction and recycling of organic materials. Paper products, for example, comprise a significant portion of solid waste in developed countries (e.g., 40 percent in the U.S.) and a growing portion of solid waste in some urban centers in developing countries (typically 5 to 20 percent) (USAID, 1988; Vogler, 1984). Paper products can be easily recycled by paper mills into a variety of products, and the markets for the recycled products are, in most cases, identical to those for virgin paper products. Waste paper recycling processes range in technical complexity, and include technologies as simple as hand-operated baling presses.

Composting is another promising waste management option that limits methane generation by reducing the amount of waste landfilled. Composting is applicable in the near and longer term, particularly in developing countries where the organic and moisture contents of municipal wastes are sufficiently high. The economics of composting projects can be favorable with appropriate levels of mechanization and labor-intensity, and if a market exists for the compost. Markets often depend on the demand for fertilizer, and are generally favorable in arid regions and other areas where organic soil supplements are needed.

Incineration of wastes is increasingly used in developed countries to reduce quantities of landfilled wastes, often combined with energy recovery from the combustion process. The costs of incineration are justified based on the increasing costs of handling municipal

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1 Gas from landfills must typically be over 95% methane to comply with minimum energy content standards; natural gas, which often contains significant quantities of other gases such as ethane, propane and butane, may contain less than 95% methane when supplied to pipelines.

solid wastes. While there is potential for this technology to expand in developed countries, there is a much lower potential in developing countries because the wastes are frequently too moist for economically viable operations (USAID, 1988).

A number of countries are planning to incorporate recycling, composting and incineration as part of their waste management programs over the next decades. These countries include the OECD countries, the Commonwealth of Independent States (CIS), Brazil, and some African countries (Thorneloe, 1992). Reductions in methane emissions will result from these activities.

Exhibit 2-3
Existing and Potential Landfill Gas Recovery Projects

Country	Landfill Recovery Projects				
	Existing Projects (#)[1]	Total Energy (10^{12} BTU)	Planned Additional Sites (#)	Sites Under Research and Development (#)	Potential for Additional Sites (#)
United States	114[2]	38.8	68		~200-300
United Kingdom	24	4.0	18	est. 20	450
Germany	70	3.3			500
Netherlands	6	1.0		1	26
Chile	1	1.0			
Sweden	20	0.6			
Italy	6	0.4		3	
France	4	0.4		7	
Japan	1	0.1			
Denmark	4	0.1		2	
Australia	3	less than 0.1	3	4	
Belgium	1	less than 0.1			6
Others	15	n/a	5	13	
TOTAL	242	50	94	50	

Source: Richards,1989
1 These projects only include commercial projects (not R&D sites). Additional gas recovery projects will result from pending landfill rule.
2 Thorneloe, 1992

2.4 The Benefits of Emissions Reductions

Reducing methane emissions from municipal wastes provides benefits to local communities. These benefits vary for the different available technologies; in many cases, the benefits alone are sufficient to justify a project.

Landfill Gas Recovery and Utilization: The benefits of recovering and using the gas generated by landfilled waste include:

- increased supply of competitively priced and otherwise wasted non-fossil based energy. This is particularly important in regions where the demand for energy exceeds the available supply, and especially in developing countries where commercial energy consumption is projected to triple in the next 30 years (OTA, 1992);

- decreased safety hazards from the migration of potentially-explosive methane beyond the landfill boundaries;

- reduced odor problems from landfills; and

- reduced emissions of air pollutants such as volatile organic compounds (VOCs) and air toxics that adversely affect air quality and human health.

Source Reduction: Benefits resulting from reducing the amount of waste that is placed in landfills include:

- savings from the avoided cost of tipping fees (i.e., landfill charges);

- delays or decreases in the demand for new landfill capacity;

- reduced landfill management and other waste disposal costs; and

- reduced environmental risk associated with landfills, such as surface and groundwater pollution and air emissions.

Composting: Benefits resulting from the composting of waste include:

- production of compost material for use as fertilizer;

- production of compost material for use as a soil amendment to improve soil porosity, water retention, erosion resistance, and tilth;

- prevention of plant disease (Kashmanian, 1991); and

- reduced environmental risk associated with landfills, such as surface and groundwater pollution and air emissions.

Incineration: Benefits resulting from incinerating waste include:

- volume reductions of up to 90 percent; and
- potential for significant energy recovery.

In the long term, methane reduction programs may facilitate the more efficient management of municipal solid waste in a manner consistent with the development goals of most countries. Improved waste management will contribute to better health conditions in addition to increased supplies of energy and fertilizer. The wastes that are currently uncollected in the urban areas of many developing countries produce odors and can result in the spread of disease. The substantial quantities of industrial waste disposed of in open dumps pose serious health risks, as they typically contain 10 to 15 percent hazardous materials (Cointreau, 1982) that leach into the groundwater, contaminating drinking water and damaging nearby aquatic life. Efforts to improve waste collection and expand the use of sanitary landfills will thus reduce many health-related and environmental problems.

2.5 Country Profiles

Programs to improve waste management systems and to recover and use landfill gas are successfully underway in many countries. Current methane recovery projects, however, represent only a small portion of the potential projects worldwide, and many opportunities for profitable landfill gas recovery exist in both developed and developing countries.

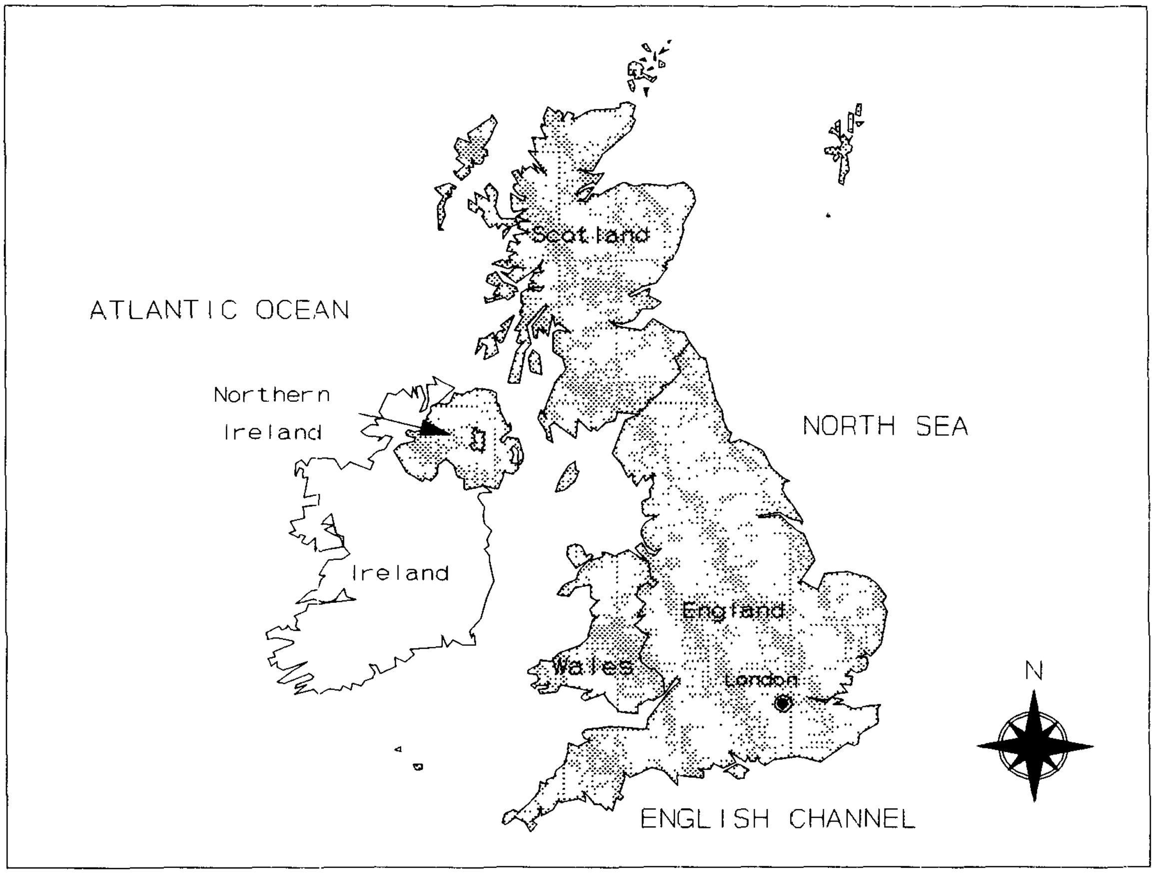
The countries profiled in this section include the United Kingdom, Brazil, India, and Poland. The United Kingdom is discussed first, as an example of an industrialized nation where landfill gas recovery and other practices have been successfully introduced. Brazil and India are representative of lesser developed countries with large potential for reducing methane emissions from landfills. Poland is an example of countries in transition from centrally planned economies. These countries also have substantial potential for landfill methane reductions. The country profiles characterize the waste management situation in each country, and the role technical assistance from industrialized countries might have in encouraging landfill gas recovery.

2.5.1 United Kingdom

Overview

The United Kingdom is an industrialized country that has extensive experience with landfill gas recovery. The United Kingdom (Exhibit 2-4), with a population of over 57 million people, generates approximately 21 to 28 million metric tons of municipal solid waste per year (OECD, 1991; Gendebien et al., 1992), or roughly 0.5 tons per capita. Although estimates vary, between 70 and 90 percent of the waste is disposed of in landfills, over one third of it in large landfills with over 200,000 metric tons of capacity (OECD, 1991; McInnes et al., 1990; Gendebien et al., 1992). The majority of the remaining waste is incinerated, mostly without heat recovery, and small amounts are disposed of in anaerobic digestion projects. The recycling of paper, glass and metal wastes is increasing with government encouragement (Gendebien et al., 1992), resulting in a waste stream relatively high in organics. Recent estimates of total annual methane emissions from municipal solid waste landfills in the UK range from about 1 to 3 Tg (Aitchison, 1993) accounting for more than 20 percent of methane emissions from all sources in the United Kingdom (McInnes et al., 1990).

Exhibit 2-4
United Kingdom



The United Kingdom has been actively recovering and using landfill gas since 1978, primarily in response to rising oil prices that made alternative energy projects more competitive, as well as growing problems caused by uncontrolled gas (e.g., explosions, odors, damage to vegetation). Gas is currently recovered and used at about 35 sites (Richards and Aitchison, 1990; Gendebien et al., 1992) which, together with those that flare recovered gas, account for 15 percent of the country's landfills. Gas is recovered but vented to the atmosphere at

31 percent of the landfills in the United Kingdom, while landfill gas remains uncontrolled at over half of the sites included in a recent study (Richards and Aitchison, 1990).

Projects in the UK have typically achieved gas recovery rates of up to 75 percent, with gas yields averaging around 135 m^3 per metric ton of waste in place (Richards, 1989; Lawson, undated). Current operations in the United Kingdom recover and use a total of about 178 million m^3 of landfill gas per year (Gendebien et al., 1992). However, there is potential to further reduce landfill methane emissions by increasing the use of recovered but unused gas, and also by developing additional recovery projects.

Landfill gas is an economically viable energy source in the UK under a wide range of conditions and for a variety of end uses. In contrast to other countries, a high proportion of individual sites provide gas for two or three different end uses (Gendebien et al., 1992). Of the existing operations, roughly 40 percent provide gas for electricity generation, about 30 to 40 percent for kilns and furnaces, 15 to 25 percent for industrial boilers, and up to 10 percent provide some gas for other uses, such as commercial greenhouse heating (Richards and Aitchison, 1990; Richards, 1989). About 13 electricity generation projects together provide over 20 MW of generating capacity in the UK (Richards, 1989). Electricity generation operations have achieved paybacks of 2.4 to 4.7 years, depending to a large extent on electricity sales taxes. Other utilization options for landfill gas, such as industrial boilers, kilns, and commercial greenhouse heating, have shown paybacks of 1 to 3 years (Energy Efficiency Office, 1990).

The Aveley Landfill, which supplies gas to the Purfleet paper mill, is an example of a successful gas recovery operation. The paper mill is a combined heat and power (CHP) operation comprised of a gas turbine and water tube boiler coupled to a steam turbine. Both the gas and steam turbines generate electricity, and exhaust gases from the gas turbine are used as combustion air in the boiler, which produces steam to generate electricity. Most of the energy generated by the CHP system is used in the plant itself, supplying 90 percent of its needs, while excess electricity is sold to the electricity company. The mill has been economically successful, achieving a payback of only 4 years (with an internal rate of return of 27.8 percent). Similar opportunities may exist for saving energy through CHP installations in any continuous process industry if electricity demand exceeds 2 MW and there is sufficient process heat or steam demand (Gendebien et al., 1992).

Although soft oil prices slowed the development of the landfill gas sector in the 1980s, government incentives for energy generation, along with regulations protecting safety and the local environment, have increased the attractiveness of gas recovery projects (Richards, 1989; Richards and Aitchison, 1990). In 1989, an estimated 20 sites were under research and development (Richards, 1989).

Opportunities to Reduce Methane Emissions in the United Kingdom

The substantial potential for methane emission reductions in the United Kingdom could be realized by promoting the increased recovery and use of landfill gas at sites where it is currently uncontrolled or vented to the atmosphere. Encouraging flaring at sites where gas recovery does not appear to be economically viable could also reduce methane emissions. Other options include expanding the use of alternative waste disposal and energy generation practices (e.g., anaerobic digestion), and continuing to minimize the amount of wastes landfilled through recycling efforts.

Recovery and Use of Landfill Gas: Both the number of landfills with gas recovery operations and the gas yield from each operation could be increased. The United Kingdom currently utilizes landfill gas generated from only 4 percent of its municipal solid wastes, which represents between 7 and 15 percent of the energy potential from landfills (Gendebien et al., 1992). Recent studies suggest that there is a potential to develop operations at 450 additional sites in the UK (Richards, 1989). Moreover, average gas yields may be increased by around 45 percent to roughly 220 m^3 of gas per metric ton of waste. While estimates of the potential landfill gas resource range from 2.5 to 3.6 billion m^3 per year using current practices, the United Kingdom could generate an estimated 9.5 billion m^3 per year by increasing both the number of projects and gas yields (Gendebien et al., 1992; Richards and Aitchison, 1990).

Recent actions by the British government to promote landfill gas operations in the United Kingdom create a favorable framework for increased gas recovery and utilization. For example, the recent Non-Fossil Fuel Obligation (NFFO), part of the Electricity Act of 1989, requires electricity distribution boards to contract for a certain amount of non-fossil fuel based generating capacity (Gendebien et al., 1992). Landfill gas projects have achieved considerable success in the preliminary phases of the NFFO: of the 75 renewable power generation schemes selected for inclusion, 25 are to be fueled by landfill gas. These projects will provide 36 MW of installed capacity and are expected to be completed by 1994. Landfill gas projects are expected to make an even larger contribution under the second phase of the NFFO (Landfill Gas Trends, 1991).

Other governmental actions to promote the expansion of the landfill gas industry include a research program, instituted by the Energy Technology Support Unit (ETSU) for the Department of Energy (DEn) in coordination with the Department of Environment (DoE), to promote the economically viable optimization of gas production and recovery. The program includes research into assessing the national landfill gas resource, understanding and enhancing the processes of gas production, and improving extraction efficiencies (Richards and Aitchison, 1990). These two Departments have also cooperated to form the nationwide Landfill Gas Monitoring, Modelling and Communication System database (LAMMCOS) to facilitate the development and implementation of gas recovery and use operations (Richards and Aitchison, 1990).

Recent regulations issued by the DoE may have mixed effects on the landfill gas industry. These include Waste Management Papers 26 and 27, aimed at ensuring effective gas controls, and the Environmental Protection Act of 1990, which mandates increased landfill gas monitoring and tighter management of landfilled wastes. These regulations may increase the incentive to develop economically viable gas recovery operations at landfills.

Alternative Waste Management Strategies: Substantial methane emissions reduction potential also exists through waste minimization and recycling in the United Kingdom. The Environmental Protection Act encourages these actions, and the DoE intends for 50 percent of recyclable wastes to be recycled each year by 2000. Because recycling removes mostly non-organic material (i.e., glass, plastic and metal), the digestibility and moisture content of the wastes is typically increased, making them even more suitable for biological processing (Richards and Aitchison, 1990). The use of anaerobic digesters for both solid and liquid waste treatment with gas recovery is also being researched by the government (Lawson, undated).

Emissions Reduction Potential

In the short term, it may be possible to profitably recover and use gas at those landfills with over 200,000 metric tons of capacity (which receive over one third of annually generated wastes), as well as at many of the larger closed landfills. Fifty percent reductions in methane emissions from these large landfills may be feasible in the short term, resulting in potential methane reductions of 0.2 to 0.5 Tg per year by the year 2000. Larger reductions on the order of 0.5 to 1.4 Tg per year may be possible over the longer term, due to expanded landfill gas programs, a trend toward larger landfills, and economic and regulatory incentives for methane recovery.

In addition to municipal solid waste, the United Kingdom generates 50 million metric tons of industrial solid waste per year. Although up to 80 percent of the industrial wastes are disposed of in landfills, they are not included in estimates of landfill gas potential (Gendebien et al., 1992). Efforts to recover gas from the non-hazardous portion of these wastes, expand alternative disposal practices (e.g., anaerobic digestion, incineration) with gas or heat recovery, or practice co-disposal with municipal and industrial wastes (Lawson, undated), could significantly increase the potential methane emissions reductions in the United Kingdom.

2.5.2 BRAZIL

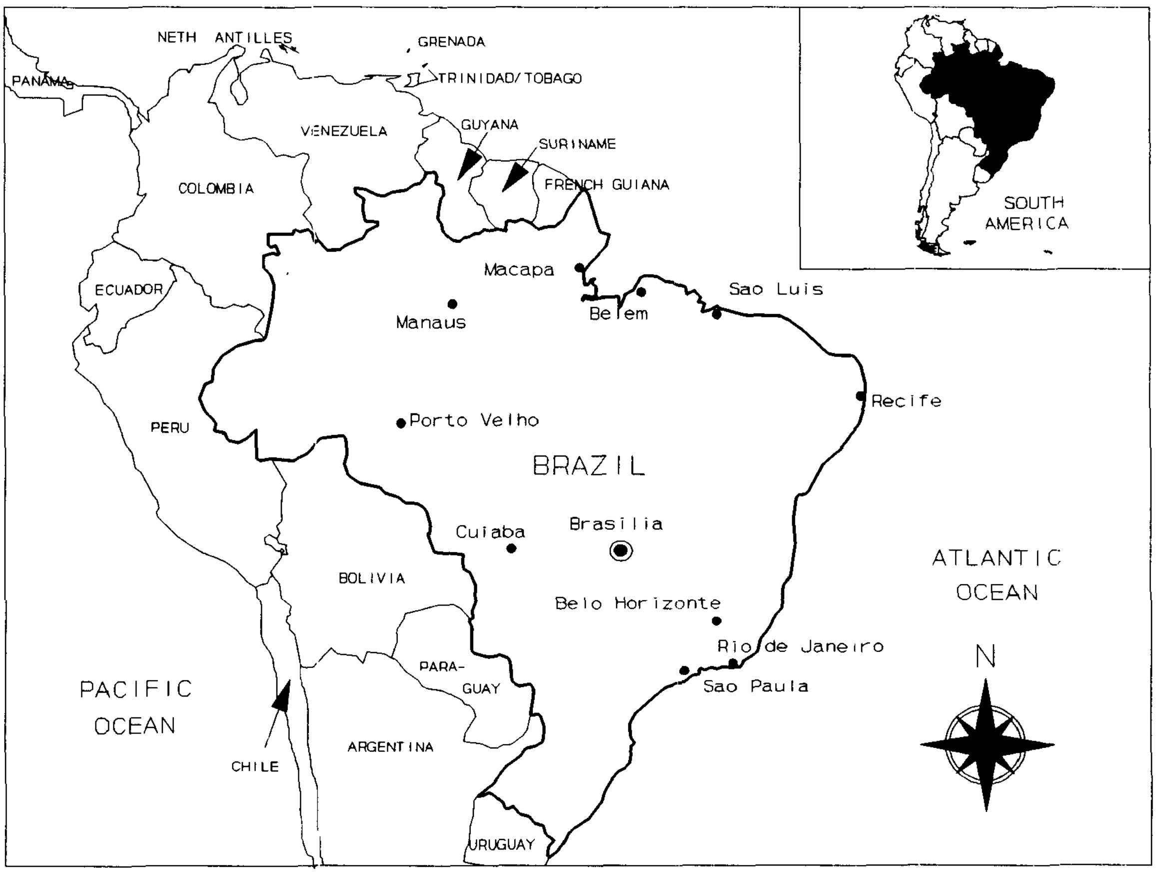
Overview

Brazil (Exhibit 2-5) is a large, rapidly industrializing country. About 75 percent of the approximately 147 million Brazilians live in urban areas, and generate from 16 to 36 million metric tons of solid waste per year. Most of this waste is collected and landfilled, and unlike most other Latin American countries, Brazil has begun a successful program to recover gas from its solid waste landfills. There is substantial opportunity to expand this program.

Waste generation in Brazil is estimated at between 0.4 and 0.9 kg per capita per day. This is thought to be higher than in many lesser developed countries, consistent with the relationship between a country's Gross Domestic Product (GDP) and its waste generation rate (Richards, 1989). Wastes generated in Brazilian cities are typically dense and moist, with a high organic content (Galvez von Collas et al., 1983). Brazil has a well-organized solid waste management infrastructure, with curbside collection of waste in the urban areas. After the economically valuable materials, such as metals, plastics, paper and glass, are manually recycled, the majority of the waste is disposed of in nearby landfills. Between 0.7 and 2.2 Tg per year of methane may be emitted by these wastes (USEPA, 1993b).

Efforts to recover methane from landfills in Brazil have been in progress for over a decade. During the world oil price increases of the 1970's, the Brazilian government began researching and developing possibilities for utilizing energy from solid waste. By 1986, experimental landfill gas recovery and utilization programs were implemented at various landfills, with assistance from the United Nations Development Programme (UNDP) and the World Bank. As a result, commercially viable gas recovery systems are now operating in cities such as Rio de Janeiro, where the municipal sanitation authority (COMLURB) extracts gas and pipes it to the City Gas Company; Sao Paulo; and Belo Horizonte, where landfill gas is produced and distributed by the state energy company (CEMIG) and its subsidiary (Gendebien et al., 1992).

Exhibit 2-5
Brazil



Recent experience has shown that landfill gas recovery and use in Brazil can be economically and technically viable. Methane collection rates at the major Belo Horizonte landfill, which is managed for optimal gas recovery using a cover of soil over impervious clay, are over 8000 m^3 per day. Total gas production rates from three Sao Paulo landfills range from 1500 to 4000 m^3/hour (Gendebien et al., 1992), which would be sufficient to generate roughly 2 to

6 MW of electricity.[2] However, these extremely high gas production rates may limit economic viability in some cases by reducing the period over which gas may be recovered. A recent study predicted that a landfill in Sao Paulo will produce 56 percent of its total gas output during its first year, and that significant gas production would end after about six years (USAID, 1988). This is in contrast to landfill gas recovery projects in the United States, which may have lifetimes of as much as 20 years. Nevertheless, observed recovery rates indicate that, depending on the gas use, energy development projects at many large landfills in Brazil could achieve payback periods of 2.5 years (Kessler, 1988).

A number of viable utilization options have been developed for landfill gas in Brazil. Gas from the Belo Horizonte landfill is compressed, cleaned, and enriched for use as vehicular fuel in city sanitation trucks and other fleet vehicles. Several operations upgrade landfill gas to pipeline quality gas, and two landfills supplement municipal gas supplies to provide boiler fuel for heating applications (Gendebien et al., 1992; Richards, 1989). In addition, government energy companies have developed the capability to replace liquid petroleum gas (LPG) with landfill gas in industrial applications. More recently, recovered gas has been substituted for acetylene in metal cutting. The potential also exists for the use of gas in electricity generation as an alternative to hydroelectricity, currently Brazil's largest electric power source; landfill gas compares favorably in this application, as potential new hydroelectric sites would require long-distance electricity transmission. Developing gas recovery and use capability is given a high priority in the Brazilian Government Natural Gas Plan (PLANGAS), due to the importance of reducing petroleum imports. The expected removal of subsidies for diesel oil and LPG should increase the economic viability of landfill gas recovery projects (Kessler, 1988).

The potential of landfills to provide economically viable biogas should increase in the near future, as Brazil addresses health and odor problems related to solid waste management. Current trends toward more sanitary landfills and more frequent use of soil covers over intermittent layers of garbage and between landfill sections should increase methane recovery rates (Kessler, 1988).

It may also be possible to reduce methane emissions by reducing the amount of waste that is landfilled in Brazil. Several options for the use of solid wastes have been explored. Experimental waste recycling and composting projects have existed since 1980, for example, along with projects to use wastes as an auxiliary fuel source through direct incineration and combustion of refuse-derived fuel (RDF) (Paraguassu de Sa, 1980). Government projects and institutions, such as the research center in Rio de Janeiro, provide technical support for recycling operations and testing of refuse as a source of energy. A national program on the biodigestion of municipal sewage was established in 1979, with the Brazilian Enterprise for Technical Assistance and Rural Extension taking the lead in research and oversight for projects (Gunnerson and Stuckey, 1986). The experience gained from this program has more recently been used in the area of solid wastes, and the economic viability of biodigesting municipal solid wastes (MSW) with biogas recovery is being researched (Kessler, 1988).

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2 Assuming 0.65 m^3/hr of medium quality gas per kW of generating capacity (Volume I).

Opportunities to Reduce Methane Emissions from Waste Management in Brazil

As the ongoing activities indicate, opportunities for methane emission reductions from solid wastes in Brazil are substantial and will continue to grow. The major opportunities will be through improving landfill disposal practices to enhance gas recovery, and substantially increasing the number of sites at which landfill gas is recovered and utilized. In addition, there is potential for increasing alternative solid waste disposal and utilization methods.

Recovery and Use of Landfill Gas: The limited use of sanitary landfilling practices in Brazil currently limits the potential for landfill gas recovery The adoption of sanitary landfilling techniques, which better seal the landfill and promote methane generation, could increase recovery efficiencies, making gas recovery economically viable at more sites. The use of sanitary landfills also reduces other important problems, such as groundwater contamination and odors. Since growing public concern over odors released from open landfills have already prompted the Brazilian government to cover some landfills (Kessler, 1988), further efforts in this direction are expected.

Although landfill gas recovery and use technologies are currently available in Brazil, only a small number of projects exist relative to the potential for energy recovery. While the development of gas recovery and use facilities has been a high priority, the resources of the Brazilian government are limited, and great potential remains to increase the number of energy recovery sites.

Alternative Waste Management Strategies: Increasing the use of alternative solid waste disposal methods may also be feasible in Brazil. The use of available composting, incineration and RDF technologies may be attractive in many areas, and the introduction of appropriate techniques may make these processes more feasible throughout Brazil. Municipal solid waste biodigestion is under development, and may serve as another alternative for economically recovering the fuel value from wastes while reducing methane emissions in Brazil.

Emissions Reduction Potential

Short term opportunities for reducing methane emissions from solid waste in Brazil include the expansion of landfill gas recovery and use facilities in urban areas. Landfill gas operations are most feasible in large city landfills, due to the high waste concentrations and the proximity of available users for the gas (e.g., fleet vehicles, industry, and electricity generation facilities). Although reductions in methane emissions from existing landfills are limited because many of them are open or uncontrolled landfills, it may be possible to reduce methane emissions from urban landfills by about 20 to 30 percent in the short term with expanded efforts. This would result in methane emission reductions of roughly 0.2 to 0.6 Tg per year.

Improving landfilling practices to enhance landfill gas recovery in many of the smaller and medium-sized cities are longer term options in Brazil. Adoption of sanitary landfilling practices where sufficient waste quantities are available should increase the number of economically viable sites. The economic viability of gas recovery in Brazilian cities with fewer than 50,000 inhabitants, which has previously been low (Galvez von Collas et al., 1983), could increase with higher gas collection efficiencies.

Alternative waste management practices may yield benefits in rural regions with low waste quantities. Solid waste biodigestion facilities may require less capital than landfill gas operations, and could provide energy for local uses. Biodigesters and composting operations could also produce fertilizer for agricultural applications.

Promoting Methane Recovery and Emission Reductions

Two key barriers hinder Brazil from promoting the more widespread use of methane recovery techniques and methane reduction practices. These are the current landfilling practices used in many parts of the country and the lack of resources with which to implement improved practices and landfill gas recovery technologies. A number of activities could help to address these barriers and significantly reduce methane emissions from solid waste management. While some of the options are discussed below, the most useful activities could be better delineated only through a series of detailed discussions with Brazilian policy makers and waste management authorities.

Information Dissemination: Many existing landfills in Brazil are not designed to maximize gas recovery. Because each municipality is responsible for its own landfills, local authorities may lack access to the information and technologies necessary to develop landfill gas projects. Providing technical, economic and environmental information on the experiences of the U.S. landfill gas industry to Brazilian policy makers, landfill operators and technical experts, could help resolve remaining technical issues and assist in the expansion of methane recovery efforts.

Technical Assistance and Training: Technical assistance and training may be useful in conjunction with the provision of informational materials. Possible areas of training and technical assistance include the management of certain gas utilization technologies, as well as assessing the economic and technical feasibility of various project options and selecting the appropriate recovery and utilization approach for a particular situation. Training could also be provided in alternative waste management options for situations where landfill gas recovery is not appropriate or feasible.

Technology Demonstration: Additional demonstration projects may be desirable to assess the applicability of different landfill gas recovery and use options, as well as the attractiveness of alternative waste management practices.

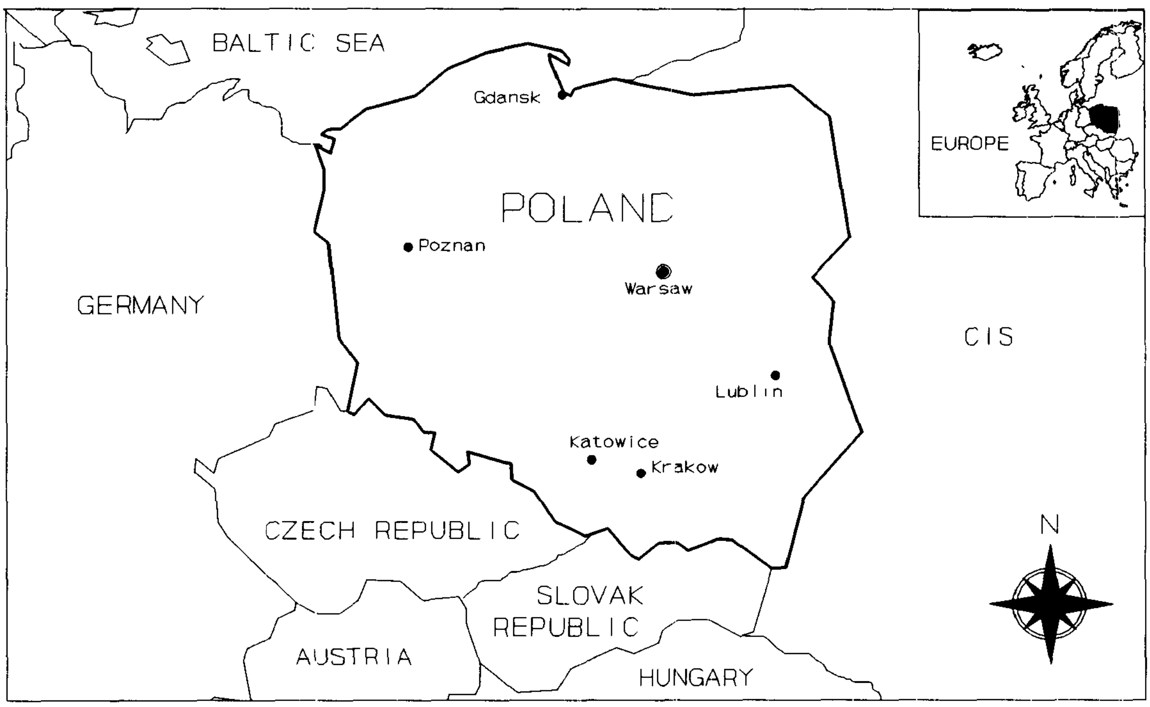
Commercialization: The successful implementation of extensive waste management projects may require joint ventures with private companies and/or international financial assistance. Efforts to generate international interest in the potential of energy generation from solid wastes in Brazil could be directed through existing Brazilian government institutions or programs, such as the waste-to-energy research center in Rio de Janeiro, national programs to research options for biodigestion of wastes, and PLANGAS. Substantial cooperative potential may also be available in the future through the planned Latin American Network of the Improvement of Waste Management (Kreese, 1992).

2.5.3 POLAND

Overview

Poland (Exhibit 2-6), with its population of approximately 38 million, generates an estimated 11.5 million metric tons of solid wastes per year (Pyka, 1993). Much of this waste is generated in the urban areas, with average generation rates twice as high in the approximately forty large cities as in the 440 towns of less than 10,000 people (Kempa and Jedrczak, 1990).

Exhibit 2-6
Poland



Waste collection services are reported to be available in most Polish communities, although no detailed data are available. Most of Poland's collected wastes are disposed of in landfills. Based on inventories in several provinces of Poland, there are approximately 700 registered landfills and over 10,000 illegal dumping sites. Of the registered landfills, 12 are sanitary landfills and about 120 are controlled semi-sanitary landfills. The rest of Poland's waste disposal sites are uncontrolled dumps. Emissions of methane from these landfills are estimated to range from 0.1 to 0.4 Tg per year (USEPA, 1993b).

Few alternatives to landfilling currently exist in Poland: about 1 percent of total generated wastes are composted at two plants, and about 12 incineration plants exist for the disposal of special wastes (Kempa and Jedrczak, 1990). However, through an informal recycling system, paper, plastics, metal scrap and returnable bottles are collected at dumpsites for use and resale. Several programs for formal, residential recycling in apartments also exist on a small scale.

Landfills in Poland are generally chosen and reserved by the Bureau of Town Planning of each province, in line with regional solid waste management plans, which are developed for 25 to 30-year spans and revised every 5 years. Despite their reported use of the World Health Organization (WHO)'s Code of Practice for constructing landfills, landfill sites in Poland have traditionally been chosen based on local road systems, with little consideration given to geological and hydrological factors and, until recently, little effort to control or recover the landfill gas (Kempa and Jedrczak, 1990). The current long-term aim for solid waste management in Poland, however, is to develop plans for closing small and exhausted open dumps and installing larger sanitary landfills to serve at least 150,000 people and receive 2 million m^3 of waste over a period of 20 years or more (Kempa and Jedrczak, 1990).

Attempts have been made to control landfill gas for safety reasons. Landfills have traditionally been built in old gravel pits with unsealed walls and bottoms, allowing the gas to migrate and resulting in explosions in nearby buildings. The projects undertaken in response to such incidents have focused on venting the gas from old landfills and ensuring that new landfills are built to meet sanitary landfill standards (i.e., compacting and covering the refuse daily, using soil or clay as a final layer). Although the newer landfills are designed for gas collection and discharge, methane utilization has not been emphasized as a major goal. Nevertheless, several attempts have recently been made to recover this energy resource from landfills.

The first two landfill gas extraction projects in Poland were unsuccessful for many reasons, including improper construction of the facilities and high ground-water levels. Poland's third and largest gas recovery project commenced near Lodz in May, 1990, with the drilling of four trial wells into a large landfill. The project plans call for building a network of degasification wells to prevent gas from migrating to nearby inhabited areas and to facilitate the recovery of the gas. All gas wells are to be connected to a gas collection pipeline, using suction pumps to collect the methane. Plans for the utilization of the gas include local water heating and electricity generation, depending on the quality and volume of gas recovered (Kempa and Jedrczak, 1990).

Opportunities to Reduce Methane Emissions in Poland

There is potential for recovering and utilizing a large amount of methane from solid wastes in Poland, due to the country's waste composition and disposal practices, as well as the government's solid waste management planning system and growing interest in recovering landfill gas. The success of existing and future programs to recover methane from Polish landfills could be significantly enhanced through the use of improved gas recovery and utilization techniques.

The expanded implementation of alternative solid waste disposal methods may also be feasible in Poland. Composting technologies are available, and the extensive use of composting for urban solid wastes in Poland could provide significant benefits to the population, including the production of high-quality fertilizer. Although this option may not be suitable for small towns, where wastes appear to be poor in organics, studies of individual sites would be useful, as the organic component in solid waste in Poland fluctuates by region and season (Kempa and Jedrczak, 1990).

Incineration and anaerobic digestion of solid wastes may also be attractive options in some cases. Advanced technologies could be introduced to enhance the economic viability and reduce any negative environmental impacts of existing incineration plants. Development and demonstration of biogas digesters may be useful to determine the feasibility of their use in Poland.

Emissions Reduction Potential

The potential for short term emissions reductions in Poland is difficult to assess, because of the large number of unregistered landfills and the preponderance of uncontrolled dumps. Based on available information, however, it is estimated that up to 0.1 Tg per year could be cost-effectively reduced by enhancing current efforts to recover methane from Poland's larger landfills.

The longer term potential for Poland to recover more methane from its solid waste is promising, as the government's interest in controlling and recovering landfill gas as an energy source is growing. The current policy of closing small landfills and open dumps and constructing larger, regional landfills may also facilitate the development of economically viable programs for the recovery and utilization of landfill gas. Reductions could likely approach 50 percent of emissions, or 0.1 to 0.3 Tg per year, over the longer term.

Promoting Methane Recovery and Emission Reductions

Several key barriers impede Poland from promoting the more extensive implementation of improved solid waste management and gas recovery techniques. These barriers include the large amount of waste managed in uncontrolled landfills in Poland, the lack of available information on Poland's landfills, limited access to and experience with technologies for waste minimization and landfill gas recovery, and the lack of a comprehensive policy framework for the development of solid waste energy recovery projects in Poland. These barriers could be addressed through domestic policy efforts, with possible international technical assistance. Some specific activities that could encourage the development of projects to reduce methane emissions in Poland are summarized below.

Policy Reform: Certain policy actions could be useful for implementing new technologies for waste management and/or landfill gas recovery. These actions include:

- Examining existing regulatory frameworks and developing appropriate regulations as necessary to effectively encourage project development;
- Assessing the potential contribution of such projects to the accomplishment of various national energy or environmental sector objectives; and

Providing incentives to encourage project development as appropriate.

Technology Transfer and Demonstration: The demonstration of gas recovery and utilization technologies, as well as various waste minimization strategies (such as composting and/or incineration), could be important components of efforts to encourage project development.

Technical Assistance: Technical assistance and training may be useful to spread knowledge of the technical aspects of sanitary landfilling and gas project development to waste management personnel throughout Poland. Providing training to government and technical personnel, in such areas as assessing the benefits and feasibility of available options for improving waste management and reducing landfill methane emissions, could also facilitate the expansion of methane recovery efforts.

Information Dissemination and Education: Informational programs for local communities and government agencies in Poland could be useful for raising awareness about the environmental, safety and economic benefits associated with reducing methane emissions from landfills, and for gaining support for landfill gas recovery projects and other methane reduction options.

Commercialization: Joint ventures by Polish entities and private companies may be useful in facilitating widespread project development. International investment may also facilitate project efforts. Information could be disseminated to private companies with experience in gas recovery and use, as well as to international development agencies, to ensure that the value of programs to reduce methane emissions from landfills in Poland is recognized.

2.5.4 INDIA

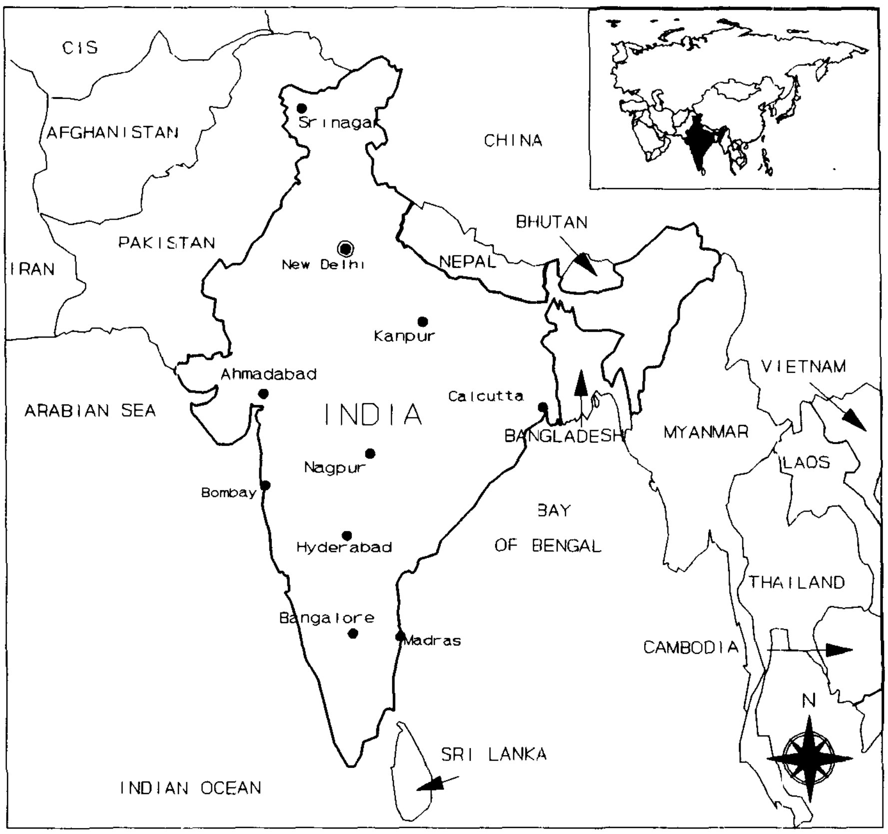
Overview

India (Exhibit 2-7), with 870 million inhabitants in 1991, is one of the most populated countries in the world, and as such has potential to generate a large volume of solid waste. Currently, the rate of waste generation varies widely throughout India, depending on such factors as population density, income level, and the degree to which reusable refuse is salvaged at the source. Most available data on waste generation in India describes urban areas, in which about 22 percent of the total population currently lives. Based on calculations of per capita waste generation in cities (0.3 to 0.6 kilograms per person per day), estimates indicate that India's nine largest metropolitan areas produce about 8.5 million metric tons of solid waste per year. Altogether, the almost 4000 urban centers in India may produce about 22 million metric tons per year (Bhide et al., 1990). Methane emissions from these wastes are estimated to be between 0.2 and 0.8 Tg per year (USEPA, 1993b). These emissions may increase over the next decades as India's population continues to increase and more people reside in the urban areas.

While the majority of India's solid wastes (up to 95 percent) is reportedly disposed of in landfills (Gendebien et al., 1992), site conditions vary widely and many "landfill" sites are really uncontrolled dumps. Most of India's few sanitary landfills are located near the city of

Delhi, which disposes of 90 percent of its daily collection of 1500 metric tons of urban solid waste in four major sanitary landfilling sites. In contrast, 90 percent of Bombay's wastes are dumped directly on coastal areas for land reclamation, and most of Calcutta's wastes are disposed of through uncontrolled dumping on municipal land. In many smaller cities, wastes are often dumped on private lands and in water. Studies indicate that the remaining, non-landfilled waste, as well as some waste initially disposed of in uncontrolled dumps (Bhide, 1993), is either transported to farms for use directly as fertilizer (Rajabapaiah, 1989), or composted to produce organic manure and soil conditioner; in some areas, up to 10 to 15 percent is composted. However, the use of raw garbage on fields may pose problems to farmers who work barefoot, because the garbage contains metals and broken glass (Bhide, 1993).

Exhibit 2-7
India



In large cities, household wastes are swept up and collected by municipal workers, and transported by handcarts or other means to large on-road collection points (open dumps or storage chambers). The wastes are then transferred to trucks and taken to disposal sites. Commercial and industrial wastes are stored in standardized containers and collected by municipal agencies or transferred by the facility to a community bin (owned and maintained by civic authorities and provided at frequent intervals along a roadside). While large cities, such as Delhi, Calcutta, and Bombay, collect about 90 percent of generated wastes, it is estimated that in smaller towns only 20 to 40 percent of the wastes are collected (Bhide and Sundaresan, 1984). At several points, the waste stream is intensively picked through by informal collectors, who remove most of the paper, plastics, and metals in the refuse.

The energy potential of solid wastes in India is a virtually unutilized resource. While some attempts have been made to produce biogas through the anaerobic digestion of solid wastes, these projects have been impaired by a lack of support resources and many are inoperative (Gunnerson and Stuckey, 1986). More recently, three experimental landfill gas utilization plants have been constructed in Delhi and Nagpur (Gendebien et al., 1992).

Recent projects to study gas recovery possibilities at existing landfills have had positive results. At a controlled and covered landfill in Delhi, experimental collection wells have yielded sustained gas flow rates of over 35 m^3 per hour, and provide gas that is 50 to 55 percent methane. The gas collected from this landfill is used (with 20 percent diesel fuel) to generate electricity in a 30 kilowatt (kW) generator. With the planned construction of about 80 wells, the gas from this landfill is expected to generate 8 megawatts (MW) of electricity over a 10-year period (Bhide et al., 1990).

Projects have also been carried out at open, uncontrolled landfills that are more typical of India's landfills. Although older landfills have been shown to produce limited amounts of gas (about 0.25 m^3 per hour), a newer landfill (completed in 1989) has produced gas at rates of 5 to 9 m^3 per hour, with a 30 to 40 percent methane concentration. Gas recovery rates increased substantially when plastic was laid on top of the landfill to prevent gas from escaping (Bhide, 1990).

Opportunities to Reduce Methane Emissions in India

The possibilities for reducing methane emissions from solid wastes in India appear to be significant and are likely to grow in the future. A number of technologies exist that could cost-effectively reduce methane emissions from solid waste in India while providing other benefits, such as energy, fertilizers, and health benefits. Cooperation between the Indian government and international entities to support current efforts to generate energy from solid wastes in India could enhance the success of programs aimed at reducing methane emissions. While the content of wastes in each area varies widely with socioeconomic circumstances and climatic factors, the composition of Indian waste in general appears to be favorable for landfill gas recovery and utilization, biogas production, and composting.

Recovery and Use of Landfill Gas: Sanitary landfilling with gas recovery and use may be a feasible option for many areas of India. The costs of sanitary landfilling even without gas recovery in India are estimated to be five times cheaper than some composting operations, and as much as twenty-five times cheaper than incineration (Nath, 1984). While sanitary landfills are currently restricted to large cities in India, studies indicate that small, non-mechanized sanitary landfilling sites could be feasible for smaller communities, costing less than 5 rupees per ton of waste (Nath, 1984). With the recent encouraging results from tests of uncontrolled landfills, short term potential for methane recovery may also exist in open landfills no longer in operation. However, suburban areas and smaller cities typically generate solid wastes with relatively low moisture, low organic content, and a high percentage of ash and silt (as high as 30 to 50 percent), all of which reduce the potential for methane generation. The most promising areas for gas recovery and utilization will thus be the larger cities, which produce wastes with high percentages of degradable matter (50 to 82 percent) and high moisture content (20 to 50 percent). Much potential exists for promoting both methane reduction and energy generation from this source.

Alternative Waste Management Strategies: Several alternative strategies for managing solid waste are potentially applicable in India, including anaerobic digestion and composting. Incineration may become a viable option if certain operational improvements are made, as discussed below. Anaerobic digestion of solid wastes is a promising option for economically viable waste management in India, producing biogas suitable for local domestic consumption, to generate electricity, or to meet local peak energy needs (Gunnerson and Stuckey, 1986). Moreover, the digester effluent can be used as valuable fertilizer.

High levels of nutrients (e.g., nitrogen, phosphorus, sodium) make composting an attractive option in India. Existing manual composting operations in India are largely self-financing (Nath, 1984). However, mechanical composting plants have to date not been sucessful (Bhide 1993). Recognizing that composting can produce good quality organic manure and soil conditioner at much lower cost than artificial fertilizers, the Indian Ministry of Agriculture has been subsidizing city compost plants and assisting in management and marketing.

Incineration may not be a suitable option for the disposal of most Indian solid wastes. The wastes generally have low calorific values, due to high levels of moisture and inert materials (e.g., sand and silt), and as a result the operation of most incineration plants would require auxiliary fuel (USAID, 1988). Methods for improving the economic viability of incineration in India could include increasing the calorific value by the following means: waste selection (burning only wastes from higher-income residential areas/commercial/industrial areas); waste separation (separating and disposing of inert wastes manually or with rotating screens); and co-firing solid wastes with other biomass (e.g., rice husks or coconut shells) from nearby processing plants.

A combination of gas recovery and utilization, anaerobic digestion with biogas production, and composting, could technically reduce landfill methane emissions in India by about 50 percent. The most appropriate strategies for each area will depend on its waste characteristics and needs, and on existing waste management strategies. The development of gas recovery facilities at existing sanitary landfills could achieve large emission reductions in India, and the construction of other facilities may be feasible, depending on their demonstrated costs and benefits. Because of the substantial need for fertilizer in India, biogas production and aerobic composting, with their nutrient-rich by-products, may be beneficial strategies.

Emissions Reduction Potential

Urban areas offer the greatest potential for the short term improvements in waste management techniques that could reduce methane emissions. Because urban waste is geographically concentrated relative to rural solid waste, and the urban population is growing at a rapid rate, these areas may also represent the most feasible and urgent opportunities for energy generation from solid wastes. For the urban populations, it may be possible to reduce methane emissions by about fifty percent (0.1 to 0.4 Tg per year) in the long term. Some fraction of this could be achieved in the next decade or so.

Improving waste management and introducing energy recovery systems into suburban and rural areas may be a longer term option, requiring new technologies and more field support for small communities. Concern about the health problems associated with poorly managed wastes is growing, however, and the Indian government is considering small scale development of biogas projects and provision of extension services for waste handling. As the population of India continues to grow, improved waste management techniques in these areas could also contribute to reduced methane emissions.

Promoting Methane Recovery and Emission Reductions

India's implementation of available solid waste management and energy recovery techniques may be hindered by a number of barriers. The largest of these include difficulties in developing a uniform collection system, lack of available land for sanitary landfill siting in urban areas, and lack of investment for new technologies. In addition, some new waste management practices developed in more industrialized nations may involve inappropriate technology, such as unnecessary mechanization (e.g., mechanized waste sorting, which does not utilize available manual labor), scale (e.g., collection equipment which does not fit on city streets), and equipment that is not designed for India's waste composition (e.g., incineration equipment). Another barrier may include the possibility of disrupting existing lifestyles. One urban mechanical composting plant was not successful, for example, because the compost was not economically competitive with the traditional sale of the usable garbage by scavengers.

Several types of activities could assist India in addressing these barriers and reducing methane emissions from solid waste. Technological and information exchange with other governments and international organizations could facilitate such efforts. Possible activities to encourage the development of improved waste management techniques and energy recovery projects are discussed below.

Technology Transfer and Demonstration: The transfer and demonstration of methane recovery and utilization technologies could help to encourage expanded recovery projects in India. Such projects could focus on the introduction of technologies appropriate for each region, and the optimal utilization of local financial, material, and human resources.

Technical Assistance: Opportunities to broaden the technical information and training programs available to national and local Indian government personnel and waste management engineers may be useful as a complement to technology transfer programs.

Possible areas of exchange could include resource assessment, cost and benefit analyses of waste management options, and technological training.

Funding: Funding from other governments, foreign development agencies, and the private sector may be useful in leveraging Indian government funds to facilitate studies of the most appropriate waste management options, construction of solid waste energy recovery facilities at demonstration sites, training of technical personnel, and public education programs. Where appropriate, funding from international environmental and development organizations may be helpful in initiating specific projects.

2.6 Summary

As can be seen in the country profiles, individual countries have different waste types and management systems, different levels of support infrastructure, and different resources available to them. While these differences require that policy responses for reducing methane emissions from waste management be designed according to varying regional and national factors, common characteristics can be identified to provide a broad understanding of:

- potential emission reductions from landfills;
- barriers hindering adoption of improved waste management techniques; and
- possible solutions for overcoming these barriers.

Emission Reductions

Based on ongoing activities and the additional potential for profitable methane recovery projects in the different regions represented by the case studies, as well as the plans of a number of countries (e.g., OECD countries, CIS, Brazil, some African countries) to incorporate recycling, composting and incineration into their waste management programs, significant global reductions in methane emissions are possible. These reductions are described below.

Near-term Reductions: Methane reductions of 10 to 15 Tg per year could be economically feasible in the near term by implementing landfill gas recovery operations at identified potential sites, such as larger landfills in developed countries and large, urban landfills in developing countries.

Reducing current emissions from the largest landfills in developed countries by 50 percent will reduce total emissions in these countries by roughly 20 percent, or 5 to 10 Tg per year. Even higher reductions may be possible in some cases: studies in Austria have indicated that reductions of almost 40 percent of current total emissions from Austrian landfills could be achieved over the next decade (Orthofer, 1991); large landfills in the United States will be subject to an impending landfill rule, potentially reducing overall U.S. emissions by 60 percent or more.

It may also be possible to reduce emissions from urban wastes in non-OECD countries by about 20 to 25 percent in the near term, or roughly 5 Tg per year. In some countries in the CIS and Eastern Europe, moreover, estimates indicate that landfill gas recovery operations could reduce current emissions from landfills by as much as one-third. In addition to these landfill gas projects, currently planned programs for recycling, composting, and incineration are expected to reduce methane emissions in the near term.

Longer-term Reductions: Larger reductions should be economically viable over the longer term as waste generation continues to grow, energy demand exceeds the available supply, and more countries implement programs to recover energy from landfills and divert organic wastes toward other disposal practices. As a result of such trends, global reductions of 10 to 25 Tg per year may be possible.

Estimates of methane emissions and potential emission reductions from landfills are summarized in Exhibit 2-8.

Exhibit 2-8
Estimates of Economically Viable Reductions in Methane Emissions from Landfilling Waste

Country	Estimated Emissions (Tg/yr)[1]	Near Term Reductions		Longer Term Reductions	
		Tg/yr	%	Tg/yr	%
United States[2]	8 - 12	4 - 6	~ 50	4 - 6	~ 50
United Kingdom	1.0 - 3.0	0.2 - 0.5	15 - 20	0.5 - 1.4	40 - 50
Brazil	0.7 - 2.2	0.2 - 0.6	25 - 30	0.2 - 0.6	25 - 30
India	0.2 - 0.8	0.1 - 0.2	25 - 40	0.1 - 0.4	25 - 50
Poland	0.1 - 0.4	0.1	~ 20	0.1 - 0.3	20 - 60
Others	11 - 39	4 - 7	15 - 35	4 - 15	15 - 40
TOTAL[3]	21 - 57	9 - 14	25 - 35	9 - 24	40 - 50

1 These emissions estimates are based on recent drafts of the report to Congress *Global Anthropogenic Emissions of Methane* (USEPA, 1993c), currently in preparation, and will likely change as this report is finalized.
2 USEPA, 1993b
3 Totals may not add up due to rounding.

Promoting Methane Recovery

The largest emitters of methane from landfills are, with the exception of China, industrialized countries that have relatively high per capita refuse generation rates. However, as the standard of living and population of developing countries grows, their contribution to global methane emissions will also grow. It is in non-OECD that programs to encourage better waste management, which includes recovery and use of landfill methane, are likely to have the greatest benefit.

There are many opportunities for successful, integrated waste management projects—projects that include landfill methane recovery as well as recycling, composting, and other source reduction activities—in countries that are or will be major contributors to global methane emissions from landfills. As the country profiles indicate, the ability to take advantage of such opportunities is constrained by informational, organizational, and technical barriers. Facilitating the development of integrated waste management will require an aggressive program designed to overcome these barriers through information exchange and dissemination, technical assistance, and technology transfer.

The near-term objectives of a program to encourage integrated waste management are to raise awareness of existing opportunities, assist countries in building the necessary institutional and policy frameworks, and demonstrate the most promising technologies. Obtaining these objectives will require close cooperation with government agencies, waste management personnel, and local communities. Once barriers are overcome and successful, economically viable demonstration projects are in place, widespread use of the technologies should occur rapidly and without extensive outside assistance.

Exhibit 2-9 summarizes the key types of barriers that exist to different degrees in different countries, and which may have to be overcome to improve waste management and encourage expanded methane recovery and use. Exhibit 2-9 also highlights the possible responses in terms of the types of programs and activities that could be implemented to remove these barriers. Of course, programs must be designed to meet the needs and circumstances of individual countries and localities rather than impose "state of the art" technology where it is not appropriate. Those attempting to reform or improve waste management systems in non-industrialized countries face different constraints than waste managers in the United States or western European countries. For example, because waste in developing countries is often wetter and contains more inert material, incineration is usually a poor choice of waste management. Official recovery and recycling programs must recognize the informal recovery of materials that takes place in many countries before waste is landfilled. Recovery of landfill gas for energy use will be a viable technology in many cases; in others, development of sanitary landfills may be the first priority. Despite these differences, the overall types of issues that can hamper development of landfill methane and waste management projects and the most promising activities to address them can be generalized among countries.

When initiating a program to identify economically viable opportunities for improving waste management and encouraging recovery and use of landfill methane, a number of key steps will likely be necessary. Many of these activities have been mentioned briefly in the country studies. The most likely components of an integrated waste management program are described here in more general form, and summarized in Exhibit 2-10 in terms of phases which reflect the natural sequence of the various components.

Initial Assessment: In many countries, preparing a national or regional assessment of the waste management infrastructure and landfill methane resource will be a logical first step in initiating a program. This assessment should evaluate the characteristics of the waste and how it is currently managed, the magnitude of the landfill methane resource, the potential role for landfill methane in the country's or region's energy economy, the capacity of the economy for recycled materials and compost, and the types of barriers that may be constraining development. Particular attention should be paid to the compatibility of landfill methane development with the nation's energy and environmental goals. The current landfill methane recovery and use practices, if any, should also be assessed, and some of the more promising project types identified.

Exhibit 2-9
Key Barriers and Possible Responses for Landfills

Key Barriers	Possible Responses
Policy & Management Issues · Unclear legal and regulatory framework · Many different groups responsible for different parts of waste management · Different groups responsible for waste management, energy generation and supplying fertilizer	· Policy reform assistance · Organize management groups overseeing all elements of waste management · Organize joint management groups for waste management and energy development · Organize joint management groups for waste management and fertilizer supply
Information Issues · Lack of awareness on part of government and others about value of fuel and fertilizer from managed wastes · Lack of awareness on part of potential project developers about potential in various countries	· Provide information on potential near-term value of resource and available technologies. · Provide information to potential project developers and lending agencies regarding role waste management projects can play in meeting country goals
Technical Issues · Lack of access by waste managers to technologies such as drills, composters, and sorters · Lack of familiarity with methane recovery and source reduction techniques · Lack of familiarity with power generation technologies · Technical problems related to the corrosiveness of landfill gas	· Encourage joint ventures and the introduction of new technologies · Establish technology demonstration projects to act as training centers · Establish technology centers to provide information on appropriate technologies and techniques · Disseminate available information on best technologies and maintenance practices for addressing corrosion
Financial Issues · Lack of capital for investment · Subsidized prices for other energy sources reduce attractiveness	· Raise awareness on profitability of landfill projects with international development agencies · Raise awareness on appropriateness of landfill projects for international loans · Assess financial needs for providing more efficient waste management overall

In several countries, such assessments have already been conducted, especially with respect to waste management infrastructure. Therefore, future assessments will primarily focus on the assessment of landfill methane recovery opportunities. Preparing such assessments will require close cooperation among international experts in the landfill methane recovery fields and in-country personnel, who are familiar with national goals, experiences, and conditions. Depending on the scope of the study, the number of regions examined, and the degree of international and in-country participation, an initial assessment should cost $100,000 to $1,000,000 ($U.S.). Assessments conducted for larger countries or more detailed analysis and data collection would mean higher costs. These assessments typically take place over the first one or two years of the project.

Policy and Management Assistance: One of the objectives of the initial assessment is to identify institutional, policy, or other barriers to integrated waste management that includes landfill methane recovery. Such barriers could include overlapping or undefined institutional responsibility, unclear project development requirements, lack of a regulatory structure, and uneconomic landfill methane or other energy source price controls. Since waste management is such an important government activity in most countries, one that involves many different functions, it is likely that existing institutional arrangements are complex and highly decentralized. The institutional and policy barriers may be difficult to overcome. Where barriers are identified, it will be necessary to assess the implications of reforms and develop recommendations for removing the barriers.

Reforms generally must be undertaken by in-country government personnel. Institutional and policy reform assistance, beginning several years into the project and continuing throughout its duration, may be useful to such personnel to provide guidance and information about how similar barriers have been addressed in other countries. Advice could be provided through seminars organized in the country and conducted by expert consultants, or through international or in-country training opportunities for the government personnel. The costs of such programs will vary considerably depending on their scope. Seminars may be provided for $25,000 or more, while long-running consulting or training assistance could cost $100,000 or more. Several seminars and training efforts may be necessary if the project includes several different waste management entities.

Information Exchange: Creating institutional arrangements within countries to disseminate information about domestic and international accomplishments in landfill methane recovery and other aspects of waste management will be an important part of any program. Actions may range from expanding and integrating the roles of existing organizations to creation of independent information clearinghouses.

The cost of information exchange activities vary depending on their scope. Providing information on an ad hoc basis is a relatively low cost activity. Establishment of clearinghouses costs considerably more because of the staffing and equipment requirements. Managing a clearinghouse may cost $75,000 to $100,000 or more annually in developing or transitional countries, costs that would continue until the clearinghouse could be managed internally (possibly after three years).

Technical Assistance: In conjunction with information exchange, technical cooperation on projects can facilitate the development and dissemination of expertise. Technical assistance may include training and cooperative work on studies and pre-feasibility assessments for demonstration projects. Activities could include arranging in-country seminars on technical issues taught by international experts, arranging international training opportunities and study tours, and organizing domestic and international teams to undertake project development activities, such as pre-feasibility assessments.

Exhibit 2-10
Summary of Project Types

Project Type	Phase I Phase II Phase III	Cost
Initial Assessment	■■	$100K-1M per country, depending on scope of study, number of regions studied, and in-country/international participation
Policy and Management Assistance	■■■■■■■■	$25-100K per country, depending on types of activities
Information Exchange	■■■■■■■■■■■■■■	Varies; $75-100K to manage clearinghouse in developing/ transitional countries
Technical Assistance	■■■■■■■■■■■■■■	$25-50K per country for seminar; $50-200K for prefeasibility study; $50K or more for study tour
Technology Transfer	■■■■■■	$500K-15M or more, depending on scope
Commercialization	■■■■■■■■■■	Varies, depending on type & magnitude of project (e.g., LFG: $2-30M)

The costs of technical assistance activities will vary according to the nature of the assistance and the number of organizations or individuals involved. In-country seminars could be arranged at relatively low cost, e.g., $25,000 to $50,000 per seminar. Depending on the degree of detail and domestic participation, pre-feasibility study costs can range from $50,000 to $200,000 or more. International training and study tours will generally cost about $50,000 or more, depending on their duration and the number of participants. Again, several technical assistance activities may be necessary if the project *includes different waste management entities.*

Technology Transfer: In many cases, technology transfer is necessary to introduce and demonstrate additional technologies. Technology transfer activities would include pilot projects that demonstrate the appropriate technology for collecting and using landfill methane, sanitary landfill practices, or methods for developing or improving recycling and composting. Such projects could also demonstrate new technologies that may be suited for a particular country or region. These activities may begin several years into the project and continue through the first decade.

Technology transfer projects will generally be relatively expensive because of the need to purchase equipment. Depending on the scope, the costs of technology transfer projects could range from $500,000 to $15 million or more. A small scale project could include drilling of test wells for assessing gas flow. More expensive projects might include full-scale waste management efforts that include collection, source reduction, sanitary landfilling, and methane recovery/use components. A project of this scope would require investment in infrastructure and equipment, such as trucks (for collection and landfilling), drills, pipes, compressors, and turbines or other gas utilization devices.

Commercialization: Commercialization of landfill gas recovery projects and other waste management practices will be the end result of international exchange programs and assistance. Technology transfer, technical assistance, and information exchange are designed to develop the necessary expertise for full-scale project development, beginning about five years into the program. Commercialization will necessitate considerable investments in gas recovery systems, purification equipment, gas supply infrastructure, and end use equipment. The costs of commercial projects can vary significantly, depending on their magnitude. In the United States, commercial landfill gas recovery project costs have ranged from roughly $2 million to more than $30 million, with most projects between $2 million and $10 million (GAA, 1992). Large scale waste management projects are likely to cost significantly more, as they typically involve infrastructure development and are broader in scope.

The expanded implementation of waste management projects could be facilitated through joint ventures with domestic and foreign private companies and/or cooperation among international governments. International interest in the potential of landfill gas recovery in the United Kingdom has already motivated collaboration with the United States Department of Energy and the USEPA on many aspects of landfill gas research and development (Landfill Gas Trends, 1991).

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CHAPTER THREE

OIL AND NATURAL GAS SYSTEMS

3.1 Introduction

There are large opportunities to reduce methane emissions by promoting the more widespread use of available technologies and practices in the production, transmission, storage and distribution of natural gas. There are additional opportunities to reduce methane emissions during the production of oil. Methane is the primary component of natural gas, and significant emissions are attributed to leakage and venting from various segments of the oil and natural gas infrastructure. Currently, the practices and technologies applied in the field vary between countries and regions, and thus the relative efficiencies of these regions' systems also vary. Methane emissions can be reduced to some extent in all natural gas systems and to a much greater extent in the less efficient systems. These efforts would provide other important benefits such as increasing the overall efficiency of energy production and supply within a country, in addition to economic, environmental, and safety benefits.

An estimated 33 to 68 Tg of methane is released annually to the atmosphere from oil and natural gas systems worldwide (USEPA, 1993b). Natural gas systems are estimated to contribute 22 to 52 Tg per year and oil systems (including associated gas production) the remaining 11 to 16 Tg per year (USEPA, 1993b). Initial investigations indicate that substantial reductions, as much as half of the reductions necessary to stabilize global methane concentrations, may be achieved through implementing available technologies and practices. Furthermore, if this lost gas was recovered and sold it would increase trade revenues for major producing and transporting countries. In addition, programs to improve the efficiency of gas systems would create substantial export potential for durable goods and technical services from countries which are technology leaders in this industry, like the United States.

In order to achieve these substantial emissions reductions and realize the associated benefits, aggressive programs of technical assistance and technology transfer may be required. The general components of such a program are outlined below, including estimates of potential reductions in methane emissions from oil and natural gas systems, and descriptions of the types of technology transfer actions that may be effective in achieving them. This chapter describes a country program designed for the Commonwealth of Independent States (CIS), and in particular Russia, which is the world's largest producer of natural gas and associated gas (gas production associated with oil production), and the world's largest emitter of methane from this source.

3.2 Methane Emissions

Methane emissions are released from processes and operations throughout the gas and oil industries, including from gas and oil production wells, processing and storage facilities, and transmission and distribution systems. Emissions result largely from both intentional and unintentional leakage, during the normal operation and maintenance of these systems. This includes emissions from compressors, gas-operated control devices, well work-overs, and other routine gas system operations, as well as fugitive emissions.

Methane emissions from oil and natural gas systems may generally be divided between those released during the production process and those from post-production processes such as gas processing, transmission, and distribution. Venting and flaring emissions are the primary component of production emissions. Venting and flaring are normal operations at production well sites and are particularly common in cases where the infrastructure to use associated gas produced from oil wells does not exist, or when oil and gas systems are operated as very independent industries. Fugitive emissions and releases of gas from equipment used during the production process are also a significant component of production emissions.

Post-production emissions include all other releases of methane from pipeline operations. These emissions occur at a wide range of locations throughout the system, and result from both intentional and unintentional releases of gas. Important locations and activities which emit methane include venting during system upsets or repairs; leaking components; start up and stopping of turbines and reciprocating engines at compressor stations; venting at pressure reduction stations; and the disposal of waste gas from some gas processing systems.

Worldwide annual emissions of methane are estimated at about 33 to 68 Tg (1.7 to 3.5 Tcf) from oil and natural gas systems (USEPA, 1993b). Emissions from production well sites may account for as much as 15 to 27 Tg per year, or about 40 to 45 percent of the global methane emissions. However, these emission estimates are highly uncertain due to small data samples. This estimate assumes that about 20 percent of gas reported to be vented and flared is in fact released (Barns and Edmonds, 1990) and is used due to the absence of country-specific information. Post-production emissions from oil and gas systems likely account for roughly 18 to 41 Tg per year, the remaining 55 to 60 percent of global methane emissions from this source (USEPA, 1993b). These emissions are largely from the natural gas industry.

The emissions estimates are based on a number of recent country studies for the CIS, Germany, United States, and Norway. The estimate remains uncertain due to remaining uncertainty in the existing studies and the lack of detailed studies for important regions of the world. As country and regional data continue to be developed, these estimates can be revised.

Emissions of methane may also be classified based on whether they come from oil or gas systems. Thus, gas systems account for roughly 22 to 52 Tg per year of methane emissions, or 66 to 76 percent of total emissions from oil and gas systems. Oil systems, including associated gas production, account for roughly 11 to 16 Tg per year, or the remaining 24 to 33 percent of emissions (USEPA, 1993b).

The majority of the 33 to 68 Tg of methane emitted annually from oil and natural gas systems comes from those countries with the highest gas production levels. The CIS and the U.S. represented approximately 40 and 24 percent of gross gas production and roughly 50 to 53 and 7 to 8 percent of worldwide emissions in 1990, respectively. As shown in Exhibit 3-1, methane emissions from the CIS and the U.S. primarily result from operations of their gas systems, with emissions from oil systems making a relatively small contribution. A number of other oil and gas-producing and consuming nations also contribute significant methane emissions. In contrast to the CIS and the U.S., however, oil production accounts for a relatively high portion of their methane emissions. This is typically because infrastructure for gas use does not exist in many other countries.

Exhibit 3-1
Natural Gas Production and Estimated Methane Emissions from Oil and Gas Producing Countries (1990)

Country	1990 Gas Production[a] (Tcf)	Total Methane Emissions[b] (Tg/yr)	Natural Gas Systems Emissions	Oil Systems Emissions
CIS	28.3	16 - 36	15.8 - 34.7	0.5 - 1.3
- Russian Federation	22.6[c]			
U.S.	17.1	2.4 - 5.3[d]	2.2 - 4.3	0.2 - 1.0
Other Countries	26.1	14.5 - 27	4.5 - 13.9	10.0 - 13.1
World Total[e]	71.2	33 - 68	22.4 - 52.0	10.7 - 16.0

a From USEPA, 1993b, based on UN, 1992 (reported in pJ, and converted to Tcf)
b USEPA, 1993b
c Sagers, 1990; 1991
d USEPA, 1993a
e Totals may not add up exactly due to rounding.

3.3 Emission Reduction Opportunities

There are a number of available technologies and practices for reducing methane emissions from oil and natural gas systems which could be implemented on a more widespread basis. These technologies and practices are commonly used in a number of countries and have resulted in significantly lower methane emissions.

For example, in the United States, the application of technologies and practices such as routine pipeline maintenance, new piping materials, leak detection practices, and pipeline rehabilitation and repair practices has reduced system losses to less than 1 percent of total marketed gas. Furthermore, emissions from the gas system can be profitably reduced by an additional 25 percent or more with increased efforts on enhanced inspection and maintenance, replacement of some components with newer designs, capturing of gas vented from dehydrators, use of better seals, and other changes in routine operations (USEPA, 1993c). These techniques also result in improved safety, increased productivity, and improved air quality. Emission reductions on the order of 20 to 80 percent are possible at particular sites, depending on site specific conditions. The different technical options for reducing methane emissions from oil and natural gas systems are summarized in Exhibit 3-2, and are discussed in more detail in Volume I of this report.

Exhibit 3-2
Summary of Options for Reducing Methane Emissions from Oil and Natural Gas Systems

Considerations	Reduced Venting and Flaring During Production	Improved Compressor Operation	Improved Leak Detection and Pipeline Repair	Low Emission Technologies and Practices
Reduction Techniques	· Recover Associated Gas · Reinject · Flare · Well Work-overs	· Reduced Fuel Use · Gas Turbines · Reduce Starts/ Stops	· Detection · System Monitoring · Reduced Venting at Blowdowns · Repair/ Replacement	· Capturing Purged Gas · Directed I/M Programs · Upgrade Equipment
Support Technologies	· Gas Infrastructure · Reinjection Well Drilling · Efficient Flares · On-site Gas Utilization	· Lean Burn Engines · Integrated Control Systems · Hydraulic Starters · Dynamic Modelling	· Gas Analyzers · Measurement Devices · Automatic Shutoff Valves · Portable Compressors	· Offtake Station Design · Low-Bleed Devices
Availability[1]	· Currently Available	· Currently Available	· Currently Available	· Currently Available
Capital Requirements	· Low[2]	· Medium	· Low/Medium	· Low
Technical Complexity	· Low	· Low	· Medium	· Low
Applicability	· Dependent Upon Current Emissions · Technology and Capital Availability	· Large Compressor Stations	· Widely Applicable: - Older Systems - Poor Conditions	· Widely Applicable
Methane Reductions[3]	· Up to 50%	· Up to 90%	· Up to 80%	· Up to 80%

Source: USEPA, 1993d
1 Available with continuing improvements expected over the next decades.
2 Large capital investment will be necessary only if developing infrastructure for associated gas use is required.
3 These are reductions that can be achieved at appropriate individual sites or systems.

In general, the potential emissions reductions for a given natural gas system depend on several factors, including the amount of gas produced and transported, the age of the system, operating pressure, the soil conditions, the level of technology applied in the system, and the market potential for increased gas supply. The most promising regions for reducing methane emissions from this source are those with high production, throughput and consumption, and lower system efficiencies. Such regions have significant potential for introducing newer technologies and practices. Lower-efficiency systems are typical of operating concerns that have been constrained by capital shortages or have recently undergone massive expansions. Both of these factors exacerbate the inefficiencies and, thus, methane leakage.

The region with the highest potential for emission reductions is the CIS, and especially Russia. The gas system in the CIS may have leakage rates many times higher than the more efficient systems in the West. Russia, which produced over 80 percent of total gas production in the CIS in 1990 and which has a relatively large emission rate estimated at 3.0 to 6.7 percent of production (Rabchuk et al., 1991), has the potential to achieve particularly large reductions.

While opportunities exist to reduce emissions from oil, the primary focus of efforts to reduce emissions will be improvements in gas systems because global emissions in general are predominantly from gas systems. The major emitters, the CIS and the United States have relatively low emissions from oil systems. The combined emissions from the major oil producing countries such as Saudi Arabia, Mexico, Iran and Venezuela are relatively small compared to emissions from natural gas systems in the U.S. and the C.I.S.

Achieving technically feasible and economically viable reductions will depend upon accurate assessments of opportunities, the development of implementation plans, government policies, and the availability of financial and technical resources.

3.4 The Benefits of Emissions Reductions

The development of projects and programs that reduce methane emissions from oil and natural gas systems will have many benefits, including improvements in energy supply and trade balance, improved safety and system efficiency, and reduced local air pollution.

Energy Supply and Trade Balance: Achieving emissions reductions through the profitable application of technologies and practices in a given country will have the benefit of cost-effectively increasing domestic energy production, thereby either reducing imports or increasing the amount of gas available for export. This can improve both energy supply security and trade balances. In cases where fossil fuel exports are a country's primary source of hard currency, like Russia, small increments in increased exports can have a proportionately larger impact on the domestic economy.

Improved System Efficiency: Methane emissions represent a system inefficiency. Lost gas is a cost which must be born by the system operator and consumer, and results in lost economic benefits. In many cases, the economic benefits of improving efficiency will cover the costs of making the improvements.

Improved Safety: Leakage and other releases of natural gas may pose a safety hazard to workers, consumers, and the general public. As existing gas systems grow older, emissions may be expected to increase, requiring increased use of detection and rehabilitation techniques. The use of advanced construction materials and technologies in new systems can reduce emissions and prevent deterioration. Reducing emissions from oil and natural gas systems can improve the overall safety of these systems.

Reduced Local Air Pollution: The increased supply of natural gas, especially through the reduction of venting and flaring, will allow natural gas to be used in place of other fossil fuels such as oil and coal, which often create significantly worse air pollution. Natural gas is also a more efficient energy source, particularly where there are fluctuating heating demands. Other air pollutants from gas systems include NO_x emissions in compressor exhaust, and sulfur dioxide and volatile organic compound (VOC) emissions from processing facilities. Improving system efficiency to reduce methane emissions will also reduce these emissions.

3.5 Country Profile: Commonwealth of Independent States

Overview

The Commonwealth of Independent States (CIS) is the largest producer, transporter, consumer, and exporter of natural gas in the world, producing almost 40 percent more gas than the next largest producer, the United States. As shown in Exhibit 3-3, the CIS produced about 30 Tcf of natural gas in 1990, as compared to about 22 Tcf in the U.S.

Exhibit 3-3
Natural Gas Production & Disposition in 1989

	CIS (Tcf)	U.S. (Tcf)	World (Tcf)
Gross Production	29.8	21.5	89.33
Vented & Flared	0.11	0.14	3.28
Reinjected	0.09	2.49	8.36
Marketed Production	29.10	18.60	76.18
Dry Gas Production	28.78	17.81	73.15
Imports	0.05	1.53	10.93
Exports	3.94	0.09	10.93
Apparent Consumption[1]	24.96	18.71	72.85

Source: US DOE, 1992
[1] Defined as dry gas production plus stock changes, plus imports, minus exports

Within the CIS, Russia is the dominant natural gas producer, with some 66 percent of total CIS production coming from the Tyumen region of Western Siberia (within Russia). Western Siberia has become the center of Russian gas production over the last twenty years as production activity shifted from the European part of Russia (IEA, 1991). Accordingly, this region has witnessed explosive growth in production levels (300 percent), compared to modest growth in Turkmenia and Uzbekistan, and declining production in the Ukraine (U.S. CIA, 1991). Exhibit 3-4 details the trends in production levels in the CIS.

Natural gas is an extremely important fuel for the CIS. As gas consumption has increased over 75 percent in the last decade (US DOE, 1992), it has come to provide about 42 percent of the 57.15 quads of primary energy consumed by the CIS in 1990. In comparison, natural gas provides only about 24 percent of primary energy used by the United States. Most of the natural gas consumed in the CIS is used by industrial facilities and power plants (see Exhibit 3-5). In addition, the CIS exports almost 13 percent of its dry gas production to Western Europe and Eastern Europe. At a European border price of $2 to $3/Mbtu[1] (IEA, 1991), CIS exports have an estimated value of $7 to $10 billion.

Exhibit 3-4
Dry Gas Production in the CIS (Tcf/year)

State	1970	1975	1980	1985	1986	1987	1988	1989	1990
Russia	2.93	4.06	8.97	16.32	17.76	19.21	20.84	21.75	22.6
- W. Siberia	0.35	1.34	5.65	13.28	14.8	16.42	18.05	19.03	20.02
Urengoy	-	-	1.77	9.01	10.31	11.02	11.48	11.83	-
Yamburg	-	-	-	-	0.14	0.99	2.47	3.18	-
Medvezhye	-	1.06	2.51	2.51	2.47	2.30	1.87	1.77	-
Vyngapur	-	-	-	0.57	0.60	0.60	0.60	0.60	-
- Eur. Russia	2.40	1.87	1.34	1.06	1.02	1.06	1.02	1.02	0.92
- Urals	0.14	0.81	1.80	1.73	1.70	1.66	1.66	1.60	1.55
Turkmenistan	0.46	1.84	2.51	2.93	3.00	3.11	3.11	3.17	3.11
Uzbekistan	1.13	1.31	1.24	1.24	1.38	1.41	1.41	1.45	1.45
Ukraine	2.15	2.43	2.01	1.52	1.41	1.27	1.13	1.09	1.02
CIS Total	7.00	10.21	15.36	22.71	24.23	25.67	27.19	28.11	28.78

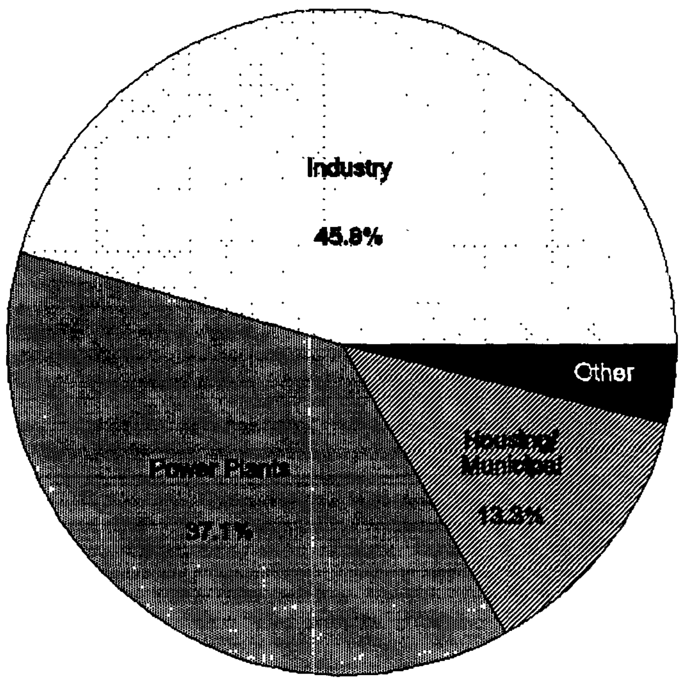
Source: Sagers, 1990; 1991
Note: Dry Gas Production does not include associated gas.

[1] Mbtu = million British thermal units (Btu's); 1 cubic foot of CIS gas = 932 Btu's of energy (US DOE 1992)

The former Soviet Union built up a sophisticated and complex system to provide natural gas to industrial and urban centers throughout its territory and for export. The extensive infrastructure currently includes[2]:

- approximately 9,000 producing wells in 200 gas and condensate fields;
- 300 small gas handling facilities to process the gas at the field sites;
- 6 large gas processing complexes, 4 of which are in Russia; and
- over 136,000 miles (220,000 km) of pipeline in the gas supply system of the CIS (Exhibit 3-6).

Exhibit 3-5
Gas Delivered to Consumers in the CIS in 1988



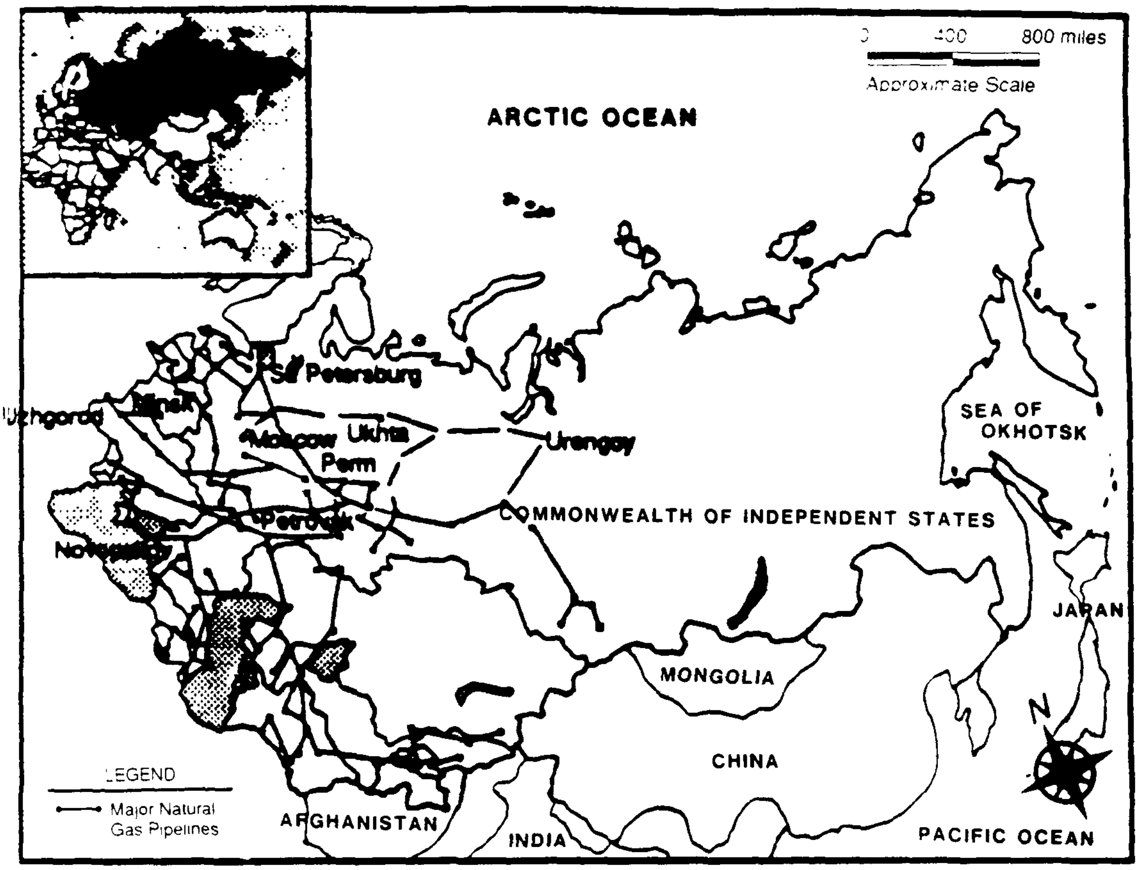
Gas Delivered (Tcf)

	Industry	Power Plants	H/M	Other
CIS	8.6	7.0	2.5	0.7
US	8.4	2.7	4.6	2.7

Source: CIS - Gorst, 1988; U.S. - DOE, 1991

2 Sources: Baudino & Volski, 1991; GAZPROM Personal Communication, 1991.

Exhibit 3-6
Major Natural Gas Pipelines in the Commonwealth of Independent States



While GAZPROM (the state enterprise controlling the natural gas system) has achieved many of its objectives for increasing the delivery of natural gas over time, it has done so with a minimum of resources. A shortfall in equipment supplies combined with rapid construction during the 1970s and early 1980s in the harsh conditions of Western Siberia, a lack of advanced pipeline technologies, and conflicting incentives and policy frameworks, has challenged the ability of GAZPROM to maintain and improve the system over time.

As a consequence of technical and operational difficulties the natural gas system has significant emissions of methane. It is estimated that the CIS oil and natural gas system may emit some 16 to 36 Tg per year (0.8 to 1.8 Tcf) into the atmosphere (USEPA, 1993b). This corresponds to emitting from 3.0 to 6.7 percent of total gas production.[3] Published

[3] This includes methane emissions from oil systems. The gas system alone (i.e., not including associated gas production, or other oil system emissions) from 2.9 to 6.5 percent of gas production.

estimates of total methane emissions from the natural gas system of the CIS have ranged from as low as 2 percent to as high as 12 percent of production (Baudino & Volski, 1991; Rabchuk et al., 1991; Foreign Scouting Service, 1989). The CIS could thus account for up to 50 percent of the world's methane emissions from natural gas systems. Exhibit 3-7 shows the results of one study estimating leakage from major stages of the CIS natural gas system. Approximately 25 percent of these emissions are from production, and 75 percent are from post-production emissions.

These estimates remain highly uncertain. Most of the uncertainty is due to three factors: the lack of measured data from transmission and distribution systems; the scarcity of data describing venting and flaring at production; and the lack of accurate accounting for gas lost in accidents. A number of efforts, including multilateral and bilateral activities, currently being initiated should begin to reduce this uncertainty over the next several years.

Opportunities to Reduce Methane Emissions

The current economic and political changes in the republics of the CIS have created a unique opportunity to work with CIS enterprises to introduce a number of technologies and practices that could cost-effectively improve the efficiency of the CIS natural gas system. These technologies and practices include:

- Drilling, Completion, and Down-hole Sand Control: Many of the gas contaminants which cause difficulties with equipment downstream from the production fields are the result of poor completion, drilling and down-hole particulate control. Introducing technology in this area has large potential to improve system performance, and reduce system and equipment failures.

- Improved Well Maintenance ("Workover") Practices: Gas wells are occasionally shut down and cleaned out, or "worked over", to maintain gas production at a desired level. In the U.S., the flow from wells is closely controlled using chokes thereby reducing formation damage, and as a result workovers are required only once every 10 years on average. In contrast, wells in the GAZPROM system may be shut down for maintenance or workovers and put back into operation two to three times per year; These gas losses each year can be 1 to 4 Tg or more (70 to 212 bcf) of gas, or 0.3 to 0.8 percent of dry gas production (Rabchuk et al., 1991). In the U.S., only 500 to 8,000 cubic feet is vented per workover (PSI, 1990). If the production associations were able to adopt western practices and technologies, methane emissions and maintenance costs could be greatly reduced.

- Increased Gas Processing Capabilities: Expanding gas processing capacity would prevent further internal damage to pipelines from corrosive impurities in the natural gas. This includes greater removal of corrosive compounds such as sand, hydrogen sulfide, carbon dioxide, and especially water vapor (which facilitates corrosion). Improving the gas processing technology and increasing its capacity would significantly reduce pipe line degradation, extend valve and pneumatic service life, and reduce gas loss from system upsets and repair blowdowns. The long term operating and maintenance cost of gas transportation would be reduced similarly.

The capacity of byproduct recovery units (especially sulfur/hydrogen sulfide) should be increased. Byproduct processing would allow GAZPROM to produce raw materials useful in the agriculture and chemical industries, in addition to reducing the local environmental impact of byproduct dumping and/or disposal.

- Improved Pipeline Leak Prevention & Rehabilitation: The deterioration of gas transmission and distribution pipelines significantly contributes to methane emissions from the CIS gas supply system. Accelerated deterioration has put some lines out of service in as little as 5 to 7 years. The rate of reconstruction has increased but does not meet the need for pipeline renovation. (GAZPROM communication, 1992). While the problems encountered in the gas supply system of the CIS are not unknown in other systems, the use of a wide variety of sophisticated techniques for preventing the deterioration of buried pipelines typically prolongs the life of pipeline systems in many other countries. Investing in the increased use of available technologies in the CIS, could reduce methane leakage, increase throughput, and extend the life of many pipelines throughout the CIS.

- Increased Compressor Engine Fuel Efficiencies: Gas compressors used in the CIS have fuel efficiencies of about 24 to 27 percent. About 12 percent of their total installed power capacity is over 15 years old and technologically obsolete. Alternatively, Western compressor units can attain fuel efficiencies of 33 percent or better. Improving the efficiency of CIS compressor engines to match those of Western units would significantly reduce fuel use, NO_x emissions, and CH_4 releases from engine exhausts.

- Improved Gas Measurement Technologies & Metering: GAZPROM officials have indicated that the move toward a market-based economic system in the CIS will create a need for improved gas measurement capabilities (GAZPROM Personal Communication, 1992). This includes real-time monitoring of particular natural gas characteristics: throughput, especially at transfer points (e.g., borders, consumers); energy content; impurity content; and volume. Improving gas measurement technologies will indirectly reduce methane emissions to the atmosphere by facilitating effective analysis of system performance.

- More Efficient End User Equipment: Commercial and industrial end user equipment, especially power stations and industrial plants, is another significant leakage source. Introducing U.S. technologies could reduce leakage losses and improve process efficiencies, as well as provide potential business prospects for U.S. companies. Improved efficiencies and advanced technologies will have trickle-down effects on other sectors of both the American and CIS economies, such as bolstering the manufacturing sector in components and finished goods, while creating the potential for new ventures to export or manufacture equipment within the CIS. The concentrated nature of end use equipment and the relatively inefficient energy conversion in the CIS indicates large potential for efficiency gains and reductions in gas demand.

Exhibit 3-7
Estimated Methane Emissions from the CIS Natural Gas System

Gas System Segment	Emissions as a % of Gas Production[1]	
	Low	High
Oil and Gas Production		
Associated Gas	0.03	0.15
Non-Associated Gas	0.72	1.62
Oil	na[2]	na[2]
Processing, Transport, & Distribution		
Cleaning, Drying, Compressing	0.18	0.45
Collection Networks	0.09	0.23
Underground Storage	0.09	0.26
Compressor Stations	0.18	0.45
Linear Part of Main Pipelines	0.81	1.49
Distribution Networks	0.14	0.45
Industrial Consumers[3]	0.68	1.49
Residential/Commercial Consumers[3]	0.07	0.17
Total Losses	**2.99**	**6.68**

Source: USEPA, 1993b

1 Assuming methane content of 90%. Pipeline gas may also include ethane, propane, butane, carbon dioxide and nitrogen.

2 Emissions of methane from dedicated oil production (not including associated gas production) is estimated to be 319 to 5,033 kg per Pj of oil produced (USEPA,1993b).

3 Emissions of methane from industrial consumers are calculated using the estimated leakage of 1 to 2.2 percent of *consumption*, as opposed to production, cited in Rabchuk (1991). Emissions of methane from residential/commercial consumers are calculated using Rabchuk's assumption that emissions from this sector are approximately half as much as in the industrial sector or 0.5 to 1.1 percent of *consumption*. Based on the total production levels used in EPA 1993b, the percent of total production emitted differs from the original estimate of emissions as a percentage of total production cited in Rabchuk. That is, the percent of production and percent of consumption emitted, in Rabchuk, are not self-consistent using current production and consumption data.

The need to implement available technologies and practices presents large opportunities for the U.S. gas industry and equipment manufacturers, who can provide these technologies and services. Moreover, state organizations responsible for gas systems in the new states (especially the Russian Federation) are increasingly interested in joint ventures, technology sharing, and cooperative efforts to improve various aspects of their existing systems. They are also interested in the potentially significant economic and local environmental benefits that would have a positive impact on the region's energy supplies and stability. These benefits are both short-term and long-term.

Environmental Benefits: GAZPROM officials have expressed concern about the emission of NO_x from natural gas compressor stations (GAZPROM Personal Communication, 1991). In 1990, NO_x emissions from GAZPROM operations totalled 615,000 metric tons (Baudino

& Volski, 1991). Improving the fuel efficiency of GAZPROM's compressor engines could significantly reduce NO_x and methane emissions, in addition to contributing to the economic benefits detailed below. Furthermore, according to GAZPROM officials, there is an insufficient supply of gas processing equipment and, as a result, gas containing highly-corrosive hydrogen sulfide is entering some transmission lines, shortening pipeline lifetimes and causing critical equipment, such as safety shut-off valves, to malfunction (GAZPROM Personal Communication, 1991). Increasing the capacity of processing plants in the CIS would, therefore, reduce methane leakage and contribute to reducing pipeline maintenance costs.

Economic Benefits: If two-thirds of current methane losses were recovered through efficiency improvements, as seems possible, another 0.5 to 1.2 Tcf of gas could be made available for export with a potential economic value of $1.1 to $3.8 billion. The potential increase in export revenues could be used to increase investment in infrastructure and technology, and to reduce GAZPROM debt. In addition to direct savings from recovering lost gas, several GAZPROM operating costs can be reduced, including 1) system maintenance and repair costs resulting from high impurity levels, and 2) the payment of emissions fees. There is also the potential for reducing imports of sulfur.

Increasing the capacity of processing plants also provides a potential source of sulfur from the hydrogen sulfide which is removed. The expansion of sulfur separation capacity would allow the CIS to more economically satisfy domestic demand for sulfur, which is currently met by expensive imports. Moreover, increasing gas processing and sulfur separation capacity will reduce the environmental damages of sulfur dioxide produced when unused hydrogen sulfide is flared, and solids are dumped.

A second indirect operating cost that might be reduced is the "pollution tax" on emissions of methane, sulfur dioxide, and nitrogen oxides which GAZPROM must pay (GAZPROM Personal Communication, 1991). The current CIS domestic gas price and the pollution tax alone are not sufficient economic incentive to justify emission reduction projects. Nevertheless, because the potential reductions discussed in this report are economically justifiable in their own right (based on border prices), tax savings represent additional savings. Expected moves towards market-based pricing and taxing should also improve the cost-effectiveness of such projects.

Energy Supplies and Stability: Maintaining energy production and supply will be critical to maintaining the economic and social stability of Russia and the new states. The current losses from the ex-soviet gas system, which can be greatly reduced with available technologies, represent a wasted energy resource. Therefore, improving the gas system is, in effect, an economically viable method of increasing production and throughput without increasing the draw on gas reserves. Taking advantage of the potential benefits of more efficient production -- reduced operating costs, expanded export earnings and domestic energy supply, improved safety, and reduced local air pollution -- can only have a positive impact on the development and stability of ex-soviet republics.

Emissions Reduction Potential

While there is considerable uncertainty over the total emissions from the CIS gas system, the system has large potential for emissions reductions. In comparison to the emission rates in the CIS, methane emissions from natural gas systems in Western countries are estimated at about 1 percent of production. Even at the low-end of these estimates, the potential for economically viable emissions reductions in the CIS exists. Moreover, because of the large production capacity of the CIS system, these reductions are larger than commensurate percentage reductions in other systems.

There is potential for even larger emissions reductions if CIS emissions are at the higher end of the emissions estimates. For example, using recent estimates of emissions of 3.0 to 6.6 percent of production, improving the efficiency of the CIS natural gas system by reducing emissions to 2 percent of production would result in annual emissions reductions of roughly 5 to 25 Tg. This reduction results in an effective 1 to 5 percent increase in productivity. Efforts to achieve these reductions and associated productivity increases are focused on the gas system because the majority of emissions result from gas system operations.

Promoting Methane Reductions

GAZPROM and its associates have faced a number of barriers in their efforts to develop, maintain, and recondition the gas system in the CIS. Many of the existing pipelines and other facilities are reaching the end of their design lives. Replacement costs, combined with continued growth, are placing a heavy demand on already scarce capital. While in the long term the gas industry is expected to become financially independent, external suppliers of capital and equipment may be necessary in the short term. Accurate assessments of the technical needs for system improvements and the capital necessary to finance them are required to begin addressing this problem.

The principal actions that could facilitate projects to reduce methane emissions are summarized below:

Pre-feasibility Studies/Pilot Projects: Pre-feasibility studies and pilot projects are necessary to complete technical and financial audits of technology transfer and service business opportunities related to improving the Russian gas delivery system. The preliminary phase of these studies would involve a technical inventory of the gas system, and the measurement of emissions at key facilities. The technical inventory would describe the physical state of each major component of the Russian gas pipeline system, including production fields, pipeline segments, processing facilities, compressor stations, and large end users of natural gas. Improved measurements of emissions from key sectors of the gas system would improve the identification of problem areas and enhance the awareness of the magnitude of the wasted resource.

Prefeasibility studies would significantly improve the information base for potential investors, financing organizations, and governments. Studies and pilot projects will demonstrate both the economic viability and environmental benefits associated with each project, and will help to prioritize investment capital allocation by GAZPROM and also direct the capital flow from international aid and financing organizations. Furthermore, the information base created in this phase will help reduce the project risk profile for companies seeking Russian markets and for the financing institutions considering project loans, hence lowering the economic hurdles for investment capital targeted for the Russian gas system.

Working with the U.S. gas industry, feasibility analyses could be performed for a variety of projects. These projects would range from well workovers and pipeline rehabilitation to manufacturing of useful gas pipeline support equipment such as gas analyzers. These analyses would identify short term (high impact) and long term (major overhaul) projects for cooperative business opportunities, emphasizing the environmental and economic benefits of these projects.

Technology Transfer and Demonstration: In many areas the CIS natural gas experts and system operators are well versed in available technologies and practices. However, in several key areas multilateral or bilateral assistance to transfer and demonstrate technologies would greatly accelerate the path toward a more efficient system. These areas include: production technology, reservoir recovery optimization, gas processing, dehydration, compressor efficiency, compressor station design and equipment, maintenance practices, pipeline design, pipeline and valve repair, accident response, city-gate station equipment, and system modelling.

Project Financing: Market-based pricing, and a healthy gas industry in general, will be particularly important in providing future investment funds. Currently, state controlled prices result in operating losses, which make it difficult to fund infrastructure improvement projects. Although the technology exists in many cases, there are often insufficient funds to obtain the equipment necessary to make widespread improvements in the gas system. Current economic plans call for the gradual establishment of market prices, which will increase the availability of capital in the long-term. In the short-term, however, funding projects will likely require external capital. An increase in export capacity and/or efficiency will provide much-needed capital by increasing the CIS' share of the hard currency export markets of Europe.

In particular, project financing could be developed to promote U.S. business efforts in the Russian energy sector. Federal financing agencies could help build the strength of US companies' bids for contracts in Russia by establishing loan guarantees, and feasibility study pilot project grants which support the export activities of such US based technology source companies. The US is somewhat slower to react than our European counterparts in these promotional activities. American companies have the best available technology and a strong reputation in Russia. There is a window of opportunity for US businesses to gain significant market share in Russia. The US government can effectively advance US technology exports and technology transfer to Russia by accelerating the flow of American capital in these areas.

Institution Building -- Establish Methane Recovery Technology Centers (MRTCs): The establishment of clearinghouse type institutions to disperse technical information, financial resources, and bilateral business contact information will greatly facilitate emission reduction programs. At present, no single source is available where current environmental, technical, financial, and business contact information is available. Establishing the MRTCs in Moscow and Kiev would help disseminate information on the full range of methane recovery and use technologies, publish journals, hold seminars, and perform other related policy activities. The MRTCs could also support critical studies conducted by in-country personnel on various technical, regulatory, and economic issues. The MRTC could address methane recovery from natural gas systems, coal mining and other methane sources, and could perform a vital role in making business opportunities in these fields accessible to U.S. and Russian companies.

3.6 Summary

Emission Reductions

Potentially economically viable reductions in methane emissions from oil and natural gas systems can be estimated based on the current range of methane emissions and estimates of the portion of emissions that can be cost-effectively reduced as derived from examinations of the CIS and the United States. Experience in the United States shows that 25 percent reductions can be profitably achieved, while the CIS situation would imply reductions on the order of 30 to 70 percent. These reductions may be as high as 10 to 35 Tg per year.

- Near Term Reductions: In the near term, there is potential to reduce annual methane emissions by 4 to 16 Tg by identifying and implementing high-impact projects that address larger leakage problems. Efforts would focus on potential improvements in the West, and on the larger reductions that could be made in Russia. The United States could likely contribute about 0.8 Tg per year of this near-term reduction (USEPA, 1993c). In addition, similar improvements made in other countries might achieve reductions on the order of 10 to 20 percent, and would result in emission reductions of 1 to 5 Tg per year or more. The remaining 3 to 10 Tg per year would be achieved by efforts in the CIS.

- Long Term Reductions: In the long term, reductions of 7 to 34 Tg per year (21 to 50 percent of total emissions from gas and oil operations) can possibly be achieved through applying available technology to recover gas and prevent leakage in gas and oil operations worldwide.

Estimates of methane emissions and potential emission reductions from oil and natural gas systems are summarized in Exhibit 3-8.

Promoting Methane Reductions

Further efforts may be needed to encourage the reduction of methane emissions from the oil and natural gas system in the CIS and other regions of the world. Currently, the opportunities for economically viable emissions reductions have not been adequately identified in many countries. In some cases, the scope of emissions is not appreciated, or the costs of wasted gas are not fully taken into account. Additionally, access to technologies, information, equipment, training and other resources may be limiting factors. Aggressive programs to identify opportunities and address the needs of different regions could encourage potential emissions reductions. Typical barriers hindering the application of apparently economically viable technologies for reducing emissions from oil and natural gas systems are summarized in Exhibit 3-9.

Future activities should be focussed on expanding opportunities for U.S. industries, particularly in the CIS and Russia. U.S. funding programs could facilitate the open involvement of U.S. industry by reducing the risk associated with potential investments and providing critical information to interested parties. These efforts could include establishing working relationships with gas experts, assessing in detail the technical status of the system, identifying sources of financing and the types of ventures that are feasible, and assisting in policy development.

Exhibit 3-8
Estimates of Economically Viable Reductions in Methane Emissions from Oil and Natural Gas Systems

Country	Estimated Emissions in 1990 (Tg/yr)[a]	Near Term Reductions		Longer Term Reductions	
		Tg/yr	%	Tg/yr	%
CIS	16 - 36	3 - 10	20 - 30	5 - 25	30 - 70
US	2.4 - 5.3	0.3 - 1.2[b]	13 - 23[b]	0.3 - 1.3[b]	13 - 25[b]
Others	14.5 - 27.0	1 - 5	10 - 20	2 - 8	20 - 30
TOTAL	33 - 68	4 - 16	12 - 24	7 - 34	21 - 50

Sources:
a USEPA (1993b)
b USEPA (1993c)

Specific activities, focussed on opportunities in the CIS, but likely applicable to other regions of the world include:

- Pre-feasibility Studies/Pilot Projects: These studies, which include the preparation of a technical inventory of the gas system and measurement of emissions from key facilities, improve the information available to both in-country organizations, as well as to potential foreign business and institutional investors.

- Technology Transfer and Demonstration: These types of projects can speed the implementation of available technologies and practices, as well as introduce new methods for improving system efficiency.

- Project Financing: The sustainable improvement in a country's gas system ultimately relies upon the availability of finances to maintain and improve the gas system. In the long term conditions which frequently result in operating losses, such as heavily subsidized energy prices, should be addressed. In the shorter term, it is often necessary to obtain external capital to finance improvements in the gas system.

- Institution Building: The establishment of institutions to develop and disseminate technical and information, as well as bilateral business contacts, can play a vital role in facilitating projects.

Exhibit 3-9
Key Barriers and Possible Responses for Oil & Natural Gas Systems

Key Barriers	Types of Actions
Legal & Regulatory Issues • Uncertain gas ownership • Unclear mechanisms for joint stock/venture project development; tax issues • Project approval process difficult	• Resolve ownership legally or legislatively • Develop system for foreign investment, repatriation of profits, etc. • Establish low or zero tax rates on foreign direct investment to encourage western business. • Utilize concession or production sharing type agreements to preserve national cashflow interests. • Streamline and clarify project approval process
Information Issues • Lack of awareness on part of government and gas industry personnel about magnitude and value of emissions reductions • Lack of awareness on part of potential project developers about potential in various countries	• Provide information to countries on emissions, reduction options, and appropriate policies • Provide information to oil and gas companies, and lending agencies regarding potential for profitable projects
Technical Issues • Lack of access to existing technologies such as low bleed valves, measurement techniques, and processing technologies • Lack of familiarity with maintenance procedures, such as wellhead work-overs • Lack of familiarity with pipeline repair and control technologies, such as polyethylene pipe replacement	• Fund demonstration projects in key technical areas • Organize study tours and training trips for key gas industry personnel • Establish technology centers to disseminate information on state-of-the-art technologies and techniques
Financial Issues • Lack of capital for investment in methane recovery projects • Dependence of gas organizations on subsidies • Low subsidized energy prices reduce economic attractiveness • Absence of economic incentives to become efficient	• Encourage the development of joint ventures to introduce new approaches • Foster free market pricing of gas at all stages of the system • Introduce cost accounting of lost gas; economic incentives for gas recovery

These activities are outlined in Exhibit 3-10 below.

Exhibit 3-10
Summary of Project Types

Project Type	Phase I	Phase II	Phase III	Cost
Prefeasibility Studies	■■■■			$100K-2M per country
Technology Transfer & Demonstration		■■■■		$100K-10M depending on scope of project
Project Finance			■■■■	Varies, depending on size of project
Institution Building		■■■■■■■■■■■		$75-100K per year; 1 or 2 per country or region

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CHAPTER FOUR
COAL MINING

4.1 Introduction

Coal mining represents a promising opportunity to reduce methane emissions because of the availability of technologies to expand methane recovery and use at coal mines, and the many benefits associated with such projects. In many countries, methane recovery could be greatly increased by degasifying coal seams in advance of mining, using proven vertical or in-mine recovery methods. This degasification can occur well in advance of mining activities and can be fairly independent of coal production. This gas can then be used for power generation or industrial and residential uses. In addition to reducing the amount of gas wasted during the mining operation, such projects should also improve coal mine productivity and safety, which are of great importance to the coal industry. In many countries, there is potential for coalbed methane to make a large contribution to primary energy supply.

Currently, many countries use degasification technologies to maintain mine safety, but only a portion of the recovered methane is used as fuel. In 1990, for example, an estimated 2.8 to 3.9 Tg per year of methane was recovered by mine degasification systems but only about 1.3 Tg per year was used (USEPA, 1993b). The remaining 1.5 to 2.6 Tg per year of methane was vented to the atmosphere, thereby wasting a medium to high quality fuel. This currently vented degasification methane represents a major near-term opportunity for reducing methane emissions in many countries. Developing uses for this gas will require investments in improved methane recovery as well as gas utilization equipment and infrastructure.

A general program for encouraging expanded methane recovery and use is outlined below, including potential reductions, technologies that are likely to be most applicable and economically viable, and activities that need to be undertaken to encourage project development. Specific opportunities and programs are also outlined for several countries with large methane emissions from coal mining. These countries include the People's Republic of China, Poland, former Czechoslovakia, Russia, and Ukraine.

4.2 Methane Emissions

Methane and coal are formed together during coalification, the process in which swamp vegetation is converted by geological and biological forces into coal. Methane is stored in large quantities within coal seams and also within the rock strata surrounding the seams. Two of the most important factors determining the amount of methane that will be stored in a coal seam and the surrounding strata are the rank and the depth of the coal. Coal is ranked by its carbon content; coals of a higher rank have a higher carbon content and generally a higher methane content. Pressure, which increases with depth, tends to keep methane in coal seams and surrounding strata from migrating to the surface. Thus, within a given coal rank, deep coal seams tend to have a higher methane content than shallow ones.

Most of the methane emitted from coal mining comes from a small number of the major coal-producing countries. As shown in Exhibit 4-1, the three highest methane emitters from coal mining--the People's Republic of China, the United States, and the Commonwealth of

Independent States (the former Soviet Union)--are estimated to account for about 70 to 75 percent of global methane emissions from this source (USEPA, 1993b). The top ten emitting countries constituted about 90 percent of total methane emissions from coal mining.

Exhibit 4-1
Estimated Methane Emissions from Coal Mining in Ten Largest Coal Producing Countries, in 1990

COUNTRY	1990 Coal Production (million tons)		Estimated Methane Emissions (Tg/yr)	
	UNDERGR.	SURFACE	LOW	HIGH
People's Republic of China	1,023	43	9.5	16.6
United States	385	548	3.6	5.7
CIS	393	309	4.8	6.0
Poland	154	58	0.6	1.5
South Africa	112	63	0.8	2.3
India	109	129	0.4	0.4
Germany	77	359	1.0	1.2
United Kingdom	75	14	0.6	0.9
Australia	52	154	0.5	0.8
Former Czechoslovakia	22	85	0.3	0.5
SUBTOTAL - TOP 10	2,401	1,762	22.1	35.9
GLOBAL TOTAL	4,740		24.4	39.6

Source: USEPA, 1993b.

Approximately 80 to 90 percent of global methane emissions from coal mines are liberated by underground mining activities. Emissions per ton of coal mined range from about 5 m^3/ton to as much as 85 m^3/ton in some of the world's gassiest mines (USEPA, 1993a; Pilcher et al., 1991; Marshall, 1993). These emissions include both the methane released from mined coal and from surrounding strata.

Most of the methane liberated by mining is currently being emitted to the atmosphere at concentrations of less than 1 percent in mine ventilation air (USEPA, 1993b). However, a significant amount of methane is currently being released from mine degasification systems. In 1990, an estimated 1.3 Tg per year of mining emissions was recovered by mine degasification systems and used instead of being vented to the atmosphere. It is estimated that this represented only 30 to 50 percent of total degasification emissions, however, and that between 1.5 and 2.6 Tg per year of medium and high-quality gas was vented by degasification systems during the same year (USEPA, 1993b).

4.3 Emissions Reduction Opportunities

Increasing methane recovery and use is technically feasible at many coal mines, but may require a shift in the traditional perception that coal companies and government authorities have of mine degasification. Techniques for removing methane from mines have been developed primarily for safety reasons, because methane is highly explosive in air at concentrations between 5 and 15 percent. At mines throughout the world, these same techniques have been successfully adapted to recover methane so that the energy value of this fuel is not wasted. However, many additional opportunities exist to expand the use of these technologies and reduce worldwide emissions of methane to the atmosphere. The principal methane recovery techniques are summarized in Exhibit 4-2, and are discussed in more detail in Volume I of this report.

The identification and design of technically feasible, economically viable projects to recover and use methane from coal mines is determined by several factors, such as:

Coal and Geological Characteristics: In general, the methane content of coal and the associated methane emissions tend to increase as mines become deeper and higher ranked coals are mined (USEPA, 1993a). Geological conditions are important because they influence the liberation of gas from the coal and surrounding strata;

Mining Method: Different mining methods can result in different methane emission levels, depending on the degree of caving of the mined areas. In general, longwall mining tends to cause greater caving, and these mines frequently have higher methane emissions (USEPA, 1993a);

Current Methane Recovery and Use Practices: Many mines around the world currently employ degasification techniques to maintain safe mining conditions. In some cases, the recovered gas is used as a fuel, but many mines vent some or all of the recovered gas to the atmosphere. An evaluation of the opportunities to expand or modify existing practices can provide valuable information about the near- and longer-term potential to increase methane recovery and use;

Potential Methane Recovery Techniques: There are many different methane recovery techniques, including surface or in-mine methods which recover methane before, during, or after mining (ICF Resources, 1990). The applicability of the full range of techniques in different countries and mining conditions should be fully assessed;

Local Conditions: The most appropriate methane recovery and use techniques can be heavily influenced by local conditions. For example, current or planned surface uses can affect the attractiveness of surface methane recovery technologies. Similarly, the characteristics of local infrastructure and industry will influence the selection of appropriate gas utilization options; and

Exhibit 4-2
Methane Recovery and Utilization Strategies

Considerations	Enhanced Gob Well Recovery	Pre-Mining Degasification	Ventilation Air Utilization	Integrated Recovery-Combined Strategies
Recovery Techniques	• In-Mine Boreholes • Vertical Gob Wells	• Vertical Wells • In-Mine Boreholes	• Fans	• All Techniques
Support Technologies	• In-Mine Drills and/or Basic Surface Rigs • Compressors, Pumps, and other support facilities	• In-Mine Drills and/or Advanced Surface Rigs • Compressors, Pumps, and other support facilities	• Surface Fans and Ducting	• All Technologies • Ability to Optimize Degasification Using Combined Strategies
Gas Quality	• Medium Quality (11-29,000 kJ/m^3) (300-800 Btu/cf) (approx. 30-80% CH_4)	• High Quality (32-37,000 kJ/m^3) (900-1000 Btu/cf) (above 90% CH_4)	• Low Quality (1% CH_4; usually below 1%)	• All Qualities
Use Options	• On-Site Power Generation • Gas Distribution Systems • Industrial Use	• Chemical Feedstocks *in addition to those uses listed for medium quality gas*	• Combustion Air for On-Site/Nearby Turbines and Boilers	• All Uses
Availability	• Currently Available	• Currently Available	• Likely to be Demonstrated by 1995	• Currently Available
Capital Requirements	• Low	• Medium/High	• Low/Medium	• Medium/High
Technical Complexity	• Low	• Medium/High	• Low/Medium	• High
Applicability	• Widely Applicable • Site Dependent	• Technology, Finance, and Site Dependent	• Nearby Utilization • Site Dependent	• Technology, Finance, and Site Dependent
Methane Reductions[1]	• Up to 50%	• Up to 70%	• 10-90% recovery	• 80-90% recovery

Source: USEPA, 1993c

1 These are reductions that can be achieved at an appropriate individual site.

Project Requirements: Different types of methane recovery and use projects will require varying levels of capital, imported equipment, infrastructure, and experience. Depending on available resources of capital, equipment and expertise, particular projects may be more or less attractive in various countries.

For those mines where methane recovery is technically feasible and local market conditions ensure that the recovered gas will be used, it may be possible to develop profitable projects to reduce methane emissions. In the near-term, these projects are likely to employ well-demonstrated mine degasification techniques, as well as common methane utilization options, such as power generation or industrial use.

As mentioned previously, degasification technologies are employed by many gassy underground coal mines throughout the world to maintain safe mining conditions. Exhibit 4-3 summarizes the available information on the use of these systems at coal mines in key countries, and it also provides important information about the potential to reduce methane emissions associated with coal mining. In most countries, mine degasification systems currently recover around 25 percent of the methane emitted by the underground mines (Pilcher et al., 1991; Bibler et al., 1992; Marshall, 1993; USEPA, 1993a). As the exhibit shows, anywhere from 25 to more than 80 percent of this recovered gas is used.

Exhibit 4-3
Estimated Degasification System Emissions in Ten Largest Coal Producing Countries

COUNTRY	Degasification System Methane Emissions (in Teragrams)		
	Total Recovered	Amount Used	Amount Wasted
People's Republic of China	0.29	0.18	0.11
United States	0.7-1.8	0.25	0.45-1.55
CIS	0.83	0.19	0.64
Poland	0.19	0.14	0.05
South Africa	n/a	n/a	n/a
India	n/a	n/a	n/a
Germany	0.35	0.25	0.10
United Kingdom	0.21	0.14	0.06
Australia	0.1	0.05-0.08	0.02-0.05
Former Czechoslovakia	0.09	0.08	0.01
TOTAL - TOP 10 COUNTRIES	2.75-3.85	1.28-1.31	1.44-2.57

Sources: Williams, 1989; UNDP, 1992; Zabourdyaev, 1992; Coal Mining Research Company, 1990; Pilcher et al., 1991; Bibler et al., 1992; Zimmermeyer, 1991; British Coal, 1991

Programs to reduce emissions from coal mining must focus on both expanding the recovery of methane at coal mines and developing additional uses for the recovered gas, as indicated in Exhibit 4-3. In the near-term, efforts should be undertaken to increase the utilization of the gas that is currently being recovered by mine degasification systems. In many countries, such as the United States, various barriers to utilization cause a large amount of high-quality gas to be emitted to the atmosphere after being recovered (USEPA, 1992). In the longer-term, efforts should focus on improving the recovery efficiency of mine degasification systems, particularly through the transfer of additional recovery techniques, and on the development of economically viable utilization options for methane in very dilute form.

With the exception of mines in the United States, for example, few countries currently use surface methane drainage techniques to degasify coal mines (Pilcher et al., 1991; Bibler et al., 1992; Marshall, 1993; JP International, 1990). The application of vertical drilling 10 or more years in advance of mining can significantly reduce methane emissions, however, perhaps by as much as 60 percent or more (Diamond et al., 1989). When vertical pre-drainage is combined with in-mine recovery or the use of surface gob wells, moreover, potential methane recovery efficiencies can reach 75 percent (Pilcher et al., 1991). The applicability of methane pre-drainage using vertical wells should be evaluated in key countries, and technologies transferred as appropriate.

In addition, utilization options for low concentration methane contained in mine ventilation air need to be demonstrated and publicized. Two mines, one in Poland and one in Germany, have been reported to use some of their ventilation air, although detailed information on these projects is not currently available. Because of the large volumes of such air, developing such utilization strategies would have a dramatic impact on methane emission levels.

4.4 The Benefits of Emissions Reductions

Developing projects to reduce methane emissions from coal mining will have many benefits. As summarized below, expanded methane recovery from coal mines can improve mine safety and productivity, increase domestic supplies of a clean-burning, versatile fuel, and improve local and global environmental air quality.

Mining Safety and Productivity: The accumulation of methane gas in underground mines has always posed a great risk of explosion, threatening both miners' lives and mine productivity. Ventilation of mines with large quantities of air can also be a large operating expense for deep underground mines. In the future, as coal is mined from increasingly deeper and gassier seams, the economically viable removal of methane from coal mines will become more important. By using recovered gas, both methane emissions to the atmosphere and the costs associated with ensuring safe mining conditions can be reduced. In some cases, the ability of a mine to generate revenue through gas sales may also provide a source of much-needed investment capital. In this way, coalbed methane recovery can spur future improvements in mine productivity and profitability.

Energy Supply and Trade Balance: In many countries, coalbed methane has the potential to be an important domestic energy source. Several countries, such as Poland and the former Czechoslovakia, have few other domestic sources of gas, and increasing the recovery and use of coalbed methane can reduce their need to import gas from Russia or other countries (Pilcher et al., 1991; Bibler et al., 1992). Because most energy imports must be purchased with hard currency, increasing the production of domestic reserves can improve energy security and reduce trade imbalances.

Clean, Efficient, and Convenient Energy Source: Natural gas has several advantages over other fossil fuels. Emissions of SO_2, NO_x, and particulates can be reduced through the displacement of coal (and to a lesser degree oil) with gas (USEPA, 1986). Natural gas combustion produces no SO_2 or particulate emissions, and lower NO_x emissions. Therefore, a 10 percent increase in gas use (e.g., in a retrofitted coal-fired burner) would result in a 10 percent decrease in SO_2 and particulate emissions.

Natural gas is also a more efficient energy source, particularly where heating demands fluctuate, such as in residential cooking and heating applications. Coal combustion cannot respond efficiently to low load operation, nor is it easy to start and stop operation as the heating load swings. In comparison, gas can respond instantaneously to heat demand and can be used for low load operation, thereby providing a more efficient fuel source.

In China, the government has sought to improve the quality of life for coal miners by providing recovered methane to nearby mine communities for residential cooking and heating, which has the added benefit of displacing coal and reducing local air pollution (JP International, 1990).

4.5 Country Profiles

The following country profiles outline specific opportunities and programs for coalbed methane recovery in the People's Republic of China, Poland, the former Czechoslovakia, Russia, and Ukraine. These countries are profiled because of the large opportunity each one presents for methane recovery, due to the magnitude of their current emissions from coal mining.

4.5.1 THE PEOPLE'S REPUBLIC OF CHINA

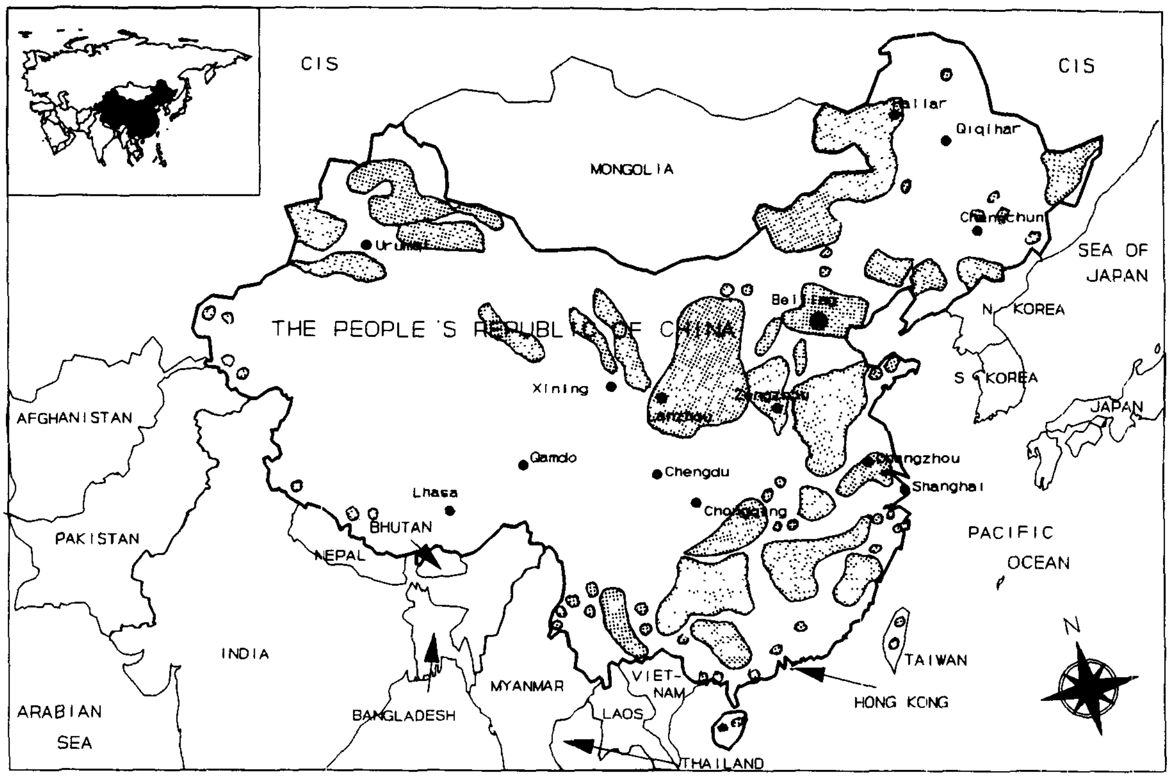
Overview

The People's Republic of China is the world's largest coal producer, producing over 1 billion tons in 1990 (Sinton, 1992). China's economy is heavily dependent on coal, which satisfied almost 75 percent of total domestic energy consumption in 1990. Large amounts of coal are used for industrial purposes, as well as for residential cooking and heating. By contrast, natural gas represented less than 2 percent of China's energy use in 1990, with consumption of about 15 billion cubic meters (bcm) (Sinton, 1992). China's current plans for energy sector development continue to rely heavily on coal production, moreover, with production predicted to increase to 1.2 billion tons in 1995 and perhaps 1.4 billion tons in 2000. Over this same period, natural gas production is expected to reach only 20 bcm (UNDP, 1992).

Not surprisingly, China is the world's largest emitter of methane from coal mining; its estimated coal mining emissions of 8.5 to 13.0 Tg per year are about one-third of the world's total emissions from this source in 1990 (USEPA, 1993b). More than 97 percent of China's coal is mined in underground mines, and many of them are extremely gassy. Of the roughly

600 state-owned coal mines, for example, more than 300 were classified as gassy and/or outburst mines (UNDP, 1992). The state-owned mines produced about half of China's coal in 1990, and the remaining production came from more than 60,000 local or provincial mines, about which there is little information. China's major coal basins are shown in Exhibit 4-4.

Exhibit 4-4
Major Coal Basins in the People's Republic of China



Chinese officials and miners have begun to realize the importance of coalbed methane as a separate energy source, and a recent Chinese estimate concluded that the resource could exceed 30 trillion cubic meters (tcm) (MOE, 1991a). Currently, about 110 coal mines have mine degasification systems, and they recovered about 434 million cubic meters (mcm) of gas in 1990 (MOE, 1991a). This represented less than 5 percent of estimated total methane emissions from underground mines, however, with the rest being emitted by ventilation systems. The government's plans call for this recovery level to increase to 500 mcm by 1995, but gas production could far exceed these projections with a more aggressive methane recovery program.

About 65 percent (270 mcm) of the methane recovered by Chinese mine degasification systems was used in 1990 (MOE, 1991a). Thus, more than 160 mcm of medium-quality gas was vented to the atmosphere, in spite of China's energy shortage. Most of the used gas was provided to residences in the vicinity of the mining enterprises, although in a few cases local industries used some of the recovered methane. There is currently one gas turbine operating on methane recovered by a Chinese coal mine, and the government is interested in developing additional electricity generation projects (JP International, 1990).

Opportunities to Expand Methane Recovery and Use

There are enormous opportunities in China to increase the recovery and use of methane from coal mines. Currently, the recovery efficiencies of many degasification systems are very low and could be significantly increased with the introduction of new technologies. In addition, there are numerous opportunities to increase methane utilization, particularly in the displacement of coal currently being used for residential cooking and heating.

Methane recovery could be significantly improved in China through the introduction of additional methane recovery techniques and the transfer of advanced technologies. Currently, Chinese coal mines use in-mine pre-mining degasification from the working and adjacent seams, as well as in-mine gob recovery, for most of their recovery operations. Some mines have experimented with recovery from vertical surface wells, but the results have largely been disappointing and additional technical assistance and technology transfer is needed to fully exploit this recovery option. Overall, Chinese methane recovery operations tend to be hampered by low permeability in the coal and technical problems related to inadequate drilling and pumping technologies (MOE, 1991b).

Thus, the methane recovery operations at most Chinese mines tend to be small and do not recover large amounts of methane. The demonstration of certain new recovery techniques--including vertical pre-drainage, in-mine pre-drainage using longholes or in-mine fracturing, and surface gob wells--could dramatically increase methane recovery efficiencies. Access to higher-powered drill rigs and other advanced equipment would also be very useful.

There is strong interest in the expanded use of methane within Chinese government agencies and among key municipalities. Many regions of China currently confront serious coal shortages and would benefit from access to additional local energy sources. In addition, the use of coal for cooking and heating has contributed to profound local air pollution in many cities, and has sparked a high level of interest in developing clean-burning natural gas resources. In fact, some of the most advanced coalbed methane projects in China have been initiated by municipalities interested in providing natural gas to their citizens (MOE, 1991b).

Despite the many existing uses for recovered methane, however, the Chinese are currently using only about 70 percent of the methane collected by their recovery systems. Most of the recovered gas is used in the mining communities, and the venting of recovered methane is common during periods of low gas demand (i.e., at night and during the summer) (JP International, 1990).

Given this situation, the key project opportunities will involve the increased substitution of methane for coal, particularly in residences and industries. In many cases, gas utilization could be improved by expanding gas storage facilities and the pipeline infrastructure necessary to transport methane to additional residential or industrial users (MOE, 1991b).

Opportunities also exist to use recovered methane to generate electricity. Although there is extensive interest in this area, natural gas is not widely used for electricity generation in China, primarily because of the lack of funds for turbine investment. One mine is currently generating electricity from a turbine using recovered methane, however, and several others are interested in developing similar projects (MOE, 1991b).

Emissions Reduction Potential

One set of promising short-term methane reduction opportunities in China involves developing projects to fully utilize the methane currently recovered in existing degasification systems. There are numerous projects underway to improve gas storage facilities and the pipeline infrastructure at key mines, which should help to improve utilization (MOE, 1991b). Using the estimated 160 million cubic meters of methane currently being vented by mine degasification systems would reduce emissions by more than 0.1 Tg per year.

Over the mid-term, China is interested in the development of projects to recover additional amounts of gas in conjunction with mining, using advanced mine degasification techniques and technologies (MOE, 1991b). These projects could improve mine degasification at those mines with existing systems, and assist additional gassy mines in the development of such systems. Through the widespread implementation of such technologies, China should be able to increase its average methane recovery efficiency from less than 5 percent to 25 percent at state-owned mines, which would reduce emissions by an estimated 1.2 to 1.6 Tg per year (1.8 to 2.4 bcm).

Given the gassiness of Chinese mines, it may be possible to achieve even higher recovery efficiencies and larger emission reductions over the longer term. Average recovery levels of 40 percent at state mines could be achieved in the long term with an aggressive program to promote coalbed methane and a Chinese government commitment to recovery. Such a program could result in emission reductions of 2.8 to 3.4 Tg per year (4 to 5 bcm).

Promoting Methane Recovery

Several significant barriers currently hinder China from achieving the full potential of its economically viable methane reductions from coal mining. The most important barriers include the lack of an appropriate policy framework, limited capital for project investments and equipment purchases, and limited information and experience with techniques and technologies (MOE, 1991b). In addition, because of factors such as the artificially low gas price set by the government and the difficulty with repatriation of profits, joint venture development to produce domestic energy resources can be very difficult.

A number of activities could help to address these barriers in China. Technical assistance from other governments, for example, could help with efforts to remove barriers through domestic policy activities. Opportunities also exist in the areas of information exchange and technology transfer, through international cooperation among governments, the international development agencies, and potential joint-venture partners. The specific types of activities that could be undertaken to develop China's coalbed methane resources are summarized below.

Policy Reform: China's Ministry of Energy (MOE) should continue its efforts to establish the necessary policy framework for coalbed methane recovery and use. Within the context of the current planning process, this means that MOE could be assisted in developing and implementing a "conversion factor" policy, under which coalbed methane recovered during coal mining is counted toward each mine's coal production quota. Further, coal displaced by methane recovery should be sold at negotiated or free-market prices, as opposed to government-established, subsidized prices.

Comprehensive Planning: Incorporating coalbed methane into China's planning framework could effectively encourage the development of this resource in China. Such efforts may require the preparation of a detailed country program for development of the resource, which includes: a resource assessment; a detailed evaluation of the best utilization opportunities and potential gas markets in key mining areas; a comprehensive assessment of the role coalbed methane can play in China's energy sector; and an analysis of the necessary investments to support its development. This type of country program could assist the Chinese government in allocating appropriate funds and enacting policies which would encourage project development. It could also guide investments by international development agencies and others.

Technology Transfer and Demonstration: One of the major components of a program to reduce China's methane emissions from coal mining should be the demonstration and transfer of key methane recovery and utilization technologies, through the implementation of demonstration projects. Currently, one such project is underway, supported by funding from the Global Environment Facility (GEF) Fund and managed by the United Nations (UNDP, 1992). This project will demonstrate a variety of methane recovery technologies, including vertical pre-mining drainage, enhanced in-mine recovery, and surface gob wells, at three mines in China. Upon completion of this project, additional demonstrations of other recovery technologies may be desirable. In addition, it may be useful to assist in the demonstration of some of the emerging utilization technologies, such as gas enrichment or the use of low-concentration methane for combustion.

Technical Assistance: In conjunction with the implementation of demonstration projects and technology transfer activities, training and technical assistance programs should be implemented. Such efforts should include training Chinese government and technical personnel in areas such as resource assessment, resource recovery and utilization technologies, and economic and financial feasibility analyses. This technical assistance could take the form of in-country training, fellowships to international project sites, and study tours.

Information Dissemination: The creation of mechanisms to transfer information within China, regarding both domestic activities and international accomplishments in the areas of methane recovery and use at coal mines, will also be important. One means of accomplishing this could be through the creation of a clearinghouse, which would hold technical seminars, publish a journal, and conduct research and studies.

Commercialization: Ultimately, methane recovery and use projects at coal mines must be commercially attractive in order to be sustainable. Given the many benefits to the mining enterprises, the existing energy shortages, and the environmental need for natural gas as fuel, it is likely that many projects will be economically viable under a market system.

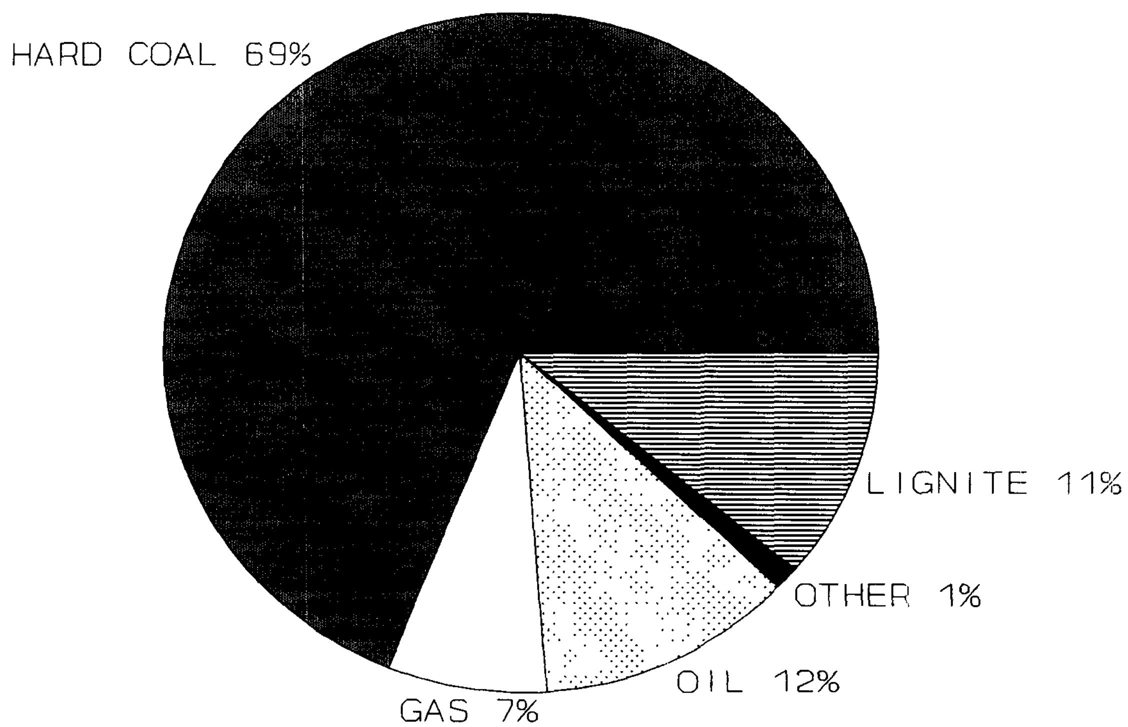
Sources of investment capital will still be required, however, and if joint ventures are to be undertaken, the fundamental needs of international investors must be addressed.

4.5.2 POLAND

Overview

Coal dominates Poland's fuel mix, as shown in Exhibit 4-5, satisfying 80 percent of the nation's energy demand in 1988, and 78 percent in 1989 (EIA, 1990 and 1991). Although all Central and Eastern European countries rely heavily on coal, Poland is more dependent on this resource than any other nation in the region (Pilcher et al., 1991). Most of Poland's coal is produced domestically, and it has historically been one of the world's largest hard coal exporters. In contrast, the country produces only small amounts of natural gas and oil and is heavily dependent on imports of these fuels (Pilcher et al., 1991).

Exhibit 4-5
Distribution of Energy Sources in Poland



Source: USEPA, 1991

Poland's energy economy is currently undergoing a dramatic shift from a high level of energy intensity and coal use to a more efficient, less polluting system. Among the goals of the

Polish government are to: (1) improve energy efficiency; (2) reduce the use of low-grade coal, particularly lignite; and (3) increase the use of clean-burning fuels such as natural gas (Szpunar et al., 1990). As part of the transition, government subsidies for coal production and energy prices are being removed, and several of Poland's hard coal mines are expected to close (Warsaw Rzeczpospolita, 1992).

In 1988, Poland was the world's fourth largest producer of hard coal, producing about 200 million metric tons (EIA, 1990). Hard coal production has declined in recent years, however, primarily due to increasing extraction costs and a deep economic recession. By 1991, hard coal production was less than 140 million metric tons (Warsaw Rzeczpospolita, 1992). This ongoing decline in Poland's hard coal production has had severe economic and environmental implications for Poland. Not only is there less hard coal for export, but domestic hard coal shortages are increasing domestic demand for low quality, high sulfur lignite.

Declining hard coal production has also increased demand for natural gas and oil. Unlike lignite, however, known domestic reserves of oil and conventional natural gas are small. In 1988, domestic oil production in Poland accounted for less than 1 percent of the amount consumed; domestic gas production accounted for only 45 percent (Pilcher et al.,1991). The gap between consumption and production is expected to widen as dependence on these fuels increases. Thus, imports of these fuels -- primarily from Russia -- are increasing, which is resulting in serious balance of payments problems.

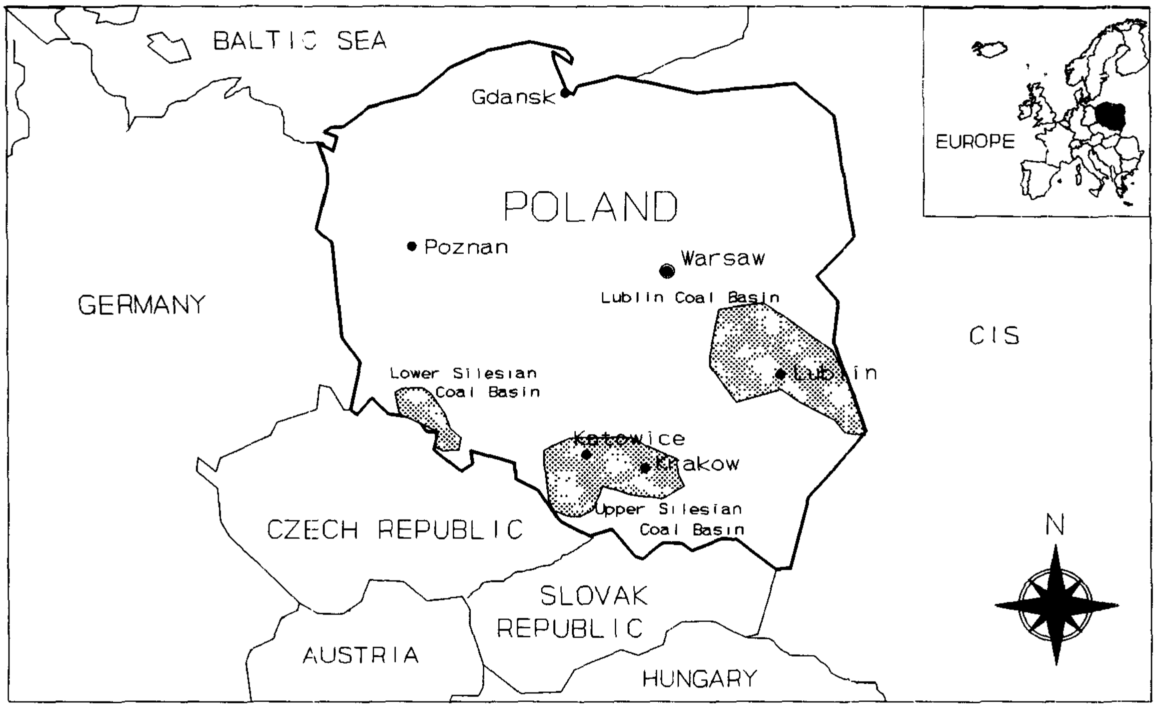
Hard coal is produced in three Polish basins: the Upper Silesian Coal Basin (USCB), Lower Silesian Coal Basin (LSCB), and the Lublin Coal Basin (LCB) (Exhibit 4-6). Poland currently has 65 active underground mines, most of which are located in the Upper Silesian Coal Basin (Pilcher et al., 1991). For the most part, these mines are very deep and gassy. More than 35 of Poland's underground mines have been classified as hazardous by the Polish Central Mining Institute, because they either have high levels of gas emissions or have suffered from outbursts of gas or rock.

The Polish government officially estimated its methane emissions from underground coal mining in 1989 to be 0.7 Tg per year (slightly more than 1 bcm) (Pilcher et al. 1991). This estimate only included emissions from the 35 gassy mines classified as hazardous, however, and emissions may have been underestimated even for these mines. Estimated emissions in 1990, including all coal sources, ranged from 0.6 to 1.5 Tg per year (USEPA, 1993b). At these levels, Poland's coal mining emissions represent about 3 to 4 percent of global emissions from this source.

About 18 Polish coal mines currently have mine degasification systems in place, and in 1989 these mines recovered an estimated 286 mcm (0.2 Tg per year) (Pilcher et al., 1991). Depending on the level of emissions from mining, the recovery efficiencies of these systems averaged 5 to 25 percent. Approximately 70 percent of this gas was used, and the remaining 86 mcm was emitted to the atmosphere. The principal uses were for industrial purposes and on-site coal-drying plants or boilers (Pilcher et al., 1992).

Currently, Polish mines rely primarily on in-mine degasification techniques to recover methane. The principal methods are in-mine drainage of methane from the coal and surrounding strata in advance of mining, as well as in-mine drainage from gob areas and abandoned mine workings. Drainage of methane from gob areas using surface wells and vertical pre-drainage has not yet been employed by Polish mines, although there is a great deal of interest in these techniques.

Exhibit 4-6
Major Coal Basins in Poland



Opportunities to Expand Methane Recovery and Use

Coalbed methane represents an attractive option for increasing domestic natural gas supplies, thereby improving mine safety, the nation's balance of payments, and local and global environmental quality. The magnitude of Poland's coalbed methane resource has been estimated to range from 0.4 to 1.3 tcm, which is large in comparison to its conventional natural gas resources (Kotas, 1992; Pilcher et al., 1991).

There are significant opportunities to expand methane recovery and use at Polish coal mines, both in advance of mining and in conjunction with active mining activities. In Poland, there are two possible types of methane recovery projects, involving either coal reserves or mining areas. These types of projects could have different impacts on methane emissions from mining.

Coal Reserves: The first type of project involves coalbed methane production in non-mining, coal reserve areas. In order to undertake such projects, companies have been invited to bid on coalbed methane concessions by the Polish government (Hoffman, 1992).

The first bidding round closed in October 1992 and awards are expected in upcoming months. These projects will involve vertical drilling into the coal seams to produce gas. Because there are currently no plans to mine the coal, the expected impact on methane emissions will be low.

Mining Areas: *The second type of project* involves coalbed methane production in active mining areas, and these projects could be undertaken as joint ventures with mining operations. Companies interested in developing these types of projects do not need to participate in the concession bidding round, but must develop partnerships with the entities that hold the rights to mine the coal (Wysocki, 1992). These projects could include vertical pre-drainage as well as the recovery of methane in conjunction with mining, using in-mine methods or surface gob wells. Because these projects would be developed in active mining areas, they could reduce methane emissions over the near-term.

For either type of project, Poland could benefit from the transfer of advanced technologies, additional information about state-of-the-art methane recovery and use opportunities, and technical assistance.

Emissions Reduction Potential

There is large potential for expanded use of coalbed methane, as well as for improved recovery techniques, in Poland. In the near-term, opportunities exist to promote projects to improve the recovery efficiencies of existing degasification systems and fully use the methane recovered by these systems. The Polish Central Mining Institute reports that about 30 percent of the recovered gas, or more than 85 mcm, was vented to the atmosphere in 1988 (Pilcher et al., 1991). Developing uses for this gas would reduce methane emissions by 0.1 Tg per year.

Poland's gassy mines have an average methane recovery efficiency of 27 percent. If these mines improve their recovery efficiencies to 30 percent on average, 0.1 to 0.3 Tg per year (0.2 to 0.4 bcm) of methane could be recovered.

Over the longer-term, projects could be developed to degasify coal reserves in advance of mining. These projects could use either in-mine or vertical pre-drainage techniques, and could potentially result in methane emission reductions of 40 percent at the gassy mines. It is estimated that these projects could recover 0.3 to 0.6 bcm of methane, corresponding to emission reductions of 0.2 to 0.4 Tg per year. The recovered coalbed methane would represent approximately 5 percent of current Polish gas demand, and does not include the coalbed methane that could be produced in coal reserve or non-mining areas.

In order to reduce emissions, expanded recovery of coalbed methane from mines must be coupled with utilization projects. Many options exist for using coalbed methane in Poland, including direct use in industrial or residential distribution systems, power generation, and district heating. Poland has multiple natural gas pipelines in the Upper Silesian area, some of which carry imported gas from the CIS, and others which carry low-quality methane or coke oven gas (Pilcher et al., 1991). These pipelines could potentially transport methane recovered from coal mines, depending on its quality and quantity. One Polish-U.S. joint venture, Elektrogaz, currently is developing a district heating project that will use coalbed methane produced from coal reserves, and possibly several coal mines, as fuel (Hobbs, 1991).

Promoting Methane Recovery

Coalbed methane development in Poland could be encouraged by a focused program by Polish government and industry, as well as extensive investment by outside investors, such as U.S. companies with resource development experience. Currently, several barriers may exist which impede Poland's coalbed methane development (U.S.-Polish Working Group, 1992). These barriers include:

- Limited experience with advanced methane recovery technologies;
- Technical concerns about various development issues;
- Uncertain project approval, regulatory and legal processes;
- Lack of information on the resource and its benefits; and
- Lack of information on the part of potential investors with respect to the project opportunities.

Several types of actions should be undertaken to address these barriers (U.S.-Polish Working Group, 1992). In particular, technical assistance will be useful for: (1) applying more advanced technologies and practices for methane recovery and use; (2) developing appropriate legal and regulatory frameworks to facilitate project development, and (3) creating joint ventures and obtaining investment capital. The actions undertaken should focus on technical personnel at Polish coal mines, as well as government personnel on the national and local levels who will be involved in project approval and management. The activities should also involve the participation of potential investors, including private companies and international development agencies.

The principal actions are summarized below:

Policy Actions: Poland's coalbed methane policies are becoming increasingly clear, and few additional policy activities should be needed in the future to encourage coalbed methane development. Principal additional policy activities could include:

- Ensuring that the competitive bidding process for non-mining coal reserve areas proceeds in a timely fashion, in order to maintain investor interest and facilitate development of coalbed methane resources;
- Clarifying the required project approval processes for development of projects in conjunction with mining enterprises will also be useful to encourage the development of joint ventures. In particular, investors have expressed interest in better understanding issues such as the roles of different agencies on the national and local level, and the applicable regulations concerning coal mine safety and disposing of produced water;

- Efforts to ensure that methane recovered from coal mines can be sold at the market price for natural gas, as opposed to the former practice of selling this methane at an artificially low subsidized price, are critical. Without a rationalization of the coalbed methane price structure, it may be difficult for investors to develop economically viable projects.

Technology Transfer: Transferring technologies for various advanced methane recovery and utilization options will facilitate resource development. For the most part, it is anticipated that this technology transfer could occur through the development of joint venture projects at Polish coal mines and in coal reserve areas. These projects will demonstrate the feasibility of methane recovery projects and familiarize Polish experts with state-of-the-art technologies and the technical aspects of project development.

Technical Assistance: In conjunction with the implementation of technology transfer activities, training and technical assistance programs are recommended to assist in coalbed methane development. Technical assistance could be useful to Polish experts in areas such as: resource assessment; the design of advanced methane recovery and use projects; the preparation of economic and technical feasibility analyses for such projects; and the design and implementation of effective programs to treat or dispose of produced water. Such assistance should be provided to technical personnel from coal mines, government agencies, and municipalities, in the form of in-country training, fellowships, and study tours.

Information Dissemination: A clearinghouse on coalbed methane has been established in Katowice, Poland, to disseminate information about domestic activities and state-of-the-art international technologies and projects. The clearinghouse is organizing seminars, publishing a journal, and conducting outreach with the Polish industry and the international private sector. It is anticipated that the clearinghouse will serve an important function in supporting the development of Poland's coalbed methane industry.

Commercialization: Ultimately, methane recovery and use projects at coal mines will be developed by Polish mines either independently or through joint ventures with private companies. Technical assistance and investment capital, from a source such as an international development agency, could enhance the ability of the mine operations to act independently. Private companies interested in joint ventures will need information about Polish project opportunities, a stable investment environment, and perhaps some financial support for initial pre-investment activities and feasibility studies. Programs to support joint venture activities are in place (such as AID's Capital Development Initiative); their expansion in Poland could be enhanced by efforts to publicize coalbed methane opportunities and reduce the actual and perceived risks associated with investing in Poland.

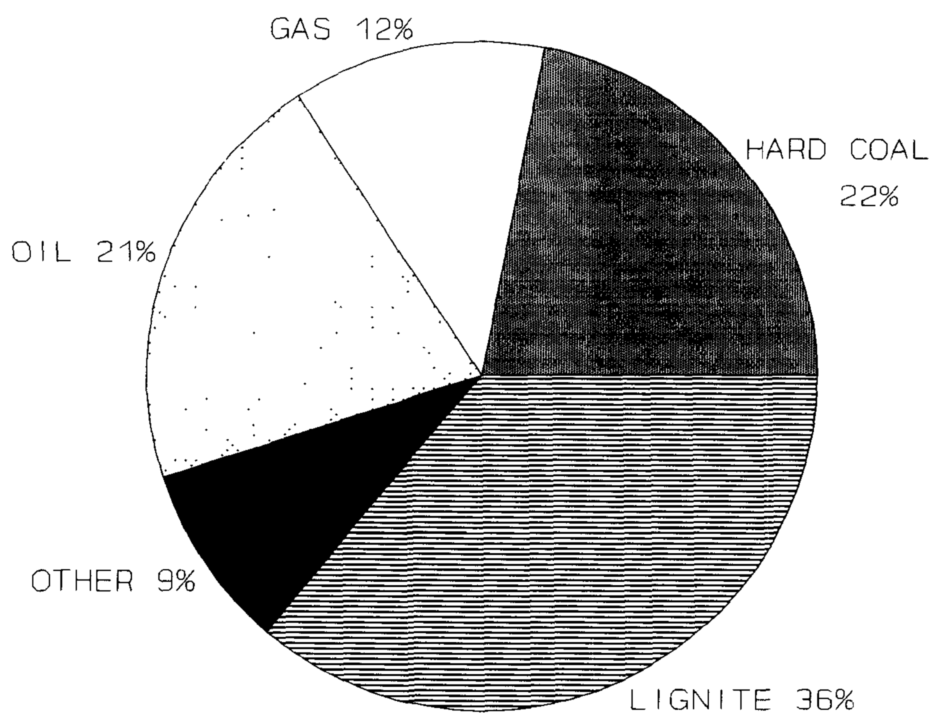
4.5.3 Czech and Slovak Republics

Overview

Coal provides about 56 percent of the former Czechoslovakia's primary energy, and the former Czechoslovakia is more dependent on lignite than any other nation in Europe, as shown in Exhibit 4-7 (Bibler et al., 1992). In 1990, the former Czechoslovakia produced about 84 million tons of lignite, primarily from surface mines, and almost 22 million tons of hard coal from underground mines (IEA, 1991). Unlike coal, which is largely produced domestically, the oil and gas on which the former Czechoslovakia is heavily dependent are imported. In 1988, the former Czechoslovakia imported more than 13 bcm of natural gas, producing less than 5 percent of its total demand domestically. In fact, the republics' natural gas reserves would satisfy only one year of gas demand (Bibler et al., 1992).

The former Czechoslovakia's underground coal has been produced in 15 mining concessions, all of which are located in the Ostrava-Karvina region in the Upper Silesian Coal Basin (see Exhibit 4-8) (DPB, 1991). Hard coal production has dropped in recent years, from 28 million tons in 1980 to 21 million tons in 1991 (Bibler et al., 1992). Production is likely to continue to decline, moreover, as one mining concession was closed in 1991 and there are plans to close four more mining concessions by 1995 (Bibler et al., 1992). In the Czech Republic, natural gas and electricity, largely imported from neighboring countries, are expected to replace coal as an energy source. Such a shift is not expected in the Slovak Republic, however, because of its poor economic conditions (Pilcher, 1993).

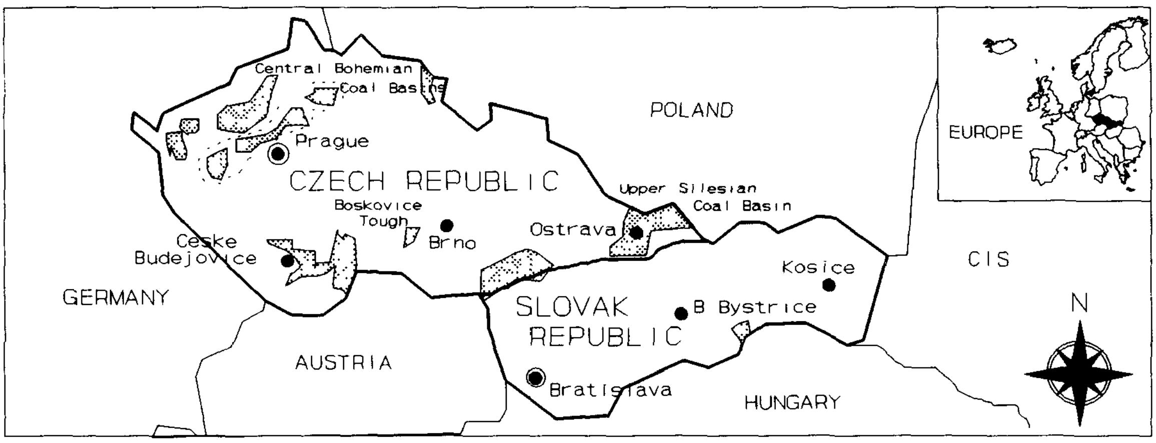
Exhibit 4-7
Distribution of Energy Sources in the Czech and Slovak Republics



Source: Bibler et al., 1992

The former Czechoslovakia's hard coal mines are uniformly deep and gassy, with reported methane emissions of 0.4 Tg per year (524 mcm) in 1990 (DPB, 1991). All of these mines have degasification systems in place, and these systems recovered an estimated 141 mcm (more than 25 percent of total emissions) in 1990 (DPB, 1991). As in other Central and Eastern European countries, the existing mine degasification systems utilize in-mine recovery methods, which include pre-mine drainage and gob recovery. Almost 90 percent (126 mcm) of the recovered methane was used in 1990. For the most part, this gas was used by the mines and by nearby industries, including a steel mill, metallurgical plants, and powerplants (*Bibler et al.*, 1992).

Exhibit 4-8
Major Coal Basins in the Czech and Slovak Republics



Opportunities to Expand Methane Recovery and Use

Significant opportunities exist in the former Czechoslovakia to expand the recovery and use of coalbed methane in conjunction with mining. The Czech coalbed methane resource has been estimated to range from 50 to 370 bcm, which represents a 5- to 30-fold increase over the former Czechoslovakia's estimated conventional gas reserves (Bibler et al., 1992).

It is likely that coalbed methane development in the former Czechoslovakia will occur both in non-mining coal reserves and in conjunction with mining enterprises. Several joint ventures have already been established or are under development with private companies from the United States and Canada to develop coalbed methane in coal reserve areas. These projects will use vertical wells to produce methane from areas that are not currently slated for mining.

Additional project opportunities exist for companies to cooperate with mining concessions to improve the recovery and use of methane liberated during mining activities. In the near term, the primary Czech hard coal mining company is planning to expand its coalbed methane pipeline infrastructure in order to reduce the emissions of recovered gas to the atmosphere

(DPB, 1991). Over the longer term, the Czech mines that remain open will seek to improve their recovery efficiencies and develop additional gas uses.

Emissions Reduction Potential

The near-term potential to reduce methane emissions from coal mines in the former Czechoslovakia is relatively small because of the current effectiveness of gas utilization. At the ten coal mines that are expected to remain open, gas recovery efficiency averages 35 percent and almost 95 percent of the recovered gas is used (Bibler et al., 1992). As mentioned previously, however, the Czech hard coal mining company is currently expanding the pipeline infrastructure that carries coalbed methane from the mines to the Nova Hut steel manufacturer in Ostrava (DPB, 1991). This steel company has expressed a willingness to purchase as much coalbed methane as the mines can recover. The mining company plans to upgrade the system and improve methane recovery so that additional methane can be sold to the steel company. If the Czech mines are able to sell all of their available gas and increase their methane recovery efficiency to 45 percent over the next few years, it is estimated that methane emissions could be reduced by 0.1 to 0.2 Tg per year (150 - 300 mcm).

Finally, it is possible that methane emissions could be reduced even more significantly in the long term if techniques for using or enriching mine ventilation air could be demonstrated. Czech and Slovakian coal mines may have particular interest in these technologies because of the high price of imported gas from the CIS, and because they can be fined for their methane emissions under the 1991 Hydrocarbons Law (Czech Ministry of Environment, 1992). By 1997, the fines for methane emissions could reach almost $50 per thousand cubic meters (about $1.50 per mcf), which could provide a significant economic incentive for developing uses even for gas of very low concentration. If uses for mine ventilation air can be demonstrated, it might be possible to reduce methane emissions by as much as 65 percent (0.2 - 0.3 Tg per year or 300 - 450 mcm) in the long term.

Types of Actions to Promote Methane Recovery

Coalbed methane development in the former Czechoslovakia could be facilitated through the implementation of a comprehensive program to assess and develop the resource. As in other countries, some key barriers which may currently limit coalbed methane development in the former Czechoslovakia include: limited experience with advanced methane recovery technologies; technical concerns about various development issues; lack of information on the resource and its benefits; and uncertain project approval and regulatory processes. Some utilization options, particularly for mine ventilation air, also remain to be demonstrated.

The principal actions that could facilitate projects to reduce methane emissions are summarized below:

Policy Actions: Many of the former Czechoslovakia's coalbed methane policies are still being developed, although the government has demonstrated a strong commitment to the rapid development of joint ventures. The principal policy activities that may be helpful could include:

- Clarifying the required project approval processes for development of projects, in order to encourage the development of joint ventures. In particular, this could include defining the roles of different agencies and the applicable regulations concerning issues such as maintaining coal mine safety and disposing of produced water;

- Evaluating the potential for coalbed methane development to help the Ostrava-Karvina region meet its energy and environmental goals, through the preparation of a comprehensive impact assessment;

- Assessing the infrastructure required to facilitate the development of the resource, incorporating any required infrastructure improvements into the regional environmental master plan, and ensuring that the most efficient uses for the recovered coalbed methane are identified.

Technology Transfer and Demonstration: The transfer of various advanced methane recovery and utilization technologies will be an important part of programs to encourage coalbed methane recovery. The Czech hard coal mining company has expressed particular interest in gob recovery from the surface and pre-mining drainage using vertical wells and longholes. Technologies for gas enrichment and the use of mine ventilation air could also be demonstrated in the former Czechoslovakia to determine if they could be technically and economically feasible.

Technical Assistance: In conjunction with the implementation of technology transfer activities and demonstration projects, training and technical assistance programs should be promoted. It is anticipated that Czech experts will be trained in various aspects of methane recovery and utilization, as well as environmental impact assessment, and economic and technical feasibility analysis. Technical assistance should be provided to technical personnel from coal mines, local and national government agencies, and municipalities.

Information Dissemination: A clearinghouse on coalbed methane has been established in Katowice, Poland, to disseminate information about regional coalbed methane projects and state-of-the-art international technologies. The activities of the clearinghouse could be expanded to include the Ostrava-Karvina region of the former Czechoslovakia. Seminars and outreach activities undertaken by the Polish clearinghouse could also be directed toward technical experts in the neighboring former Czechslovakia.

Commercialization: The former Czechoslovakia is already moving forward with the commercialization of coalbed methane production in the Ostrava-Karvina region. Full-scale development could be encouraged with large investments from international development agencies or joint venture partners. Programs that are being developed by international agencies to finance environmental and energy sector projects, as well as programs aimed at creating business opportunities for the private sector, could have a large impact if directed toward the development of coalbed methane resources.

4.5.4 RUSSIA

Overview

Russia has abundant resources of coal, oil and natural gas, and has historically produced large quantities of all of these fuels. In addition, Russia is one of the few former Soviet republics that is a net energy exporter, providing natural gas and oil to Western and Eastern Europe, as well as to other former Soviet republics (e.g., Ukraine) (Marshall, 1993).

In 1990, Russia produced about 640 bcm of natural gas and about 260 million metric tons of hard coal (PlanEcon, 1992). This republic accounted for almost 80 percent of the total gas produced in the CIS, and more than 50 percent of the coal. Most of the coal was consumed in Russia, but about 25 percent of the natural gas (170 bcm) was exported to Western and Eastern Europe (Marshall, 1993).

Russia's coal is produced in several coal basins, the major ones including the Kuznetz, the Pechora and the Eastern Donetsk Basins (Exhibit 4-9). The Kuznetz basin is the largest coal-producing region in Russia, in terms of both surface and underground coal production. It is located in Western Siberia and is a center of heavy industry. The Donetsk basin is located primarily in Ukraine, but extends into Russia. It has several underground mines and is another very industrialized area. The Pechora basin is located in the far north of Russia, far from major population and industrial centers.

Natural gas is produced predominantly in Western Siberia, in the Urengoi field. Major transmission pipelines have been constructed to move the gas to the more populous regions of the CIS, as well as through Ukraine for export to Europe.

Altogether, there are about 70 to 90 underground mines in the Kuznetz and Pechora coal basins, and about 20 surface mines in Kuznetz. Many of the underground mines are deep and gassy. In 1990, reported methane emissions were about 1.7 Tg per year (2.5 bcm), of which more than 80 percent was emitted in ventilation air and about 20 percent was recovered in mine degasification systems (Marshall, 1993).

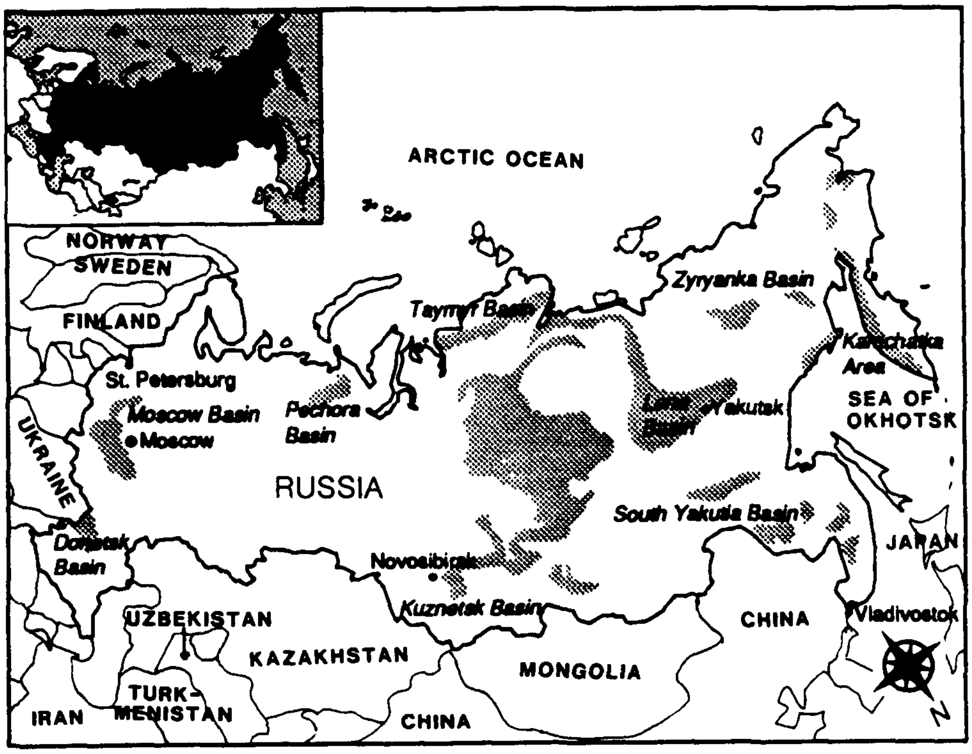
Opportunities to Expand Methane Recovery and Use

There are many opportunities for expanded methane recovery and use at mines in Russia, particularly in the Kuznetz and Eastern Donetsk coal basins. There may also be opportunities in Pechora: the cold climate and high energy demands have in this area already resulted in some methane recovery and utilization programs. As in Central and Eastern Europe, coalbed methane development is likely to be attractive both in advance of mining and at operating coal mines. The most potential for coalbed methane development may be in facilities located in coal mining regions, given the abundant supply of conventional natural gas in other regions.

The development of coalbed methane projects is particularly important in coal mining regions because of the uncertain future of the coal industry. Many of Russia's coal mines may not be profitable enough to operate in a free market economy, and several are likely to close over the coming years. Without alternative sources of energy and employment, the economic and social costs of closing coal mines may impose unacceptable burdens on the residents of the mining communities.

In the near term, opportunities exist to reduce emissions of methane recovered in degasification systems by developing additional gas uses. Over the longer term, it is likely that larger projects to capture methane in advance of mining will be developed. As Russia's economic system continues its transition to a market economy, it is likely that many opportunities will arise for these projects to be undertaken in conjunction with the private sector.

Exhibit 4-9
Major Coal Basins in Russia



Emissions Reduction Potential

The near-term potential to reduce methane emissions from coal mines in Russia could include expanding methane recovery and use at certain mines in the Kuznetz, Eastern Donetsk and, potentially, Pechora basins. Currently, the Pechora basin has the only mines that use methane recovered by degasification systems. These mines recovered about 0.3 Tg per year (441 mcm) in 1990 and used about 0.1 Tg per year (100 mcm) (Skochinsky Mining Institute, 1992). The remaining 0.2 Tg per year (350 mcm) is vented to the atmosphere (Skochinsky Mining Institute, 1992) but could be recovered in the near-term with appropriate investment.

Developing uses for this recovered methane would reduce emissions by at least 0.3 Tg per year (388 mcm).

Over the longer term, even larger emission reductions could be obtained if methane recovery programs were expanded. According to Russian data, methane recovery efficiency is about 23 percent at gassy mines (Zabourdyaev, 1992). If recovery efficiencies were improved to an average of 30 percent at gassy mines by improving existing methane recovery techniques, 0.3 - 0.5 Tg per year (0.5 - 0.8 bcm) of methane could be recovered.

Introducing advanced methane recovery systems, such as pre-mine drainage using vertical wells, could result in even larger emission reductions, perhaps reaching 40 percent of emissions at gassy mines. Overall, the longer-term emission reduction potential associated with extensive mine degasification using pre-drainage could approach 0.4 - 0.6 Tg per year (0.6 - 0.9 bcm).

Promoting Methane Recovery

The promotion of rapid coalbed methane development in Russia could be facilitated by providing technical assistance, demonstrating additional technologies, and encouraging private investment. As in other countries, the current barriers to coalbed methane development include limited experience with and information on advanced methane recovery technologies. In addition, the high degree of uncertainty in the Russian legal and regulatory frameworks is currently limiting private sector investment.

The principal actions that would help facilitate projects to reduce methane emissions are summarized below:

Policy Actions: Russia is currently developing new policies and regulations in many areas, which creates a changing and uncertain environment for investors. Several policy activities could help address these uncertainties and encourage private investment in the coalbed methane sector:

- Clarifying the required project approval processes for development of projects, in order to encourage the development of joint ventures. In particular, this should include defining the roles of different agencies and the applicable regulations concerning certain issues (e.g., maintaining coal mine safety) and environmental regulations; and

- Clarifying key business issues, including relevant tax regulations and joint venture requirements. To the extent that Russia can formalize its legal and regulatory frameworks for business investment, the development of joint ventures will be expedited.

Technology Transfer and Demonstration: The transfer of technologies for various advanced methane recovery and utilization options will contribute to improved methane recovery and use in Russia. The technical capabilities of Russian scientists and engineers are excellent, and a great deal of research has been conducted on innovative recovery and use options. There have only been limited demonstrations, however, due to lack of funding. In addition, providing mining personnel with access to both Russian and foreign advanced technologies would be useful. It is likely that vertical pre-drainage, surface gob wells and longhole in-mine gas recovery will be of particular interest to Russian mining associations.

Technical Assistance: In conjunction with the implementation technology transfer activities and demonstration projects, training and technical assistance programs could be beneficial for the development of coalbed methane. It is anticipated that Russian experts will be trained in various aspects of methane recovery and utilization, as well as environmental impact assessment, and project feasibility analysis. Technical assistance should be provided to technical personnel from coal mines, local and national government agencies, and municipalities.

Information Dissemination: Establishing a coalbed methane clearinghouse in Russia could assist in the communication of results of methane recovery projects in Russia and internationally, and could facilitate important analyses. This institution could also provide independent input to the Russian government on coalbed methane policy, and serve as a contact point for international investors interested in developing coalbed methane joint ventures.

Commercialization: Full-scale development of Russia's coalbed methane resources will require large investments from international development agencies or joint venture partners. Coalbed methane projects should be included in programs that are being developed by international agencies to finance environmental and energy sector projects, as well as programs aimed at creating business opportunities for the private sector.

4.5.5 UKRAINE

__Overview__

Although Ukraine is one of the largest coal producing republics of the CIS, it imports large amounts of oil and natural gas from Russia. In 1991, Ukrainian coal mines produced 127 million tons of coal, down from 155 million tons in 1990 (PlanEcon, 1992). Most of this coal was produced in the Donetsk coal basin. Ukraine also produced about 30 bcm of natural gas and imported another 90 bcm of Russian gas in order to satisfy its gas demand (PlanEcon, 1992). Most of the natural gas exported by Russia to Eastern and Western Europe also passed through the Ukraine in large transmission pipelines.

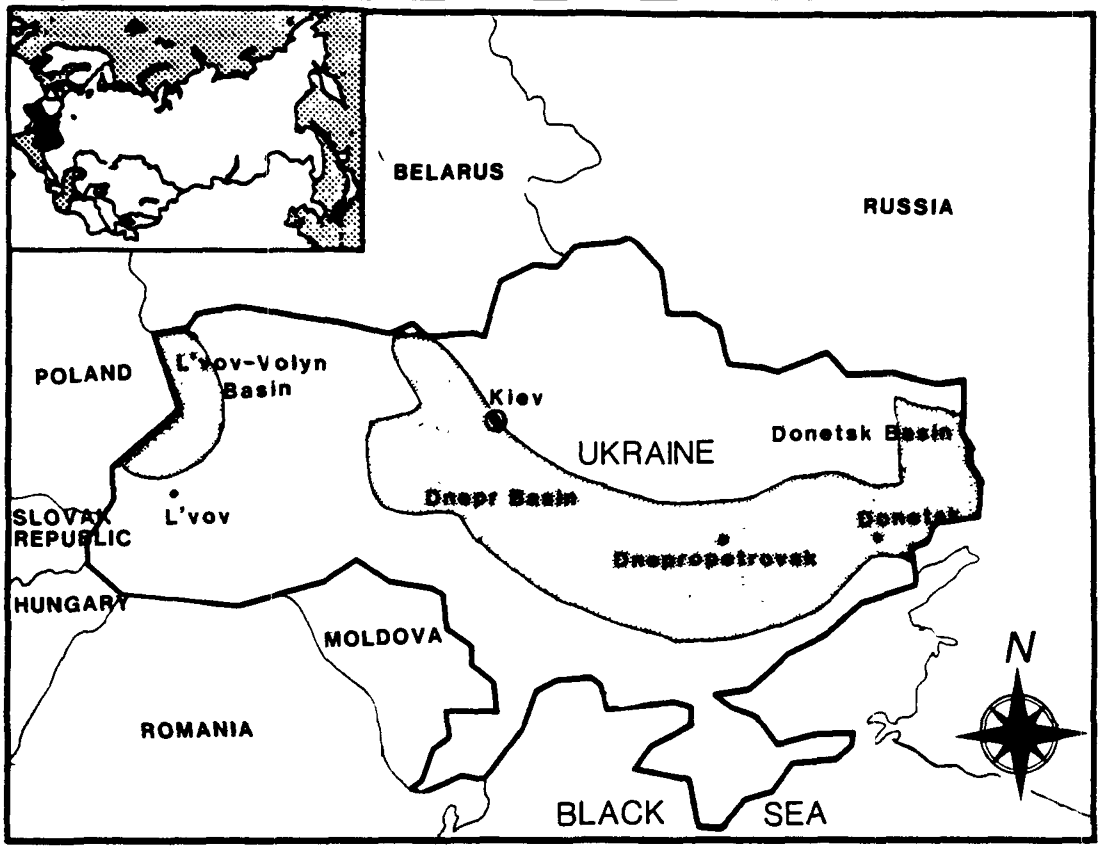
Ukraine's coal is produced in 319 underground coal mines, of which 298 are located in the Donetsk basin and the remaining 21 in the Lvov-Volyn basin along the Polish border (Exhibit 4-10) (Marshall, 1993). The Donetsk coal basin is the oldest and largest basin in the CIS, and its future is currently uncertain due to the difficult economic and mining conditions. The closure of several Ukrainian coal mines is likely.

Most Ukrainian coal mines are very deep and gassy, and mining conditions are quite dangerous. In 1990, reported methane liberations were 2.3 Tg per year (3.4 bcm) (Zabourdyaev, 1992). About 100 mines have degasification systems, and these systems recovered an estimated 600 mcm of methane in 1990 (Zabourdyaev, 1992). Only 170 mcm of this gas was used, however, mostly in industrial boilers located near the mine (Zabourdyaev, 1992; Marshall, 1993). As in other Central and Eastern European countries, the existing mine degasification systems utilize in-mine recovery methods, which include pre-mine drainage and gob recovery.

Opportunities to Expand Methane Recovery and Use

Ukraine has significant opportunity to expand its recovery and use of coalbed methane in conjunction with mining. Given its dependence on imported natural gas and the likelihood that coal production will continue to decline, there will be a growing need for additional domestic gas resources. Ukraine has relatively limited conventional gas reserves, but its coalbed methane resources are estimated to be very large.

Exhibit 4-10
Major Coal Basins in Ukraine



It is likely that coalbed methane development in Ukraine will occur both in non-mining coal reserves and in conjunction with mining enterprises. Before these projects can proceed, however, it is likely that the political and economic situation in the country will need to stabilize, and additional definition of relevant laws and regulations will be necessary.

The principal project opportunities will probably involve the introduction of methane recovery from virgin coal reserves or at mining areas several years in advance of mining. Surface gob wells and improved in-mine longhole drilling may also be used in conjunction with mining. The recovered gas will likely be used for additional industrial applications, as well as power generation. If the quality is high enough, moreover, it may be possible to export the gas to Eastern or Western Europe.

Emissions Reduction Potential

The near-term potential to reduce methane emissions from coal mines in Ukraine includes both developing uses for the recovered gas that is currently vented, and improving methane recovery at certain mines. As mentioned previously, Ukrainian mines are currently using less than 30 percent of the gas recovered by mine degasification systems, and venting the remaining amount (430 mcm) to the atmosphere. Developing additional uses for this recovered gas could reduce emissions by 0.3 Tg per year.

The average recovery efficiency for Ukrainian coal mines with degasification systems is about 23 percent, moreover, and could be improved in the near term with the introduction of new and advanced methane recovery methods (Zabourdyaev, 1992). If the recovery efficiency were improved to 30 percent at gassy Ukrainian mines, as much as 0.4 - 0.6 Tg per year (0.6 - 0.9 bcm) of gas could be used.

Over the long term, the introduction of advanced pre-mining drainage and other technologies could enable gassy Ukrainian coal mines to achieve recovery efficiencies of 40 percent. Recovery of this level of methane at mines with existing methane recovery systems would result in the capture of 0.9 - 1.2 bcm, and could reduce methane emissions by 0.6 - 0.8 Tg per year.

Promoting Methane Recovery

Coalbed methane development in Ukraine will be facilitated through the removal of existing barriers to project development, which include limited experience with advanced methane recovery technologies, technical concerns about various development issues, lack of information on the resource and its benefits, and uncertain project approval and regulatory processes.

The principal actions to facilitate projects are summarized below:

Policy Actions: Because its economy is in transition, Ukrainian regulations and legal frameworks are changing rapidly and are uncertain. The principal activities that may be required include:

- Clarifying the required project approval processes for development of coalbed methane projects, which may include defining the roles of different agencies and explaining the applicable regulations concerning issues such as maintaining coal mine safety and disposing of produced water;
- Evaluating the potential for coalbed methane development to help the Donetsk region meet its energy and environmental goals, and the potential relationship between improving coalbed methane recovery and use, and restructuring the coal industry.

Technology Transfer and Demonstration: The introduction of new recovery technologies (e.g., higher-powered drills) and utilization technologies (e.g., gas turbines) could greatly improve methane recovery and use. There is strong interest in Ukraine in utilization options, as well as in surface methane recovery technologies.

Technical Assistance: Training and technical assistance programs may also be valuable in Ukraine. Ukrainian experts may desire training in various technical aspects of methane recovery and use, the development of appropriate regulatory frameworks, and the preparation of economic and technical feasibility analyses. Technical assistance should be provided to technical personnel from coal mines, local and national government agencies, and municipalities.

Information Dissemination: It may be desirable to establish a coalbed methane information center in Ukraine to disseminate information on new technologies, modeled on the Coalbed Methane Clearinghouse in Katowice, Poland.

Commercialization: The full-scale development of Ukraine's coalbed methane resources will require large investments either from international development agencies or from joint venture partners. Programs that are being developed by international agencies to finance environmental and energy sector projects, as well as programs aimed at creating business opportunities for the private sector, should be directed toward the development of coalbed methane resources, with the goal of creating a stable investment climate.

4.6 Summary

As can be seen in the profiles of key coal mining countries, individual countries have different coal mining practices, different levels of associated technologies and different resources available to them. However, common characteristics can be identified to provide a broad understanding of:

- potential emission reductions from coal mining;
- barriers hindering the recovery and use of methane emitted from coal mines; and
- possible solutions for overcoming these barriers.

Emissions Reductions

The potential for economically viable reductions in methane emissions from coal mining can be roughly estimated based on information about current methane emissions from underground coal mines throughout the world, existing mine degasification practices, and available technologies. The reduction estimates are shown in Exhibit ES-7 and are based on these factors where they are known worldwide, and on feasible reductions estimated in the country profiles in this chapter. These reductions assume the implementation of programs which focus on both improving the recovery efficiency for mine degasification systems (e.g., through the transfer of additional recovery techniques), and developing additional uses for the recovered gas. Additional, country-specific research is warranted to improve these estimates.

Near-Term Reductions: In the near-term, it appears that emissions could be reduced by as much as 1.5 to 2.6 Tg per year through the efficient use of the methane that is currently being recovered by degasification systems but vented to the atmosphere. The principal uncertainty in this estimate concerns the effectiveness of efforts to remove key barriers to methane utilization in the United States (USEPA, 1993a). Developing uses for this gas will require investments in improved methane recovery as well as gas utilization equipment and infrastructure.

Mid-Term Reductions: Over the near to mid-term, reducing methane emissions from coal mining will require additional investments in equipment and infrastructure for methane recovery and use and the introduction of advanced technologies for coalbed methane production. By 2000, an aggressive program to encourage recovery and use at the world's gassiest coal mines could yield emission reductions of 4.4 to 6.4 Tg per year. Such a program would include the improvement and wider application of commonly used mine degasification technologies, the introduction of advanced pre-mining in promising areas, and the wider scale introduction of technologies (such as turbines) for using medium quality fuel. These reduction estimates assume that gassy underground coal mines will achieve an average methane recovery efficiency of 25 percent and that all of the recovered methane is used. In practice, these emission reductions would likely result from more aggressive degasification programs at the gassiest mines and smaller reductions at less gassy mines. These estimates may be conservative, moreover, in that they assume that methane emissions remain constant between 1990 and 2000, while it is likely that emissions will increase.

Longer-Term Reductions: Even greater methane reductions could be achieved over the longer-term if additional technologies are widely introduced and new technologies are developed. Of particular importance is the demonstration of technically and economically feasible uses for the low concentration methane contained in mine ventilation air. With these types of advances, methane recovery efficiencies of 40 percent or more could be achieved at gassy underground coal mines, which would result in emission reductions of 8 to 11 Tg per year. For comparison, total methane emissions from coal mining in 1990 were estimated to be 25 to 40 Tg per year, not including the methane that was used by mines (USEPA, 1993b). Significant technical advances may be required to achieve reductions of this magnitude, however, and they are thus considered longer-term and more uncertain.

Estimates of methane emissions and potential emission reductions are summarized in Exhibit 4-11.

Promoting Methane Recovery

As indicated in the country studies, a number of barriers have constrained the widespread development of coalbed methane recovery and use projects at coal mines throughout the world. For centuries, methane has been perceived as a safety hazard in underground mining that can be most effectively addressed by venting to the atmosphere. In addition, many of the key methane emitting countries are heavily dependent on coal as their major energy source and may not be fully prepared to exploit the methane recovered from coal mines for fuel.

Facilitating the development of projects to encourage expanded methane recovery and utilization at the world's gassy underground coal mines will require aggressive programs directed at removing barriers by exchanging information, providing technical assistance, and transferring technology. Because of the likely favorable economics, the widespread development of projects should proceed rapidly once initial barriers are removed and the key technologies are demonstrated in the major countries. Over the next few years, however, it will be necessary to work closely with government agencies, mining personnel and local communities to raise their awareness of existing opportunities, assist in the development of appropriate policy frameworks, and demonstrate the most promising technologies.

Exhibit 4-11
Estimates of Potential Economically Viable Reductions in Methane Emissions from Coal Mining

Country	Estimated Emissions (Tg/yr)	Near Term Reductions		Longer Term Reductions (Tg/yr)	
		Tg/yr[1]	%	Tg/yr	%
China	9.5 -16.6	1.2 - 1.6 (0.1)	10 - 15	2.8 - 3.4	25 - 35
United States	3.6 - 5.7	1.0 - 2.2 (0.4 - 1.5)	35 - 40	1.7 - 3.1	45 - 55
CIS[2]	4.8 - 6.0	0.7 - 1.1 (0.6)	10 - 20	1.0 - 1.4	20 - 25
Poland	0.6 - 1.5	0.1 - 0.3 (0.1)	15 - 20	0.2 - 0.4	25 - 35
Former Czechoslovakia	0.3 - 0.5	0.1 - 0.2	30 - 40	0.2 - 0.3	60 - 65
Others[3]	3.3 - 5.6	0.9 - 1.8 (0.2)	20 - 30	1.5 - 2.8	35 - 45
TOTAL	22.1 - 35.9	4.0 - 7.2 (1.5 - 2.6)	15 - 25	7.4 - 11.4	30 - 40

1 Emission reduction estimates in parentheses can be achieved by utilizing gas currently recovered and vented to the atmosphere.
2 Emissions estimates are for entire CIS; reductions estimates include Russia and Ukraine.
3 Emissions estimates include several important coal-producers, such as Australia, Germany, India, South Africa, and the United Kingdom.

Exhibit 4-12 summarizes the key types of barriers that may exist to different degrees in different countries, and which may have to be overcome to encourage expanded methane recovery and use at underground coal mines. Exhibit 4-12 also highlights the types of programs and activities that could be implemented to remove these barriers. Of course, the conditions in a specific country or at a specific coal mine will be unique, and the programs developed would need to address the particular conditions and needs of that country. However, the overall types of issues that can hamper coalbed methane development and the most promising activities to address them can be generalized among countries.

Exhibit 4-12
Key Barriers and Possible Responses - Coal Mining

Key Barriers	Possible Responses
Legal Systems: · Gas ownership uncertain · Concession system undeveloped · Joint venture project requirements unclear	· Resolve ownership legally or legislatively · Develop resource leasing mechanisms · Develop system for foreign investment, repatriation of profits, etc.
Regulatory Issues: · Project approval process unclear · Mine safety regulations inappropriate for gas recovery · No produced water regulations for CBM development · No specialized "field rules" for CBM development	· Streamline and clarify project approval/permit requirements · Determine how to incorporate gas recovery with mine safety regulations · Develop produced water regulations and industry "field rules" specific to CBM development
Information Issues: · Lack of awareness on part of government, mining personnel and others about magnitude and value of resource · Lack of awareness on part of potential project developers regarding potential in various countries	· Provide information to countries on resource, appropriate policies, technologies, etc. · Provide information to development companies and lending agencies regarding potential attractiveness of projects
Technical Issues: · Lack of access to new technologies, such as advanced drill rigs, reservoir simulators, etc. · Lack of familiarity with new methane recovery approaches, such as vertical pre-mine drainage or in-mine fracturing of longholes · Lack of familiarity with new methane utilization technologies, such as power generation · Need to demonstrate utilization options for low-concentration methane in ventilation air	· Encourage the development of joint ventures to introduce new approaches · Fund demonstration projects in key technical areas · Organize study tours and training trips for key personnel to advanced CBM projects · Establish technology centers to disseminate information on appropriate technologies and techniques
Financial Issues: · Lack of capital for investment in methane recovery projects · Poor financial condition of coal mines and historic dependence on heavy subsidies · Low subsidized energy prices reduce economic attractiveness	· Foster joint ventures · Raise awareness on part of international development agencies about coalbed methane potential · Encourage development of methane recovery and use projects that can improve coal productivity and mining economics

When initiating a program to identify economically viable opportunities to reduce methane emissions and encourage coalbed methane recovery, a number of key steps will likely be necessary. Many of these activities have been mentioned briefly in the country studies. The most likely components of a methane recovery program are described here in a more general form, and are summarized in Exhibit 4-13. These programs would be most effective if some of the components are implemented sequentially, as indicated in Exhibit 4-13.

National or Basin Assessment: In many countries, preparing a national or basin level assessment of the coalbed methane resource will be a logical first step in initiating an emission reduction program. This assessment should evaluate the magnitude of the coalbed methane resource, the potential role for coalbed methane in the country or region's energy economy, and the types of barriers that may be constraining development. Particular attention should be paid to the compatibility of coalbed methane development and the nation's energy or environmental goals. Current practices with respect to coalbed methane recovery and utilization should also be assessed and some of the more promising project types identified.

Exhibit 4-13
Summary of Project Types

Project Type	Phase 1 Phase2 Phase 3	Cost
National or Basin Assessment	■■	$100K-1M per country
Policy Analysis and Assistance	■■■■■■■■■■■■■	$25-100K per country, depending on types of activities
Information Exchange	■■■■■■■■■■■■■■■	Varies; $75-100K/year to manage clearinghouse in developing/ transitional economies
Technical Assistance	■■■■■■■■■■■■■■■	$25-50K per country for seminars; $25-150K for prefeasibility studies; $50K or more for study tours
Technology Transfer	■■■■■■	$1-15M or more, depending on scope of project
Commercialization	■■■■■■■■■■	Varies, depending on magnitude of project ($25-300M in U.S.)

Preparing such studies will require close cooperation among international experts in the coalbed methane field and in-country personnel, who are familiar with national goals, experiences, and conditions. Depending on the scope of the study, the number of coal basins or regions examined, and the degree of international and in-country participation, a national assessment should cost $100,000 to $1,000,000 ($U.S.). Higher costs would be associated with larger countries (such as China) and/or more detailed analysis and data collection efforts. These assessments will typically take place over the first one or two years of the project.

Policy Analysis and Assistance: One of the objectives of the national assessment is to identify policy, regulatory or other barriers to coalbed methane development. Examples of such barriers could include uncertain coalbed methane ownership laws, unclear project development requirements, undeveloped regulations regarding coalbed methane development, or uneconomic state-mandated prices for coalbed methane produced by mines. Where such barriers are identified, it may be necessary to assess the implications of policy reforms and develop recommendations for removing the barriers.

For the most part, policy reform activities will need to be undertaken by in-country government personnel. Policy reform assistance, beginning several years into the project and continuing throughout its duration, may be useful to such personnel to provide information about how such barriers have been addressed in other countries. Such advice could be provided by expert consultants, through seminars on various issues organized in the country, or by arranging for training opportunities for the government personnel either internationally or in-country. The costs of such programs will vary significantly, depending on their scope. Seminars may be provided for $25,000 or more, while long-running consulting or training assistance could cost $100,000 or more.

Information Exchange: Creating institutions within countries to disseminate information about domestic and international accomplishments in coalbed methane will be an important part of any program to encourage coalbed methane recovery. One effective means of exchanging information may be through the creation of coalbed methane clearinghouses in target countries. The clearinghouse concept has been modelled on a domestic U.S. information exchange program that was initiated by the Gas Research Institute to support the U.S. coalbed methane industry in the early 1980s. A coalbed methane clearinghouse has also been supported by U.S. EPA in Katowice, Poland and is serving an important function in organizing the coalbed methane industry and transferring information about accomplishments.

Information exchange activities can range from low cost to higher cost, depending on their scope. Low cost activities would include the provision of public domain information on an ad hoc basis. Higher costs are associated with actually creating clearinghouses, because of the costs associated with staffing and equipment requirements. As a rough estimate, managing a clearinghouse may cost about $75,000 to 100,000 annually in developing countries or countries in transition. An appropriate approach might be to fund such centers for a three-year period, after which time they would be responsible for securing funding from internal sources.

Technical Assistance: Technical assistance includes many activities, such as training and cooperative work on studies and pre-feasibility assessments. Typical activities could include arranging in-country seminars on technical issues taught by international experts, arranging international training opportunities and study tours, and organizing domestic and international teams to undertake project development activities, such as pre-feasibility assessments.

The costs of technical assistance activities will depend on their nature. Arranging in-country seminars can be relatively low cost, at $25,000 to $50,000 per seminar. Often these seminars can be coupled with pre-feasibility studies, moreover, to save funding. Depending on the degree of detail and domestic participation, pre-feasibility study costs can range from $25,000 to $150,000 or more. International training and study tours will generally cost about $50,000 or more, depending on duration and number of participants. With these types of activities, it is critical that participants be selected who will receive maximum benefit from the international experience.

Technology Transfer: Technology transfer activities can include necessary research activities and pilot projects. In the research area, possible activities could include drilling and mining through vertical wells to test the impact of hydraulic fracturing on coal mine safety. Pilot projects could be implemented to demonstrate advanced mine degasification technologies, new utilization options, water disposal technologies, and innovative uses of mine ventilation air. These activities may begin several years into the project and continue through the first decade.

Technology transfer projects will generally be more expensive because of the need to purchase equipment and other hardware. Depending on the scope, the costs of these projects could range from $1 million to $15 million or more. At the low end, small-scale test wells could be drilled and evaluated. The more expensive projects might include drilling several wells, as well as investments in surface facilities, infrastructure, or gas utilization devices, such as turbines.

Commercialization: The commercialization of coalbed methane development, beginning about five years into the project, will necessitate large investments in vertical wells, more aggressive in-mine degasification, infrastructure for gas processing and transportation, and gas utilization devices. The costs of commercial projects can very significantly, depending on their magnitude. In the U.S., project costs have ranged from $25 million to more than $300 million.

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CHAPTER FIVE
RUMINANT LIVESTOCK

5.1 Introduction

Ruminant livestock contribute large quantities of methane worldwide and present a large opportunity for methane reductions through increases in the efficiency and productivity of animal herds. These animals are characterized by a large fore-stomach, or rumen, in which microbial fermentation converts feed into products that can be utilized by the animal. It is the microbial fermentation of feeds that allows ruminants to digest coarse plant material which monogastrics, including humans, cannot digest. Methane is produced by rumen bacteria as a byproduct of this normal digestive process and is exhaled or eructated to the atmosphere.

Increasing the efficiency and productivity of ruminant animals is economically and technically feasible in many countries, under a variety of conditions. Cattle and buffalo, in particular, have shown large increases in productivity through improved management practices. In addition to the economic and social benefits resulting from increased productivity, methane emissions are reduced per unit of production as more of the carbon in the feed is converted to useful product such as meat or milk, as opposed to being wastefully emitted to the atmosphere as methane. Methane emissions can thereby be reduced for a particular level of milk or meat production, or per unit of feed that is consumed. Methane produced per unit product can be reduced by up to 60 percent in some animal management systems with available options (USEPA, 1993a).

Opportunities exist to expand productivity enhancing programs in a variety of countries. Recent assessments indicate that the largest opportunities for both reducing methane emissions and achieving development goals are found in developing countries, where livestock are typically raised in conditions which constrain animal productivity to well below genetic potential (Leng, 1991; ATI, 1992; Sollod and Walters, 1992).

This chapter describes the possibilities for improving the productivity of livestock worldwide and the implications for reducing methane emissions. It assesses in detail the potential expansion of economically viable options in several key countries, including India, China, Tanzania, Bangladesh, Eastern Europe and the Commonwealth of Independent States (CIS), and it outlines technology transfer programs that would be useful in promoting these options.

5.2 Methane Emissions

Methane is produced as part of the normal digestive processes of animals. Referred to as "enteric fermentation," these processes produce emissions that have been estimated to account for a significant portion of the global methane budget, about 65 to 100 teragrams (Tg) annually (IPCC, 1992). About 80 percent of these emissions are from the large ruminants: cattle and buffalo (USEPA, 1993c; Reuss et al, 1990). The extent of this range results from uncertainties in estimates of the emissions from individual animals, as well as uncertainties about animal populations. Due to a growing body of knowledge on the numbers and conditions of animals worldwide, more accurate estimates are becoming available.

In general, methane emissions from a given region depend upon the animal population and both the quantity and quality of feed consumed. Therefore, although animal populations for a particular region (shown in Exhibit 5-1) provide some information about the magnitude of methane emissions for the region, it is also important to know the conditions under which animals are managed. For example, cattle in developed countries which are relatively large, and consume large quantities of high quality feed, typically emit from 50 to 130 kg of methane per year (USEPA, 1993b). In comparison, cattle from developing countries, which are typically 30 to 50 percent as large and consume low quality feed, can emit 20 to 60 kg of methane per year (USEPA, 1993c; Reuss, 1990). Estimates of methane emissions from ruminants (particularly cattle and buffalo) are shown by region in Exhibit 5-2.

In addition to total regional methane emissions, a second important measure of methane production is methane produced per unit product. For example, while a highly productive cow can emit 120 kg of methane per year, it may also produce 7000 kg of milk, resulting in a release of 17 grams per kg of milk produced. In comparison, a cow on a straw based diet can emit 50 to 60 grams of methane per kg of milk produced (Leng, 1991). The measurement of methane produced per unit product emphasizes that increasing the productivity of ruminant animals can substantially reduce overall methane emissions.

Exhibit 5-1
Animal Populations (thousands)

Region	Cattle	Buffalo	Sheep	Goats	Camels	Humans
Africa	187,771	2,500	205,094	173,944	14,509	628,507
N. America	110,449	-	12,123	1,927	-	422,703
Latin America	313,502	1,209	119,731	35,302	-	290,904
Asia	364,863	135,335	233,977	282,938	3,739	3,049,930
W. Europe	99,831	653	141,043	25,771	-	498,373
Oceania	30,858	-	225,577	2,064	-	26,075
E.Europe/CIS	154,171	682	179,672	9,257	300	288,750
Total	1,279,257	140,758	1,190,500	557,030	19,450	5,205,242

Source: FAO Yearbook, 1991

5.3 Emission Reduction Opportunities

There are a number of available methods for cost-effectively improving ruminant animal management systems so that livestock utilize the energy in their feed more efficiently, and hence convert a smaller portion of their feed to methane. These methods have largely been developed through research and development efforts over the last fifty to one hundred years, as a direct result of the interest of governments and other organizations in increasing the supply of animal products.

Continued improvements in animal productivity can reduce methane emissions across a range of country-specific conditions. In many developed countries, for example, the market for animal products has been saturated and demand is therefore relatively constant. In these cases, improvements in animal productivity result in the ability of livestock managers to meet demand with fewer animals, and thus less methane is produced. Alternatively, in many developing countries there is great disparity between supply and demand of animal products, and production is therefore constrained by feed resources and other conditions. In these cases, efficiency improvements allow greater production, and consequently less methane is produced from relatively constant feed resources. The principal emission reduction options are summarized in Exhibits 5-3(a-d), and are discussed in detail in Volume I of this report (USEPA, 1993a).

Exhibit 5-2
Regional Methane Emissions from Cattle, Buffalo, and Other Ruminants (Tg/yr)[1]

Region	Cattle	Buffalo	Sheep	Goats	Camels	Other[2]	Total
Africa	6.1	0.1	1.0	0.9	0.7	0.2	9.1
N. America	6.0	0.0	0.1	0.0	0.0	0.2	6.3
Latin America	15.7	0.1	0.6	0.2	0.0	0.6	17.2
Asia	11.8	7.3	1.1	1.4	0.1	1.0	22.8
W. Europe	6.4	0.0	1.1	0.1	0.0	0.2	7.9
Oceania	2.0	0.0	1.1	0.0	0.0	0.0	3.1
E.Europe/CIS	9.8	0.0	1.4	0.0	0.0	0.3	11.7
Total	58.1	7.7	7.0	2.8	0.9	2.7	79.1

Source: USEPA, 1993c
1 These emissions estimates are based on recent drafts of the report to Congress, *Global Anthropogenic Emissions of Methane*, currently in preparation, and will likely change as this report is finalized. These estimates represent the middle of a range of estimates where the range is on the order of ± 25%.
2 This category includes swine, horses, and mules, which are all monogastrics.

Identifying the most promising opportunities for promoting the available methods requires an examination of the current productivity of an animal management system and the feasibility of implementing the methods. Importantly, the magnitude of emissions from a region is not necessarily a good indicator of potential emission reductions. The largest potential reductions are in those regions where animal management systems are inefficient -- and thus where methane per unit of production is highest. Furthermore the largest potential reductions are with animal management systems where:

- the animals are accessible through weekly, if not daily contact with their managers;
- markets and related infrastructure necessary to sell the additional products are available; and
- programs can be developed to address local economic and cultural factors, and gain the acceptance of farmers.

The applicability of available methods in different systems are discussed in more detail below and summarized in Exhibit 5-4.

Roughly 20 percent of the emissions from large ruminants come from animals which are raised under intensive or other highly managed conditions in the developed countries of North America and Western Europe, and to a limited extent in other countries. These advanced animal production systems have generally achieved low methane emissions per unit product through the use of high quality feeds, selective breeding, and other management techniques as they became available. These systems have seen large efficiency gains over the last fifty years. For example, the U.S. now produces more milk with less than half the dairy cows than in the 1940s, and similar improvements have been seen in the beef industry. The current level of high productivity leaves room for relatively marginal improvements, although there remain opportunities to develop and implement new techniques. Programs appropriate for these management systems include the development and application of production-enhancing agents, improved reproduction, and targeted nutrient supplementation technologies.

Significant improvements may be made in animal management systems in the CIS and Eastern Europe, which account for 15 to 20 percent of the emissions from large ruminants. Animals in this region are typically raised on large collective or state-run farms, where unbalanced and relatively low quality feed contribute to low productivity compared to large intensive systems in developed countries. The accessibility of animals on these large farms suggests that opportunities may exist to introduce improved management practices, such as nutrient supplements, productivity enhancing agents, and improved reproductive methods.

Substantial increases in productivity may also be made in the developing regions of the world, such as the Indian subcontinent, China, and Subsaharan Africa. About half of the world's cattle and buffalo, representing perhaps as much as 30 percent of emissions from large ruminants are raised in these countries in conditions which result in extremely low productivity. In the past, increasing demand for animal products has been met by increasing the number of animals rather than increasing productivity.

Alternatively, opportunities are likely much lower in South (Tropical) America, which represents about 20 to 25 percent of total global emissions, since the majority of emissions is from cattle which are predominantly managed on extensive ranches. Although these animals are fed mostly on grasses (i.e., grazed), which is generally associated with high methane yields and technical potential for methane reduction, the relative inaccessibility of these animals makes the application of technologies less feasible. Compared to management

Exhibit 5-3(a)
Summary of Options for Improved Nutrition through Mechanical and Chemical Feed Processing

Considerations	Alkali/Ammonia Treatment of Low Digestibility Straws	Chopping of Low Digestibility Straws	Treat and Wrap Rice Straw[1]
Reduction Techniques	alkali/ammonia treatment lignin removal/separation	chopping/grinding lignin removal/separation	wrapping ensilation
Support Technologies and Services	handling and supply of caustic material	grinding equipment	wrapping material
Availability	currently available	currently available	demonstration needed
Capital Requirements	low	low/medium	low/medium
Technical Complexity	low	low	medium
Applicability	widely applicable crop byproducts	widely applicable crop byproducts	crop byproducts grasses
Methane Reductions[2]	10% or more	10% or more	10% or more

Exhibit 5-3(b)
Summary of Options for Improved Nutrition through Strategic Supplementation and Other Techniques

Considerations	Molasses/Urea Multinutrient Blocks	Molasses/Urea Blocks with Bypass Protein	Defaunation	Targeted Mineral/ Protein Supplements	Bioengineering of Rumen Microbes[1]
Reduction Techniques	rumen nutrients for improved microbial growth	microbial growth protein/energy ration	protozoa removal	essential nutrients	digestion efficiency suppress methane production
Support Technologies and Services	block production extension services	block production protein processing extension services	defaunation agents	diet analysis	-
Availability	currently available	currently available	not available commercially	currently available	further research needed
Capital Requirements	low	low/medium	low	low	-
Technical Complexity	low	low	low	low/medium	medium/high
Applicability	low digestibility/ low energy diet cash markets	low digestibility/ low energy diet cash markets	grazing animals low energy diets	adequate feed energy specific deficiencies	-
Methane Reductions[2]	Up to 40%	Up to 60%	Up to 25%	5-10%[3]	-

1 Significant research remains to be done before this strategy can be made available. Therefore, it is premature to assess many aspects of this strategy, such as cost and potential methane reductions.
2 Methane reductions are calulated on a per unit product basis, and can be achieved at an appropriate individual site.
3 Estimated range of reductions.

Exhibit 5-3(c)
Summary of Production Enhancing Agents

Considerations	Bovine Somatotropin (bST)	Anabolic Steroid Implants	Other Agents[1]
Reduction Techniques	growth hormone injections	anabolic steroids implants	isoproterenol clenbuterol cimaterol
Availability	subject to gov't approval	subject to gov't approval	further research needed
Capital Requirements	low	low	-
Technical Complexity	low/medium	low	-
Applicability	intensively managed high quality feed	commercial beef production intensively managed	-
Methane Reductions[2]	nearly 10% or more	5-10% or more	-

1 Significant research remains to be done before this strategy can be made available. Therefore, it is premature to assess many aspects of this strategy, such as cost and potential methane reductions.
2 Methane reductions are calculated on a per unit product basis, and can be achieved at an appropriate individual site.

Exhibit 5-3(d)
Summary of Options for Improved Genetic Characteristics, Improved Reproduction, and Other Techniques.

Techniques	Availability	Capital Requirements	Technical Complexity	Applicability
Improved Genetic Characteristics				
Crossbreeding	currently available	low/medium	medium	conditions in which genetic potential can be realized
Genetic Improvement in Dairy Cattle	currently available	low/medium	medium	conditions in which genetic potential can be realized
Transgenic Manipulation	research needed	-	-	-
Improved Reproduction				
Twinning	through 2005	low/medium	medium	commercial beef production
Embryo Transplant	demonstration needed	medium	medium/high	highly managed dairies and cow-calf operations
Artificial Insemination/ Estrus Synchronization	currently available	low/medium	medium	dairy operations
Other Techniques				
Milk Marketing	currently available	-	-	surplus countries
Disease Control	currently available	low/medium	low/medium	widely applicable
Beef Marketing: U.S.	currently available	-	-	U.S. beef grading & marketing system

Source: USEPA, 1993a

Exhibit 5-4
Applicability of Emission Reduction Options to Animal Management Systems

	% of Animals (% of Emissions)[1]	Feed Processing	Improved Rumen Function	Production-Enhancing Agents	Genetic Improvement	Improved Reproduction	Other
Intensive Dairy--Non-grazing	10-15% of animals (20-25% of emissions)	Processed feeds are used routinely	Balanced rations used routinely	Candidate for additional implementation (e.g., bST)	Strong programs in place in main dairy countries	Strong programs in place in main dairy countries	Candidate for additional implementation (e.g., milk surplus)
Intensive Dairy--Grazing		(NA)	Candidate for targeted supplementation in selected areas with deficiencies	Candidate for additional implementation (e.g., bST)	Strong programs in place in main dairy countries	Strong programs in place in main dairy countries	Candidate for additional implementation (e.g., milk surplus)
Extensive Commercial Ranching	35-40% of animals (40-45% of emissions)	(NA)	Possible candidate for targeted supplementation in selected areas with deficiencies, depending on deliverability	Candidate for additional implementation	Candidate for additional implementation	(NA)	Candidate for additional implementation (e.g., beef marketing)
Non-Extensive Commercial Ranching		(NA)	Candidate for targeted supplementation in selected areas with deficiencies; candidate for defaunation	Currently used routinely	Candidate for additional implementation	Possible candidate for targeted implementation in cases with adequate access to animals	Candidate for additional implementation (e.g., beef marketing)
Feedlot Production	1-2% of animals (2-4% of emissions)	Processed feeds are used routinely	Balanced rations used routinely	Currently used routinely where allowed	(NA)	(NA)	Candidate for additional implementation (e.g., beef marketing)
Small Scale Dairy and Draft	15-20% of animals (10-15% of emissions)	Candidate for additional implementation	Candidate for additional implementation of MUB and/or MUB/BPF	(NA)	Candidate for additional implementation	(NA)	Candidate for additional implementation (e.g., disease control)
Subsistence Mixed Farming	20-25% of animals (10-15% of emissions)	Candidate for additional implementation	Candidate for additional implementation of MUB and/or MUB/BPF	(NA)	Candidate for additional implementation	(NA)	Candidate for additional implementation (e.g., disease control)
Migratory Livestock Systems	5-10% of animals (2-8% of emissions)	(NA)	(NA)	(NA)	(NA)	(NA)	(NA)

Source: (IPCC, 1992b)

1 Estimates of cattle population are based on 1991 FAO production yearbook population data and assessments of animal management practices described in Reuss et al. (1990).

systems where animals are confined continually (e.g., feedlot) or at regular intervals (e.g., dairy), there is smaller scope for widespread implementation of reduction options.

In developing regions of the world, small-scale dairy and draft animal management is an important component of a predominantly subsistence type agricultural system. The integration of animal husbandry with crop production efficiently utilizes agricultural by-products as the basal feed for cattle and buffalo which provide milk and meat for consumption, draft power for plowing, transportation and other work, and manure for fertilizer and fuel. It is important to recognize the overall efficiency of these traditional management systems although the methane produced per unit of feed intake is high. Within the current resources and conditions of developing countries, existing management systems are often more efficient than is realized (Preston and Leng, 1987). Thus, experts in the field advocate approaches to improving productivity which match production systems with locally available resources.

Major constraints on traditional systems are mainly related to low inputs including insufficient quantity and poor quality feeds, inefficient draft implements, and limited infrastructure to handle increased production levels. Large ruminants rarely receive high quality grains, which are grown for human consumption, and subsequently exist on maintenance levels of energy and protein intake. Competing uses for scarce arable land largely preclude the cultivation of high quality fodders.

Programs to improve animal productivity would have a large impact on reducing methane production under these conditions. Furthermore many of the benefits resulting from improved animal productivity can contribute to meeting both the increase in demand for animal products due to increasing populations and government development goals to improve the conditions of rural populations. These benefits are discussed below.

5.4 The Benefits of Emissions Reductions

Programs that reduce methane emissions and increase animal production will have numerous important benefits, including increased production, animal health, farmer security, and reduced animal product imports.

Increased Production: In many developing countries, milk and meat produced on small scale farms are a major protein source in an otherwise largely vegetarian diet. Improved production of animal products can increase the nutritional quality of the diet, and will be necessary to meet the demand from a rapidly increasing human population. These programs will be an economically viable alternative to increasing the numbers of animals, since feed resources are scarce in many regions. Additional benefits can be expected from the increased production of other animal products: draft power, which may increase agricultural productivity; and products such as wool, hides, and excess milk and meat, which can be sold in cash markets.

Increased Animal Health and Farmer Security: A secondary effect of increased productivity is the ability of small farmers, often living at subsistence levels, to better meet their needs and to sell excess production where adequate infrastructure exists. In addition, programs which increase the efficient utilization of poor-quality forage will decrease the pressure on land use, and improve the health and reduce the mortality of animals. These changes will improve the economic security of small farmers in developing regions.

Reduced Animal Product Imports: Improving the productivity and supply of animal products will reduce expensive food imports, which currently drain scarce foreign exchange.

5.5 Country Profiles

Programs to improve animal productivity are successfully underway or successfully demonstrated for certain animal populations in a number of countries. Recent assessments of some programs indicate that the largest opportunities for both reducing methane emissions and achieving development goals are found in developing countries, where animal productivity remains well below genetic potential. The primary approach of programs in developing countries is to improve the nutrition available to animals through supplementation of feed with locally available products, and through processing of currently available feeds, such as rice straw, to improve their digestibility. A follow-on approach, applicable where adequate nutrition is available, introduces genetically superior traits through cross-breeding programs. These techniques have shown significant increases in productivity, especially milk production, and reductions in methane production per unit product of up to 60 percent (USEPA, 1993a).

For programs to be successful, it is necessary to design them to meet the particular needs and conditions of individual countries because of the different animal ownership and management systems that exist. Potential programs for improving animal productivity in India, China, Tanzania, Bangladesh, Eastern Europe, and the CIS are discussed in the following sections. These non-OECD countries were chosen because several major types of animal management systems are represented.

5.5.1 INDIA[1]

Overview

India (Exhibit 5-5) has a large population of ruminant livestock, with around 200 million cattle and 75 million buffalo, or roughly one quarter of the world's population of large ruminants (Mitra, 1991; FAO, 1991). As in most developing countries, livestock are managed predominantly on smallhold farms (e.g., 1 to 5 animals), where they meet a number of needs. The religious prohibition of the slaughter of cattle in India precludes the existence of a market for beef, and as a result large ruminants mostly provide draft power, milk, and manure for fuel and fertilizer. About 30 percent of India's large ruminants are used for draft power. These animals, therefore, are integral to the system of mixed farming practiced in India, where they are fed crop residues and provide important agricultural inputs. Moreover, livestock ownership

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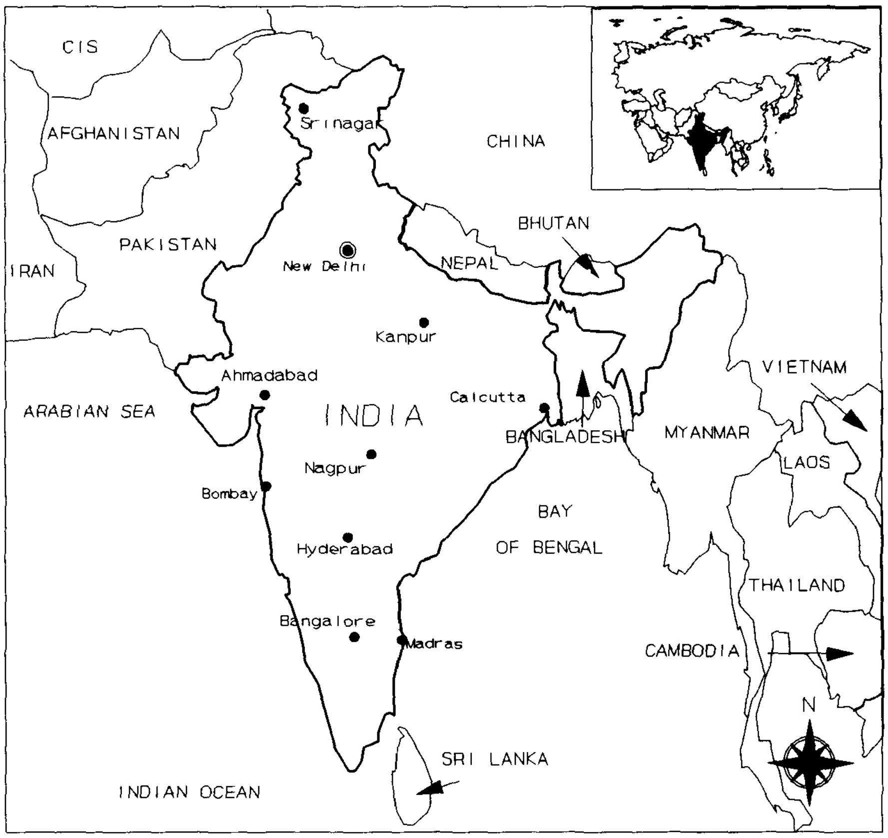
[1] This assessment is drawn primarily from AT International, 1992.

and the sale of excess animal products is often the only source of income at the village level. Milk is also a vital component of the diet of India's rural population, providing as much as 70 percent of the daily protein intake.

Exhibit 5-5
India



Many of India's ruminants are fed nutritionally inadequate diets as a result of seasonal fluctuations in the availability of forages and crop residues. For example, during the crop planting period, grazing is extremely limited and both dairy and draft animals are fed almost exclusively on residues such as rice straw, hulls and sugarcane processing wastes. Overall, the feed is low in digestibility, crude protein and bypass protein, and lacking in minerals and vitamins. Poor nutrition causes inefficient rumen digestion and, in the case of dairy animals, there is therefore less digestible energy available to the animal for lactation; in general, less energy is available for growth, production, and work. As a direct result of inefficient rumen function, the fermentation process produces more methane for a given level of feed intake.

The efficiency of digestion is greatly reduced by inadequate levels of dissolved ammonia in the rumen fluid, a condition which can easily be corrected. Dissolved ammonia provides rumen microbes with non-protein nitrogen, a nutrient that is essential to a healthy microbial population and a well balanced rumen. To correct an ammonia deficient rumen, nitrogen can be supplied by supplementing the diet with urea in the form of a molasses-urea multinutrient block (MUB). Government agencies in India have shown a strong interest in introducing MUBs and other technologies to increase the production of animal products. State agencies, non-governmental organizations and cooperatives have been involved in successful demonstrations of the technology since the early 1980s, but further work is needed.

Experience feeding dairy animals has shown that a basal diet supplemented with MUBs increases both milk yields and butterfat content. Milk production may be increased by up to 30 percent in some cases (Leng, 1991). Other benefits include increased liveweight gains, reduced mortality, earlier maturation and reduced calving intervals. For example, the age of first calving in India is typically 5 years and the calving interval is 2 years, whereas first calving at 2 to 3 years and calving every 12 to 15 months can be achieved with available nutritional supplements (Leng, 1991).

As a result of the constrained nutritional management of ruminant livestock that is common in India, most animals have higher methane yields[2] than genetically similar animals raised on properly balanced diets, in addition to being significantly less productive. Methane yields for these animals may reach as high as 15 percent of the digestible energy of the feed consumed, compared to 5 to 8 percent for animals that are raised on complete diets (Leng, 1991). Cattle in India are estimated to produce 4.2 to 7 Tg of methane per year, and buffalo an additional 3 to 5 Tg per year (USEPA, 1993c).[3] This represents 70 percent of emissions from South and East Asia.

Increasing the productivity of livestock is an important part of India's development goals. Increased production is necessary to meet the demands of a rising population, and to achieve the government's goal of increasing daily per capita milk consumption from around 160 grams per capita to 200 grams per capita. Moreover, because livestock constitute a major portion of the wealth of the rural population, increasing animal productivity can greatly contribute to raising the living standards and security for much of India's population.

During the mid-1980s, India's National Dairy Development Board (NDDB) initiated several programs to help improve the standard of living of small farmers in rural areas by improving dairy production. One of these programs, called Operation Flood, was designed to "flood" a major portion of Gujarat State with new technologies to increase milk production. Major efforts were made to produce molasses urea multinutrient blocks (MUBs) and distribute them for general application to straw fed animals. Although they were not developed specifically for drought feeding, farmers discovered the advantages of their use during the severe drought

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2 Methane yield is the percentage of feed energy intake that is converted to methane in the rumen.

3 Recent country-specific data indicates that emissions may in fact be lower than these estimates, especially for buffalo. The lower emission estimates result from lower animal weight and feed intake values.

of the mid-1980s. In seven of India's territories, processing plants were set up and operated by local District Dairy Unions under the guidance of the NDDB.

Although the shortage of feedstuffs resulting from the harsh drought made the use of MUBs (which maximize the efficient use of scarce feed resources) potentially highly beneficial, several problems hindered widespread adoption of the new technology. In many cases the MUBs were not used appropriately and farmers did not fully benefit from their investment. A major problem was encountered in the formulation of the MUBs: a high salt content and scorching from the heat used in preparation seemed to reduce their palatability, and many animals ignored the blocks. Also, a poorly trained extension service was unable to properly instruct farmers on the details of their use, such as their placement (cows and buffalo often have preferences as to whether the blocks are placed on the ground or on a post). In cases where the extension agents were trained, the target audience was primarily men, when in fact the women of the village were largely responsible for the management of the animals. Another important problem was that the cooperative feed mills which produced and sold concentrated feeds were responsible for commercialization of the MUBs, and probably had little incentive to promote the sales of the MUBs that were meant to replace their main product. As a result of these and other factors, MUB use during the early 1980s never reached the levels that the NDDB had targeted, and from 1987 to 1988 declined sharply.

More recently, the use of bypass proteins in addition to MUBs has proven to greatly increase dairy production (Leng, 1992). In 1988, the NDDB began to produce bypass proteins on a large scale. The AMUL feed mill in Anand, once a major producer of MUBs with a capacity of 100 metric tons per day, converted to producing only bypass proteins. The bypass proteins produced by AMUL are used in feeding approximately 500,000 animals which raises the milk production of these animals by over 50 percent. In Ghandinagar, the NDDB is planning to build a plant capable of producing 1000 metric tons of bypass proteins per day (Leng, 1992).

Overall, these potentially beneficial technologies have not been successfully introduced on a wide scale into the animal management systems which could most benefit: smallhold farms managed primarily by resource poor farmers and women, which account for roughly 85 percent of India's dairy herds (FAO, 1989; Reuss et al., 1990). Currently, only larger and centralized, state-run dairy farms use properly balanced feeds and other advanced management techniques. Subsequently, it is only these operations which have significantly increased their productivity. The success of larger farms, and the lessons of Operation Flood and other programs indicate that there is significant potential to expand the use of these technologies if aggressive and appropriate programs are developed.

Opportunities to Expand Methane Reductions

There are a number of opportunities in India to enhance current efforts to improve the productivity of ruminant livestock, thereby reducing methane emissions from this source. India's large ruminant population and the importance of their animal products provide incentives to increase productivity. Furthermore, current feed resources and management practices have not allowed many animals to achieve their genetic potential. Experience with productivity improvement programs, as well as availability of feed resources and infrastructure within India, suggests that there is a large potential to expand the use of appropriate technologies.

In the near term, efforts to improve the productivity of dairy animals will likely be most successful where there are already established milk markets. Currently, inadequate nutrition is the primary factor limiting dairy animal productivity, and nutrition could be greatly improved with the expanded use of supplements such as MUBs or by processing the feeds to increase their digestibility. Examples of feed processing techniques include grinding, chopping and ammoniation of straw. Other technologies for improving productivity could include the use of bypass proteins, the promotion of breeding programs, and expansion of improved animal health programs.

Most regions of India are capable of producing molasses-urea blocks, and feed mills throughout India currently produce a variety of animal feed supplements. There is, therefore, sufficient infrastructure and technical experience to produce MUBs and to implement other feed processing technologies. Moreover, economic analyses show that MUB production has a high degree of commercial feasibility, with small capital investments and short payback periods. The initial capital investment for a small feed mill equipped to produce MUBs is generally $70,000, with a payback period of 3 to 4 years. The raw materials for production are also readily available.

While improved nutrition in the dairy herd could provide sustainable gains in the short term, there are several longer term approaches which could also yield significant benefits. One approach would be to use these techniques with those animals raised for draft power. This approach is less likely to be introduced in the short term because increased draft power is a less quantifiable benefit than increased milk production, and because draft power is typically not a directly marketable product. Nevertheless, successful application in the dairy herd leading to improved reproductivity will encourage the extension of MUBs into the draft herd.

Additionally, improved animal health practices can be introduced into both dairy and draft herds. There is also continuing opportunity for larger state dairies and research stations to develop improved breeding programs to increase the genetic potential of livestock. Such programs could be especially successful with buffalo, which are better adapted to the climate, do not require as high-quality concentrate feeds, and produce milk that is preferred because of its high butterfat content. In order for these techniques to be successful, however, it is first necessary that the basic nutritional needs of the animals are met.

Emissions Reduction Potential

In the short term, programs encouraging MUB production and use could reach a significant portion of the animal population. These programs could focus on milk-producing animals where the productivity increases will be most visible, and the milk can be sold in existing markets. These animals include dedicated (i.e., single use) dairy herds, as well as dual-purpose animals. These programs should concurrently address the need for increased collection, processing and marketing of milk, to ensure that excess production can indeed be sold. In some cases, other options including feed processing technologies could be implemented. Previous experience in western India (e.g., Gujarat) suggests that conditions, available resources, and government interest make this region particularly suitable for implementation in the short term.

The portion of the animal population that can be reached by these technologies may be less in India than most developing countries because of India's unique cultural and religious restrictions that prohibit the slaughter of cattle. This prohibition increases the portion of old, unproductive cows and bulls, which would otherwise be slaughtered for meat. Since productivity increases are not achievable (or do not provide any benefits) for these animals, they would not be included in methane reduction efforts. In spite of this fact, the overall number of animals that could be affected by these technologies is high because of the extremely large animal population. Because buffalo are not subject to restrictions on slaughter, the proportion of female to male buffalos is higher (because males are selectively slaughtered for meat), and a greater portion of the total population would be amenable for methane reduction strategies. Considering these factors, aggressive nation-wide extension programs may reach 40 to 50 percent of the total animal population, or about 110 to 135 million animals (primarily lactating cows). By supplementing traditional diets, methane reductions on the order of 0.8 to 1.2 Tg per year are possible.[4] Further reductions could be achieved in the longer term by eliminating the need for some animals through increased production and reproductivity.

In the longer term, improvements in animal nutrition could be extended to other sections of the animal population (i.e., draft animals). Further assessments will help to identify technologies appropriate for the various types of animal management systems found in other regions of the country. Once efficient rumen function has been achieved, the use of bypass protein feeds, disease control, and improved breeding programs could successfully be introduced.

Promoting Methane Reductions

There is large potential for improving animal productivity and reducing methane emissions in India, through the expansion of proven options. A number of barriers exist, however, which currently hinder India's widespread use of these technologies and practices, despite the potential benefits and successful past projects.

One key barrier is the current need for expanded extension services to provide necessary information on animal nutrition to small farmers, primarily the women who are responsible for the care of the dairy animals. Other barriers include the need to adapt technologies to local conditions and resources, the limited funds available to small farmers to invest in feed supplements, and the need for a guaranteed outlet for increased production.

Addressing these barriers will require extensive cooperation between local institutions, the Indian government, international development agencies, and other non-governmental organizations with experience in this area. A strong focus on domestic activities could allow

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4 This estimate assumes that emission reductions of 20 to 25 percent are achieved for 40 to 50 percent of the population. This estimate may be conservative as it does not take into account the fact that the targeted animals have relatively high methane emissions factors.

individual projects to be customized to local conditions. International assistance may be useful, however, for the coordination of project planning, technology demonstration, the development of regional infrastructure, and investment. The specific types of activities which may be helpful in realizing the benefits of improving India's agricultural productivity are summarized below.

Policy Support: The actions described in this report are primarily development projects, with benefits including increased productivity, financial security, and welfare of both rural and urban populations. It may be useful to focus domestic policy support on these primary benefits, which could contribute to India's current development plans, rather than on the additional benefit of methane emission reductions.

Project Planning and Evaluation: The effective introduction of these types of projects could be facilitated through efforts to plan and evaluate opportunities at the national, regional, and local level. In addition to the inclusion of livestock productivity goals in India's national development plans, these actions could include assessments of regional resources and animal management practices, selection of demonstration sites, adaptation of technologies to local conditions, and the evaluation of dissemination opportunities and extension services.

Technology Transfer and Demonstration: Additional efforts to demonstrate appropriate technologies may be particularly useful. A number of projects have successfully demonstrated certain technologies and practices to reduce methane emissions in various regions of India. There is a need for demonstration of these proven technologies, such as MUBs, under different conditions to show their adaptability. Also, projects could be undertaken to test additional technologies, including bypass protein feeds and longer term developments such as breeding programs, in these same regions. Technology transfer and demonstration projects may also be useful to help develop adequate production and marketing infrastructure.

Training and Extension Services: Along with demonstration projects to prove the suitability of certain technologies, well-designed local extension services could help introduce new practices into rural animal management systems. These extension services would be most useful if they met a number of criteria. Extension workers need access to adequate technical assistance and training to be able to implement different technologies, and especially to be able to present a range of choices for farmers rather than delivering a set technology. Extension workers should also be trained to reach and educate those actually responsible for livestock management (typically women), if technologies are to be adopted by small farmers. Finally, extension services and the local efforts they support should be self-sustaining. Without extension services or a similar infrastructure for promoting new technologies, the lack of widespread knowledge and experience with new technologies could present a barrier to the widespread implementation of these technologies.

Production and Marketing Infrastructure Development: India's current development plans, which are focused on the introduction and adoption of new technologies, could be enhanced by developing an expanded infrastructure to support these technologies and the increased production they will create. Toward this goal, feed supplement production and the capacity of feed processing facilities could be expanded. These efforts would require capital investment in addition to the technical assistance described previously. Successful projects may also need to address the need for improved milk storage, processing, and distribution capabilities, to ensure that excess production can reach the market.

Financial Sustainability: Economic analysis indicates that the production and use of feed supplements is an economically viable method of increasing the production of animal products, and should be financially self-sustaining. Nevertheless, it will be necessary to identify sources of initial investment funds.

5.5.2 PEOPLE'S REPUBLIC OF CHINA[5]

Overview

The People's Republic of China (Exhibit 5-6) has approximately 100 million large ruminant animals (cattle, buffalo, and yaks), accounting for approximately 7 percent of the world's large ruminant population. The vast majority of these animals are managed on smallhold farms and used primarily for agricultural draft power and transportation purposes, as well as for providing dung for fertilizer and fuel. The production of meat and milk, when it occurs, has traditionally been a secondary activity. Smallhold traditional farming systems account for 50 million draft cattle (indigenous yellow cattle), most of the 21 million buffalo, and a portion of the 15 million purebred yak and cattle-yak hybrids. The second largest portion of the animal population is raised on semi-arid grasslands in north China, and comprised of 10 million pastoral cattle, as well as some 10 million yak and associated hybrids.

In addition to animals on smallhold farms and pastoral grasslands, there are roughly 4.5 million head of dairy and beef breeds imported from Europe and the U.S., which are mainly being raised on state dairies and privately-owned small farms. (Crossbreeds are also raised in some traditional and pastoral systems in limited numbers). The state dairy sector comprises 32 percent (800,000 head) of the dairy population, and has been instrumental in introducing imported breeds. Total methane emissions are estimated to be about 3.5 to 5.9 Tg per year; 2.5 to 4.3 Tg per year from cattle, and 1 to 1.6 Tg per year from buffalo (USEPA, 1993c).

After the cultural revolution ended in 1976, agricultural policy shifted from favoring collective farms to favoring privatization. This resulted in the emergence of small farms which integrate animal husbandry into their crop production activities, or specialize in a certain type of animal husbandry. These types of enterprises constitute China's small but rapidly growing transitional agricultural sector. Management of ruminant animals in this sector is oriented towards a diverse range of activities, including the production of meat, milk, live animals for sale, and draft power. Over half of China's dairy cattle, which until very recently were raised almost entirely by state-run or collective operations, are now raised on these transitional farms.

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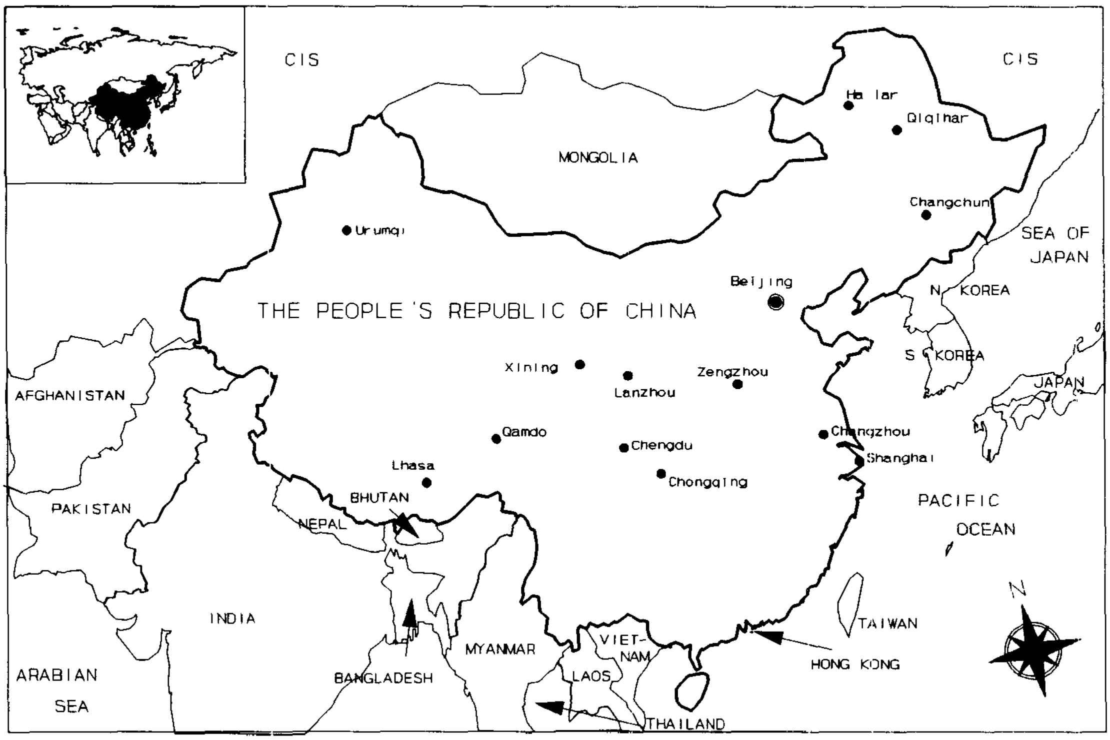
5 This assessment is drawn primarily from Sollod, 1992.

Exhibit 5-6
The People's Republic of China



Large ruminants in China generally are fed an unbalanced diet inadequate in digestible nutrients, and especially lacking in protein and energy. Typical diets are based on straws, with varying attempts to supplement the diet with bran and concentrate meals depending on the animal management system. Except in state dairy operations and a few transitional farms, animals fail to achieve their genetic potential and in some cases are permanently stunted from lack of nutrition. For example, average milk production in China is 1,500 kg per lactation which is slightly less than half of the production achieved in forage based systems in areas such as Australia and New Zealand (Leng, 1992). Meat production per head is less than 5 percent of production levels in the United States. Moreover, poor nutrition results in inefficient rumen digestion, causing less energy to be made available to the animal, and more methane to be produced for a given level of feed intake. (A notable exception are some of the well managed state dairies which have production levels in excess of 6000 kg per lactation, equivalent to those in the U.S.).

There is currently a large agricultural extension network throughout China, but the emphasis of these services and other improvements has been on animal health and crossbreeding using European breeds. In the past, relatively little attention has been paid to improving feed resources or educating small farmers about the value of improved nutrition, and there is a lack of awareness on the part of small farmers about nutritional requirements and possible techniques to increase animal productivity.

Milk and beef are not traditional components of the human diet in China. Nevertheless, there is a rising level of consumption of both these products, especially in urban populations. Meeting the increasing demand for ruminant animal products through increasing the numbers of animals would place unrealistic strains on land use and feed resource availability. A more logical way to meet this demand would be to increase animal productivity and to better utilize the potential productivity of draft animals.

Opportunities to Expand Methane Reductions

There are several possible strategies to meet the increasing demand for non-traditional animal products in China through increasing productivity rather than increasing animal populations, presenting significant opportunities to reduce methane emissions from this source. These strategies seek to encourage the use of the improved nutritional management techniques already being adopted in the more production-oriented transitional sector, and to extend these techniques to incorporate increasing numbers of draft animals currently managed in traditional systems. These strategies require an increase in the energy ruminants receive from their base diet.

It is unlikely, however, that the animals' base diet of straw and other low-quality agricultural by-products will change, due to the more efficient use of high quality feeds by monogastric animals (e.g., swine and poultry), and due to the pressure on land use for other crops. There is, therefore, a strong incentive to improve the digestibility of these straws by expanding the use of existing technologies. Treating straw with urea is one method to improve the nutritional quality of the diet, and is well suited to available resources and experience in China. Other possible options for increasing livestock productivity include improving forage production and continuing efforts in improved breeding and veterinary services.

Although there are a number of possible straw treatment methods, the most appropriate option for promotion in China may be the use of urea to ammoniate straw. Not only is urea less caustic than alternative chemicals, such as ammonia or sodium hydroxide, but urea is familiar to small farmers as an agricultural fertilizer. Moreover, urea is relatively inexpensive and widely available in China.

When urea is applied to straw, a portion of the urea is converted to ammonia. The coarse lignin straw fibers are chemically broken down by the ammonia, exposing the plant's internal components. This process increases the digestibility of the straw by allowing microbes greater access to the structural carbohydrates for fermentative digestion. The portion of unconverted urea is also a valuable nutritional supplement, providing rumen microbes with a source of non-protein nitrogen. The combined effect increases digestion efficiency and, therefore, increases animal productivity. Using urea, methane produced per unit product can be reduced by up to 10 percent or more (USEPA, 1993a).

The primary cost of this treatment method is the urea itself. The estimated cost of treating straw is 150 yuan ($25) per ton of straw, based on a state-controlled price of 600 to 700 yuan ($100 - $120) per ton for urea. The low cost and large benefits make this economically viable if milk or beef is produced. Currently, however, urea is predominantly applied to the land as an agricultural input, with less than 1 percent used in the feed sector; state price controls in China currently encourage the use of urea for agricultural rather than feed purposes.

A second strategy which may be used to supplement the base diet of straw is the cultivation of improved forages, such as legumes. The cultivation and use of legumes has gained acceptance in other tropical and temperate regions because they can provide a necessary source of protein for large ruminants, but farmers in China have little experience with improved forages because draft animal management has generally minimized nutritional inputs. Although using dedicated agricultural land for growing forages is unlikely to be competitive, it may be possible to identify legumes which can grow on marginal sites where other crops are not cultivated, including roadsides and river banks.

There are a number of other strategies which may be applicable in some regions of China, but do not appear to be widely feasible based on current studies. Additional research would be useful to identify and assess these options. For example, feeding ruminants agro-industrial byproducts, such as plant and fish processing wastes, can provide valuable protein and increase the utilization of low quality feeds. However, many of these byproducts are more efficiently utilized by monogastric animals. Nevertheless, there are potentially large quantities of underutilized low-quality process wastes which could be used as animal feed. For other strategies, such as the use of molasses-urea blocks (MUB) common in India, the resources are often not available or would have a greater economic return if used in swine or poultry feed. In particular, China is not a large sugar producer, and molasses production is insufficient. Although most molasses in China is used for alcohol production, however, distillery wastes could be used for the production of MUBs in place of molasses. There is some experience using distillery waste as a cattle feed, but its feasibility in China needs to be studied further (Leng, 1991).

Emissions Reduction Potential

In the short term, ammoniation of straw and perhaps the cultivation of high-protein legume forage on marginal sites could be introduced and expanded in regions with a rapidly growing transitional farm sector. These strategies primarily target the roughly 24 million cattle in the central agricultural region of China where extension services are strongest and straw as a feed resource is most available. In addition, farmers in this area have experience producing milk and meat, and are relatively close to urban markets.

In the long term, these techniques could be expanded to include draft cattle, accounting for almost half of China's ruminant population (50 million animals). Another 17 million animals may also be included if milk production increases from buffalo in southern China.

Less opportunity exists in other regions of China. There is little potential for improvement in the state-run dairies, due to small animal numbers and the current use of good management practices, and the extensive grazing of herds makes it difficult to implement options in pastoral regions.

Implementation of these programs could reach 50 to 60 percent of China's animal population in the long term. Potential methane reductions achievable in the near-term may be 0.5 to 0.7 Tg per year, with methane reductions of up to 1.5 Tg per year possible in the long term through improved nutritional management of the existing herd, resulting in lower methane yields.[6] Reduction of the animal population size, as draft animals are slowly replaced by mechanization, would reduce potential future methane production.

Promoting Methane Reductions

The introduction and dissemination of certain technological options, notably the ammoniation of widely available wheat and rice straw, has a large potential to increase animal productivity while offsetting or reducing methane emissions from large ruminants in China. A number of important barriers may exist, however, which currently impede the widespread adoption of these technologies and practices. These barriers include: the lack of awareness of technologies among small farmers; the focus of extension services on breeding and health (as opposed to productivity); the current predominance of draft management systems; and the small (although rapidly growing) quantity of ruminant livestock products sold in cash markets, which provide the immediate incentive for increasing productivity.

These barriers may best be addressed through a combination of China's domestic actions to introduce and support new practices, and international assistance by development agencies and other international organizations. These combined efforts may facilitate many of the areas of action required to achieve productivity improvements. The specific types of activities useful for overcoming these barriers are summarized below.

Policy Support: While the concept of increasing animal productivity is supported in China on the national level, the widespread expansion of practices to improve nutrition and productivity in China's ruminant population may be limited without coordinated action on many levels. China's eighth five-year plan (1991-95) includes the goal of increasing meat production through the increased utilization of improved feed resources, rather than the number of animals, thereby reducing the competition for land and agricultural inputs. In conjunction with this national support, strong local and regional policy support could help to successfully train and prepare an effective extension service. Additional policy support could involve removing price disincentives for the use of urea as a feed resource.

Project Planning and Evaluation: The effective introduction of these types of projects could be facilitated through efforts to plan and evaluate opportunities at the national, regional, and local levels. In addition to the inclusion of livestock productivity goals in China's national development plans, these actions could include assessments of regional resources and animal management practices, selection of demonstration sites, adaptation of technologies to local conditions, and the evaluation of dissemination opportunities and extension services.

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[6] This estimate assumes that emission reductions of 20 to 25 percent are achieved for 50 to 60 percent of the population. This estimate may be conservative as it does not take into account the fact that the targeted animals have relatively high methane emissions factors.

Technology Transfer and Demonstration: The ammoniation of straw is practiced in China to a limited extent, but additional demonstration projects may be desirable on a wider scale and under a variety of conditions. A number of other mechanical and chemical feed processing technologies could also be introduced and evaluated for use in China. Technology transfer and demonstration projects could also be useful for the dissemination of the types of legumes which have proven successful in similar temperate and tropical regions.

Training and Extension Services: In order to spread awareness among small farmers of the potential benefits of producing additional animal products, such as meat and milk, it may be beneficial to incorporate practical nutrition and feeding aspects into the training of China's agricultural extension service. Adding these topics to the existing program of improved breeding and animal health could help to familiarize farmers with the nutritional needs of large ruminants and the types of technologies and practices which lead to increased productivity. Strategies could include training extension workers in these technologies and methods and introducing them at the grass roots level, as well as using agricultural schools as training institutions, with the cooperation of the Ministry of Agriculture.

Market Development: The increased production and sale of meat and milk provide a direct incentive for small farmers worldwide to increase animal productivity through improved nutrition. Transitional private farms in China, which have a generally more innovative and entrepreneurial approach to livestock management, have realized the potential for increasing the production of a diverse range of animal products by improving animal management techniques. Continued growth of this transitional sector is an important step in strategies to improve ruminant management, and could be enhanced by the development of markets for non-traditional products. In the short term, efforts to introduce technologies could focus on central agricultural regions with access to urban markets. Long term success may require the development of more extensive markets for milk and meat products.

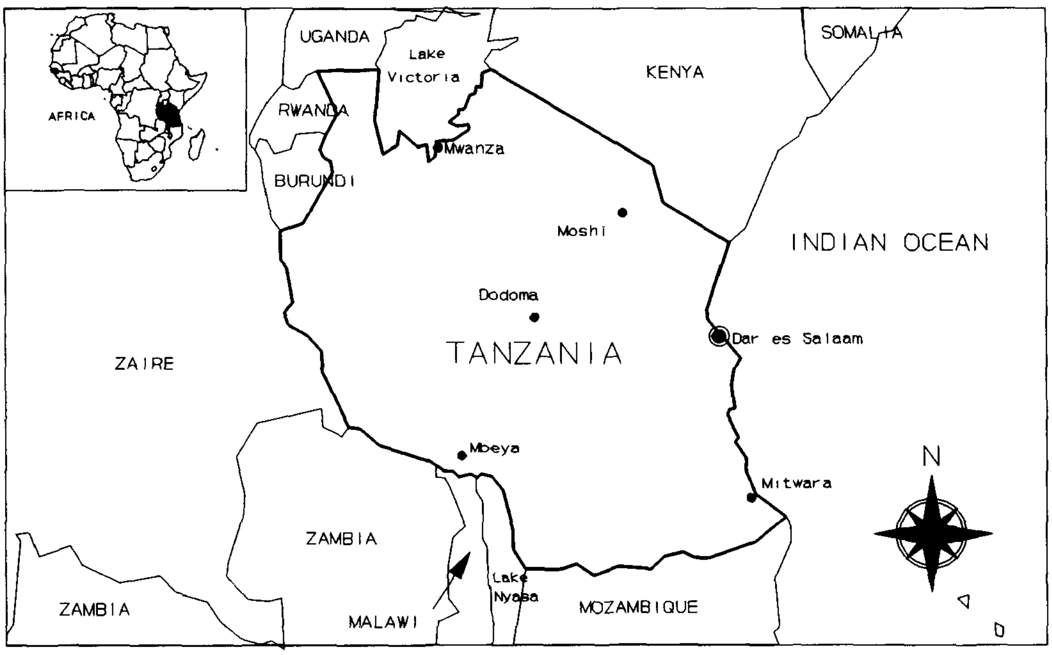
Funding Development: In the long term, increasing the productivity of milk and meat production is commercially viable. However, the introduction, demonstration, and dissemination of new practices may require funding for initial action.

5.5.3 TANZANIA

Tanzania (Exhibit 5-7) has the third largest cattle population in Africa, with nearly 14 million head, accounting for roughly 8 percent of the cattle in Subsaharan Africa (a region comprised of 38 countries). There are currently two systems of small-scale dairy production in Tanzania, intensive and extensive, with the vast majority of farmers practicing the extensive system. The intensive system is characterized by crossbred animals from local Zebu stock crossed with Jerseys or Friesians and managed in herds of 1 to 7 cows. The animals are confined at all times and are fed cut and carry forages. Milk production can vary from 5 to 30 liters per day. Intensive dairy production is practiced mainly in the highland areas where cash crop production dominates agricultural activity. Assuming an annual methane production rate of

32.7 kg per head (USEPA, 1993c), approximately 0.4 to 0.6 Tg per year of methane are produced by large ruminants in Tanzania.

Exhibit 5-7
Tanzania



The extensive system is characterized by the husbandry of a pure stock of traditional Zebu cattle managed in larger herds of 10 to 30 head. Confinement of the animals only occurs at night. The basal diet consists almost entirely of grazing low quality grasses with very few supplementary nutritional inputs. These cows are milked regularly, yielding approximately one liter per day. The extensive system is practiced primarily in the lower lying areas of central and southern Tanzania (Bowman, 1992).

Current per capita annual consumption of milk and meat is 22 liters and 5.7 kg, respectively. The Tanzanian government intends to increase this consumption level to 30 liters of milk and 9 kg of meat per capita by the year 2000. Because the population of Tanzania is expected to increase by over 50 percent by the year 2000, an increase in milk consumption of just over 30 percent (as planned) will require milk production to roughly double. If production remains constant, however, simply maintaining current consumption levels will require imports valued at over US $100 million per year.

Increasing production levels by increasing animal numbers will be severely constrained by the availability of feed resources, as already most cattle are not adequately fed. Moreover, increasing the demands on relatively poor agricultural land may exacerbate environmental degradation. Increasing the efficiency of feed utilization may thus be the most feasible way to achieve production increases within the constraints of feed and financial resources.

A number of factors indicate that opportunities exist to improve animal productivity and reduce methane emissions in Tanzania. Tanzania has one of the largest populations of ruminants in Africa, and these animals have a technical potential for large productivity improvements because of their currently inadequate diet. Moreover, the small-scale mixed farming systems which are most prevalent provide ready access to the animals, and the high ratio of female to male animals indicates that animals are managed intensively for dairy production. As with many developing countries, improving animal management techniques in Tanzania can contribute towards the existing development goals of the government. Although further study is needed to fully assess the potential improvements, it is expected that existing and proven methods can be adapted to the specific conditions within Tanzania, with a reduction in methane emissions per unit product on the order of 30 to 40 percent likely achievable. Developing institutional resources could be an important part of efforts in this country, as extension services in Tanzania are more limited than those in India and China.

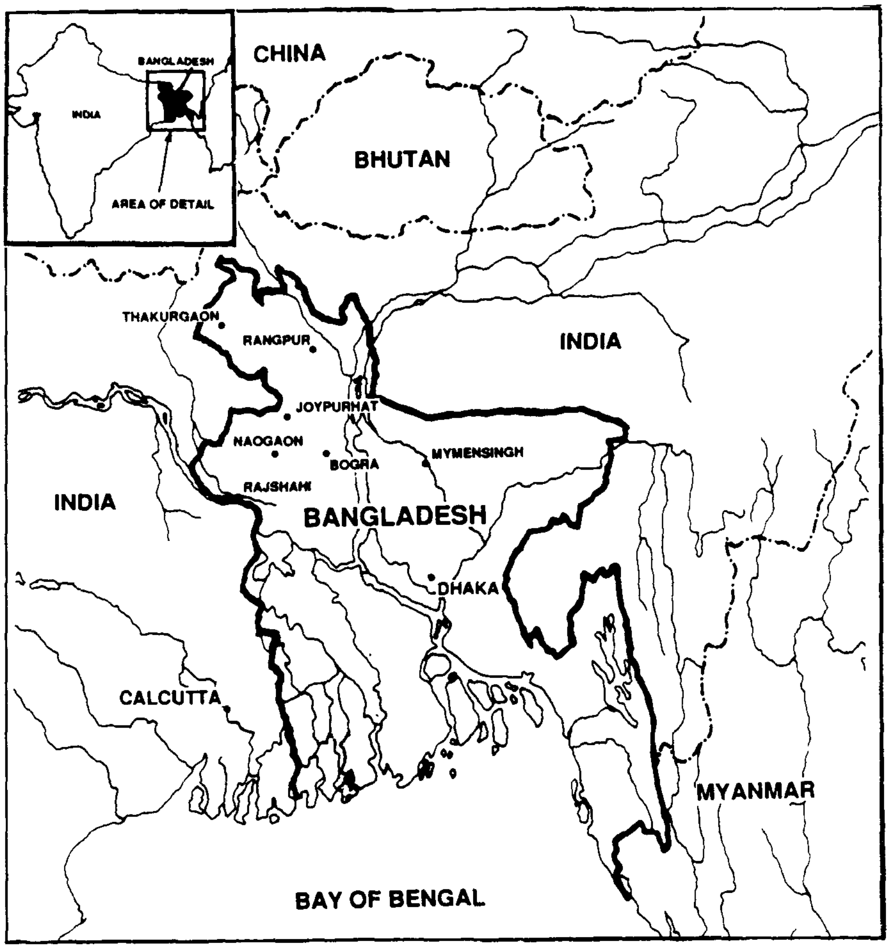
In addition to Tanzania, a number of other countries in Subsaharan Africa could possibly benefit from similar programs. Small-scale mixed farming systems are the predominant management system throughout subhumid, semi-arid, and highland regions of Africa, and may account for as much as 70 percent of all cattle in this region. Methane emissions from cattle and buffalo in Subsaharan countries may be about 4.5 to 7.5 Tg per year (USEPA, 1993c).

5.5.4 BANGLADESH

Bangladesh (Exhibit 5-8) has a significant population of large ruminants, estimated at 22.5 million cattle and 0.7 million buffalo, accounting for 5 to 10 percent of the large ruminant population in the Indian Subcontinent (Ahmed, 1992). The management of livestock and the role they play in Bangladeshi society is similar to the Indian situation, where livestock are raised as an integral part of smallhold farms. Large ruminants provide 98 percent of the agricultural draft power and large amounts of manure for fuel and fertilizer, and in turn are fed primarily crop residues. Meat and milk are an important supplement to the diet of the rural population, and when sold, are often the sole source of cash. It is estimated that livestock management accounts for over 6 percent of the Bangladeshi Gross Domestic Product (GDP) (Ahmed, 1992; Ministry of Fisheries and Livestock, 1992), and that these animals may emit between 0.6 and 1.2 Tg of methane per year (USEPA, 1993c).

The poor performance of large ruminant animals in Bangladesh is directly related to the inadequacy of the quantity and quality of feed resources. The average large ruminant diet in Bangladesh, which typically consists of rice straw, poor quality grasses, and leaves, is usually deficient in critical nutrients and by-pass proteins. Productivity is therefore low: native cows typically produce 180 liters of milk per lactation, and cattle reach a liveweight of 150 to 200 kg. Productivity is higher for cows at the few larger dairies and for the small number of crossbreeds which account for roughly 4 percent of the animal population. However, without improvements in nutrition, higher productivity cannot be sustained across the entire animal population (Ahmed, 1992).

Exhibit 5-8
Bangladesh



A number of recommendations for improving ruminant nutrition appear to be applicable to the situation in Bangladesh, based on the concept of matching the ruminant production system with the available resources, and aiming for efficiency and economic optimization rather than biological maximization. In particular, the use of molasses-urea blocks has been demonstrated in Bangladesh with significant productivity improvements including longer lactation times, increased daily milk yields, and better reproductive performance (Saadullah, 1991). Moreover, large quantities of molasses, for which there are currently few local markets, are apparently available from agro-industrial processing byproducts. Other studies indicate that there may be potential for chemical processing of straw such as ammonia treatment (Davis et al., 1983).

Potential also exists for increasing the protein supply for ruminant diets, in addition to other methods of improving ruminant nutrition. There are a number of existing ruminant feed sources that are currently unused, undeveloped, or poorly utilized, that could significantly increase livestock output. Examples of these feed sources include sugarcane tops, banana leaves or pseudostems, unused molasses, and stillage (distillery wastes). High-protein crops may also be available from other unconventional sources. One possibility could involve utilizing the country's estimated 500,000 hectares of abandoned wastewater ponds, which currently contribute to disease problems, to grow high-protein plants such as duckweed (Robson, 1991). In addition, there may be large potential to cultivate mixed-use trees, using forage-producing trees to provide fuelwood, instead of traditional varieties. Alternative options may include growing fodder on marginal land areas and expanding the joint cultivation of forages such as cowpea with existing crops (e.g., maize), although the considerable pressure on land use in Bangladesh makes it unlikely that arable land available to farmers could cost-effectively support the cultivation of forages. Other potential crops to grow on marginal land that is poorly drained, or even with standing water, include german grass and para (Ahmed, 1992).

Potential emissions reductions in Bangladesh may be around 0.1 Tg per year in the short term, and as high as 0.3 Tg per year in the longer term. There is a need, however, to assess the feasibility of various methane reduction strategies, with special attention given to the applicability of different methods, the availability of local resources, and the barriers which must be overcome. Initial actions could involve establishing contacts among international organizations, government institutions, and regional experts to initiate demonstration projects and promote the eventual dissemination of appropriate methods.

5.5.5 COMMONWEALTH OF INDEPENDENT STATES & EASTERN EUROPE[7]

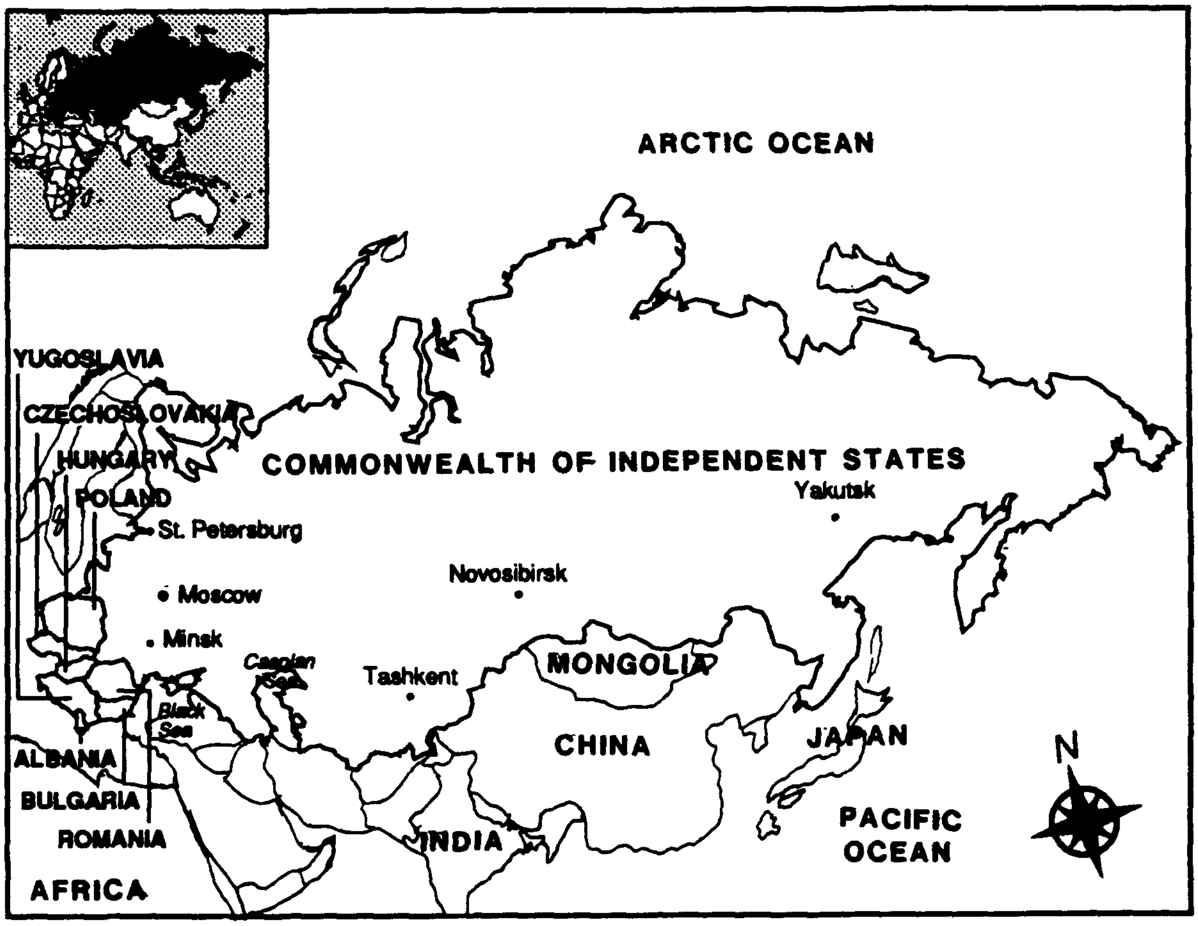
The Commonwealth of Independent States (CIS) and Eastern Europe (Exhibit 5-9) support a population of over 150 million large ruminants, the vast majority of which are cattle. The CIS accounts for 120 million animals, or 80 percent of this population. Despite these large numbers, there is a general shortage of animal products throughout the region. Government policy has been to increase production through centrally-planned promotion of collectives and large-scale farms. Although agricultural policy is likely to change due to recent political changes, it is not clear what the rate of change will be, how far production will be decentralized, and what the overall effect will be. While the prospect of change offers new opportunities, economic dislocations and institutional rebuilding are likely to pose obstacles to rapid, short-term action.

The most prominent agricultural regions are the lowland and central zones, which include all of Eastern Europe and stretch through the Ukraine and into much of southern Russia (excluding Siberia). Animals in these regions are typically raised on large collective or state-run farms with forage-based diets, supplemented with hay and grain. However, total diets are often unbalanced, lacking in digestible protein and important micro- and macrominerals. Productivity is low, compared to large intensive animal systems in developed countries: milk yields average around 2,200 liters per year; and liveweight for slaughter averages 350 kg. Methane emissions for the region may be about 7.5 to 12.5 Tg per year (USEPA, 1993c).

[7] This assessment is drawn primarily from Reuss et al., undated; and Reuss et al., 1990

The accessibility of animals on these large farms suggests that opportunities may exist to promote improved management practices, such as nutrient supplements, productivity enhancing agents, and improved reproductive methods. In addition, some studies suggest that large contributing factors to the nutritional inadequacy of the average diet are poor feed harvesting and storing technologies, and an increasing shortfall in grain production. Moreover, at this time, it is not clear which regions possess the agricultural and infrastructural resources to improve ruminant nutrition. Thus, further study is needed to ascertain the specific situation facing each region, and to identify appropriate technologies. Despite the uncertainty as to the shape of future programs to improve productivity in these regions, it is clear that there is a large technical potential for achieving emission reductions, perhaps in excess of 1 Tg.

Exhibit 5-9
Commonwealth of Independent States and Eastern Europe



5.6 Summary

As can be seen in the country profiles, individual countries have different livestock management systems, different levels of support infrastructure, different resources available to them, and different production incentives. While these differences lead to varying regional and national abilities to increase animal productivity and thereby reduce methane emissions, particularly in the near term, common characteristics can be identified to provide a broad understanding of:

- potential emissions reductions from ruminant livestock;
- barriers hindering adoption of improved management techniques; and
- possible solutions for overcoming these barriers.

Emission Reductions

Large ruminant livestock in many developing countries can be characterized as animals with diets that are often deficient in nutrients critical for efficient fermentative digestion. Depending on the extent of these deficiencies, improving nutritional management can actually reduce the production of methane per unit of product by 10 to 60 percent (USEPA, 1993a; Leng, 1991). In many of the densely populated countries of the world, the amount of livestock feed is strictly limited because arable land is too scarce and valuable to plant forages and other feeds for livestock. With limited feed resources, feed intake per animal is often restricted. In this case, an improvement in the feed conversion efficiency translates directly into a reduction in methane emissions on a per animal basis.

In addition, by reducing the amount of feed energy that is converted to methane, livestock productivity can be significantly increased. For example, using supplements such as molasses-urea multinutrient blocks and bypass proteins can double liveweight gains and milk yields. Moreover, the age at first calving and the calving interval for cows can be greatly reduced. These reductions of unproductive periods lead to substantial increases in the lifetime productivity of cows, both in terms of calves and milk. Calf survivability can also be improved, with the herd becoming more productive overall.

Given these increases in productivity, the reduction in methane emissions per unit product will be larger than the absolute reductions achieved from improving the feed conversion efficiency. Because production must increase to feed growing human populations, improvements in animal nutrition would not only reduce emissions from current levels, but would prevent increases in emissions that would result from the expansion of animal production (and animal populations) using current management practices.

Near Term Reductions: Dairy herds present the greatest opportunity for achieving emission reductions, with reductions in annual emissions of 4 to 10 Tg possible in the near term. A large proportion of the methane produced by dairy animals on poor diets comes from the unproductive time that animals spend in reaching maturity and the long inter-calving periods. Improved nutrition can reduce the age of first calving from 4 to 3 years and reduce the calving interval from 2 years to 1.5 years, thereby increasing the number of calves and the number of lactations over a 14 year lifetime by 33 percent. Calf survivability would also improve and milk production per lactation could double, further increasing production and reducing methane emissions per unit of milk produced.

The expansion of agricultural extension services to promote nutrient supplementation, improved health and reproductive performance with dairy animals is likely to succeed in the short term because increased production of milk is an easily seen improvement, and because the excess milk may be sold in cash markets. The additional cash generated by daily milk sales would enable poor farmers to afford the necessary inputs to maintain elevated production levels. Furthermore, dairy animals are readily accessible for application of technologies.

Longer-Term Reductions: In the longer term, projects could lead to a reduction in annual methane emissions from ruminant livestock on the order of 10 to 19 Tg below present levels. For example, improvements may be made in draft and beef animal management systems, in addition to continued improvements with dairy herds. In some cases, however, the lack of direct economic benefits (e.g., cash markets) may hinder the adoption of improved management techniques for draft animals. Longer term projects would continue to emphasize nutrition as well as to implement breeding and animal health programs, and other technologies.

Estimates for methane emissions and potential emission reductions from ruminant livestock, which are mostly achieved from cattle and buffalo, are summarized in Exhibit 5-10.

Promoting Methane Reductions

Meeting the challenge of livestock development with the introduction of new technology alone is not sufficient. In order to be sustainable in developing countries, livestock development programs must be consistent with country development goals including improving the welfare of the rural poor, who are the major producers of food for the world, and for whom animal ownership plays an important economic and cultural role. Moreover, development projects must take account of the unique conditions of each region and site, with particular attention paid to the available technical, financial, human and natural resources.

Future development efforts will also have to incorporate lessons of the past. The experience of livestock development programs suggests several important considerations for future programs. These lessons include the limitations of direct transfer of agricultural technology, the difficulty and importance of information and technology transfer among developing countries, and the artificially low milk prices common in developing countries. Failure to address these issues may create serious obstacles to the successful introduction of sustainable productivity improvements. In the past, failure to address these issues has in ome cases harmed the economic welfare of rural peoples and created distrust of new technologies. These issues are discussed below, and are summarized with other more site-specific barriers in Exhibit 5-11.

Exhibit 5-10
Estimates of Potential Economically Viable Reductions in Methane Emissions from Cattle and Buffalo

Country	Estimated Emissions (Tg/yr)[1]	Near Term Reductions (Tg/yr)		Longer Term Reductions (Tg/yr)	
		Tg/yr	%	Tg/yr	%
CIS/E.Europe	7.5 - 12.5	up to 1	5 - 10	over 1	5 - 15
India	7.2 - 12.0	0.8 - 1.2	5 - 10	1.2 - 2.5	15 - 20
United States[2]	4.4 - 6.6	up to 1	~ 25	over 1	~ 25
China	3.5 - 5.9	0.5 - 0.7	10 - 15	0.7 - 1.5	20 - 25
Bangladesh	0.6 - 1.2	0.1	10 - 15	0.2 - 0.3	25 - 30
Tanzania	0.4 - 0.6	0.1	15 - 20	0.1 - 0.2	25 - 35
Others	38 - 62	2 - 6	5 - 10	6 - 12	15 - 20
TOTAL	50 - 82	4 - 10	~ 10	10 - 19	20 - 25

1 These estimates are for cattle and buffalo only.
2 Estimates being developed in USEPA (1992), "Options for Reducing Methane Emissions in the United States."

First, direct transfer of agricultural technology to developing countries from industrialized countries has often created problems rather than solutions. For example, past programs focused on increasing animal productivity through the introduction of high energy feed grains and specialized breeds, which was simply not feasible over the long term in many areas. Developing countries, especially in tropical regions, are not capable of producing highly nutritious feed grains and forages such as those produced relatively inexpensively in industrialized nations. In addition, many countries do not have the financial means to purchase the inputs necessary to maintain production levels attained by the specialized dairy and beef herds of western countries. The conditions which supported the evolution of this specialization either do not exist or are extremely difficult to reproduce and maintain in most developing countries.

Furthermore, the introduction of exotic breeds of cattle to tropical countries may have resulted in the neglect of better adapted, disease-resistant indigenous breeds. Also, temperate breeds can be physically stressed by tropical climate, decreasing productivity and increasing calving intervals. It has been suggested that, instead of importing technologies directly, developing countries should import sound scientific principles to be used in research and development of local technologies (Preston and Leng, 1987). In general, caution should be exercised when attempting to transfer non-indigenous technologies and practices to developing countries.

Exhibit 5-11
Key Barriers and Possible Responses - Ruminant Livestock

Key Barriers	Possible Responses
Information Issues • Lack of knowledge about ruminant methane and animal productivity on part of government officials, extension personnel, and producers • Institutional capabilities are weak at the extension level • Appropriate literature is lacking for farmers with varying levels of literacy • Lack of awareness of potential production benefits on part of funding agencies	• Provide information to countries on potential benefits, resources, appropriate policies, technologies, etc. • Provide information to international development and lending agencies about benefits of ruminant methane reduction efforts • Conduct training of extension personnel • Develop range of texts for farmers
Technical Issues • Access to remote and small-scale farms is difficult • Limited infrastructure for development, production, and dissemination of technologies • Limited availability of land for production of improved forages and feed supplement inputs • Inadequate field-testing of technologies; past problems of improper application • Supplement formulation often does not address specific deficiencies • Genetic improvement of production is hampered by poor nutrition	• Improve extension services through training, increased mobility, and closer contact with producers • Match technologies to existing infrastructure and level of development within region • Maximize efficient use of existing resources, including agro-industrial byproducts, crop residues, and marginal land cultivation • Ensure field testing, and proper use of technologies • Conduct forage analyses as part of project assessments to determine nutritional imbalances
Sociocultural Issues • In many cultures, numbers of animals are more important than liveweight • Religion and cultural factors may prohibit slaughter of animals • Extension programs may facilitate communication with men, while ignoring women who play important roles in livestock management	• Address the role of women directly in project development • Maintain an awareness of sociocultural factors and their impact on project development
Financial Issues • Lack of capital for investment in feed processing facilities and other infrastructure and resource improvements • Livestock traditionally kept as savings and security, not production; reduced incentive for increasing productivity • Direct economic incentives lacking for draft animals • Artificially low milk prices	• Raise awareness on part of international development agencies and other sources of capital • Encourage development of economically feasible projects; emphasize economic sustainability • Use multi-purpose animals, increasing value of animals • Inform farmers of the benefits of managing animals for increased production; develop markets

Second, the sharing of successful technologies and practices among developing countries is often constrained by language barriers and poor communication infrastructure. This is in contrast to the rapid transfer of technology between industrialized nations, aided by good communication, competitive open markets for both products and inputs, as well as infrastructural, environmental, economic and sociocultural similarities. Technology transfer among developing countries is also much less common than the direct transfer of agricultural technology from North to South. The creation of regional livestock research and information centers could perform the valuable function of allowing developing countries with similar economic situations, environmental conditions, and feed and animal resources, to freely share locally-developed technologies and ideas, thus expanding the potential for adoption of new technologies within a region.

Third, the price of milk in developing countries is often very low, both reducing the incentive to produce milk, and limiting the income which small-scale milk producers could use to invest in production inputs. Often, countries strictly control the price of their locally produced milk to make it more available to poor people. Also, inexpensive imports from western countries marketed in developing countries compete with locally produced milk, keeping prices low. Deregulation of milk prices and an assessment of imports would allow prices to increase and would stimulate domestic production. Higher milk prices would provide an economic stimulus and the financial means to increase the efficiency of production, resulting in a reduction of methane per unit of feed consumed.

In addition to these more general obstacles, there are numerous barriers which may affect individual programs on a site-specific basis. These might include weak in-country institutional capabilities, limited access to rural regions, limited infrastructure, a lack of product markets, and severely limited potential feed resources. In addition, financial and sociocultural issues can often be key barriers to development programs.

In light of these potential barriers, criteria can be outlined for selecting regions where increased implementation of technologies in the near term is likely to be most successful. These regions should have large numbers of ruminants, a high percentage of which are raised to produce marketable products, but where typical animal diets limit animal productivity. Infrastructure, available resources, and product demand must be such that there is no major missing or weak link in the chain of production, from feed sources and supplement raw materials, to feed processing, local markets, collection and storage, processing, delivery, and final consumption. Furthermore, near-term programs will be most successful where there are nearby institutions with experienced agricultural extension programs.

Specific programs to improve animal productivity and reduce methane emissions will involve conducting regional and local feasibility studies, followed by designing and implementing technology demonstration and extension projects. Extension projects would be backed up by research at local institutions as well as by "village based" research of appropriate technologies. Eventually, these types of options are expected to be financially self-sustaining, although funding and organizational support from external sources could facilitate demonstration and pilot projects, and catalyze technology adoption. Investments in education and research are long-term options that would increase the expertise of future policy planners and livestock specialists. The components of a program to reduce methane emissions from ruminant livestock are described below, and summarized in Exhibit 5-12. These programs would be most effective if some of the components are implemented sequentially, as indicated in Exhibit 5-12.

Prefeasibility Studies: A prefeasibility study is a preliminary step in designing and implementing a country program. These studies should identify potentially appropriate methane reduction options, and assess the locally available resources, the needs for project implementation, as well as the types of barriers and other factors which may interfere with development. The identification of options should include an assessment of the compatibility of project development with the country's broader development goals. Prefeasibility studies should assess existing livestock management practices and propose suitable pilot demonstration projects. In addition, current emissions and potential reductions should be estimated. Prefeasibility studies may range from $50,000 to $75,000 per country, with higher costs associated with larger countries such as India and China, and with more detailed assessments. These studies may typically involve one month in-country and one month of follow-up analysis.

Demonstration/Pilot Projects: Demonstration and pilot projects provide an assessment of the potential impact, replicability, and cost of implementing options in full scale development projects. New or improved technologies and management practices, identified in prefeasibility studies, are first demonstrated with individual animals or small herds. Once these management options have been adapted to local conditions, extension pilot projects can promote proven technologies and practices in the farming community (within a limited geographical area) in order to establish successful methods for larger

Exhibit 5-12
Summary of Project Types

Project Type	Phase I	Phase II	Phase III	Cost
Prefeasibility	■■■■			$50-75K per project
Demonstration/Pilot Project		■■■■		$50-500K per country, depending on area, technologies and economy.
Full Scale Development Project			■■■■	Depends on area, economy, etc.
Education		■■■■■	■■■■■	Varies
Research		■■■■■	■■■■■	Small grants $5-25K

scale efforts. Extension pilot projects must identify and overcome any existing barriers to program implementation. Pilot projects typically involve training for extension personnel and project managers.

The cost of implementing pilot projects in specific countries may be $50,000 to $500,000, but will vary considerably depending on the area covered, the particular technologies being used, and other country and site specific conditions. Demonstration and pilot projects may take place over 6 months to 3 years or more.

Full Scale Development Projects: Full scale development projects are designed to introduce proven technologies throughout a wider geographical area (e.g., regional, national as appropriate) using the extension and training methods developed in pilot projects. These development projects should address the broader development goals of increasing food supply and improving the welfare of rural populations. These activities should be coordinated with both field research and research at local and regional institutions. As with pilot projects, project costs will vary widely depending on the scope, area, and duration, which may be several years or more. Successful development projects will lead to the widespread adoption of effective technologies and practices.

Education: Education can play a crucial role in developing the knowledge and expertise of local animal research scientists, project managers, and policy makers. Expanding educational opportunities may include providing higher education for experts, developing regional training centers for livestock specialists, study tours between other developing countries with similar conditions, and the development of educational material suitable for a range of literacy levels.

Research: In conjunction with increased educational opportunities, additional research is necessary to develop and assess the impact of various feeding strategies and other technologies and practices. This research should include quantification of productivity gains, gains in rural living standards, and methane emissions reductions. Small research grants may range from $5,000 to $25,000.

To be successful the projects at all levels must be supported by national policies and institutions. In some cases this may require modifying existing agriculture and trade policies. Assistance for the analyses of these issues and support for the development of the necessary institutions may be warranted.

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CHAPTER SIX
OTHER SOURCES

6.1 Introduction

In many countries, there is potential to reduce methane emissions from sources in addition to the ones discussed in other chapters of this report. These sources include livestock manure, wastewater management, rice cultivation, biomass burning, and fossil fuel combustion. For some of these sources, knowledge of reduction options and country-specific data are relatively limited. In these cases, potential reductions are difficult to quantify and are likely to be achieved over a longer timeframe. A number of reduction options exist for some sources which have proven technically and economically feasible, however, and others are being researched, developed, and demonstrated and should be available in the future.

The magnitude of current annual emissions of methane from these sources is uncertain. Best emissions estimates to date are summarized in Exhibit 6-1.

Exhibit 6-1
Global Annual Methane Emissions from Various Sources[1]

Emissions Source	Emissions Estimates (Tg/yr)	Proven Reduction Options
Livestock manure[a]	10 - 18	yes
Wastewater management[b]	20 - 25	yes
Rice cultivation[b]	20 - 150	no
Biomass burning[b]	20 - 80	no
Fossil fuel combustion[a]	2 - 3	yes

a USEPA, 1993b
b IPCC, 1990b; IPCC, 1992

Potential emission reductions vary for each of these sources, and depend to a large extent on the magnitude of the emission source and the conditions and types of operations in each country. The economic viability of each reduction option is also dependent on many country-specific variables.

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1 These emissions estimates are based, where possible, on the Report to Congress *Global Anthropogenic Emissions of Methane*, which is still in preparation. Emission estimates will likely change as this report is finalized.

This chapter briefly describes the options for reducing global methane emissions from these five sources. Each section contains the following information:

- discussion of methane emissions;
- outline of available options for reducing emissions;
- regional potential;
- benefits provided by methane reduction options; and
- types of actions to promote or identify economically viable reduction options.

For each source, regions with the highest potential for large reductions are identified, along with possible actions which could assist in reduction efforts. These actions include:

- improved assessments of methane sources and emissions reduction potential;
- technology transfer and demonstration of key technologies and practices;
- information transfer and training;
- development of funding mechanisms; and
- assistance in policy development.

6.2 Livestock Manure

Methane Emissions

Methane is produced during the anaerobic decay of organic material in livestock manure. Current estimates of methane emissions from livestock manure worldwide range from 10 to 18 teragrams (Tg) per year (approximately 2 to 5 percent of global annual anthropogenic methane emissions). Three animal groups account for more than 80 percent of total emissions: swine account for about 40 percent; non-dairy cattle account for about 20 percent; and dairy cattle account for about 20 percent (USEPA, 1993b).

Manure management systems which promote anaerobic conditions produce the most methane. In particular, these include liquid/slurry storage systems, pit storage systems, and anaerobic lagoons. While a relatively small percentage of livestock manure worldwide is managed in this manner, these types of systems are responsible for about 60 percent of global livestock manure methane emissions (USEPA, 1993b). In contrast, management techniques which involve contact of the manure with air (e.g., uncollected on the range or spread directly on crops or pastureland) have limited methane production potential.

The precise amount of methane emitted from livestock manure is determined by many factors. These include:

- quantity of manure;
- characteristics of manure (percentage of volatile solids);
- biodegradability of manure;
- management practices (e.g., degree of anaerobic conditions, water content); and
- climatic variables (e.g., temperature, moisture).

The estimated distribution of regional worldwide emissions, taking into account the above factors, is summarized in Exhibit 6-2. Three regions are estimated to account for nearly 90 percent of emissions from livestock manure: Europe; Asia and the Far East; and North America. While current estimates indicate that developed countries account for the largest percentage of total methane emissions, emissions from developing countries are substantial, and their share of emissions is expected to rise along with industrialization and population growth (USEPA, 1993b; Safley et al, 1992).

Exhibit 6-2
Global Methane Emissions from Livestock Manure

Region	Emissions (Tg/yr)	% World Emissions
Western Europe	2.3 - 3.9	22
Eastern Europe	2.0 - 3.5	20
Oceania	0.2 - 0.4	2
Latin America	0.7 - 1.1	6
Africa	0.2 - 0.4	2
Near East and Medit.	0.2 - 0.4	2
Asia and Far East	2.9 - 4.9	28
North America	1.7 - 2.9	17
WORLD	10 - 18	100

Source: USEPA, 1993b

Emission Reduction Opportunities

The potential for reducing methane emissions from livestock manure in different regions depends on several factors, the most important of which are the characteristics of existing manure management systems (e.g., percent total solids in manure, and storage/handling practices). Other factors include climatic and economic conditions, as well as technical and regulatory factors, and the varied needs of the livestock farmers for developing biogas as an energy resource and/or slurry as a fertilizer.

Methane recovery technologies have been successfully used and demonstrated under a variety of conditions. These technologies are designed to improve anaerobic decomposition and methane recovery and, when introduced in areas generating large amounts of methane, have been shown to reduce emissions by up to 70 or 80 percent (USEPA, 1993a). The available technologies are described in USEPA (1993a), discussed below, and summarized in Exhibit 6-3.

Exhibit 6-3
Summary of the Technical Assessments for Livestock Manure

Considerations	Covered Lagoons	Large Scale Digesters	Small Scale Digesters
Recovery Techniques	• Impermeable Lagoon Covers	• Complete Mix • Plug Flow	• Fixed Dome • Floating Holder • Flexible Bag
Gas Quality	• Medium Quality (600-800 Btu/cf) (22-29 MJ/m^3)	• Medium Quality (600-800 Btu/cf) (22-29 MJ/m^3)	• Medium Quality (600-800 Btu/cf) (22-29 MJ/m^3)
Use Options	• Electricity Generation • Boilers, Refrigeration, Other • Fertilizer, Feed Supplement, Other	• Electricity Generation • Boilers, Refrigeration, Other • Fertilizer, Feed Supplement, Other	• Electricity Generation • Domestic Gas Use • Fertilizer, Feed Supplement, Other
Availability	• Currently Available	• Currently Available	• Currently Available
Capital Requirements	• Low/Moderate	• Moderate	• Low
Technical Complexity	• Low Technology	• Moderate Technology	• Low Technology
Applicability	• Temperate, Tropical • Flush Systems; Low %TS[2]	• Temperate, Tropical • 2-15 %TS[2]	• Temperate, Tropical • 7-15 %TS[2]
Methane Reductions[1]	• Up to 80%	• Up to 70% or more	• Up to 70%

1 These are reductions which may be achieved at an appropriate individual site.
2 Percent Total Solids (%TS) is a measure of the concentration of the manure in water.

Source: USEPA, 1993a

Covered Lagoons: Covered lagoons store manure along with the large quantities of water used to wash the manure solids out of livestock housing facilities. The manure is treated under anaerobic conditions, resulting in the production of significant amounts of methane, which is recovered using impermeable floating lagoon covers and the application of negative pressure. The methane generated from these systems is often sufficient for the energy needs of large scale, intensive farm operations common in developed countries. Because their technology and capital needs are relatively low, covered lagoons may also be appropriate for some farm operations in developing countries, especially those which need the high quality liquid fertilizer that lagoons produce. The use of lagoons in arid regions, however, may be constrained by their high water requirements.

Small Scale Digesters: Digesters are designed to enhance the anaerobic decomposition of organic material and to maximize methane production and recovery. Small scale digesters typically require a small amount of manure and are relatively simple to build and operate. As such, they are an appropriate strategy for small to medium confined or semi-confined farm operations. These digesters are also well-suited for regions with technical, capital, and material resource constraints, and have already met with great success in countries such as China and India (United Nations, 1984; see Exhibit 6-4). The digesters offer additional benefits in agricultural regions where manure is currently burned for fuel, as the generated methane is a cleaner and more efficient fuel. In addition, digested manure retains its fertilizer value, which is important due to increasing prices for artificial fertilizers in many areas. Small scale digesters generally operate well with manure containing 7 to 15 percent total solids and, as they are not heated, are most appropriate in temperate and tropical areas. Three common types of these digesters include the fixed dome, floating gas holder, and flexible bag.

Larger Scale Digesters: These digesters are also designed to enhance anaerobic decomposition and maximize methane recovery, but have larger capacities and are often more technologically advanced. They are generally heated, and can operate in relatively cold regions. Because larger scale digesters require greater capital investment, are more complex to build and operate, and require large concentrations of manure, they are best suited for large livestock operations in industrialized countries. These technologies are especially suitable at operations which handle manure as liquids (less than 10 percent solids) or slurry (10 to 20 percent solids). The type of digester used (e.g., complete mix or plug flow) depends on the manure quantity and characteristics.

The potential for reducing methane emissions from livestock manure depends mainly upon the current manure management practices in an area, with the greatest potential in areas where manure is managed anaerobically in liquid or slurry form or stored over time as a solid.

Substantial opportunities for methane reduction likely exist in developed countries. Eastern Europe, Western Europe, and North America contribute about 60 percent of global emissions from this source. Livestock in these regions are often managed in confined areas, with some method for collecting and managing the resultant concentrated quantities of manure. Much of the manure in these regions is either handled in liquid systems (25 to 75 percent of many types of manure) or stored as a solid (USEPA, 1993b; Safley et al, 1992). Although technologies for methane recovery are available, only small amounts of methane are currently recovered for use. The most promising methane recovery technologies for these regions are larger scale digesters and covered lagoons.

The specific regional opportunities to reduce methane emissions through expanded methane recovery and utilization in developed countries are summarized below:

Eastern Europe: Due to this region's current emissions of 2 to 3.5 Tg per year (20 percent of world emissions), there is large methane reduction potential in Eastern Europe. The methane recovery potential is also high because most livestock are managed in confinement, and substantial amounts of manure are handled in liquid systems (about 10 to 40 percent of non-dairy cattle, poultry and swine manure). Substantial amounts of manure are also stored as solids (USEPA, 1993b; Safley et al., 1992). In addition, many Eastern European countries are interested in developing new, clean-burning domestic energy sources to displace low-quality coal and imported natural gas. Electricity generation with recovered methane could thus be extremely economically viable for farm operations.

Western Europe: This region also offers potential for methane reduction, as current emissions are about 2.3 to 3.9 Tg per year (22 percent of world emissions) and large amounts of manure are managed as liquids (about 50 percent of cattle and 75 percent of swine manure) (USEPA, 1993b). In addition, ground and surface water pollution and odor problems have raised concern about livestock manure management in many parts of Western Europe. This concern, compounded by the dearth of cropland for spreading manure, has resulted in longer storage times for the manure (Safley et al., 1992). Promoting energy recovery from digesters and covered lagoons could solve the environmental and odor problems while providing an extra energy source for farm operations.

North America: Large methane reduction potential exists in this region due to the current emissions of about 1.7 to 2.9 Tg per year (17 percent of world emissions). In addition, about 33 percent of manure from dairy cattle and 75 percent of swine manure in this region is handled in liquid systems (USEPA, 1993b; Safley et al., 1992). Implementing improved management and methane recovery techniques could result in a number of benefits, including odor control, improved ground and surface water quality, and energy production.

Oceania: Methane emissions from livestock manure in Australia, New Zealand and other countries in this region are estimated to be about 0.2 to 0.4 Tg per year or 2 percent of world emissions from this source (USEPA, 1993b). In a number of swine operations in this region, a large fraction of manure is already managed in anaerobic lagoons. Recovering and utilizing the methane generated from these operations could result in substantial environmental and economic benefits to the area. Limited potential exists, however, for the large populations of non-confined sheep raised in this region.

Developing countries, in contrast, are generally characterized by few livestock confinement facilities and little concentrated manure production. The majority of the livestock manure in these regions decomposes on the range, producing little methane and offering limited potential for implementing recovery technologies.

Certain types of livestock manure do, however, offer some potential for methane recovery in some developing countries. Confined management practices are used in some instances, and certain types of livestock manure (e.g., swine and poultry) are managed as liquids or in solid storage. These areas of potential methane production are likely to expand in the future, increasing the benefits of introducing available recovery technologies in these regions now. A lesser area of potential methane reduction may exist in areas characterized by small-scale, semi-confined livestock operations. Although manure managed under these conditions accounts for relatively small methane emissions, the use of recovery techniques is possible and could result in substantial other benefits for the farmers involved.

The most suitable methane recovery technologies for each area should be chosen according to many factors, and certain technologies (e.g., small scale digesters and covered lagoons) are likely to be more appropriate for developing regions. Current opportunities for methane recovery and utilization may exist in the following areas:

Asia and the Far East: The majority of livestock manure-related methane emissions from developing countries is likely released from Asia and the Far East (about 2.9 to 4.9 Tg per year or 28 percent of world emissions). About 55 percent of this methane is emitted from liquid/slurry systems and anaerobic lagoons (USEPA, 1993b), which are chiefly used to manage dairy cattle and swine manure. Some solid storage systems, used for non-dairy cattle and swine manure, may also offer potential for methane recovery. In addition, this region is characterized by a large number of semi-confined family operations.

Achieving widespread acceptance of methane recovery technologies may be possible in Asia and the Far East because of the relative scarcity of other types of fuel, and because biogas produced by digesters is a more efficient form of fuel than the dried manure patties commonly used in the region. For this reason, a number of biogas digesters have already been introduced in the region (see Exhibit 6-4). Since these digesters represent only a small percentage of farms in most of these countries, there is substantial potential to expand the use of digester technologies, as well as to increase the number of existing digesters in use by improving operation and maintenance practices.

Latin America: Methane emissions from livestock manure in Latin America are estimated to be about 0.7 to 1.1 Tg per year (6 percent of world emissions); this region supports about one third of the world's cattle population and 20 percent of the world's swine. Although most livestock manure in the region is currently deposited on pasture and rangelands, methane recovery potential exists in some countries, including Brazil, where ten percent of the manure from swine operations is managed in liquid systems and anaerobic lagoons are used in some poultry operations. In addition, half of Latin America's swine manure is managed in solid storage, and are thus feasible candidates for digester technologies (Safley et al., 1992). These technologies are already available in Brazil, and their use could be expanded.

Africa: Although methane emissions from livestock manure in Africa are only about 0.3 Tg per year (2 percent of world emissions) and most cattle manure is deposited on the range, potential for methane recovery exists from swine manure, which is managed either as a liquid or in solid storage (USEPA, 1993b; Safley et al., 1992). Potential also exists in South Africa, where conditions differ from those in the rest of Africa because large numbers of both cattle and swine are managed under confined conditions, and much of their manure is stored as a solid.

Exhibit 6-4
Biogas Digesters in Asia and the Far East

Country	Number Built	Number in Use
China	7,000,000	over 4,500,000
India	700,000	525,000
North Korea	50,000	37,500
South Korea	31,400	11,470
Thailand	7,500	5,625
Pakistan	4,000	3,000
Nepal	1,600	1,200

Source: Safley et al., 1992

The Benefits of Emissions Reduction

The livestock manure management strategies discussed above can result in important benefits, in addition to reducing methane emissions to the atmosphere. Recovered methane from livestock manure can be used to generate electricity for sale or on-site use, and the slurry remaining after digestion can be utilized as livestock feed, an aquacultural supplement, or fertilizer. These benefits can increase the self-sufficiency of farms of all sizes. The techniques discussed above can also reduce environmental and health risks, such as ground and surface water contamination or eutrophication from manure runoff, and the spread of pathogens and diseases. Finally, anaerobic decomposition virtually eliminates odors from livestock manure.

Identifying and Promoting Emission Reductions

Domestic energy sources are frequently the cheapest ones to develop and are an intrinsic part of every country's efforts to reduce energy supply costs, as well as a potentially important means of achieving greater energy independence. The events of the 1970's reminded many countries of their vulnerability to external shocks, due to their dependence on imported oil, and many countries have been seeking greater control over the supply and cost of energy as a matter of national security (Baum and Tolbert, 1985). The livestock and agricultural sectors are closely tied to these energy issues. For example, the production of crops, grains, meat, and milk are primarily based on fossil energy resources (e.g., mechanical energy from diesel and gasoline fuels); electrical energy (e.g., from coal, nuclear, lower grade liquid fuels, and natural gas) is the primary ingredient for commercial fertilizer manufacturing.

The livestock and agricultural sectors can potentially be large contributors to energy development efforts. The resource potential of livestock manure offers a promising alternative to fossil fuels, through the use of proper anaerobic treatment processes and technologies that recover and utilize methane for on-farm energy. This energy potential and many other benefits offer large incentives for developed and developing countries to promote the widespread use of the livestock manure management systems discussed in this chapter.

While international transfer and development programs could greatly increase the understanding and use of these energy systems, it is important for such programs to be appropriately designed and implemented. During an international effort to promote manure management systems in the mid-1970's in numerous countries (Exhibit 6-5), only China and India achieved significant success in transferring sustainable technologies. Many failed efforts may have resulted from insufficient consideration of local variables (e.g., management practices, economic limitations, energy needs, and educational level) in identifying the technologies appropriate to meet the needs of livestock farmers. In many cases, technical designs were chosen based on their success in other regions of the world, and replicated at government or university-owned farms. These types of farms were often not representative of typical farms in the country, which did not have the resources or experience to successfully introduce complex technologies. In addition, much of the infrastructure essential to promote the widespread use of these technologies was never established. Some essential mechanisms include: locally available expertise in design, construction, and maintenance of the systems; effective communication methods between the project implementation teams and farmers, in order to promote and evaluate technology; and networks for distributing goods, services, and information. The lessons learned from this international effort can be used to develop some important guidelines in designing high-impact programs for key countries, with long-term sustainability. The components of a program to reduce methane emissions from livestock manure are described below, and summarized in Exhibit 6-6. These programs would be most effective if implemented sequentially in phases, as indicated in Exhibit 6-6.

Prefeasibility Studies: As a first step in the development of a country program, these studies should identify typical livestock manure management practices (solid or liquid) across various farm sizes for swine, dairy and poultry. The compilation of information on climatic conditions in targeted areas, farm energy sources, and available construction materials and expertise across farm types will also be helpful. Prefeasibility studies should include market analyses, surveys, and meetings with livestock producers to evaluate potential demand for new technologies. The cost of such studies may range from $50,000 to $75,000 per country, depending on the size of the country and the level of detail in the assessments. These studies may typically involve one month in-country and one month of follow-up analysis.

Demonstration/Pilot Projects: Demonstration and pilot projects provide an assessment of the potential impact, replicability, and cost of implementing options in full scale development projects. Technology demonstrations, performed at individual sites, help to identify the best project design for a site or region in terms of costs, benefits, construction materials and energy requirements, daily manure input, climatic conditions, farm management practices, and available markets. Following the demonstration projects, evaluations should be conducted at each site, with the participation of livestock producers, to assess the larger impact of each project. Extension pilot projects can then be implemented to promote proven technologies and practices in the farming community and to establish successful methods for larger scale efforts.

Exhibit 6-5
Countries Adopting Biogas Promotional Programs (1970-1980)

Asia and Pacific Region		Latin America	European and Other Countries	
Afghanistan	Malaysia	Argentina	Austria	Poland
Bangladesh	Nepal	Brazil	Belgium	Spain
Burma	Pakistan	Chile	Czechoslovakia	Switzerland
China	Papua New	Columbia	Denmark	Russia
India	Guinea	Costa Rica	France	United Kingdom
Indonesia	Philippines	Guatemala	Germany	Northern Ireland
Iran	Singapore	Mexico	Hungary	United States
Japan	Sri Lanka	Peru	Italy	
Korea	Thailand	Trinidad and Tobago		
Laos				

Source: United Nations, 1984.

Exhibit 6-6
Summary of Project Types

Project Type	Phase I	Phase II	Phase III	Cost
Prefeasibility	■■■■			$50-75K per country
Demonstration/Pilot Project		■■■■		$50-500K per country, depending on climate, livestock density, and energy needs
Full Scale Development Project			■■■■	Depends on climate, livestock density, numbers of farms, and energy needs
Education		■■■■■	■■■■■	Varies
Research		■■■■■	■■■■■	Small grants $5-25K

The cost of implementing demonstration and pilot projects in specific countries may range from $50,000 to $500,000, depending on the climate, farm-specific livestock density, and energy needs. Demonstration and pilot projects may take place over 6 months to 3 years or more.

Full Scale Development Projects: Full scale development projects are designed to introduce locally proven technologies throughout a wide geographical area, using extension and training methods developed in pilot projects. These projects should address the broader development goals of enhancing the supply of fertilizer and improving the welfare of rural populations. These goals can be pursued through the expanded development of indigenous end-use technologies (e.g., locally manufactured generator sets, refrigerators, lights, etc.). As with pilot projects, program costs will vary widely depending on climate, farm specific livestock density, numbers of farms targeted, energy needs, and duration, which may be several years or more.

Education: Education can play an important role in developing the knowledge and expertise of local farmers, agricultural engineers, and policy makers. Efforts to expand educational opportunities may include creating regional centers for training in manure management, and developing broader educational materials on system benefits and product utilization. In addition, programs may include the development of an international network for the effective transfer of scientific, technical, and economic information. Education program costs will vary widely depending on the types and scope of program activities.

Research: In conjunction with increased educational opportunities, additional research is necessary to lower the costs and improve the performance of technologies in applicable areas, and to develop and improve on effluent applications in agricultural systems (e.g., aquaculture, enhancing fertilizer quality). Small research grants may range from $5,000 to $25,000.

6.3 Wastewater Management

Methane Emissions

Wastewater and sludge, its residual solids byproduct, produce methane emissions if they are stored or treated under anaerobic conditions (in the absence of oxygen). In some cases this methane is flared, but in others the gases produced are released to the atmosphere. Although data are very limited, current global estimates of methane emissions from the management of residential, commercial and industrial liquid and water-carried wastes range from 20 to 25 teragrams (Tg) per year (based on calculations of the organic content of wastewater in different regions). The majority of these methane emissions originate in developing countries, where domestic sewage and industrial waste streams are often unmanaged or maintained under anaerobic conditions without control of the methane (Bartone, 1992). These emissions are expected to increase with population growth.

Emission Reduction Opportunities

Methane emissions can be virtually eliminated if wastewater and sludge are stored and treated under aerobic conditions. Alternatively, wastewater can be treated under anaerobic conditions and the generated methane can be captured and used as a fuel or flared, preventing its release to the atmosphere. The following methane reduction technologies are in widespread use, and are described in greater detail in USEPA (1992b):

Prevention of Methane Production During Wastewater Treatment and Sludge Disposal: Options for this strategy include aerobic primary and secondary treatment, and land treatment. Aerobic primary wastewater treatment is achieved by sustaining sufficient oxygen levels during the primary phase of wastewater treatment (i.e., in oxidation ponds or in primary ponds in treatment plants), using controlled organic loading techniques or providing oxygen to the wastes through mechanical aeration. Aerobic secondary treatment consists of stabilizing wastewater by prolonging its exposure to aerobic microorganisms which are either suspended (due to mechanical aeration) or attached to a fixed bed or a rotating cylinder. Finally, land treatment involves applying wastewater to the upper layer or the surface of soil, which acts as a natural filter and breaks down the organic constituents in the wastewater.

Recovery and Utilization of Methane from Anaerobic Digestion of Wastewater or Sludge: This is an alternative to preventing methane production. If the wastes are treated (digested) under controlled anaerobic conditions, the resulting emissions of methane and other gases can be recovered and utilized as an energy source to heat the wastewater or sludge digestion tank, produce power in other parts of the plant, or sell to nearby homes, industrial plants or utilities. Flares are frequently used as part of these operations to dispose of excess methane.

The largest potential for reducing current emissions from wastewater and sludge may exist in developing countries. Although very little specific data exists on wastewater management in these regions, it appears that in many areas up to 60 percent of municipal wastewater is unmanaged (Escritt, 1984; Bartone, 1992). In addition, much of the managed wastewater receives only partial treatment, and the wastes are often stored under anaerobic conditions. Despite a widespread awareness of the health risks caused by poorly-managed waste streams, many countries lack the resources with which to build treatment infrastructure. Two broad options for assisting in the reduction of this source of methane are discussed below.

Promote and Assist in the Development of Comprehensive Wastewater Management Policies, Infrastructure and Treatment Systems: In areas where no wastewater treatment systems exist, assistance could include policy development, funding and technological aid for the development of municipal collection and drainage systems, construction of municipal and industrial wastewater and sludge treatment facilities, and operation training programs. For areas with wastewater treatment systems in place, assistance could include promoting the improvement or expansion of existing facilities, and the development of methane recovery and use technologies. This option may be most appropriate for large cities and densely populated areas, where the large quantities of waste will justify such efforts.

An additional incentive for these efforts may be provided by the increasing amount of responsibility placed on industries for treating and disposing of industrial wastewater in many countries (e.g., China, Colombia) (Maber, 1992). In these cases, demonstrating the economic viability of recovering and utilizing methane could benefit the industries while preventing methane emissions.

Assist in the Design and Development of Smaller-scale, Community Wastewater Management Systems: Small communities, where domestic wastes are often washed into streams or allowed to collect in gutters, latrines or ponds, may account for a large part of methane emissions from developing countries. While complex treatment systems may not be feasible in such areas, smaller scale projects designed to divert wastestreams into designated ponds and maintain aerobic or facultative (aerobic in the upper layers) conditions could reduce both methane emissions and health risks. Additional incentives for such projects may include reduced odors and the potential for using stabilized sludge as fertilizer.

Potential economic benefits may also exist for constructing small-scale digesters. In India, for example, community digestion tanks are used to stabilize domestic wastes, with the methane providing energy to heat and light households and the digested sludge providing fertilizer for the community (Escritt, 1984). International technology transfer programs and additional funding could assist in the widespread expansion of such technologies.

While many developed countries (e.g., the U.S., most of western Europe, and Japan), utilize advanced wastewater management systems and release little methane to the atmosphere from these activities, the following strategies may have some potential for further reducing emissions in these areas.

Expand Management Infrastructure to Serve Entire Population: Some regions and population segments in developed countries may not be served by regulated waste management infrastructures. The expansion of treatment systems to these regions could potentially result in decreased methane emissions, as well as providing the benefits of improved wastewater management.

Improve Operation of Existing Aerobic Treatment Facilities: Many communities depend on aerobic or facultative oxidation ponds for primary treatment of wastewater; these ponds tend to become partly or completely anaerobic if overloaded with wastes. Efforts to reduce methane emissions could include the promotion of techniques to ensure aerobic conditions, such as adjusting waste inflows, following proper loading techniques or utilizing mechanical aeration.

Increase Utilization of Methane from Anaerobic Digestion Facilities: A large part of the methane generated is not utilized because of the impurities and/or relatively low energy value of the gas, or because of the absence of storage or use facilities. Most of this methane is flared (burned off) and not released to the atmosphere, and it represents a wasted energy source. Efforts to increase rates of methane use could make advanced digestion systems more economically viable, thus avoiding greenhouse gas emissions from conventional power generation systems.

The Benefits of Emissions Reductions

In addition to reducing the amount of methane which is released to the atmosphere, wastewater management and treatment techniques can result in a variety of environmental, health-related and economic benefits, including the following:

- reduction in the risk of water-borne diseases (Loehr, 1984) such as hepatitis, giardiasis, cholera, etc;[2]

- reduced eutrophication of receiving waters, which can be caused by high levels of phosphorus and/or nitrogen;

- production of valuable methane from anaerobic digestion;

- elimination of odors from standing wastewater; and

- production of treated wastewater and sludge for various uses (e.g., recharging ground water, irrigation, soil enrichment, production of potting mixes and topsoil, turf production and maintenance, reclamation of disturbed lands).

Identifying and Promoting Emission Reductions

Some potential actions to promote the use of suitable technologies for reducing methane emissions from wastewater management include:

Country Planning Studies: Country-specific research could help to determine the most favorable combination of wastewater management options for each region. Strategies could be developed based on the location of the operation, the quantity and characteristics of the waste, the degree of treatment required, environmental and health factors, and technical and economic feasibility.

Policy Assistance: Assistance may be useful to facilitate the implementation of policies aimed at developing comprehensive wastewater management systems in regions without existing infrastructure, and improving existing wastewater treatment systems. Policy assistance may also be effective for setting minimum treatment standards for wastewater and sludge, and assigning responsibility for their treatment.

Technology Transfer: The transfer and demonstration of efficient wastewater and sludge treatment technologies to countries with potential for reductions could facilitate the widespread adoption of these technologies.

[2] In 1991 there reportedly were 594,694 cases and 19,295 deaths worldwide due to cholera (WHO, 1992). Recent statistics indicate that annual incidence of hepatitis A infection range from about 113,000 to 564,000 cases in industrial countries and about 2,056,000 to 12,386,000 cases in developing and Eastern European countries (WHO, 1993).

Information Transfer and Training: The transfer of information regarding domestic wastewater and sludge management needs and international treatment practices could facilitate the introduction of management techniques and the development of beneficial projects. Training could also be provided to government and technical personnel in regions adopting new technologies for the construction, operation and maintenance of wastewater and sludge treatment systems, and assessing the most suitable treatment options.

Financing: International assistance may be useful for financing the demonstration of wastewater and sludge treatment systems, and providing the initial capital for constructing facilities in many countries.

6.4 RICE CULTIVATION

Methane Emissions

Wetland rice cultivation is likely the largest anthropogenic source of methane. Current estimates of methane emissions from flooded rice fields worldwide range from 20 to 150 Tg per year, accounting for up to 20 percent of global methane emissions from all sources (IPCC, 1992). Emissions from rice fields may increase by 20 percent in the next decade, as cropping areas are expanded and cultivation is intensified to meet production demands which are increasing along with population growth (IPCC, 1990b).

Most of the methane associated with rice cultivation is produced in irrigated and rainfed wetland rice fields, which comprise over 75 percent of the area of global cultivated rice fields. Neither dry upland rice fields nor deepwater rice are believed to produce significant amounts of methane. Because 90 percent of worldwide rice production occurs in Asia (Braatz and Hogan, 1991), this region accounts for the majority of methane emissions from rice cultivation. Estimates of regional distributions of rice croplands are summarized in Exhibit 6-7.

The emission of methane from rice fields is a very complex process. Methane is produced in the soils of flooded rice fields during the anaerobic decomposition of organic materials. The methane which is not oxidized (in the upper layers of soil or inside the plant itself) is released into the atmosphere by plant-mediated transport or diffusion through the floodwater. The amount of methane which is released is affected by the following factors:

- soil factors (temperature, pH, redox potential);
- nutrient management;
- water regimes; and
- cultivation practices.

Current estimates of global methane emissions are based on laboratory studies and measurements from individual rice fields which have been extrapolated to a global scale. The numbers are highly uncertain, as very little data has been available from Asia, where most of the world's rice is produced.

Exhibit 6-7
Global Rice Cultivation in Key Regions

Region	Irrigated (10^6 ha)	Rainfed (10^6 ha)	Deep Water (10^6 ha)	Upland (10^6 ha)	Total Area (10^6 ha)
East Asia[a]	34.0	2.8	--	--	36.8
Southeast Asia[b]	13.9	13.7	3.75	4.65	36.0
South Asia[c]	19.4	20.0	7.3	6.7	53.4
South/Central Amer., Caribbean, USA	2.5	0.5	0.4	5.65	9.2
Africa	0.9	1.95	--	2.7	5.45
World	73.8	39.0	11.5	19.7	142.9

Sources: FAO, 1988; Mistra et al., 1986; Huke, 1982; N.N., 1987; in Braatz and Hogan, 1991
a China, Taiwan, Korea DPR, Korea Rep., Japan
b Indonesia, Laos, Kampuchea, Malaysia, Myanmar, Philippines, Thailand, Vietnam
c Bangladesh, Bhutan, India, Nepal, Pakistan, Sri Lanka

Emission Reduction Opportunities

While there are currently no known options which may be routinely employed to reduce methane emissions from rice cultivation, efforts to date have identified a number of areas for further investigation which could reduce methane emissions from rice cultivation, while maintaining the productivity of the rice fields (IPCC, 1990b; Braatz and Hogan, 1991). These areas include:

Cultivar Selection: Developing rice cultivars which result in lower methane emissions may be a feasible option, and can be practical as long as rice productivity and other desirable characteristics are not compromised.

Nutrient Management: Research indicates that adding some nitrogen (N) fertilizers and reducing the use of raw organic materials as fertilizer can reduce methane emissions from rice fields. This option is especially feasible because N fertilizers are already a major nutrient source for flooded rice fields in Asia. The major constraints to this option are the cost of N fertilizers, which may be prohibitive in some regions, and the existence of cultural fertilization techniques, which may be difficult to change.

Water Management: Intermittent draining of rice fields during the growing season or between croppings appears to decrease methane production, as does increasing the water percolation rate in the fields. These methods are feasible in regions such as lowland and flatland irrigated areas, which have secure and controllable water supplies. Proposed *changes in water management practices must be researched carefully in order to avoid* decreasing productivity.

Cultural Practices: Opportunities may also exist for mitigating methane emissions by altering existing rice cultivation practices, such as tillage and seeding techniques. While certain changes in practice have been shown to reduce emissions, however, this strategy may be impractical. Existing cultivation practices have often been developed to suit physical, biological and socioeconomic conditions, and may be the most appropriate methods for each region.

A comprehensive research approach which includes consideration of the above factors could help in the development and demonstration of practices that maintain or increase rice productivity while reducing methane emissions. Recognizing that increasing productivity as well as satisfying other social and cultural constraints are fundamental objectives, experts in the area generally believe that such an approach could achieve a 10 to 30 percent reduction in methane emissions from rice cultivation, relative to current levels, over the long term (IPCC, 1990b; Braatz and Hogan, 1991).

EPA is funding a major research effort to obtain such information through a cooperative agreement with the International Rice Research Institute (IRRI). The International Atmospheric Chemistry Activity (IGAC) is also carrying out a major coordinating effort regarding methane and other trace gases emitted from rice fields.

Benefits

While the relative costs and benefits of each mitigation option should be assessed, research has indicated that many actions taken to reduce methane emissions (e.g., improved cultivar selection and nutrient management) can have the added benefit of increasing the productivity of rice cultivation.

Identifying and Promoting Emission Reductions

The research needs for reducing global methane emissions from rice cultivation may best be served through the formation of a research consortium involving the major rice-growing countries, in order to facilitate regional and international collaboration and research on methane emission issues. The consortium could focus its efforts in Asia, where most of the world's rice is produced and where experimental data is lacking. China, India, Japan, Indonesia, Malaysia, Thailand, and the Philippines have been identified as having the most appropriate infrastructure and key research sites for such a project (Braatz and Hogan, 1991). The global benefits of this type of cooperative body could include the following:

Organized Information Sharing: The consortium could facilitate the sharing of information from research efforts around the world, and could greatly accelerate progress in global research by collecting, synthesizing, and interpreting regional data for integration into both global-scale and location-specific data systems.

Identification and Demonstration of Options: Much further research is needed to better understand the processes involved in methane production and emission from rice fields, and to identify the best options for reducing emissions. The consortium could promote cooperation among numerous countries and organizations in order to facilitate research, and to assist in the subsequent demonstration and implementation of those options found to be most promising.

Training: The research consortium could also facilitate widespread training in these promising options for rice researchers and farmers throughout rice-growing regions.

Financing: Financing for the consortium may need to be secured from national and special donor sources. A central institution could be created to coordinate this effort and to guarantee consistent and continued support and coordination during the lifetime of the proposed program.

6.5 Biomass Burning

Methane Emissions

Most major sources of biomass burning are anthropogenic and fall into two general categories: 1) large open fires associated with land management practices (common in forest, savanna and crop ecosystems), and 2) small-scale fires in which wood and crop residues are burned for fuel in households or industry. Methane is one of the forms in which carbon is released into the atmosphere when biomass is burned. Although typically more than 95 percent of the carbon burned as biomass is released in the form of CO_2 and CO, a small but significant component is released as methane. Current estimates of methane emissions from biomass burning range from 20 to 80 teragrams (Tg) per year, or 5 to 20 percent of total annual methane emissions from all sources (IPCC, 1990; Andrasko et al., 1991); these emissions are expected to increase along with growing rates of deforestation (Norse, 1991). Emissions estimates are calculated by multiplying estimated total biomass consumed globally by methane emission factors for different types of fuels and fires. The emission factors are based on models and experimental data.

The amount of methane emitted when biomass is burned is determined by the following factors:

- fuel size, composition and distribution;
- fuel chemistry; and
- moisture content of fuel.

These fuel characteristics influence emissions by determining the combustion efficiency of the fire. The release of methane, non-methane hydrocarbons and particulates is enhanced during incomplete combustion.

The majority of methane emissions from biomass burning are likely produced in developing countries, where many common land use techniques (e.g., shifting cultivation and crop rotation) involve regular burning, and where biomass, primarily in cookstoves, often accounts for over 90 percent of total energy consumed (Ahuja, 1990). Although country-specific data is limited, it is also generally agreed that most anthropogenic biomass burning (up to 87 percent) occurs in the tropics (Andrasko et al., 1991; Ward and Hao, 1991). Much of this *is due to deforestation for the sake of agriculture; it is estimated that shifting cultivation in* the tropics accounts for over 25 percent of total global biomass burned each year (USEPA, 1990).

Emission Reduction Opportunities

Ongoing work has identified a number of longer term options that could potentially reduce methane emissions from biomass burning. In general, these options require additional research to fully determine the best means of implementation. The options include:

Reducing the Frequency, Area and Amount of Biomass Burned Worldwide (in forests, grasslands and croplands):

- Forests. Reducing the burning that takes place in forest ecosystems can be accomplished by minimizing the need for forest clearing through improved productivity of existing agricultural lands and/or by lengthening rotation times of shifting agriculture. Other strategies include enhancing forest resource utilization or silvicultural practices to promote sustainable forest use. The magnitude and effects of fires can also be mitigated through fire management programs, or incorporating charcoal into the soil after burning.

- Grasslands. Improved grassland management and fire prevention programs could potentially reduce the frequency and area of both wild and intentionally- set fires. Other options include: switching from raising domestic livestock to native animals adapted to naturally occurring vegetation (to eliminate the need for burning to create new growth suitable for grazing); and developing fodder trees to feed livestock.

- Croplands. The need for biomass burning on croplands can be reduced by incorporating crop residues into the soil or composting, or replacing annual or seasonal crops with permanent tree crops.

Improving the Efficiency of Biomass Used as Fuel: Options for improving biomass energy efficiency include increasing the efficiency of biomass cook stoves and developing high-efficiency gasifiers for crop residues. Methane and other greenhouse gas emissions can also be reduced overall by switching to alternative fuels (e.g., kerosene or LPG).

The largest potential for reducing emissions from biomass burning may exist in developing countries, where the majority of biomass burning occurs and few reduction or control programs exist. Although most of the strategies are relatively simple to implement, the required regional research and the time needed for the development and acceptance of new policies make these feasible only in the longer term. The most promising strategies may include the following:

Forests and Grasslands: Forest and grassland fire management programs currently are rare in developing countries. The development of such programs, modeled on successful programs in other regions, could result in substantial reductions in biomass burning where they are applicable.

Replacing shifting agriculture with sustainable systems may be another promising option for reducing deforestation rates, if the productivity of croplands is maintained. This may be possible through the expansion of financial and educational fertilizer use programs, or through the promotion of forestry as an economically viable enterprise, using sustained forest management programs (especially in highly productive tropical forests). Reforestation efforts, aimed at enhancing sustainable tropical and temperate forest ecosystems and ensuring adequate carbon sinks, could also be beneficial.

Croplands: Composting or incorporating crop residues into soil are simple and feasible options which could reduce biomass burning on a large scale while providing adequate nutrients for crops.

Biomass as Fuel: Studies have shown that it is possible to double the overall efficiency of existing household biofuel cookstoves. Programs to improve their performance could have substantial economic and health benefits (i.e., reduced exposure to smoke) for the users, and reduce methane and other greenhouse gas emissions by decreasing the fuel needs of the stoves. Programs to develop and promote advanced stoves should take into account local needs, diets, technologies, and accessible fuels.

Reducing the demand for biomass products by promoting fuel switching may also be a feasible option if the prices of alternative fuels are competitive.

Opportunities may also exist for reducing biomass burning in developed countries. Although practices such as shifting cultivation, burning crop residues, and using biomass as an energy source are not common in most developed countries, significant methane emissions may be released from wild forest fires (Ward and Hardy, 1991). Successful fire management programs are in place in many temperate and boreal forests and in some semi-arid areas (e.g., Canada, the United States, Australia, the Mediterranean). Improving existing fire management techniques and promoting them in areas which lack programs could yield significant reductions in biomass burning. Reforestation efforts are also a valuable goal in developed countries.

Benefits

In addition to emissions reductions, other benefits may result from efforts to reduce biomass burning. These include maintenance of forest and agricultural resources, reduced soil erosion, and the protection of human health, life and property. Several options, such as agroforestry programs, have already gained international acceptance for their potential to protect species diversity and reduce rates of deforestation.

Identifying and Promoting Emission Reductions

Some potential actions to promote the use of suitable technologies for reducing methane emissions from biomass burning include:

Country Planning and Policy Studies: Country-level policy analysis may be useful to assess the feasibility, costs and benefits of options for reducing biomass burning in specific ecosystems. Priority should be given to identifying and developing national and regional policies and institutions needed to support the programs for reducing emissions. Net greenhouse gas balance analyses considering both sources and sinks of the gases involved may also be useful in order to develop strategies aimed at reducing total emissions.

Technology Transfer: Technology transfer programs could assist in reducing emissions from biomass burning, particularly through developing and promoting the expansion of improved cooking stoves in developing countries.

Information Transfer and Training: Intensive education and training programs could help to achieve a widespread reduction of biomass burning and related gas emissions. Programs could be especially useful for promoting the adoption of new land management and agricultural practices such as: lengthening rotation times of shifting agriculture; raising native animals; developing fodder trees to feed livestock; composting agricultural residues; and planting tree crops. Information transfer and training could also facilitate the implementation of fire management programs.

International Agreements: International cooperation in the form of forest protection and reforestation agreements could play a large role in reducing global biomass burning. Such agreements could also expedite technology and information transfer to countries with potential reductions in biomass burning and greenhouse gas emissions.

6.6 Fossil Fuel Combustion

Methane Emissions

Fossil fuels, which include coal, oil, natural gas, shale oil, and bitumen, release methane and other gases during combustion. Current estimates of methane emissions from fossil fuel combustion, based on measured emission factors and available estimates of fossil fuel use worldwide, are 2 to 2.6 Tg per year (USEPA, 1993b), but may be as high as 3 Tg per year (IPCC, 1990b; Darnay, 1992).

When fossil fuels are burned, carbon is released in the form of carbon dioxide (CO_2), methane and other hydrocarbons (HC), carbon monoxide (CO), and other trace substances. The amount of methane in these emissions is determined to a large extent by the completeness of the combustion process; the release of methane is proportionally greatest during incomplete combustion.

The majority of emissions is currently released in developed countries because of their extensive use of fossil fuels. Fossil fuels provide over 90 percent of all of the energy needs in these countries, as compared to about 55 percent in developing countries, where biomass is frequently burned for fuel (USEPA, 1990).

The magnitude and composition of emissions released during a combustion process vary according to the following factors:

- amount and type of fuel combusted;

- methane content of the fuel;
- completeness of the combustion process;
- type and condition of combustion engine; and
- use of exhaust control technologies.

The distribution of emissions from fossil fuel combustion is expected to change over the next few decades. Growth in fossil fuel use is expected to continue, particularly in developing countries, due to rapid population growth, urbanization, increasing transportation needs, and accelerating industrialization. The proportion of world energy used and emissions created by developed countries is expected to significantly decline due to these changes as well as advanced energy-efficient technologies and emission control regulations adopted in developed regions (USEPA, 1990).

Emission Reduction Opportunities

Methane and other greenhouse gas emissions from fossil fuel combustion can be reduced by modifying the combustion process to decrease the amount of gases produced, or by using exhaust control technologies, such as catalytic converters, to reduce emissions of some gases after the combustion process has taken place. Unless such exhaust control technologies are employed, the gases produced during fossil fuel combustion are emitted to the atmosphere. Many potential emissions reduction techniques could be applied in both the short and longer terms. The reduction options for stationary and mobile combustion sources are discussed separately, due to differences in appropriate emission reduction technologies for each type of combustion. The available technologies are described in USEPA (1992b). They are discussed below and summarized in Exhibit 6-8.

Stationary Sources: A number of technologies are available to reduce emissions from sources such as powerplants and factories worldwide. Although rising energy prices have promoted the recent development of many energy efficient technologies, and increasingly strict air quality regulations have resulted in the development and use of advanced exhaust control technologies in developed countries, potential exists for further large improvements in both areas (USEPA, 1990). Potential may also exist for emissions reductions in developing countries, as new technologies replace older and less efficient ones. Opportunities in these countries may be limited, however, to the more affluent areas where fossil fuels (as opposed to biomass) are the primary source of energy.

- Increasing energy efficiency. The energy use efficiency of stationary sources can be increased in the residential and commercial sectors by constructing more efficient building shells, and using more efficient appliances, lighting, and heating and cooling equipment. Large potential also exists for recycling waste heat and improving combustion efficiency in the industrial sector through the use of cogeneration, advanced combined cycle turbines, variable-speed drives, fuel cells, and inorganic wastes recycling.

- Exhaust control technologies. Exhaust control technologies for stationary sources include non-selective catalytic reduction and oxidation/selective catalytic reduction technologies. Larger reductions can be achieved in stationary and mobile combustion engines with these technologies by maintaining high exhaust gas temperatures.

- Alternative fuels. Non-fossil fuels which may be feasible for use with stationary sources include biomass fuels, hydrogen, and nuclear energy. In addition to switching to non-fossil alternative fuels, shifting to fossil-derived alcohol fuels can result in lower direct emissions of methane and other exhaust gases.

- Alternative energy. Non-fossil energy which may be feasible for use with stationary sources include solar thermal, wind, photovoltaic (PV), hydroelectric and geothermal energy.

Mobile Sources: A number of opportunities exist for reducing emissions of methane and other gases from this sector in developing countries. Emissions in these countries are likely to be high as a result of the old age of existing vehicles, poor vehicle maintenance practices, traffic congestion, poor fuel quality, and lenient or non-existent emissions standards (USEPA, 1990). Although methane and other gas emission rates from mobile sources are comparatively low in developed countries, due to recent fuel efficiency improvements and standard exhaust control practices, opportunities exist for reducing these emissions further.

- Increasing fuel efficiency. It may be possible to increase the efficiency of fuel use in new light-duty vehicles by up to 35 percent by reducing vehicle weight, using low friction tires, five-speed automatic transmissions, improved aerodynamic designs, and/or continuously variable transmissions. Opportunities for efficiency improvements, such as adiabatic diesel truck engines, are also available for freight transport.

- Post-combustion exhaust control technologies. The most common examples of these technologies are catalytic converters, which promote the oxidation of unburned HC and CO and in some cases the reduction of oxides of nitrogen (NO_x). Air injection into the exhaust manifold can also control HC and CO emissions. Although exhaust control technologies are standard in many developed countries due to increasingly strict regulations governing allowable levels of NO_x, CO and HC emissions, potential still exists for further emissions reductions.

- Alternative Fuels. Some non-fossil fuels which may be feasible for automotive technologies include solar and hydrogen fuels, fuel cells, electricity, and biomass-derived alcohol. The use of fossil-derived gaseous and liquid fuels (e.g., methanol, ethanol) can also result in lower direct exhaust gas emissions.

Particular short-term and longer-term actions with potential to reduce emissions from fossil fuel combustion are listed below. Potential exists worldwide to reduce emissions from stationary sources. Emissions reduction efforts in the mobile sector may have the largest effect in developing countries, where the largest potential reductions exist.

Stationary Sources:

Short Term:

- Increase the use of energy efficient technologies in new industrial and electricity generating applications; retrofit existing facilities with these technologies;

Exhibit 6-8
Summary of Options for Reducing Methane Emissions from Fossil Fuel Combustion

Techniques	Availability	Capital Requirements	Technical Complexity	Applicability	Benefits
Stationary Sources					reduced emissions of other greenhouse gases and pollutants improved energy efficiency reduced costs due to reduced fuel use reduced dependence on foreign sources of oil
Increase Energy Efficiency	available/RD&D*	low/medium	low/med/high	widely applicable	
Optimize Engine	available	low	low	widely applicable	
Exhaust Control	available	low/medium	medium	widely applicable	
Alternative Fuels	available/RD&D*	medium/high	medium/high	specialized engines	
Mobile Sources					
Increase Fuel Efficiency	available/RD&D*	low/med/high	low/med/high	widely applicable	
Improve Combustion Efficiency	available/RD&D*	low/med/high	medium/high	widely applicable	
Optimize Engine	available	low	low	widely applicable	
Exhaust Control	available	low/medium	medium	widely applicable	
Alternative Fuels	available/RD&D*	medium/high	medium/high	specialized vehicles	
Reduce Emission Sources	available	-	-	widely applicable	

* RD&D: Some technologies within this category require further research, development and demonstration

- Expand the use of exhaust control technologies;
- Substitute cleaner fossil fuels or renewable fuels in industrial applications or electricity generation, and in residential areas where coal is used for cooking and space heating;
- Construct new buildings with more efficient shells, lighting, heating and cooling systems;
- Improve technologies and strengthen standards for energy efficiency in residential appliances;

Longer Term:

- Expand the use of advanced technologies for locally available renewable fuels (e.g., large and small-scale hydroelectric);
- Expand research, development and use of advanced space conditioning technologies and energy management systems (e.g., heat pumps, "Smart" electronic systems, thermal storage techniques); and
- Introduce cogenerated district heating and cooling systems in dense urban areas.

Mobile Sources:

Short Term:

- Expand the use of low emitting technologies;
- Introduce or strengthen exhaust control standards in countries with less stringent regulations (may include sharing of most advanced control technologies);
- Improve automobile inspection and maintenance programs;
- Increase research, development and implementation of fuel switching to alternative fuels;

Longer Term:

- Develop and introduce advanced technologies for renewable alternative fuels (e.g., hydrogen);
- Implement urban planning, road improvement and mass transit programs to alleviate traffic congestion; and
- Promote the use of advanced telecommunications as a substitute for transportation.

Benefits

The strategies discussed in this section may result in numerous national benefits, in addition to reducing emissions of methane and other greenhouse gases. These benefits include increased energy security (reduced reliance on foreign sources of oil and other fuels), enhanced air quality, and cost savings resulting from energy efficiency improvements.

Identifying and Promoting Emission Reductions

Some potential actions to promote the use of technologies for reducing methane emissions from fossil fuel combustion include:

Country Planning Studies: Country-level analyses may be useful to determine the most appropriate strategies for reducing methane emissions from fossil fuel combustion in each region. In each case, a unique combination of energy efficiency, fuel switching, and emissions reduction technologies may most successfully achieve these reductions.

Policy Assistance: Strategies aimed at reducing methane emissions from fossil fuel combustion may be constrained by diverse economic, regulatory, and political systems. Useful efforts in all countries could include developing policies that encourage improved energy efficiency and provide appropriate incentives.

Technology Transfer: While many of the technologies discussed above are currently available in most developed countries, technology transfer programs could facilitate their successful adoption in developing countries.

Information Transfer and Training: Information transfer and training programs may be useful to promote the widespread adoption of efficient fossil fuel combustion technologies and emissions control techniques. Information about current technologies could be made available to all countries through such mechanisms as shared journals and information clearinghouses. Training in the implementation of these technologies could be made available to government and technical personnel.

Financing: The introduction of advanced technologies into many developing countries could be facilitated by financial assistance from other governments, foreign development agencies or international organizations, or by subsidies from manufactures of advanced technologies.

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