III. Waste

Section III presents international emissions baselines and marginal abatement curves (MACs) for waste sources. There are two chapters, one addressing individual sources from the landfill sector and one addressing sources from the wastewater sector. These sources include emissions of methane (CH_4) and nitrous oxide (N_2O). MAC data are presented in both percentage reduction and absolute reduction terms relative to the baseline emissions. These data can be downloaded in spreadsheet format from the USEPA's Web site at <http://www.epa.gov/nonco2/econ-inv/international.html>.

Section III—Waste chapters are organized as follows:

Methane (CH_4)

III.1 Landfill Sector

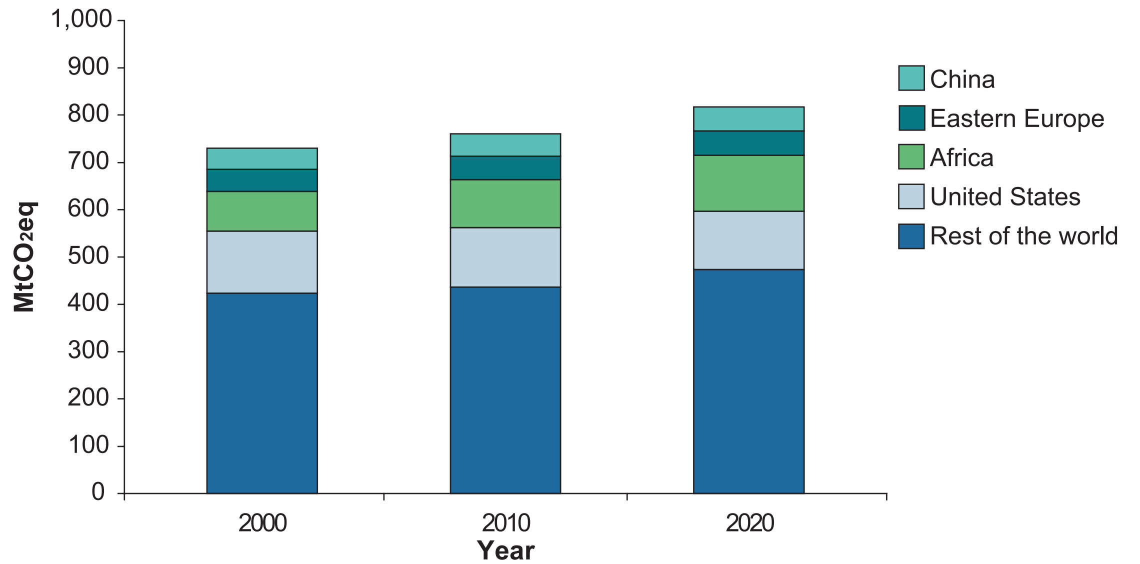
Methane (CH_4) and Nitrous Oxide (N_2O)

III.2 Wastewater Sector

III.1 Landfill Sector

Worldwide methane (CH_4) from the landfilling of municipal solid waste (MSW) accounted for over 730 million metric tons of carbon dioxide ($MtCO_2eq$) equivalent in 2000 and represented over 12 percent of total global CH_4 emissions. The United States, Africa, Eastern Europe, and China combined account for 42 percent of the world's CH_4 emissions from landfills (see Figure 1-1). Global CH_4 emissions from landfills are expected to grow by 9 percent between 2005 and 2020. Most developed countries have regulations that will constrain and potentially reduce future growth in CH_4 emissions from landfills. However, areas of the world such as Eastern Europe and China are projected to experience steady growth in landfill CH_4 emissions because of improved waste management practices diverting more MSW into managed landfills.

Figure 1-1: CH_4 Emissions from Municipal Solid Waste by Country: 2000–2020



Source: Environmental Protection Agency (USEPA), 2006.

III.1.1 Introduction

CH_4 from landfills is produced in combination with other landfill gases (LFGs) through the natural process of bacterial decomposition of organic waste under anaerobic conditions. The CH_4 along with other LFGs is generated over a period of several decades (usually beginning 1 to 2 years after the waste is put in place). CH_4 makes up approximately 50 percent of LFG, with the remaining 50 percent being CO_2 mixed with small quantities of other gases. If landfill CH_4 is not collected, it will escape to the atmosphere.

The production of landfill CH_4 gas depends on several key characteristics, including waste composition, landfill design, and operating practices, as well as local climate conditions. Two factors that will accelerate the rate of CH_4 generation within a landfill are an increased share of organic waste (paper, food scraps, brush) in the mix of MSW being landfilled and increased levels of moisture in the waste. In addition, if the landfill has used a soil cover (daily cover, intermediate cover, or final cover) in its operations, a portion of the CH_4 will be oxidized as it passes through these soil layers and converted to CO_2. Many landfill management practices are regulated to control for health and environmental concerns.

The U.S. federal government currently requires all landfills to monitor and control landfill gas migration and requires larger landfills to collect and combust landfill gas to destroy the non-CH_4 organic compounds. Landfills with a design capacity greater than 2.5 million megagrams (or 2.8 million short tons) are subject to the New Source Performance Standards and Guidelines (NSPS/EG) of the Clean Air Act (USEPA, 1999a), referred to in this chapter as the "Landfill Rule." Similar regulations exist in the European Union (EU-15) and other developed countries to control the CH_4 emissions from large landfills. However, in most developing countries, there are no regulations covering landfill CH_4 emissions. Despite efforts to control large landfill emissions, the landfill sector remains a significant source of CH_4 emissions.

Abatement options include the capture of CH_4 for flaring or energy production and enhanced waste management practices to reduce waste disposal at landfills (such as recycling-and-reuse programs). CH_4 recovery for energy use is another approach and is the focus of this report's marginal abatement curve (MAC) analysis. Because of its low cost, flaring is the most commonly adopted abatement option; however, this report also considers two energy recovery options as viable alternatives to flaring that may provide greater financial incentive to landfill managers.

The following sections discuss the activity data and emissions factors used to develop baseline emissions, abatement options and their costs, and CH_4 MACs for the landfill sector. The chapter concludes with a discussion of uncertainties and limitations. As an appendix to this analysis, we discuss recent efforts to improve on the MAC methodology by incorporating technology change and by building the MACs from a population of individual landfills.

III.1.2 Baseline Emissions Estimates

This section discusses the characteristics of landfills and how the characteristics affect CH_4 emissions. In this section, we also describe historical and projected trends that influence baseline emissions from MSW landfills. In general, the quantity of CH_4 generated is determined by four main factors:

- population
- quantity of waste disposed of per capita
- composition of waste disposed of
- type of waste disposal site (landfill versus open dump)

It is commonly accepted that waste generation grows approximately proportional to a country's population. In addition, countries with higher gross domestic product (GDP) per capita typically generate more waste per capita. The amount of waste generated per capita multiplied by the population determines the amount of MSW available for disposal.

The composition of waste, which influences CH_4 emissions rates, varies across countries. The level of recycling or reuse of plastics, metals, organics, and other inorganic waste affects both the amount of waste disposed of and the type of waste available to generate CH_4. Generally, formal recycling-and-reuse programs are incremental improvements employed by countries that already have sanitary landfills in place. However, open dumps often have high levels of recovery of both organic and inorganic materials from informal programs involving human activities and animal scavenging.

The type of waste disposal site also significantly influences CH_4 generation. There are generally three types of waste disposal sites—open dumps, controlled or managed dumps, and sanitary landfills. Open dumps are characterized by open fills with loosely compacted waste layers. Managed dumps are similar to open dumps but are better organized and may have some level of controls in place. Open and controlled dumps are not conducive to CH_4 generation primarily because of aerobic conditions as well as other factors such as shallow layers and unconsolidated disposal (i.e., waste disposed in different parts of the same landfill site on different days). Sanitary landfills are sites designed and operated to accept MSW and employ waste management practices, such as mechanical waste compacting and the use of liners, daily cover, and a final cap (Intergovernmental Panel on Climate Change [IPCC], 1996). Developed countries primarily employ sanitary landfills. In developing countries, there is a mix of open dumps (in rural and some urban sites), managed dumps (mainly in larger townships), and sanitary landfills (in large cities).

III.1.2.1 Activity Data

This section discusses the historical and projected activity factors that determine CH_4 generation at solid waste disposal sites and policies set to improve waste management practices.

Historic Activity Data

Industrialized countries traditionally have the highest per capita waste generation rates and have accounted for the dominant share of global MSW production each year. Industrialized countries have also been the first to adopt sanitary landfills, employing waste compaction, dirt covers, and final caps. Sanitary landfills enable more waste to decay in an anaerobic environment, which ultimately leads to an increase in CH_4 production. However, industrialized countries have also led the way in adopting landfill gas (LFG) regulations and LFG utilization projects.

Developing countries historically have high population growth rates but use open dumps for waste disposal because of decentralized waste management programs and cost factors. Open dump waste disposal sites often do not provide the anaerobic conditions necessary to produce large quantities of CH_4. Some developing countries may have managed dumps that could create the anaerobic conditions required to generate CH_4 emissions. When calculating a country's baseline emissions, it is important to determine whether the country has any managed dumps. Additionally, economic growth in developing countries may result in an increased migration from rural communities to larger urban settings. Larger amounts of waste landfilled in the sanitary and managed dumps in these larger urban cities may potentially increase the amount of CH_4 generated.

Projected Activity Data

Globally, projections indicate that the amount of MSW being deposited into sanitary landfills is expected to grow. Developing countries are expected to move away from open dumps toward more sanitary landfills. The fraction of waste disposed of in landfills versus open dumps is expected to increase at the rate of per capita GDP growth.

Industrialized countries are expected to increase the level of LFG regulation and LFG utilization projects. These countries will also continue to improve or implement composting, recycling, and reuse programs. For example, in the United States the fraction of waste generated that is landfilled has decreased from 72 percent of all waste generated in 1989 to 56 percent of all waste generated in 2000 (USEPA, 2003b).

III.1.2.2 Emissions Factors and Related Assumptions

The emissions factors for sanitary landfills are defined as the CH_4 generated per ton of waste accumulated and are primarily determined by, but are not limited to, four factors: the type and age of the waste buried in the landfill, the quantity and types of organic compounds in the waste, the moisture content of the waste, and temperature of the waste. Temperature and moisture levels are influenced by the surrounding climate. CH_4 emissions factors are significantly higher for sanitary landfills compared with open dumps because of the presence of anaerobic conditions.

Historical Emissions Factors

Industrialized countries have only recently begun adopting waste management practices such as recycle-and-reuse programs for organic materials. Before these programs were instituted, industrialized MSW had a higher organic material composition, which resulted in higher emissions factors.

Developing countries' emissions factors for landfills have historically been lower than industrialized countries because of the use of open dumps, which have shallow layers of rapidly decaying organic matter under aerobic conditions, preventing the accumulation of CH_4. In addition, open dumps make it easy for both animal scavengers and human waste pickers to remove food and paper, effectively reducing the amount of organic waste that would otherwise decay and ultimately generate CH_4. Fires are also common at open dump sites and can alter the composition of the MSW, reducing its ability to generate CH_4.

Projected Emissions Factors

Industrialized countries' emissions factors for landfills are projected to decrease. As these countries continue improving their waste management practices, more of the organic waste will be taken out of the MSW disposed of at landfills, thereby lowering the landfill's CH_4 generation potential. One example is the EU Landfill Directive, which has limited the amount of organic matter that can enter MSW facilities. Additionally, steady economic growth and small or negative population growth may again lower emissions factors for landfills in industrialized countries.

Emissions factors for developing countries' landfills will increase as these countries move away from open dumps toward sanitary landfills. Sanitary landfills typically do not allow for scavengers to reduce the organic composition of the MSW. This possibility, in combination with the lack of established recycling programs, could lead to a dramatic increase in the emissions factors for these landfills.

III.1.2.3 Emissions Estimates and Related Assumptions

This section discusses the historical and projected baseline landfill emissions for both industrialized and developing countries. Figure 1-2 summarizes the components of landfill baseline CH_4 emissions, where incremental landfill management improvements, such as increased recycling programs, are accounted for through a reduction in the amount of waste accumulating at a landfill. This has a direct effect on the quantity of CH_4 generated at MSW landfills. In countries for which no emissions estimate was available, the IPCC Tier 1 methodology was used to estimate baselines using IPCC default values. For more detailed discussion of baseline emissions calculation methodology, see the USEPA's (2006) *Global Emissions Inventory Report*.

Historical Emissions Estimates

Table 1-1 lists the historical baselines for the world's leading countries in CH_4 emissions from landfills. The United States, by far the largest emitter of CH_4 from landfills, experienced a decline in baseline emissions as a result of the Landfill Rule and LFG utilization. Former Soviet countries of Eastern Europe, such as the Ukraine and Poland, have experienced gradual increases as these newly independent states begin to develop their waste management programs and a larger fraction of the MSW generated is disposed of at managed landfills.

Figure 1-2: Components of CH_4 Emissions from Landfills

Total landfill CH_4 emissions

equal

CH_4 generated from MSW landfills

minus

CH_4 recovered and flared or used for energy

minus

CH_4 oxidized from MSW landfills

plus

Methane emissions from industrial waste sites

Source: USEPA, 1999b.

Table 1-1: CH_4 Emissions from Municipal Solid Waste by Country: 1990–2000 ($MtCO_2eq$)

Country	1990	1995	2000
United States	172.2	162.4	130.7
China	40.4	42.6	44.6
Mexico	26.0	28.5	31.0
Canada	18.5	20.4	22.9
Russian Federation	37.8	37.8	35.1
Saudi Arabia	12.5	14.4	16.8
India	10.7	12.2	13.9
Brazil	13.0	14.5	15.6
Ukraine	14.2	14.5	12.1
Poland	16.1	15.9	17.0
South Africa	14.1	15.2	16.3
Turkey	8.2	8.9	9.7
Israel	6.6	7.8	8.8
Australia	7.5	8.3	8.0
Dem. Rep. of Congo (Kinshasa)	5.0	5.9	6.4
Rest of the world	**358.7**	**360.4**	**341.6**
World Total	**761.4**	**769.7**	**730.3**

Source: USEPA, 2006.

Historically, in developed countries, baseline CH_4 emissions from landfills are decreasing because of improved recovery technologies and mandated regulation to capture and control LFG (which includes CH_4) produced at the world's CH_4-producing landfills. Many countries have instituted regulations that require large landfills to install CH_4 capture-and-flaring systems either for safety or environmental concerns. For example, the United States enacted the Landfill Rule in 1996; the EU and the United Kingdom have enacted similar legislation to limit LFG generation or require its collection and control. The landfill rule requires landfill gas to be collected and combusted either through flaring or use at landfills that have a design capacity greater than 2.5 million metric tons (Mt) and 2.5 million cubic meters

(m^3). This rule and similar rules in other developed countries have reduced the amount of CH_4 in the baseline estimates for each year after 1999.

Developing countries are increasing the fraction of waste disposed of at landfills as the amount of waste generated increases with per capita GDP. However, as discussed earlier, open dumps have been the primary method for waste disposal in developing countries, and because of the characteristics of these landfills, they tend not to produce large amounts of CH_4. Open dumps have kept CH_4 baseline emissions from landfills in developing countries low. However, very large open dumps and managed dumps can be significant sources of CH_4 emissions given sufficient conditions, such as depth, the amount of waste in place, and the rate of waste accumulation annually.

Projected Emissions Estimates

Worldwide CH_4 emissions from landfills are expected to decrease in industrialized countries and increase in developing countries. Industrialized countries' baselines will continue to decline because of expanding recycling-and-reuse programs, increased LFG regulation, and improved LFG recovery technologies. Developing countries' baseline landfill emissions are expected to increase because of their rapidly expanding populations—trending away from open dumps to sanitary landfills to improve health conditions—and because of a lack of formal recycling programs in the near future. Formal recycling programs typically follow the adoption of sanitary landfills. Table 1-2 lists the projected baseline emissions for the world's top emitters over the period from 2005 to 2020 in $MtCO_2eq$.

Table 1-2: Projected Baseline CH_4 Emissions from Municipal Solid Waste by Country: 2005–2020 ($MtCO_2eq$)

Country	2005	2010	2015	2020
United States	130.6	125.4	124.1	123.5
China	46.0	47.5	48.8	49.7
Mexico	33.3	35.5	37.4	39.2
Canada	25.3	27.7	30.7	33.6
Russian Federation	34.2	33.2	32.2	31.1
Saudi Arabia	19.4	22.1	24.8	27.5
India	15.9	17.1	18.1	19.1
Brazil	16.6	17.5	18.3	19.0
Ukraine	13.4	14.7	16.4	18.0
Poland	17.0	17.0	17.0	17.0
South Africa	16.8	16.6	16.4	16.2
Turkey	10.4	11.0	11.6	12.1
Israel	9.7	10.6	11.3	11.9
Australia	8.7	9.4	10.6	11.9
Dem. Rep. of Congo (Kinshasa)	7.4	8.6	9.8	11.2
Rest of the world	**342.7**	**346.7**	**360.5**	**375.9**
World Total	**747.4**	**760.6**	**788.1**	**816.9**

Source: USEPA, 2006.

Developing nations are projected to experience only slight declines in baseline emissions through government policies such as the Landfill Rule passed in the United States in 1996. As recovery techniques improve, the number of landfills that can profit from the LFG recovery will increase, which will continue to drive down the level of baseline emissions in developed as well as developing countries.

III.1.3 Cost of Emissions Reductions from Landfills

CH_4 emissions from landfills can be reduced using two approaches:

- capture the CH_4 and flare it or use it for energy and
- change waste management practices to reduce waste disposal at landfills by adding composting and recycling-and-reuse programs.

CH_4 recovery for flaring or energy is the most popular approach and is the focus of this report's cost analysis. However, documented or expected changes in disposal rates due to composting and recycling are accounted for in the baseline emissions estimates for each country.

III.1.3.1 Abatement Option Opportunities

Collection systems are present in most landfills as a mechanism to prevent migration of the gas to on-site structures or away from the landfill to adjacent property and to prevent the release of non-CH_4 organic compounds to the atmosphere. Following the collection of CH_4, the landfill operator must make a decision to flare, pump the gas to an end user for process heat, or generate electricity. Table 1-3 specifies the components of the gas collection and flaring system and direct-use system.

Table 1-3: Components of Collection and Flaring and LFG Utilization Abatement Options

System	Type of Equipment
Collection and flaring	Wells
	Wellheads and gathering pipeline system
	Knockout, blower, and flare
Utilization (i.e., electricity production and direct use)	Skid mounted filter
	Compressor
	Dehydrator unit
	Pipeline
	Turbine, engine, or boiler

Source: USEPA, 2003a.

The USEPA's LFG cost model estimates LFG generation, one-time capital costs, annual operation and maintenance (O&M) fees, and the quantity of gas recoverable for flaring or utilization for individual landfills. An expected technology lifetime of 15 years is used. This section discusses the one-time capital and annual costs and the annual cost savings for the two most popular options: collection and flaring and utilization. For a complete list of the technology options considered by the Economic Modeling Forum (EMF) 21 study for the landfill sector, see Table 1-4 below.

Collection and Flaring

The presence of CH_4 can be a public health concern, as well as a safety hazard at landfills if the concentration builds up. For this reason, large landfills have historically removed the CH_4 and then combusted the gas through flaring. Gas is collected through vertical wells and a series of horizontal collectors typically installed following the closing of a landfill cell. Vertical wells are the most common type of well, while horizontal collectors are used primarily for deeper landfills and landfill cells that are actively being filled. Once captured, the gas is then channeled through a series of gathering lines to a main collection header. The USEPA recommends that the collection system be designed so that an operator can monitor and adjust the gas flow.

- **Capital Costs.** This abatement option requires the installation of vertical or horizontal wells; wellheads and gathering pipeline system; and a knockout, blower, and flare system. The USEPA's cost model estimates one well for every acre of landfill at a cost of $7,200 per well. The gathering pipeline system's cost is determined by the number of wells at the landfill. The USEPA estimates the cost for the collection system as a fixed cost of $19,000, plus a cost of $8,756 per well. Finally, the cost of the knockout, blower, and flare system is determined by the gas flow rate. For example, if a landfill produced 1,000,000 cubic feet per day, the USEPA estimates the cost to be approximately $200,000.
- **Annual Costs.** Annual costs include labor costs associated with monitoring the gas flows, moving or maintaining gas collection systems, and maintaining the flare. Additionally, there is an annual cost associated with the electricity used by blowers. Annual costs are typically 10 percent of one-time capital costs.
- **Cost Savings/Benefits.** Increased environmental and public health benefits, as well as increases in safety at the landfill site, are the primary benefits. The flaring system is an effective way of reducing large quantities of CH_4 emissions from landfills. Additional nonmarket benefits include the reduction of volatile organic compounds (VOCs) and reduced odor.

LFG Utilization Systems

Components of a capture and utilization abatement option for the landfill sector include a landfill gas collection system, utilization pumping system, or some mechanism such as a turbine for generating energy through the combustion of landfill CH_4 gas. LFG is extracted from landfills using a series of vertical or horizontal wells and a blower (or vacuum) system. This system directs the collected gas to a central point, where it can be processed and treated depending on the ultimate use of the gas. From this point, the gas simply can be flared or used to generate electricity, or the gas can be pumped to an end-user for process heat. Additional direct-use options, such as fuel to run leachate evaporators and liquid natural gas production, also reduce CH_4 emissions.

In addition, landfill CH_4 gas can be transported and used in industrial processes, such as boilers, drying operations, kiln operations, and cement and asphalt production. Gas collected from the landfill can be piped directly to local industries where it is used as a replacement or supplementary fuel. The ideal customers will have a steady, annual energy demand that will use a large percentage or all of the landfill's gas flow.

- **Capital Costs.** Utilization systems may require the installation of a skid-mounted filter, compressor, and dehydrator unit and mile(s) of pipeline to carry gas to the customer. Costs for the skid-mounted filter, compressor, and dehydrator unit are based on the gas flow rate. For a landfill with a gas flow rate of 1 million cubic feet per day, the USEPA estimates the installed costs of the filter, compressor, and dehydrator to be approximately $180,000. The USEPA estimates the installation cost for the pipeline is $264,000 per mile.
- **Annual Costs.** Annual costs are composed primarily of electricity usage by the compressor and dehydrator unit. Estimated annual costs for O&M and electricity are $100,000.

- **Annual Savings/Benefits.** Annual benefits are determined by the quantity of gas sold, the British thermal unit (Btu) content of the landfill gas, and the current market price of natural gas. Given the 2004 price of natural gas in the United States, annual benefits can be up to 10 times as great as annual costs.

III.1.4 Results

This section presents the EMF-21 study's MAC results in tabular format.

III.1.4.1 Data Tables and Graphs

Table 1-4 presents the average breakeven price and the reduction in absolute and percentage terms for the mitigation options discussed in Section III.1.3.1. Table 1-5 presents the baseline emissions for landfills by EMF regional grouping. Table 1-6 presents the percentage reduction in the baseline emissions at specific breakeven prices, and Figure 1-3 provides MACs for the five EMF countries/regions with the largest estimated emissions from MSW landfills in 2020.

Table 1-4: Breakeven Prices of MSW Landfill Technology Options

Technology	Breakeven Cost ($/t$CO_2$eq)	Emissions Reduction (% from baseline)	Emissions Reduction in 2010 (MtCO_2eq)	Emissions Reduction in 2020 (MtCO_2eq)
	Assuming a 10% discount rate and a 40% tax rate			
Anaerobic digestion 1 (AD1)[a]	$36.03	10%	0.16	0.16
Anaerobic digestion 2 (AD2)[b]	$428.74	10%	0.16	0.17
Composting (C1)[c]	$243.45	13%	0.45	0.52
Composting (C2)[d]	$265.41	12%	0.43	0.49
Mechanical biological treatment	$362.94	10%	0.16	0.16
Heat production	–$16.70	9%	0.31	0.36
Increased oxidation	$265.20	6%	0.21	0.24
U.S. direct gas use (profitable at base price)	$0.90	10%	0.34	0.39
Electricity generation	$73.02	10%	0.34	0.39
Direct gas use (profitable above base price)	$8.09	10%	0.34	0.39
Flaring	$24.69	10%	0.34	0.39

Source: USEPA, 2003c. Adapted from landfill technology tables in Appendix B.

[a] AD1 expedites the natural decomposition of organic material without oxygen by using a vessel that excludes oxygen and maintains the temperature, moisture content, and pH close to their optimum values. CH_4 can be used to produce heat and/or electricity.

[b] AD2 expedites the natural decomposition of organic material without oxygen by using a vessel that excludes oxygen in the same way as AD1, but with additional income from compost.

[c] C1 involves degradation of the organic matter under aerobic conditions. It requires separating organic matter from the waste stream. Finished compost has a market value because it is used to enhance soil in horticulture/landscape and agricultural sites.

[d] C2 involves the degradation of organic matter under aerobic conditions and the separation of organic matter from the waste stream in the same way as C1, but there are larger costs.

Table 1-5: Baseline Emissions by EMF Regional Grouping: 2000–2020 ($MtCO_2eq$)

Country/Region	2000	2010	2020
Africa	84.2	101.1	118.8
Annex I	**349.6**	**315.7**	**312.4**
Australia/New Zealand	9.4	11.0	13.6
Brazil	15.6	17.5	19.0
China	44.6	47.5	49.7
Eastern Europe	47.2	49.7	51.9
EU-15	84.6	46.3	32.7
India	13.9	17.1	19.1
Japan	3.9	3.1	2.4
Mexico	31.0	35.5	39.2
Non-OECD Annex I	**62.2**	**65.1**	**69.1**
OECD	**328.6**	**297.0**	**293.5**
Russian Federation	35.1	33.2	31.1
South & SE Asia	23.6	27.9	31.5
United States	130.7	125.4	123.5
World Total	**730.3**	**760.6**	**816.9**

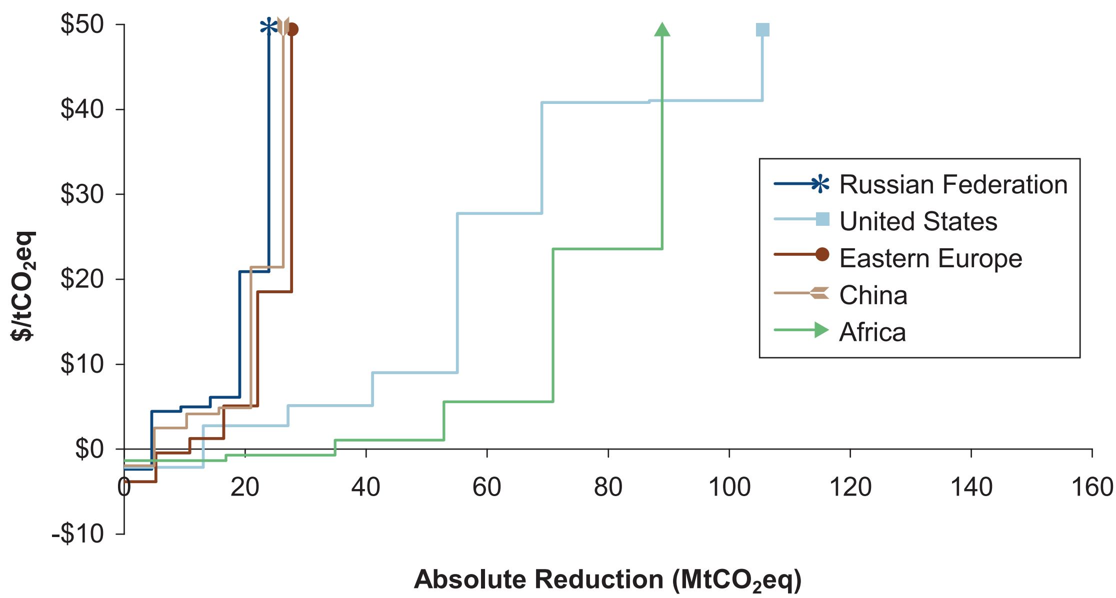
Source: USEPA, 2006.
EU-15 = European Union; OECD = Organisation for Economic Co-operation and Development.

Table 1-6: MSW Landfill MACs for Countries Included in the Analysis

	Percentage Reduction from Baseline in tCO_2eq									
	2010					2020				
Country/Region	$0	$15	$30	$45	$60	$0	$15	$30	$45	$60
Africa	20.71%	42.14%	52.86%	52.86%	87.31%	20.71%	42.14%	52.86%	52.86%	87.31%
Annex I	**11.16%**	**38.89%**	**45.45%**	**63.58%**	**88.25%**	**11.54%**	**40.18%**	**46.96%**	**65.70%**	**91.19%**
Australia/New Zealand	7.00%	29.50%	46.50%	46.50%	90.12%	7.00%	29.50%	46.50%	46.50%	90.12%
Brazil	20.71%	42.14%	52.86%	52.86%	87.31%	20.71%	42.14%	52.86%	52.86%	87.31%
China	10.00%	42.14%	52.86%	52.86%	87.31%	10.00%	42.14%	52.86%	52.86%	87.31%
Eastern Europe	20.71%	42.14%	52.86%	52.86%	87.31%	20.71%	42.14%	52.86%	52.86%	87.31%
EU-15	7.00%	29.50%	46.50%	46.50%	90.12%	7.00%	29.50%	46.50%	46.50%	90.12%
India	10.00%	52.86%	52.86%	52.86%	87.31%	10.00%	52.86%	52.86%	52.86%	87.31%
Japan	31.50%	66.00%	66.00%	66.00%	90.12%	31.50%	66.00%	66.00%	66.00%	90.12%
Mexico	10.00%	42.14%	52.86%	52.86%	87.31%	10.00%	42.14%	52.86%	52.86%	87.31%
Non-OECD Annex I	**10.00%**	**42.14%**	**52.86%**	**52.86%**	**87.31%**	**9.20%**	**38.76%**	**48.61%**	**48.61%**	**80.30%**
OECD	**11.42%**	**38.42%**	**44.53%**	**64.55%**	**88.37%**	**11.91%**	**40.05%**	**46.43%**	**67.31%**	**92.14%**
Russian Federation	10.00%	42.14%	52.86%	52.86%	87.31%	10.00%	42.14%	52.86%	52.86%	87.31%
South & SE Asia	10.00%	42.14%	52.86%	52.86%	87.31%	10.00%	42.14%	52.86%	52.86%	87.31%
United States	10.00%	42.14%	42.14%	80.71%	87.31%	10.00%	42.14%	42.14%	80.71%	87.31%
World Total	**11.71%**	**40.54%**	**48.95%**	**58.35%**	**87.81%**	**11.82%**	**40.68%**	**49.62%**	**56.84%**	**87.76%**

Source: USEPA, 2003c.
EU-15 = European Union; OECD = Organisation for Economic Co-operation and Development.

Figure 1-3: EMF MACs for Top Five Emitting Countries/Regions from Landfills: 2020



The MACs presented in this section represent static abatement curves using breakeven prices built on the assumption of fixed mitigation cost, and aggregate countrywide landfill statistics. Appendix E presents more recent efforts to develop an alternative framework for conducting MAC analysis that addresses the limitations of the EMF-21 MAC analysis for the landfill sector.

III.1.4.2 Uncertainties and Limitations

Uncertainty and limitations persist despite attempts to incorporate all publicly available information on international landfill sectors. Additional information would improve the accuracy of the MACs' projections.

- **Landfill Populations.** A major source of uncertainty in the MACs is due to a lack of reliable information on the landfill population for all countries. Improved information on waste acceptance rates, waste composition, trends in waste management practices, and landfill capacity data by landfill for each country would greatly improve the analyst's ability to calculate benefits and hence breakeven prices.
- **Climate Change.** The presence of moisture plays a large role in determining the CH_4 generation rate for landfills in each country. Improved projected and historical data on the weather conditions at future and existing landfills would contribute to improving the accuracy of our estimations of CH_4 generation. This would also contribute to the heterogeneity of each country's MAC and of the landfills within each country.
- **Country-Specific Waste Management Practices.** Improved documentation of waste management practices would allow deviations from the normal assumption that waste generation increases along with population. Instituting recycling-and-reuse programs reduces the fraction of waste deposited in the landfills.

- **Adjusting Costs for Specific Domestic Situations.** Currently, the technologies considered in this report are available in the United States, Canada, and Western Europe for the costs reported. However, countries other than these countries may be faced with higher costs because of transportation and tariffs associated with purchasing the technology from abroad or could be faced with lower costs due to domestic production of these technologies. Data on domestically produced technologies, both costs and reduction efficiencies, are not available.
- **Country-Specific Tax and Discount Rates.** A single tax rate is applied to landfills and landfills in all countries to calculate the annual benefits of each technology. Tax rates can vary across countries and in the case of state-run mines and landfills in China, taxes may be less applicable. Similarly the discount rate may vary by country. Improving the level of country-specific detail will help analysts more accurately calculate benefits and hence breakeven prices.

III.1.5 Summary and Analysis

The methodology and data discussed in this section describe the MAC analysis conducted for the landfill sector by the EMF-21 study. MACs for 2010 and 2020 were estimated based on aggregated industry data from each country or region. The MACs represent estimates of potential CH_4 mitigation from landfills based on available information regarding MSW practices, infrastructure, climate, and country reported emissions estimates provided through the United Nation's Framework Convention on Climate Change (FCCC) emissions inventory reports.

III.1.6 References

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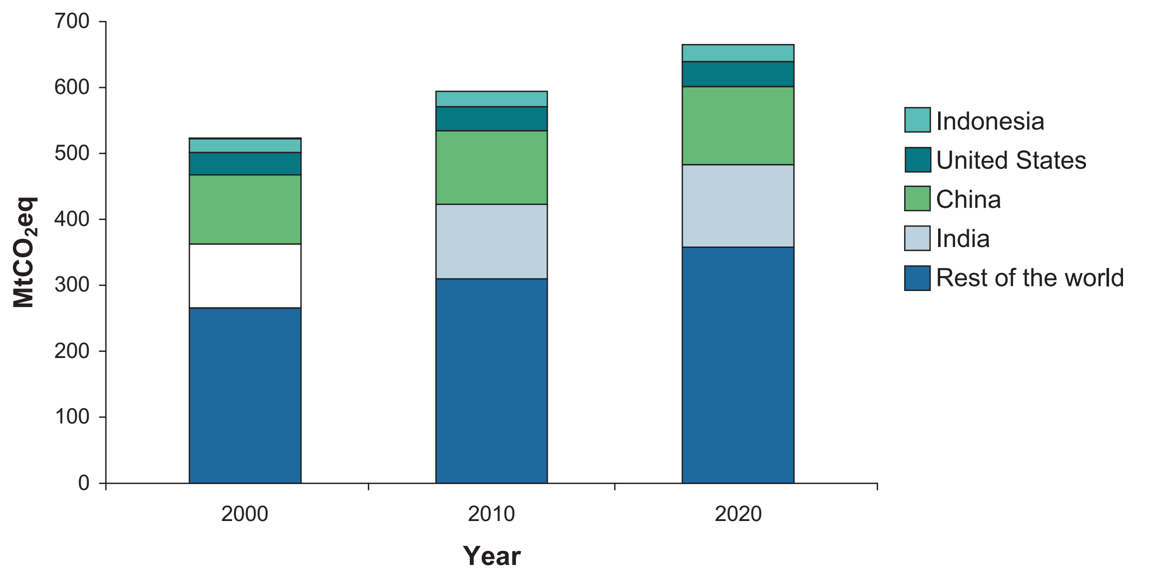
III.2 Wastewater Sector

Worldwide CH_4 from wastewater accounted for more than 523 $MtCO_2eq$ in 2000. Wastewater is the fifth largest source of anthropogenic CH_4 emissions, contributing approximately 9 percent of total global CH_4 emissions in 2000. India, China, the United States, and Indonesia combined account for 49 percent of the world's CH_4 emissions from wastewater (see Figure 2-1). Global CH_4 emissions from wastewater are expected to grow by approximately 20 percent between 2005 and 2020.

Figure 2-1: CH_4 Emissions from Wastewater by Country: 2000–2020



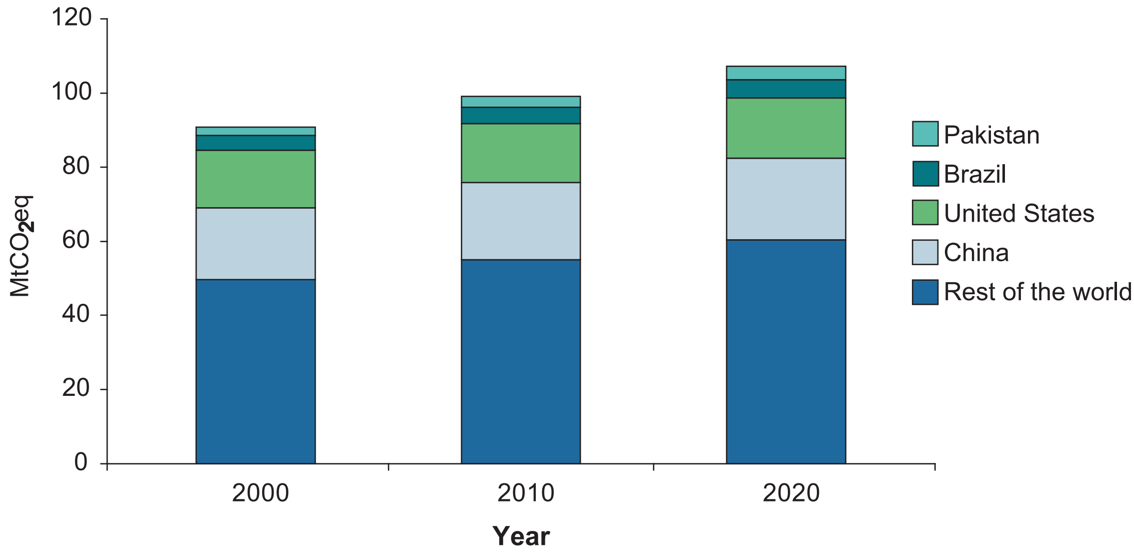
Source: USEPA, 2006.

Wastewater is also a significant source of nitrous oxide (N_2O). Worldwide, N_2O emissions from wastewater accounted for approximately 91 $MtCO_2eq$ in 2000 (see explanatory note 1). Wastewater as a source is the sixth largest contributor to N_2O emissions, accounting for approximately 3 percent of N_2O emissions from all sources. Indonesia, the United States, India, and China accounted for approximately 50 percent of total N_2O emissions from domestic wastewater in 2000 (see Figure 2-2). Global N_2O emissions from wastewater are expected to grow by approximately 13 percent between 2005 and 2020. This chapter only discusses the mitigation options that may be available to control CH_4 at wastewater treatment plants. No formal MAC analysis is presented for this sector because data are insufficient on wastewater systems' infrastructure and abatement technology costs.

III.2.1 Introduction

Wastewater from domestic (sewage) and industrial sources is typically moved through a wastewater sewer system to a centralized wastewater management treatment center. At the treatment center, soluble organic material, suspended solids, pathogenic organisms, and chemical contaminants are removed from water using biological processes in which microorganisms consume the organic waste. This results in the production of biomass sludge. The microorganisms can perform this biodegradation process in aerobic and anaerobic environments, the former producing CO_2 and the latter producing CH_4.

Figure 2-2: N_2O Emissions from Wastewater by Country: 2000–2020



Source: USEPA, 2006.

Wastewater treatment plants (WWTP) may be located on-site or off-site. In the case of domestic wastewater, septic tanks are an example of an on-site treatment plant for domestic wastewater, while a centralized municipal WWTP is an example of an off-site facility. The USEPA estimates that 25 percent of domestic wastewater is treated through on-site facilities such as septic tanks (USEPA, 2004). Centralized WWTP requires that the wastewater be transported to the facility through a municipal sewer system.

III.2.1.1 Emissions from Wastewater Systems

CH_4 is produced by decay of organic material in wastewater as it decomposes in anaerobic environments. CH_4 emissions from wastewater are determined by the amount of organic material produced and the extent to which this material is allowed to decompose under anaerobic conditions. The organic content of wastewater is typically expressed in terms of either biochemical oxygen demand (BOD) or chemical oxygen demand (COD) (IPCC, 1996a). Most developed countries use centralized aerobic wastewater treatment facilities with closed anaerobic sludge digester systems to process municipal and industrial wastewater. Employment of these practices increases CH_4 generation but ultimately reduces baseline emissions.

N_2O is produced during both the nitrification and denitrification of urea, ammonia, and proteins. These waste materials are converted to nitrate (NO_3) via nitrification, an aerobic process converting ammonia-nitrogen to nitrate. Denitrification occurs under anoxic conditions (without free oxygen) and involves the biological conversion of nitrate into dinitrogen gas (N_2). N_2O can be an intermediate product of both processes but is more often associated with denitrification (Sheehle and Doorn, 2001).

An overview of treatment methods, wastewater composition, and sources of CH_4 emissions for domestic and industrial wastewater systems is provided below, followed by a discussion of N_2O emissions.

Domestic Wastewater

The process of treating domestic wastewater (sewage) involves three major phases. First, the wastewater collected at a centralized WWTP goes through a primary treatment phase. During this phase, large solids are removed through a filtration process where grit is removed and oxygen is added. Next, the wastewater enters a primary clarifier that removes almost 95 percent of settleable solids. This process takes approximately 30 minutes to an hour, and the initial biodegradation by microorganisms begins. Primary sludge is separated from the effluent at this stage. During this process, wastewater is generally aerated ensuring that the decomposition of the organic matter occurs in an aerobic environment.

Following the primary treatment, it is common to subject the remaining effluent to a secondary treatment. During this phase, the effluent undergoes bio-oxidation through an aerobic process in which aerobic microorganisms break down any remaining organic solids. In the secondary treatment, the effluent is passed through a trickling filter or aeration basin for approximately 4 to 6 hours. Next, the remaining effluent moves into a final clarifier where further biodegradation can occur. This secondary treatment produces additional secondary sludge (biomass). Following the secondary treatment, the effluent is released to a receiving stream.

The sludge (biomass) produced during the primary and secondary phases of treatment is then combined and moved into an encapsulated silo-like digester where it undergoes an anaerobic decomposition process using microorganisms that continue to break down the organics. The digester comprises a holding tank, a gas capture system, and a heating element. Over a period of time (weeks), microorganisms break down the large organic molecules in the feed sludge. Still smaller organisms convert this organic material into CH_4 and CO_2. On average, 40 to 45 percent of feed sludge is converted to CH_4 and CO_2 during the process. The CH_4 produced is closely monitored for safety concerns and then combusted either in the form of a flare or used to generate heat required during this process. The remaining sludge is sent to landfills.

Industrial Wastewater

Industries producing large volumes of wastewater and industries with high organic COD wastewater load are likely to have significant CH_4 emissions. In the United States, the meat and poultry, pulp and paper, and produce (i.e., fruits and vegetable) industries are the largest sources of industrial wastewater and contain high organic COD. These industries are also considered CH_4-emitting industries because they employ either shallow lagoons or settling ponds in their treatment of wastewater, which promotes anaerobic degradation.

The meat and poultry industry in the United States has been identified as a major source of CH_4 emissions because of its extensive use of anaerobic lagoons in sequence to screening, fat traps, and dissolved air flotation. It is estimated that 77 percent of all wastewater from the meat and poultry industry degrades anaerobically (USEPA, 1997a).

Treatment of industrial wastewater from the pulp and paper industry is similar to the treatment of municipal wastewater. Treatment in this industry generally includes neutralization, screening, sedimentation, and flotation/hydrocycloning to remove solids. Anaerobic conditions are most likely to occur during lagooning for storage, settling, and biological treatment (secondary treatment). During the primary treatment phase, lagoons are aerated to reduce anaerobic activity. However, the size of these lagoons makes it possible for zones of anaerobic degradation to take place. Approximately half of the initial COD remains following the primary treatment. This remaining COD is passed into a secondary treatment phase where anaerobic degradation is more likely to take place. The USEPA estimates that 25 percent of COD in secondary treatment lagoons degrades anaerobically (USEPA, 1997b).

The fruit, vegetable, and juice-processing industries generate large amounts of wastewater. The treatment of wastewater from these industries generally includes screening, coagulation/settling, and biological treatment (lagooning), while effluent is typically discharged into municipal sewer system. Anaerobic degradation can occur within the lagoons during biological treatment. In the United States it is assumed that these lagoons are intended for aerobic operation, but during peak seasonal usage, anaerobic conditions may occur. The USEPA estimates that approximately 5 percent of wastewater organics degrade anaerobically (Sheehle and Doorn, 2001).

N_2O from Wastewater

The two most significant sources of N_2O identified in the United States are emissions from wastewater treatment processes and emissions from effluent discharge into aquatic environments. IPCC assumes that nitrogen disposal associated with land disposal, subsurface disposal, and domestic wastewater treatment are negligible as sources of N_2O emissions. Generally countries use the IPCC methodology (IPCC, 2000) for estimating national emissions from wastewater. However, current methodologies do not allow for a complete estimate of N_2O emissions. As a result, N_2O baselines reported in this chapter represent the human sewage component only; no methodology exists to estimate N_2O emissions from industrial wastewater.

The remainder of this chapter discusses the activity data and emissions factors used to develop baseline emissions and CH_4 MACs for wastewater systems. The chapter concludes with a discussion of uncertainties and limitations.

III.2.2 Baseline Emissions Estimates

CH_4 generation occurs as organic matter undergoes decomposition in anaerobic conditions. However, CH_4 generation varies widely depending on waste management techniques. Specifically engineered environments can increase the CH_4 generation rates.

The quantity of CH_4 generated can be expressed in terms of several key activity and emissions factors:

Domestic Wastewater

$$CH_4\ Generation = (POP) * (BOD) * (PAD) * (CH_4P) \quad (2.1)$$

where

POP = total population,
BOD = production of BOD per capita per year,
PAD = percentage of BOD anaerobically digested per year, and
CH_4P = CH_4 generation potential per kg of BOD.[1]

Industrial Wastewater

$$CH_4\ Generation = (IP) * (COD) * (PAD) * (CH_4P) \quad (2.2)$$

[1] IPCC emissions factor of 0.6 kilogram CH_4 per kilogram of BOD, cited in the USEPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2002*.

where

IP = industry production,

COD = production of COD per unit of output,

PAD = percentage of COD anaerobically digested per year, and

CH_4P = CH4 generation potential per kg of COD.[2]

III.2.2.1 Activity Factors

Activity factors determine the quantity of wastewater produced and the intensity of organic content (see explanatory note 2). Domestic wastewater production is related to the population size. The population size, in conjunction with the level of organic waste present in the wastewater (BOD), determines a country's CH_4 generation potential. The per capita production of BOD may vary over time or by country depending on a population's consumption preferences.

Industrial wastewater generation is based largely on the annual product output from major wastewater-producing industries, including meat and poultry packing; pulp and paper manufacturing; and vegetable, fruits, and juices processing. Differences in production processes and recycling practices can influence the COD per unit of production in these industries.

N_2O production is typically estimated using an activity factor of annual per capita protein consumption (kilograms per year). However, it has been suggested that this factor alone underestimates the actual amount of protein entering wastewater treatment systems. Food (waste) that is not consumed is often washed down the drain using garbage disposals. In addition, laundry water can contribute to nitrogen loadings. For these reasons, multipliers are commonly applied to the annual per capita protein consumption activity factor to account for these other sources of nitrogen loading.

Historic Activity Data

Wastewater production is directly related to a country's domestic population and industrial production of select industries. Population growth rates are traditionally higher in developing countries, while more industrialized countries have recently tended to experience smaller increases in population over time. Along with population growth, production of BOD per capita has also been growing, which means that more organic material is present in wastewater. Increases in BOD per capita can result from various economic improvements, which could lead to a change in the availability of food types and consumption preferences.

Industrial growth rates and treatment practices differ by country. Whereas most developed and developing countries have thriving meat and poultry and produce industries, differences exist in the local regulation and treatment practices. Developing countries are more likely to employ lagoons or settling ponds in their treatment of industrial waste, which promotes anaerobic degradation.

Projected Activity Data

Both domestic and industrial wastewater production are expected to increase in the future as populations continue to grow and key industries continue to expand.

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[2] IPCC emissions factor of 0.25 kilogram CH_4 per kilogram of COD, cited in the USEPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2002*.

III.2.2.2 Emissions Factors and Related Assumptions

The primary determinants of wastewater emissions factors are

- CH_4 generation potential per unit of BOD or COD and
- the percentage of BOD or COD that degrades in anaerobic conditions.

CH_4 generation potential per unit of BOD or COD is likely to remain constant because this is a measure of chemical potential, not the result of varying preferences. However, wastewater management practices vary across cities and countries, affecting the percentage of BOD or COD that degrades under anaerobic conditions. Even for managed systems, differences in operations and maintenance can result in unintended anaerobic conditions that lead to additional CH_4 emissions.

Historical Emissions Factors

A CH_4 generation factor of 0.6 kilogram CH_4 per kilogram BOD is provided in the IPCC Good Practice Guidance (IPCC, 2000) for domestic wastewater. This generation factor is also applied to the pulp and paper and meat and poultry industries. A CH_4 generation factor of 0.4 kg CH_4 per kilogram BOD is applied to the fruit, vegetable, and juice-processing industries. This generation factor represents the potential CH_4 generation from a given unit of BOD, assuming that a unit of BOD degrades under anaerobic conditions.

Most developed countries have adopted municipal wastewater treatment practices that prevent the formation of anaerobic conditions in managing and treating wastewater. Developing countries have traditionally employed wastewater management practices that foster controlled anaerobic environments where the CH_4 is captured for flaring or direct use. Settling ponds that are open to the atmosphere are typically aerated to promote the production or CO_2 as opposed to CH_4. However, in developing countries, industries, such as the pulp and paper or meat and poultry, are less likely to have adopted practices to prevent anaerobic degradation of COD in wastewater.

Projected Emissions Factors

Projected emissions factors from wastewater are expected to follow historic trends. The CH_4 generation potential per unit of BOD will remain constant over time. Improvements to wastewater management practices are projected to occur with increased GDP. These improvements may result in decreased baseline emissions for developing countries. As developing countries adopt better management practices, their baseline emissions will approach the baselines of developed countries with established wastewater infrastructure already in place. Overall, reductions in CH_4 emissions factors from wastewater will occur because of improvements in wastewater management and treatment.

III.2.2.3 Emissions Estimates and Related Assumptions

This section discusses the historical and projected baseline emissions from wastewater. As shown in Equations (2.1) and (2.2), the amount of CH_4 generated each year from wastewater is determined by a country's population, the per capita production of BOD or COD (in the industry), and the percentage of BOD that degrades under anaerobic conditions.

Historical Emissions Estimates

Tables 2-1 and 2-2 provide emissions by country for CH_4 and N_2O. Historically, China and India have the largest baseline CH_4 and N_2O emissions from wastewater. China and India are the two most populous countries in the world with 1.3 and 1.1 billion people, respectively, in 2002 (World Bank, 2005). Their large populations in highly concentrated urban areas, combined with limited infrastructure for

Table 2-1: CH_4 Emissions from Wastewater by Country: 1990–2000 ($MtCO_2eq$)

Country	1990	1995	2000
India	81.8	89.7	97.6
China	94.4	99.7	104.2
United States	24.9	29.9	34.3
Indonesia	18.0	19.5	20.9
Brazil	18.0	19.3	20.7
Pakistan	10.9	12.2	14.0
Bangladesh	10.4	11.7	13.0
Mexico	10.0	11.0	11.9
Nigeria	6.8	7.9	9.0
Philippines	6.2	7.0	7.7
Viet Nam	6.7	7.4	8.0
Iran	6.0	6.6	7.2
Turkey	5.7	6.3	6.8
Russian Federation	9.4	9.4	9.3
Ethiopia	3.9	4.5	5.1
Rest of the world	**132.8**	**141.7**	**152.7**
World Total	**445.9**	**483.8**	**522.5**

Source: USEPA, 2006.

Table 2-2: N_2O Emissions from Wastewater by Country: 1990–2000 ($MtCO_2eq$)

Country	1990	1995	2000
China	17.6	18.5	19.4
United States	13.0	14.2	15.6
Brazil	3.7	3.7	4.0
Pakistan	1.8	2.0	2.3
Indonesia	2.1	2.3	2.5
Russian Federation	3.7	3.6	3.4
India	2.0	2.2	2.4
Germany	2.2	2.2	2.2
Nigeria	1.0	1.1	1.3
Iran	1.3	1.4	1.6
Mexico	1.3	1.4	1.6
Bangladesh	0.9	1.1	1.2
Saudi Arabia	0.7	0.8	0.9
Viet Nam	1.0	1.1	1.2
Egypt	0.9	1.0	1.1
Rest of the world	**27.4**	**28.4**	**30.3**
World Total	**80.7**	**85.1**	**90.8**

Source: USEPA, 2006.

handling wastewater, result in substantial emissions. Similar conditions exist in Cambodia and Indonesia where densely populated areas produce significant CH_4 emissions.

Projected Emissions Estimates

Worldwide CH_4 emissions from wastewater are expected to increase in both developed and developing countries because of expanding populations and increases in GDP. Tables 2-3 and 2-4 list projected baseline emissions by country for CH_4 and N_2O. India is projected to replace China as the world's leading emitter of wastewater CH_4. The World Bank projects India's average annual growth rate in population of 1.2 percent over the next 10 years, while China's is projected to be 0.6 percent over the same time period (World Bank, 2005). Although both countries' GDP is projected to increase over time, the most influential factor in determining each country's baseline will be the extent to which these countries improve their wastewater management practices.

III.2.3 Emissions Reductions from Wastewater

Components of abatement options for the wastewater sector include the incremental addition of CH_4 mitigation equipment not already included in the initial construction of a municipal wastewater treatment plant. This section discusses opportunities for emissions reductions beyond existing baseline practices qualitatively but, because of data limitations, does not attempt to model MACs.

III.2.3.1 Abatement Option Opportunities

We describe two approaches to reducing CH_4 emissions from wastewater following the implementation of municipal infrastructure:

- improved wastewater treatment practices (domestic and industrial) and
- anaerobic digester with collection and flaring or cogeneration.

Improved wastewater treatment practices include reducing the amount of organic waste anaerobically digested. This reduction can be achieved through improved aeration and/or the scaling back of the use of stagnant settling lagoons. Costs for improving treatment practices vary widely based on the technology applied and specific characteristics of the wastewater. Improvements to existing wastewater treatment practices assume that infrastructure is already in place and that the cost of any improvements would represent the incremental addition of technology as a capital improvement or increases in O&M costs.

Anaerobic digesters can be flared or the CH_4 used for cogeneration to reduce CH_4 emissions from biomass or liquid effluents with high organic content. The IPCC estimates construction costs for anaerobic digesters to be $0.1 to $3 million (IPCC, 1996b). This estimate includes the construction of a collection system and either a flare or a utilization system. IPCC estimates annual O&M costs for this type of system at between $10,000 and $100,000, assuming wastewater flows of 0.1 to 100 million gallons (400 to 0.4 x 106 m3) per day (IPCC, 1996b).

Table 2-3: Projected Baseline CH_4 Emissions from Wastewater by Country: 2005–2020 ($MtCO_2eq$)

Country	2005	2010	2015	2020
India	105.4	112.7	119.1	125.0
China	108.0	111.7	115.3	118.3
United States	35.2	36.1	37.0	37.8
Indonesia	22.2	23.5	24.7	25.9
Brazil	22.0	23.2	24.4	25.5
Pakistan	15.9	18.0	20.2	22.6
Bangladesh	14.5	15.9	17.4	18.8
Mexico	12.8	13.6	14.4	15.1
Nigeria	10.3	11.6	13.1	14.6
Philippines	8.5	9.2	9.8	10.3
Viet Nam	8.5	9.0	9.6	10.2
Iran	7.7	8.2	8.9	9.5
Turkey	7.3	7.7	8.1	8.5
Russian Federation	9.0	8.7	8.5	8.3
Ethiopia	5.8	6.5	7.3	8.2
Rest of the world	**165.2**	**178.3**	**192.2**	**206.4**
World Total	**558.1**	**594.0**	**629.9**	**665.0**

Source: USEPA, 2006.

Table 2-4: Projected Baseline N_2O Emissions from Wastewater by Country: 2005–2020 ($MtCO_2eq$)

Country	2005	2010	2015	2020
China	20.1	20.8	21.5	22.0
United States	15.7	15.9	16.1	16.3
Brazil	4.2	4.5	4.7	4.9
Pakistan	2.6	2.9	3.3	3.7
Indonesia	2.6	2.8	2.9	3.0
Russian Federation	3.3	3.2	3.1	3.0
India	2.5	2.7	2.9	3.0
Germany	2.2	2.2	2.2	2.2
Nigeria	1.5	1.7	1.9	2.1
Iran	1.7	1.8	1.9	2.1
Mexico	1.7	1.8	1.9	2.0
Bangladesh	1.3	1.4	1.6	1.7
Saudi Arabia	1.1	1.2	1.4	1.6
Viet Nam	1.3	1.4	1.5	1.6
Egypt	1.2	1.3	1.4	1.5
Rest of the world	**31.9**	**33.4**	**35.0**	**36.5**
World Total	**95.0**	**99.1**	**103.2**	**107.2**

Source: USEPA, 2006.

III.2.3.2 Uncertainties and Limitations

Uncertainty and limitations persist despite attempts to incorporate all publicly available information on international wastewater sectors. Limited information on the wastewater systems of developing countries increases this uncertainty. Additional information would improve the accuracy of baseline emissions projections.

- BOD Production Rates: Improved information on specific population diets and consumption habits would greatly improve the analyst's ability to calculate baseline emissions.
- Country-Specific Waste Management Practices: Improved documentation of wastewater management practices would allow deviations from the normal assumption, allowing country-by-country estimates of percentage of BOD undergoing anaerobic degradation.
- Improved Cost Data: Improved documentation of wastewater CH_4 abatement options and their cost components would improve the analyst's ability to estimate baseline reductions given some estimate of market penetration.

III.2.4 Summary

The data discussed in this chapter demonstrate that wastewater is a significant source of greenhouse gas emissions. However, policy approaches directly targeted at mitigating CH_4 emissions from wastewater are limited, and no specific abatement options are presented as part of the analysis in this chapter. Several factors contribute to difficulties in developing MACs for wastewater abatement options.

The primary factor for determining emissions from the wastewater sector (in terms of CH_4 emissions per BOD) is the type of treatment system employed to manage the waste. Centralized, managed treatment facilities can control anaerobic environments and have a greater potential to capture and use CH_4. Because most centralized systems automatically either flare or capture and use CH_4 for safety reasons, "add-on" abatement options do not exist. As a result, potential emissions reductions depend on large-scale structural changes in waste management practices. In contrast, smaller decentralized systems have less control over the share of aerobic versus anaerobic decomposition and have few feasible options for capturing CH_4.

At issue is that overriding economic and social factors influence wastewater treatment practices throughout the world. The benefits of installing a wastewater system in a developing country for the purpose of disease reduction greatly outweigh potential benefits associated with CH_4 mitigation. This is not to say that CH_4 mitigation is not one of many factors to be potentially considered in selecting wastewater treatment systems. However, because of the scope of the costs and benefits of the investment decision, it would be misleading to imply that potential carbon prices (reflected in MACs) would be the driving force behind investment decisions that influence CH_4 emissions from wastewater.

III.2.5 References

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Explanatory Notes

1. Assuming a global warming potential (GWP) value of 310.
2. The wastewater treatment practices that determine the share of BOD that degrades under anaerobic conditions are included in the emissions factor discussion.

Section III: Waste Sector Appendixes

Appendixes for this section are available for download from the USEPA's Web site at http://www.epa.gov/nonco2/econ-inv/international.html.