MUNICIPAL WASTEWATER TREATMENT SECTOR: OPTIONS FOR METHANE EMISSION MITIGATION

Prepared for:

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Draft: August 27, 2009

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1.0 Introduction

The Methane to Markets Partnership is an international initiative that advances cost-effective, near-term methane recovery and use as a clean energy source. The goal of the Partnership is to reduce global methane emissions in order to enhance economic growth, strengthen energy security, and improve air quality and industrial safety. The Partnership acts as a mechanism to bring together interested parties from governments and the private sector to facilitate methane project development and implementation around the world.

In January 2009, the Methane to Markets Steering Committee met to discuss the status of the Partnership and identify potential future directions. At the suggestion of several Partners, the Steering Committee directed the Administrative Support Group (ASG) to explore opportunities for the Partnership to engage in the wastewater sector. The purpose of this paper is to evaluate the magnitude of global methane emissions from this sector, provide an overview of methane emissions from wastewater handling and treatment operations, identify mitigation opportunities, discuss the economic feasibility and potential barriers to implementing mitigation opportunities, and scope out possible options for engagement by the Partnership.

In 2005, estimated global methane emissions from wastewater totaled approximately 558 million metric tons of carbon dioxide equivalent ($MtCO_2Eq$), representing 9 percent of global anthropogenic methane emissions (EPA, 2006a).[1] The majority of emissions originated in South and Southeast Asia (195.48 $MtCO_2Eq$), China/Central Asia (121.29 $MtCO_2Eq$), Africa (72.19 $MtCO_2Eq$), Latin America (66.76 $MtCO_2Eq$), and the United States (35.21 $MtCO_2Eq$) (EPA, 2006a).[2] Methane to Markets partner countries[3] emitted an estimated 373 $MtCO_2Eq$ in methane from wastewater in 2005, representing 67 percent of global methane emissions from this sector (EPA, 2006a).

Methane is emitted both incidentally and deliberately during the handling and treatment of domestic, commercial, and industrial wastewater through the anaerobic decomposition of organic material. Most developed countries rely on centralized aerobic wastewater treatment to collect and treat domestic and commercial wastewater, resulting in small and incidental methane emissions. In developing countries with little or no collection and treatment of wastewater, however, anaerobic treatment systems such as lagoons, septic systems, open sewers, and latrines are more prevalent, resulting in greater methane emissions.

Industrial wastewater can also be treated anaerobically, with significant methane being emitted from those industries with high organic loadings in their wastewater stream. Industrial wastewater may be treated at the production site prior to discharge to a receiving water system, or it can be collected and co-treated with domestic and commercial wastewater. Certain industrial wastewater treatment sources with a high potential to generate methane include agro-industrial wastewater (e.g., food processing), which are currently being evaluated under the Methane to Markets Agriculture Technical Subcommittee. Other types of industrial wastewater treatment may yield potential mitigation opportunities, but these require evaluation on an industry-by-industry basis.

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[1] Total methane emissions are combined emissions from domestic (household), commercial, and industrial wastewater.

[2] Appendix A provides definitions for regional groupings used throughout this paper.

[3] Methane to Markets partners as of 15 August 2009 include Argentina, Australia, Brazil, Bulgaria, Canada, Chile, China, Colombia, Ecuador, Finland, Georgia, Germany, India, Italy, Japan, Kazakhstan, Mexico, Mongolia, Nigeria, Pakistan, Philippines, Poland, Republic of Korea, Russia, Thailand, Ukraine, United Kingdom, United States, and Vietnam.

The most significant source of methane from these other industrial wastewaters is from pulp and paper wastewater treatment. Current data on the individual industrial contributions to global wastewater methane emissions from pulp and paper operations are not readily available. Therefore, this scoping paper focuses on the opportunities associated with municipal wastewater, meaning domestic wastewater collected centrally, which may also include commercial and industrial contributions.

The paper consists of the following elements:

- Section 2 presents key findings.
- Section 3 provides an overview of global methane emissions from wastewater.
- Section 4 introduces aerobic and anaerobic wastewater treatment options and associated co-benefits.
- Section 5 discusses current economically feasible mitigation technologies and practices during the wastewater treatment process, including barriers to deployment, mitigation potential, and associated costs.
- Section 6 highlights key international organizations and efforts currently engaged in mitigating emissions in the wastewater sector and options for Methane to Markets to leverage these efforts.
- Section 7 presents examples of global wastewater methane project development.

2.0 Summary of Findings

Worldwide methane emissions from wastewater are expected to increase in both developed and developing countries because of expanding populations, increases in gross domestic product (GDP), and industrial growth. In 2005, estimated methane emissions from wastewater accounted for 9 percent of global anthropogenic methane emissions, with China, India, the United States, Indonesia, and Brazil constituting the top five emitters. Four of these five countries—India, China, the United States, and Brazil—are Methane to Markets Partners and combine to account for 48 percent of the world's methane emissions from wastewater. Regionally, China/Central Asia and Southeast Asia have the highest percentage of methane emissions from wastewater, and should Methane to Markets decide to engage the wastewater sector, focused efforts in these geographic areas may provide the greatest opportunity to bring about meaningful emissions reductions and creation of stable sources of energy.

Most developed countries have adopted centralized collection of municipal wastewater[4] and utilize treatment operations that prevent or minimize the formation of anaerobic conditions while managing and treating wastewater. Developing countries have traditionally employed wastewater management practices that utilize anaerobic treatment processes that result in higher methane emissions. The most influential factor in determining future wastewater methane emissions will be the extent to which countries utilize collection systems with aerobic treatment systems and/or capture biogas for energy use.

The three most promising mitigation opportunities include:

- Installation of anaerobic sludge digestion (new construction or retrofit of existing aerobic treatment systems);
- Installation of biogas capture systems at existing open air anaerobic lagoons; and
- Installation of new centralized aerobic treatment facilities or covered lagoons.

Many facilities in the developed world effectively use anaerobic digesters in tandem with aerobic treatment processes to process wastewater biosolids, producing biogas that is used onsite to offset the use of conventional fuel that would otherwise be used for energy at the wastewater treatment facility. In addition to producing a "free fuel" that can be used to generate energy, anaerobic digesters can improve water quality, isolate and destroy disease causing organisms that might pose a risk to human and animal health, and can provide additional revenue streams, such as soil fertilizers that can be produced from digester effluent. The greatest potential for installation of anaerobic sludge digesters is either through the construction of new centralized aerobic facilities driven by increasing population growth, or through the retrofit of existing centralized aerobic treatment facilities.

Biogas capture systems for anaerobic lagoons are the simplest and easiest method of biogas implementation, and have been used around the world as a manure management practice at livestock farms. Many parts of the world currently rely on open air anaerobic lagoons to treat wastewater. Rather than investing in a new centralized aerobic treatment plant, covering an existing lagoon and capturing the biogas can be the most economically feasible means to reduce methane emissions. This is especially true in regions of the world that do not have the resources to invest in new infrastructure or cannot support and maintain a centralized aerobic treatment facility. However, several barriers exist that have prevented widescale use, including lack of need to install covers, lack of experience applying the technology to municipal systems in developing

[4] Municipal wastewater consists of domestic plus commercial, and possibly industrial wastewaters.

countries, and a lack of capacity in developing countries to support design, construction and installation of covered lagoons.

Installation of new centralized aerobic treatment systems or new covered lagoons to treat wastewater in place of less-advanced de-centralized treatment options (or no treatment at all) can also greatly reduce current and future methane emissions associated with wastewater. This option is most viable in areas with expanding populations that have the infrastructure and energy available to support such systems. Although conversion of anaerobic systems to aerobic systems can be quite costly for existing communities, it is less so for a new community under development or experiencing high growth. For these communities, installation of a centralized aerobic treatment system can avoid increases in future emissions due to the increasing population, and may in fact result in decreases to overall methane emissions even while populations increase.

Despite the advantages associated with these three primary options, there are still several barriers to emission mitigating technologies and practices including high initial capital costs, lack of local capacity to design and maintain systems, site-specific design characteristics, utility policy barriers, and social taboos.

Should Methane to Markets decide to engage the wastewater sector, the greatest potential to bring about meaningful emissions reductions are to focus on (1) the retrofit of existing aerobic facilities to include anaerobic sludge digestion coupled with biogas capture and use where feasible (most likely in large cities), (2) the covering of existing open air anaerobic lagoons (most likely in small urban and rural areas of developing countries), and (3) the development of new centralized aerobic treatment facilities or covered anaerobic lagoons in areas that have the infrastructure and policy conditions to support such systems (most likely in large cities and countries that are able to support the required investment).

In addition, while the possibilities for methane mitigation through improved wastewater handling are clear, there is a dearth of solid, organized information on real applications and implementation costs. Methane to Markets could play a catalytic role in supporting the analysis and documentation of economical options for methane emissions reduction. Methane to Markets could tackle questions such as: how to cost-effectively cover existing anaerobic lagoons to minimize emissions and recover biogas; and what are the most cost-effective and technology appropriate options for anaerobic digestion of sludge, especially in developing country contexts. Through desk studies, expert forums, pilot project development and data collection and analysis, Methane to Markets can provide key input to technical and economic discussions on wastewater management. Given its experience with anaerobic digestion of agro-industrial wastes, and in-country experiences around the world, Methane to Markets is uniquely positioned to provide technical and policy leadership on improved wastewater handling.

In addition to its own efforts, Methane to Markets can also leverage the efforts of key international wastewater organizations and multilateral banks. Many international organizations are involved with wastewater research and technology development, but none of them currently have specific or explicit efforts related to wastewater methane mitigation technologies and applications. Specifically, Methane to Markets could approach the Water Environment Federation, the International Water Association, and the Global Water Partnership to explore partnerships in promoting methane emissions reductions in wastewater treatment. Specific activities to undertake together with these institutions might include:

- Organizing data on system designs, costs, and most importantly, actual installation experiences to date.
- Participating in pilot installations, possibly sharing costs of measurement and documentation of performance.
- Promoting anaerobic digestion in the sector. Methane to Markets could access its already established network of water and sanitation professionals, local institutions, utilities, and others to transfer knowledge and technologies.
- Facilitating policy and regulatory reform where required, as well as developing national standards and norms for anaerobic digestion in the wastewater sector.
- Facilitating the retrofitting of current wastewater treatment facilities through its affiliates and networks.

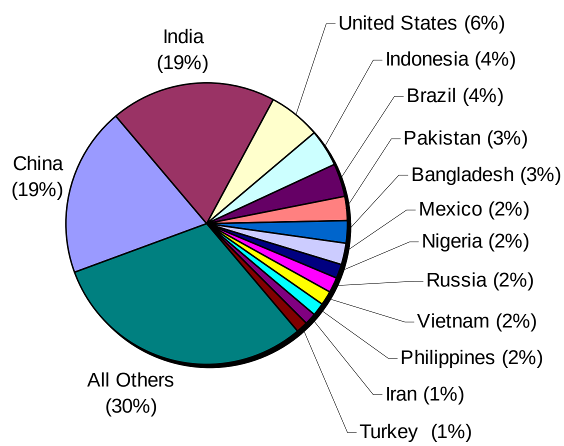
With respect to multilateral banks, many of the projects financed include methane mitigation options, but few focus explicitly on this objective. The reach of multilateral banks and their commitments to environmentally sustainable projects, makes them good potential partners to promote methane reduction projects internationally, even more so because of their in-country offices around the world and their lending to country governments and local project implementers. Methane to Markets could meet with the World Bank, the Asian Development Bank, and the Inter-American Development Bank to understand the extent of their lending and project development in the wastewater sector, as well as to explore their understanding of greenhouse gas reduction projects. Meetings could be held both in the Carbon Finance Unit of the World Bank, and in the regional divisions, where large wastewater projects are designed. Specific activities to undertake together with these institutions might include:

- Providing programmatic and technology expertise to include anaerobic digestion in future infrastructure investments.
- Developing wastewater methane reduction efforts as climate change projects.
- Participating in pilot installations and sharing costs and data.
- Providing technical advice on potential impacts of anaerobic digestion at local, national, and regional levels.
- Serving as a repository of data on wastewater emissions reduction projects, technologies, applications and experiences
- Providing a forum for the coordination of investment programs and donor assistance at the country level.

3.0 Overview of Global Methane Emissions from Wastewater

Estimated worldwide methane emissions from wastewater accounted for 558 million metric tons of carbon dioxide equivalent ($MtCO_2Eq$) in 2005, representing 9 percent of global anthropogenic methane emissions—more than both manure management (4 percent) and coal mining (6 percent). The five largest emitters—India, China, the United States, Indonesia, and Brazil—combined to account for 52 percent of the world's methane emissions from wastewater (see Figure 1), and Methane to Markets Partners accounted for nearly 70 percent of global wastewater emissions (EPA, 2006a).

Figure 1. Percent of Global Methane Emissions from Wastewater



Source: EPA, 2006a

Appendix B provides a listing of estimated wastewater methane emissions by country for 1990 to 2020, including the percentage of total methane emissions attributable to wastewater for 2005.

The remainder of this section describes how wastewater methane emissions occur, the countries and regions generating the majority of emissions (and thus with the highest potential to implement mitigation options), and the expected growth of methane emissions from wastewater.

3.1 Methane Production from Municipal Wastewater Treatment

Methane generation occurs as organic material undergoes decomposition in anaerobic conditions; however, methane generation varies widely depending on waste management techniques. Countries with extensive wastewater collection infrastructure treat wastewater at centralized wastewater treatment plants. During treatment, the solids and organic content of the wastewater are reduced using physical processes to settle or filter out solids and biological processes in which micro-organisms consume the organic constituents. Biodegradation can occur either aerobically (where microorganisms produce carbon dioxide) or anaerobically (where microorganisms produce methane). These biological systems also produce biosolids, or sludge, which has the potential to biodegrade and generate methane. Most developed countries use centralized aerobic wastewater treatment facilities, with some also using closed anaerobic sludge digester systems, to process municipal and industrial wastewater. Developing countries rely more on anaerobic treatment in lagoons and non-centralized systems such as latrines, septic tanks, and open sewers, all of which can result in considerable methane emissions.

The extent of methane production depends primarily on the quantity of degradable organic material in the wastewater, the temperature of the wastewater, and the type of treatment system. With increases in temperature, the rate of methane production increases. Common parameters used to measure the organic component of the wastewater are biochemical oxygen demand (BOD) and chemical oxygen demand (COD). BOD represents the amount of oxygen that would be required to completely consume the organic matter contained in the wastewater through aerobic decomposition processes, while COD measures the total material available for chemical oxidation (both biodegradable and non-biodegradable). With all other conditions being the same, wastewater with higher BOD or COD concentrations will generally yield more methane than wastewater with lower BOD or COD concentrations. BOD is typically used to estimate methane generation in domestic wastewater. Domestic wastewater production is related to population size. Population size, in conjunction with the level of organic waste present in the wastewater (i.e., BOD), determines a country's methane generation potential. The per capita production of BOD may vary over time or by country depending on a population's consumption preferences. For example, the IPCC estimates a range of daily BOD production per capita as 27-41grams/person/day in India; 45-55 grams/person/day in Brazil; and 50-120 grams/person/day in the United States. As an indicator of the degree to which a wastewater system is anaerobic, the IPCC recommends the use of a methane correction factor (MCF). The MCF indicates the extent to which the methane producing capacity is realized in various types of treatment and discharge pathways and systems. A higher MCF indicates greater methane emissions.

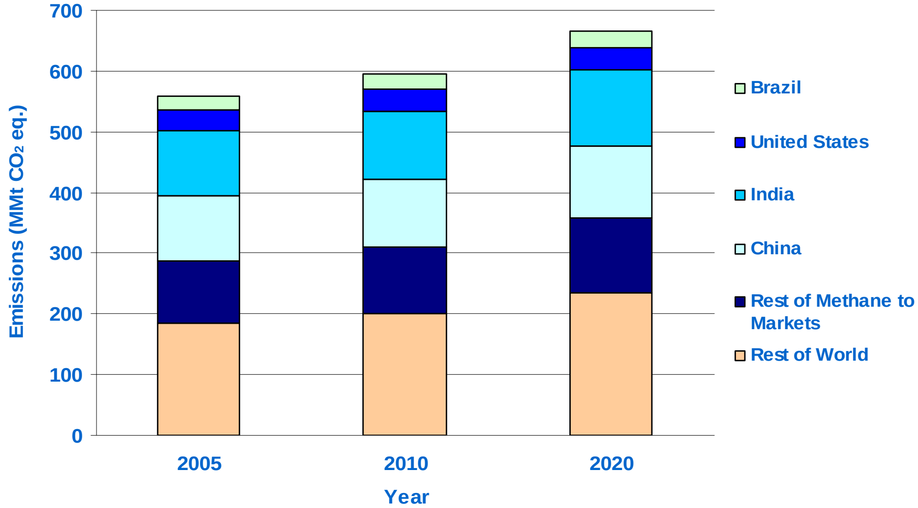
3.2 Global and Methane to Markets Partner Emissions

As discussed above, Methane to Markets Partners comprise more than two-thirds of the estimated global methane emissions from wastewater. As shown in Figure 1, China and India alone account for nearly 40 percent of emissions from wastewater given their large populations and reliance on anaerobic treatment processes. The percentages of total methane emissions from wastewater in China and India are 12.7 percent and 19.2 percent, respectively. These emissions from wastewater in China and India represent approximately 3 percent of global methane emissions. For an additional seven Methane to Markets partner countries, emissions from wastewater contribute more than 10 percent of each country's total methane emissions. Figure 2 illustrates methane emissions from wastewater by Methane to Markets partners and the rest of the world. Table 1 presents the percent of total and percent of regional wastewater methane emissions from each world region. China/Central Asia and Southeast Asia have the highest percentages of methane emissions from wastewater and are the only two regions exceeding 10 percent. The remainder of this section highlights the top countries and their respective regions generating methane from wastewater, with a focus on Methane to Markets Partners.

China and Central Asia

In 2005, China's wastewater methane emissions accounted for 19 percent of global methane emissions from wastewater. It is estimated that more than 80 percent of domestic wastewater goes uncollected and untreated in China, Central Asia, and Southeast Asia. For rural areas, the amount is likely to be even higher. Much of this untreated wastewater is found in open sewers, pits, latrines, or lagoons where there is potential for methane production. For example, nearly 75 percent of China's wastewater emissions come from latrines, with the majority of wastewater generated in rural China being untreated (EPA, 2006a). The Chinese government estimates that approximately 45 percent of urban municipal wastewater (excluding that from townships) is treated. Where centralized municipal wastewater treatment facilities exist, secondary treatment processes are commonly used, especially in the larger plants. Such processes include screening, primary sedimentation, conventional activated sludge, and secondary sedimentation. The greatest potential for methane mitigation in China from wastewater comes from installing new centralized, aerobic treatment systems that incorporate anaerobic sludge digesters, or covering existing lagoons.

Figure 2. Methane Emissions from Wastewater by Methane to Markets Partners



Source: EPA, 2006a

Table 1. Percent of Total and Percent of Regional Wastewater Methane Emissions from World Regions

Region*	Percent of Total Worldwide Methane Emissions	Percent of Region's Methane Emissions From Wastewater
Africa	13.3	8.5
China/Central Asia	15.4	12.3
Latin America	15.7	6.7
Middle East	4.3	7.3
Non-EU Eastern Europe	0.4	6.3
Non-EU FSU	10.0	2.8
OECD90 and EU	21.3	4.6
SE Asia	19.6	15.6

* Appendix A lists the countries within each regional grouping
Source: EPA, 2006a

India
India currently emits more than 100 $MtCO_2Eq$ in methane annually from wastewater and also has one of the faster growing emission rates among the Methane to Markets Partners. India accounts for 19 percent of global methane emissions from wastewater, and 19.2 percent of India's methane emissions are from wastewater. The largest share of India's wastewater emissions—about 62 percent—comes from latrines, but open sewers contribute an additional 34 percent (EPA, 2006a). Like China, installation of centralized, aerobic treatment systems with anaerobic digesters offers the greatest potential for methane mitigation, given there is appropriate infrastructure to support such systems. Alternatively central collection of wastewater in covered lagoons can help mitigate methane emissions.

Latin America

On an individual basis, Latin American countries do not emit considerable amounts of methane from wastewater because of relatively lower populations compared to larger emitters. Collectively, however, emissions as a region are significant. Methane to Markets Partners located in Latin and South America, including Mexico, Argentina, Brazil, Chile, Colombia, and Ecuador, account for approximately 9 percent of global methane emissions from wastewater, totaling nearly 50 $MtCO_2Eq$ annually. Brazil is the largest emitter in South America, ranking fifth globally behind China, India, the United States, and Indonesia. An estimated 80 percent of Brazil's population is not connected to sewage systems. The most likely option for methane mitigation from wastewater in Latin America is to cover existing lagoons. However, in areas with appropriate infrastructure, construction of new centralized aerobic treatment systems with anaerobic sludge digestion is a viable option.

Africa

Africa generates approximately 14 percent of the global methane emissions from wastewater. While Nigeria is the only African Methane to Markets Partner, the country emits 2 percent of global methane emissions from wastewater. Nigeria could provide the opportunity to influence other African nations with improvements to wastewater handling and treatment. Collection of wastewater in covered lagoons offers the greatest potential for methane mitigation in Africa.

Largest Emissions by Non-Methane to Markets Partner Countries

Table 2 lists the top ten emitters of methane from wastewater that are not Methane to Markets Partner countries. Of these ten, Indonesia and Bangladesh emit the largest amounts of methane from wastewater. Based on estimates from 2005, Indonesia ranks fourth and Bangladesh seventh in global methane emissions from wastewater, totaling 22 $MtCO_2Eq$ and 14.5 $MtCO_2Eq$, respectively. Approximately 12 percent of Indonesia's and 27 percent of Bangladesh's methane emissions are from wastewater. In both countries, very little wastewater is centrally collected and treated. The majority of the population is located in rural areas, and the vast majority of wastewater is either uncollected or managed with latrines. As such, development of covered lagoons where appropriate, offers the greatest potential for methane emissions mitigation. The installation of centralized aerobic wastewater systems in these areas may prove to be cost prohibitive or provide difficulties in upkeep of the systems.

Table 2. Top 10 Non-Methane to Markets Partner Countries Methane Emissions from Wastewater

Country	Global Ranking	2005 ($MtCO_2eq$)	2005 % of Total from Wastewater
Indonesia	4	22.25	12.15%
Bangladesh	7	14.48	27.03%
Iran	13	7.69	8.04%
Turkey	14	7.27	6.90%
Ethiopia	16	5.79	10.66%
Egypt	18	5.49	14.46%
Myanmar	19	5.16	6.89%
Democratic Republic of Congo (Kinshasa)	21	4.91	8.46%
South Africa	23	4.15	7.51%
Peru	24	3.37	16.38%

Source: EPA, 2006a

3.3 Expected Growth of Methane Emissions from Wastewater

Worldwide methane emissions from wastewater are expected to increase in both developed and developing countries because of expanding populations and increases in GDP. In 2020, EPA estimates that methane emissions will grow to 665 $MtCO_2Eq$, a 20-percent increase from 2005 levels (EPA, 2006a). India (125 $MtCO_2Eq$) and China (118 $MtCO_2Eq$) are projected to be the two largest emitters of methane from wastewater, followed by the United States (38 $MtCO_2Eq$), Indonesia (26 $MtCO_2Eq$), and Brazil (25.5 $MtCO_2Eq$). The primary factors leading to increases in emissions from wastewater include the following:

- The majority of population growth is occurring in areas without advanced domestic wastewater treatment facilities. Low cost wastewater collection systems that are often used in areas of high population growth, such as septic tanks, open sewers, and lagoons, encourage anaerobic decomposition and methane production.
- Production of BOD per capita is increasing everywhere as economic conditions improve and consumption habits change, resulting in more organic material present in wastewater and higher methane generation potential.
- The growth of industry in the developing world is expected to contribute to rising methane emissions from wastewater. Industries such as meat, fish, and poultry processing; pulp and paper; milk processing; and produce are all heavily dependent on water for industrial processes. In addition to the heavy use of water, these industries also generate large volumes of organic waste, resulting in very high COD levels in wastewaters. While these industrial facilities are usually located outside urban areas, population growth often causes them to be surrounded by newly established areas, and part or all of their wastewater discharge may be routed to municipal sewage systems.

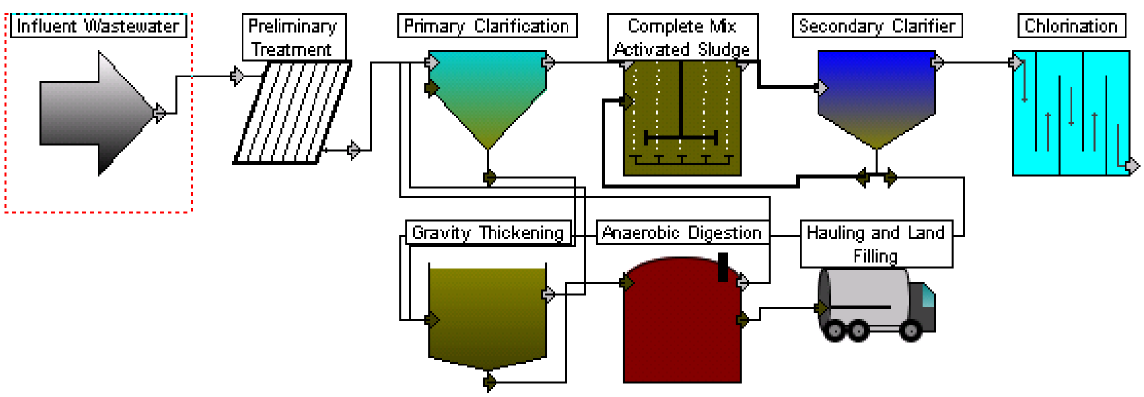
4.0 Aerobic and Anaerobic Wastewater Treatment Options

Methane is emitted during the handling and treatment of municipal and industrial wastewater. The organic matter in the wastewater produces methane when it decomposes anaerobically. Centralized aerobic wastewater treatment systems (with or without anaerobic sludge digesters) result in small and incidental methane emissions. In locations with little or no wastewater collection and treatment, anaerobic systems such as lagoons, open sewers, septic systems, and latrines are more prevalent and yield considerable methane emissions. The following section describes the most common aerobic and anaerobic wastewater treatment options.

4.1 Aerobic Treatment Options

Figure 3 presents a typical flow diagram for a centralized aerobic treatment system. The process starts with a primary treatment phase. During this phase, large solids are removed through a filtration process where grit is eliminated and oxygen may be added. Next, the wastewater enters a primary clarifier that removes the vast majority of settleable solids. These solids, known as primary sludge, are separated and handled independently. Following primary treatment, the wastewater undergoes biological reduction of organic matter, typically referred to as secondary treatment. Secondary treatment may occur under aerobic or anaerobic conditions. Next, the wastewater is clarified again and secondary sludge is separated and handled independently. Prior to discharge, wastewater typically undergoes disinfection, such as chlorination. In Figure 3, solids are shown being thickened and then treated in an anaerobic sludge digester prior to hauling off site for end use.

Figure 3. Conventional Activated Sludge Treatment System



Source: CapdetWorks v2.5

Most developed countries use centralized aerobic wastewater treatment facilities, with some using closed anaerobic sludge digester systems, to process municipal and industrial wastewater. Centralized aerobic systems minimize methane emissions. The IPCC allocates a MCF of 0.0 for a well-managed centralized aerobic treatment plant and an MCF of 0.3 for one that is not well managed (IPCC, 2006). Employment of sludge digesters increases methane generation but ultimately reduces baseline emissions since the methane is captured as biogas and flared or burned to produce energy. This section discusses the most typical aerobic treatment configurations used today—namely the activated sludge process and certain biological nutrient removal processes. Other types of aerobic treatment options include aerated lagoons, trickling filters, and rotating biological contactors.

4.1.1 *Activated Sludge Systems*

The activated sludge process is a type of suspended-growth biological treatment process used for the aerobic removal of organic matter. These systems are designed for reduction of BOD or COD and total suspended solids (TSS). Wastewater is transferred to a reaction tank, which is aerated through use of diffused or mechanical aeration. The reaction tank also contains an aerobic bacterial population that is maintained in suspension. The bacterial population decomposes the organic matter, ultimately creating carbon dioxide, water, and ammonia. The reactor contents, known as mixed liquor, are then transferred to a settling tank where the solids are separated from the treated effluent. A portion of the settled solids are returned to the reaction tank to facilitate the ongoing reaction, while the remaining solids are removed from the system.

Biosolids removed from the process can be handled in a number of ways, each with a different potential for generating methane. Biosolids may or may not be dewatered first to reduce their moisture content. Dewatering may occur naturally (through use of sludge drying beds, for example) or mechanically (through use of filtration and drying). Typical sludge disposal techniques include land application, landfilling, and lagooning. Increasingly, operations are incorporating anaerobic sludge digesters for the management of sludge and to reap the benefits of producing energy. See Section 4.2.1 for more information on sludge digesters.

The primary obstacle for facilities choosing to install centralized aerobic systems, such as activated sludge, is the cost and energy requirements associated with aeration. Tables 3 and 4 present capital and annual operating and maintenance (O&M) costs and electrical energy requirements for construction of an activated sludge system with sludge drying beds and one with anaerobic sludge digestion.[5] Table 4 also presents the methane generation potential from biogas for the anaerobic digester (assuming biogas is 60 percent methane), the electric generation potential with an electric only system, the thermal generation potential with a thermal only system (e.g., boiler), and the electric and thermal generation potential with a combined heat and power (CHP) system. Costs and energy data are presented for three flow ranges, 20 million liters per day (MLD), 115 MLD, and 280 MLD, and do not include the cost of a collection system. In the case of developing countries, having the required infrastructure to collect wastewater and provide energy for the system can be a limitation to implementation.

Table 3. Cost and Energy Requirement for Conventional Activated Sludge w/Sludge Drying Beds Treatment System

Flow Range (in million liters/day)	20 MLD	115 MLD	280 MLD
Capital Cost (million $)	18.6	70.4	180
Annual O&M Cost (million $)[1]	0.893	3.78	8.55
Electrical energy requirements (1,000 kWh/yr)	1,510	8,010	19,400

Costs are presented in 2007 dollars and are rounded to three significant figures.
[1]O&M estimates include labor, chemicals, materials, and energy.
Source: CapdetWorks v2.5

[5] Costs presented throughout Section 4 were modeled using CapdetWorks v2.5, developed by Hydromantis (12/10/07). All systems were modeled using an influent COD concentration of 500 mg/L.

Table 4. Cost and Energy Requirement for Conventional Activated Sludge w/Anaerobic Digestion Treatment System

Flow Range (in million liters/day)	20 MLD	115 MLD	280 MLD
Capital Cost (million $)	23.8	89.6	224
Annual O&M Cost (million $)[1]	0.906	3.39	7.14
Electrical Energy Requirements (1,000 kWh/yr)	1,700	8,620	20,600
Digester Heat Required (1,000 kWh/yr)	1,620	8,790	23,200
Methane Generation Potential from Collected Biogas (MT CH_4/yr)	304	1,740	4,290
Electric Generation Potential from Biogas (1,000 kWh/yr)[2]	1,430	8,170	20,100
Thermal Generation Potential from Biogas (1,000 kWh/yr)[3]	3,800	21,800	53,700
Combined Heat and Power Generation Potential from Biogas (1,000 kWh/yr)[4]	1,430 (elec.) 2,380 (therm.)	8,170 (elec.) 13,600 (therm.)	20,100 (elec.) 33,500 (therm.)

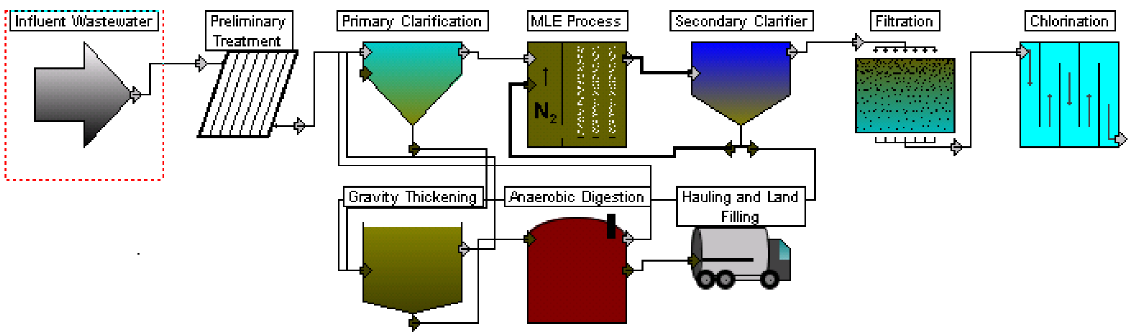
Costs are presented in 2007 dollars and are rounded to three significant figures.
[1]O&M estimates include labor, chemicals, materials, and energy.
[2]Assumes electric generation efficiency of 30 percent and operation 100 percent of year.
[3]Assumes thermal generation efficiency of 80 percent (typical for onsite boilers) and operation 100 percent of year.
[4]Assumes electric generation efficiency of 30 percent, a power to heat ratio of 0.6, and operation 100 percent of year.
Source: CapdetWorks v2.5

4.1.2 *Biological Nutrient Reduction Systems*

Biological nutrient reduction (BNR) systems are designed to achieve significantly increased removals of nutrients (nitrogen and/or phosphorus) compared to activated sludge systems (which are designed for BOD and TSS removal), and as such are a more expensive aerobic treatment option. However, for locations where nutrient discharges are a concern, BNR systems are increasing in popularity as a relatively low-cost method for removing nitrogen and phosphorus from wastewater. Overall, aeration requirements for a BNR system tend to be higher than for a conventional aerobic system, like activated sludge. A wide range of operational configurations are available, dependent on the end goal for the wastewater treatment system. Most systems operate under a combination of aerobic, anoxic (i.e., without oxygen), and anaerobic (i.e., oxygen limited) conditions. For example, nitrification is the biological oxidation of ammonia with oxygen into nitrite, followed by the oxidation of these nitrites into nitrates. Organic nitrogen present in municipal wastewater (typically in the form of proteins or urea) may ultimately be transformed into ammonia-nitrogen through bacterial decomposition and hydrolysis. The nitrification process can then be used to transform ammonia-nitrogen into nitrite-nitrogen, and then nitrate-nitrogen. Nitrification systems are often combined with denitrification, which is accomplished under anoxic conditions, to ultimately convert the nitrate-nitrogen into nitrogen gas. Recent studies suggest that these systems may in fact liberate nitrous oxide, a potent greenhouse gas; however, the specific mechanisms are not yet fully understood.

Figure 4 presents a flow diagram depicting a BNR system utilizing the Modified Ludzack and Ettinger (MLE) process, which is a continuous-flow suspended-growth process with an initial anoxic stage followed by an aerobic stage. Table 5 presents capital and annual operating and maintenance (O&M) costs and electrical and thermal energy requirements for construction of a BNR system utilizing the MLE process with anaerobic sludge digestion. Table 5 also presents the methane generation potential from biogas for the anaerobic digester (assuming biogas is 60 percent methane), the electric generation potential with an electric only system, the thermal generation potential with a thermal only system (e.g., boiler), and the electric and thermal generation potential with a CHP system. Costs and energy data are presented for three flow ranges, 20 million liters per day (MLD), 115 MLD, and 280 MLD, and do not include the cost of a collection system.

Figure 4. Typical Flow Diagram of Biological Nutrient Reduction System Using MLE Process



Source: CapdetWorks v2.5

Table 5. Cost and Energy Requirement for Biological Nutrient Reduction w/Anaerobic Digestion Treatment System

Flow Range (in million liters/day)	20 MLD	115 MLD	280 MLD
Capital Cost (million $)	31.1	117	308
Annual O&M Cost (million $)[1]	1.31	5.07	11.2
Electrical energy requirements (1,000 kWh/yr)	4,150	21,700	54,000
Digester Heat Required (1,000 kWh/yr)	1,540	8,220	20,400
Methane Generation Potential from Collected Biogas (MT CH4/yr)	270	1,540	3,810
Electric Generation Potential from Biogas (1,000 kWh/yr)[2]	1,270	7,230	17,900
Thermal Generation Potential from Biogas (1,000 kWh/yr)[3]	3,380	19,300	47,700
Combined Heat and Power Generation Potential from Biogas (1,000 kWh/yr)[4]	1,270 (elec.) 2,120 (therm.)	7,230 (elec.) 12,100 (therm.)	17,900 (elec.) 29,800 (therm.)

Costs are presented in 2007 dollars and are rounded to three significant figures.
[1]O&M estimates include labor, chemicals, materials, and energy.
[2]Assumes electric generation efficiency of 30 percent and operation 100 percent of year.
[3]Assumes thermal generation efficiency of 80 percent (typical for onsite boilers) and operation 100 percent of year.
[4]Assumes electric generation efficiency of 30 percent, a power to heat ratio of 0.6, and operation 100 percent of year.
Source: CapdetWorks v2.5

The use of biological nutrient removal processes improves water quality but may in fact increase greenhouse gas emissions (compared to aerobic biological treatment) and may increase energy requirements for the system.

4.2 Anaerobic Treatment Options

A variety of anaerobic technologies and processes exist to treat wastewater. Some, such as anaerobic sludge digesters, maximize methane generation through optimizing anaerobic decomposition, but can be used to control overall methane emissions from the system through the capture and utilization of the generated biogas. Other types of anaerobic treatment processes are widely used in the developing world due to simplicity, low cost, and lower operating and maintenance requirements. This section discusses the most typical anaerobic treatment processes used today, namely anaerobic sludge digesters, lagoons and open sewers, and septic systems.

4.2.1 *Anaerobic Sludge Digesters*

Anaerobic digesters are encapsulated vessels where biosolids removed from the wastewater treatment process degrade anaerobically to produce biogas (comprised of approximately 60 to 65 percent methane; 25 to 30 percent carbon dioxide; and small amounts of nitrogen, hydrogen, hydrogen sulfide, water vapor, and other gases). Anaerobic digesters are most commonly used in developed countries at centralized wastewater treatment plants in conjunction with aerobic treatment processes. Rather than storing the sludge on site for drying, anaerobic digesters are used to process the sludge separated from the primary and secondary wastewater treatment stages. Figure 3, displayed in Section 4.1, illustrates how anaerobic digesters are incorporated into the overall treatment process. Anaerobic digester systems consist of a holding tank, a gas capture system, and a heating element. Two conventional anaerobic digestion processes exist: mesophilic and thermophilic. Both have heat loads. The mesophilic process takes place at ambient temperatures, typically between 70° F and 100° F. The thermophilic process takes place at elevated temperatures, typically up to 160° F. Due to the temperature differences between the two processes, the residence time of the sludge varies. In the case of mesophilic digestion, residence time can be between 15 and 30 days. The thermophilic process is usually faster, requiring only about two weeks to complete. Thermophilic design and operation is usually more expensive, however, because it requires more energy and is less stable than the mesophilic process.

Anaerobic digesters can improve water quality, isolate and destroy disease-causing organisms that might pose a risk to human and animal health, and can provide additional revenue streams, such as soil fertilizers that can be produced from digester effluent. In addition, there are multiple benefits associated with the produced biogas. Biogas generated from anaerobic digesters can:

- Generate heat, hot water, and electricity in an electric-only, thermal-only, or combined heat and power (CHP) system, thus offsetting fuel purchases.
- Enhance power reliability for the wastewater facility.
- Generate power at a cost below retail electricity.
- Control odors through flaring if energy recovery is not feasible.

Table 6 presents capital and annual operating and maintenance (O&M) costs and electrical and thermal energy requirements for installation of anaerobic digesters as part of the construction of an overall treatment system for three flow ranges, 20 million liters per day (MLD), 115 MLD, and 280 MLD. Table 6 also presents the methane generation potential from biogas for the anaerobic digester (assuming biogas is 60 percent methane), the electric generation potential with an electric only system, the thermal generation potential with a thermal only system (e.g., boiler), and the electric and thermal generation potential with a CHP system.

Table 6. Cost and Energy Requirement for Anaerobic Digesters (w/Conventional Activated Sludge System)

Flow Range (in million liters/day)	20 MLD	115 MLD	280 MLD
Capital Cost (million $)	3.57	14.5	35.4
Annual O&M Cost (million $)[1]	0.095	0.354	0.786
Electrical energy requirements (1,000 kWh/yr)	139	536	1,100
Heat Required (1,000 kWh/yr)	1,620	8,790	23,200
Methane Generation Potential from Collected Biogas (MT CH4/yr)	304	1,740	4,290
Electric Generation Potential from Biogas (1,000 kWh/yr)[2]	1,430	8,170	20,100
Thermal Generation Potential from Biogas (1,000 kWh/yr)[3]	3,800	21,800	53,700
Combined Heat and Power Generation Potential from Biogas (1,000 kWh/yr)[4]	1,430 (elec.) 2,380 (therm.)	8,170 (elec.) 13,600 (therm.)	20,100 (elec.) 33,500 (therm.)

Costs are presented in 2007 dollars and are rounded to three significant figures.
[1]O&M estimates include labor, materials, and energy.
[2]Assumes electric generation efficiency of 30 percent and operation 100 percent of year.
[3]Assumes thermal generation efficiency of 80 percent (typical for onsite boilers) and operation 100 percent of year.
[4]Assumes electric generation efficiency of 30 percent, a power to heat ratio of 0.6, and operation 100 percent of year.
Source: CapdetWorks v2.5

4.2.2 *Lagoons and Open Sewers*

Anaerobic lagoons are used for the treatment of high-strength organic wastewater that also contains high concentrations of solids. Typically, wastewater in a centralized anaerobic lagoon system is split among more than one lagoon either in parallel, or in series. Ponds may be up to 9 meters deep to facilitate the conservation of heat and maintain anaerobic conditions. Wastewater solids added to the ponds settle to the bottom while the clarified effluent is discharged, sometimes for further treatment.

Table 7 presents capital and annual operating and maintenance (O&M) costs and electrical energy requirements for an open-air anaerobic lagoon treatment system. Table 8 presents capital and annual operating and maintenance (O&M) costs and electrical energy requirements associated with the cover for an anaerobic lagoon that can be used to capture biogas. Costs are presented for three flow ranges, 20 million liters per day (MLD), 115 MLD, and 280 MLD, and do not include the cost of a collection system.

Table 7. Cost and Energy Requirement for Open-Air Anaerobic Lagoon Treatment System

Flow Range (in million liters/day)	20 MLD	115 MLD	280 MLD
Capital Cost (million $)	17.4	89.5	241
Annual O&M Cost (million $)[1]	0.211	0.626	1.29
Electrical energy requirements (1,000 kWh/yr)	524	2,990	7,350

Costs are presented in 2007 dollars and are rounded to three significant figures.
[1]O&M estimates include labor, chemicals, materials, and energy.
Source: CapdetWorks v2.5

Table 8. Cost and Energy Requirement for Lagoon Cover

Flow Range (in million liters/day)	20 MLD	115 MLD	280 MLD
Capital Cost (million $)	1.4	8.3	20.3
Annual O&M Cost (million $)[1]	0.07	0.42	1.0
Electrical energy requirements (1,000 kWh/yr)	< 1	< 1	< 1

Costs are presented in 2007 dollars and are rounded to three significant figures.
[1]O&M estimates include labor, chemicals, materials, and energy, including engine O&M.
Source: PA Consulting, Inc.

Open lagoons are a likely source of methane emissions, but the emissions are difficult to quantify because the systems are used in remote areas of less developed and developing countries where emissions estimation rarely takes place. The IPCC allocates a MCF of 0.2 and 0.8 for shallow and deep lagoons respectively, as compared to 0.0 for a well-managed centralized aerobic treatment plant, indicating the high methane generation potential of these systems (IPCC, 2006). Lagoons are commonplace in developing countries because land is readily available, operations are simple, minimal energy is needed, and capital costs and operating expenses are low.

Open sewers and lagoons are often used in tandem, with open sewers discharging to a lagoon. Open sewers or lagoons in developing countries often result in uncontrolled discharges to rivers and lakes, especially in areas prone to seasonal flooding or other extreme weather events.

4.2.3 *Septic Systems*

Septic systems are onsite treatment systems common in areas with no connection to centralized treatment facilities. Septic systems can be used to collect and treat wastewater from individual households or small communities. A properly cared-for system can last for decades and possibly a lifetime. Preventive maintenance is required to remove the irreducible solids that settle and gradually fill the tank, otherwise efficiency is reduced and methane emissions are greater.

The IPCC allocates an MCF of 0.5 for septic systems, indicating a relatively strong potential for methane generation (IPCC, 2006). In the United States, septic systems only treat 20 percent of the wastewater, but they are responsible for approximately 80 percent of wastewater methane emissions (EPA, 2009). Advantages of septic systems include relatively low cost and the ability to collect and treat wastewater remotely. However, the systems do require local capacity for maintenance.

5.0 Economically Feasible Mitigation Technologies and Practices

This section discusses the three most promising approaches to reducing methane emissions from wastewater, including a discussion of cost, policy, and infrastructure barriers to technology deployment and project development, as well as methane mitigation potential:

- Installation of anaerobic sludge digestion (new construction or retrofit of existing aerobic treatment systems)
- Installation of biogas capture systems at existing open air anaerobic lagoons
- Installation of new centralized aerobic treatment facilities or covered lagoons

Table 9 presents a comparison of costs and energy requirements for a 20 MLD system, as well as the potential methane emitted to the atmosphere or collected from biogas, the electric generation potential with an electric only system, the thermal generation potential with a thermal only system (e.g., boiler), and the electric and thermal generation potential with a CHP system for each of the options. In addition to mitigation potential and costs, one of the key opportunities to reduce methane emissions and realize other co-benefits is to capture and use biogas at wastewater treatment facilities. In many countries, however, social barriers exist that prevent this from happening. The end of this section, therefore, discusses key factors in overcoming social and cultural barriers to improve the acceptance of biogas programs.

Table 9. Comparison of Mitigation Technologies for a 20 MLD Treatment System

Mitigation Technology/Practice	Cost (million $)		Energy Usage (1,000 kWh/yr)	Methane Emitted to Atmosphere	Potential Methane Generation from Collected Biogas for Energy Use (MT CH_4/yr)	Electric Generation Potential from Biogas (1,000 kWh/yr)[3]	Thermal Generation Potential from Biogas (1,000 kWh/yr)[4]	Combined Heat and Power Generation Potential from Biogas (1,000 kWh/yr)[5]
	Capital	Annual O&M[1]						
Open-Air Anaerobic Lagoon	17.4	0.211	524	~500 - 700	0	0	0	0
Cover for Anaerobic Lagoon (Cover Only)	1.4	0.07	< 1	Negligible[6]	820	3,850	10,300	3,850 (elec.) 6,420 (therm.)
Conventional Activated Sludge w/Sludge Drying Beds	18.6	0.893	1,510	0-270	0	0	0	0
Conventional Activated Sludge w/Anaerobic Digestion	23.8	0.906	3,320[2]	Negligible[6]	304	1,430	3,800	1,430 (elec.) 2,380 (therm.)
Biological Nutrient Reduction System w/Anaerobic Digestion	31.1	1.31	5,690[2]	Negligible[6]	270	1,270	3,380	1,270 (elec.) 2,120 (therm.)

Costs are presented in 2007 dollars and are rounded to three significant figures.
[1]O&M estimates include labor, chemicals, materials, and energy.
[2]Energy usage for systems with anaerobic digesters includes system electric requirements and energy required to heat digester.
[3]Assumes electric generation efficiency of 30 percent and operation 100 percent of year.
[4]Assumes thermal generation efficiency of 80 percent (typical for onsite boilers) and operation 100 percent of year.
[5]Assumes electric generation efficiency of 30 percent, a power to heat ratio of 0.6, and operation 100 percent of year.

[6]Emissions from sludge digesters range from 0-2% of collected biogas. Emissions from covered lagoon systems range dependent on the type of cover installed and can be significant if modular covers are used. This table assumes use of a bank to bank cover, with emissions ranging from 0-5% of collected biogas.

5.1 Installation of Anaerobic Sludge Digesters

The utilization of anaerobic digesters at wastewater treatment facilities can reduce emissions in two ways. First, sludge that is removed from earlier stages of treatment and processed in anaerobic digesters reduces emissions that would occur through uncontrolled anaerobic degradation on site and from subsequent sludge processing (e.g., composting, application). Facilities that do not utilize anaerobic digesters typically store sludge in drying beds or employ mechanical means of drying before sending the dried sludge to a landfill. Methane is emitted during the drying process and through the storage and use of undigested sludge, which still contains significant organic content that converts to methane under anaerobic conditions. However, it should be noted that the methane emitted during the drying process is less than what can be generated with an equal amount of sludge in an anaerobic digester, making energy recovery a more attractive option. At some facilities, especially in developing countries, sludge removal is minimal, leaving a greater amount of organic material to degrade anaerobically in lagoons or open sewers. Even if energy recovery is not feasible, the flaring of biogas from anaerobic digesters reduces onsite methane emissions because the use of sludge drying methods is not required (facilities that utilize anaerobic digesters never vent the produced biogas due to environmental and safety dangers).

Second, biogas that is captured and used in an energy generation device can offset the use of dirtier fuel that would otherwise be used for energy at the wastewater treatment facility. The combustion of wastewater treatment biogas typically produces fewer greenhouse gas emissions than are created through the production of electric and thermal energy used at facilities (typically through combustion of fossil fuels). The biogas flow from the digester can be used as “free” fuel to provide energy and/or generate electricity in an electric-only, thermal-only, or combined heat and power (CHP) system using a boiler, turbine, microturbine, fuel cell, or reciprocating engine. The electric energy generated can be used on site to operate pumps, blowers, and other electrical equipment throughout the treatment process, or it can be exported to the grid. The thermal energy produced by an onsite boiler or through a CHP system is typically used to meet digester heat loads and for space heating for the facility. Anaerobic digesters produce biogas continuously, allowing for constant electricity and thermal energy production. Based on an analysis completed by the U.S. EPA CHP Partnership, CHP has the greatest technical and economic potential at centralized wastewater treatment plants that have anaerobic digesters and influent flow rates greater than 20 MLD.

Barriers, Mitigation Potential, and Costs

Despite the advantages of anaerobic digester technology, barriers to widescale implementation still remain, such as:

- Utilizing anaerobic digesters involves high capital and project development (e.g., consulting and design, installation, permits and inspection) costs. In addition, if the biogas is to be used in an energy recovery system, facilities must bear the additional capital and project development costs associated with the gen-set, fuel treatment and compression equipment, switchgear and controls, and heat recovery equipment. Without adequate financing, digestion technology is simply too expensive for the majority of facilities to merit wide-scale adoption. This is particularly true for small wastewater facilities (e.g., influent flow rate less than 20 MLD) treating wastewaters from relatively small population centers.
- Construction and installation of anaerobic digesters does not follow a “cookie cutter” approach. The need for specialized and experienced professionals in the design, construction, and installation of anaerobic digesters is important to ensure success.
- Local technical experience is needed to properly operate and maintain anaerobic digesters.

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of electricity and thermal energy difficult. Even in the developed world, biogas from anaerobic digestion systems must compete with established infrastructure, and without proper government support and policy, biogas recovery and use projects can often fail or not be cost effective.

- In most cases to effectively use anaerobic digesters, centralized treatment facilities must utilize aerobic treatment processes and be able to process sludge that is separated from primary, secondary, and tertiary treatment. Population centers that rely on decentralized treatment or whose central facilities primarily utilize anaerobic treatment options (e.g., lagoons) and do not have the ability to separate adequate quantities of sludge for use in digesters, have limited opportunities to employ anaerobic digesters.

The greatest potential for increased use of anaerobic digesters is to (1) retrofit existing centralized aerobic facilities to include them, or (2) include them in the construction of new centralized aerobic treatment facilities. The costs presented in Table 6 are associated with new construction, but retrofitting existing facilities will most likely be comparable or less expensive. Population centers that are expanding and have the infrastructure and capital to support the energy requirements associated with the use of anaerobic digesters represent particularly good areas for anaerobic digester incorporation. For example, much of the wastewater in China goes uncollected, and given rising levels of investment, an opportunity exists to construct new centralized aerobic facilities that use anaerobic digesters.

As was discussed in Section 4.2.1, the primary benefit of anaerobic digesters is their ability to generate biogas that can be used to generate heat and power, thereby offsetting the combustion of conventional fuels. However, energy recovery systems are required to do this which adds to the cost associated with these systems. In the United States, sample capital costs for energy recovery systems, including costs associated with consulting and design, installation, and permitting include (EPA CHPP, 2007):

- 126 kW microturbine – $565,000
- 300 kW fuel cell – $2.2 million
- 1 MW internal combustion engine – $2.1 million

As Table 9 indicates, biogas generation from anaerobic digesters used in tandem with aerobic treatment processes at a 20 MLD facility can generate approximately 300 metric tons of methane per year that can be used to offset use of conventional fuels. Biogas generation potential is greater for the anaerobic lagoon option due to greater amounts of BOD, but the use of anaerobic digesters is a proven technology for domestic wastewater operations and has added benefits, as described in Section 4.2.1. In addition, although the gas generated in a digester is more than that which would be emitted through sludge storage onsite, use of digesters eliminates these potential emissions.

5.2 Installation of Biogas Capture Systems at Existing Open Air Anaerobic Lagoons

Biogas capture systems for anaerobic lagoons are the simplest and easiest method of biogas implementation, and have been used around the world as a manure management practice at livestock farms. Many parts of the world currently rely on open air anaerobic lagoons to treat wastewater. Rather than investing in a new centralized aerobic treatment plant, covering an existing lagoon and capturing the biogas can be the most economically feasible means to reduce methane emissions. This is especially true in regions of the world that simply do not have the resources to invest in new infrastructure or do not have the infrastructure that is required to support a centralized aerobic treatment facility.

Barriers, Mitigation Potential, and Costs

Although covering lagoons are the simplest and easiest method of biogas implementation, several barriers exist that have prevented widescale use:

- While anaerobic digestion is well known in most developing countries, covered lagoons have not been widely used outside the United States until the last few years, mostly in the livestock sector for CDM projects.
- There is very little local capacity in many countries to support design, construction, and installation of covered lagoons. Local professionals in most countries lack the knowledge and experience of working with cover materials and equipment.
- To date, there has been a lack of need to cover lagoons. Methane emissions have not been a consideration until recently. Furthermore, in many countries, wastewater treatment facilities are state or government owned and their electricity bills paid by the government, so there hasn't been a clear benefit in capturing methane and using it as an alternative fuel to reduce costs.
- While capital costs for covered lagoons are less than for other systems (see tables in Section 4), cost still remains a major barrier because of the lack of real cost recovery and general lack of funding wastewater facilities around the world. This is particularly true for small facilities treating wastewaters from relatively small population centers.
- The lack of policies to promote renewable energy and the incentives to sell to the grid are a barrier in most developing countries. Covered lagoon projects would also compete with subsidized electricity in many countries.

The mitigation potential of covering lagoons is theoretically high given the high methane generation associated with open air lagoons. Since anaerobic and facultative lagoons are a common treatment strategy in much of the world, and are large emitters of methane emissions, the emission reductions would be immediate from the installation of covered lagoons. However, the numbers or extent of open lagoons worldwide is not readily available.

Assuming existing lagoons are sufficiently sized, and there are no other environmental issues related to their operation (e.g., no infiltration to the groundwater), the capital costs of just covering the lagoon are fairly low (see Table 8). As with anaerobic digesters, if the biogas is to be used in an energy recovery system, facilities would also need to bear the additional capital and project development costs associated with the gen-set, fuel treatment and compression equipment, switchgear and controls, and heat recovery equipment.

5.3 Installation of New Aerobic Treatment or Covered Lagoons

In areas of new population growth, or in areas with no centralized collection and treatment of wastewater, the installation of centralized treatment facilities or covered anaerobic lagoons can greatly decrease methane emissions. For example, a rural community served by onsite septic systems could consider installing a centralized collection and treatment system utilizing aerobic treatment as a means of reducing its overall emissions. This approach requires installation of sewer collection infrastructure and can be quite costly for existing communities that would need to retrofit existing treatment systems. However, the cost would be less for a new community under development or a community experiencing high growth that can plan for the implementation of advanced wastewater collection and treatment. For these communities, installing a centralized aerobic treatment system can prevent increases in future emissions resulting from the increasing population.

Installation of new covered lagoons represents another option for existing communities with little or no centralized treatment or that are experiencing population growth. As demonstrated with animal waste lagoons, anaerobic lagoon systems can be used for energy production through the use of a cover over the primary lagoon. The cover captures the methane which can be either used to generate energy or flared.

Covered lagoons require more space than aerobic treatment facilities, so they may be more appropriate for smaller cities or rural areas. In addition, covered lagoons are less costly than advanced aerobic systems and have less infrastructure and energy requirements than aerobic systems.

Barriers, Mitigation Potential, and Costs
The primary obstacles to installing new aerobic treatment systems involve infrastructure requirements and cost. Aerobic treatment systems are energy intensive so they require a reliable energy supply. Aerobic systems that utilize anaerobic digesters can utilize energy recovery systems to capture biogas for use at the facility, but this is not always possible (due to the barriers discussed above). As presented in the tables in Section 4, the energy requirements for an aerobic system are several times higher than for a covered lagoon. In addition, the costs associated with a new aerobic facility can be 50-100 percent higher than for a new covered lagoon. In addition to the barriers presented in Section 5.2 for covering existing lagoons, space is a key consideration for development of new covered lagoons. Lagoons require more space than centralized aerobic systems, and may not be appropriate for urban or semi-urban areas. Experience shows that open lagoons are typically limited to small and medium-scale treatment systems because of land area requirements.

The methane mitigation potential of both of these options is theoretically high. However, experience in the field shows that it is likely that aerobic facilities will not operate at optimum conditions due to high O&M costs, therefore reducing the efficiency of the process and the quality of the water discharged from the facility. Currently, only a few developing countries (e.g., China) are able to support (or subsidize) the energy costs of an aerobic system. Covered lagoons offer the potential to collect wastewater and capture biogas that would otherwise be generated through decentralized systems. As illustrated in Table 9, approximately 820 metric tons of methane per year can be generated in a covered lagoon associated with a 20 MLD treatment system that can be used for energy generation; several times more than with a centralized aerobic treatment facility processing the same flow.

5.4 Social Acceptance of Biogas Collection and Use

It is critical to obtain social acceptance of biogas collection and use before projects can be implemented or deployed in both the developed and developing world. Throughout the developing world, there can be taboos against the collection, handling, and use of human and animal waste which can threaten the viability of biogas collection projects.

Despite many cultures’ aversion to waste collection and treatment, very few societies have issues using biogas as a fuel source. Key factors in overcoming social and cultural barriers and improving acceptance to biogas programs include:

- Institutional champions who promote the program. For example, when locals see a hospital—an institution that they know provides health services—safely using waste, acceptance is more likely.
- Village leaders and prominent social figures who promote the program. In many cases the benefits of power and heating from biogas quickly override the existing cultural taboos, particularly when biogas is used by local prominent figures. This is more relevant for projects in rural areas as opposed to potential projects in urban areas.

6.0 International Organizations and Efforts

This section provides information on some of the many international organizations and key multilateral banks involved in wastewater/sanitation research and technologies and project development (some of which include methane reduction or methane recovery and reuse). This section also discusses wastewater project development under flexibility mechanisms contained in the Kyoto Protocol and opportunities for Methane to Markets to leverage existing efforts.

6.1 Key International Organizations

Many international organizations are involved with wastewater research and technology development. Four of the most important relative to wastewater methane emissions are discussed below. While all of them have both information and capabilities relative to methane mitigation technologies and applications, none of them have specific or explicit efforts or programs on these topics. As a result, these organizations represent opportunities for Methane to Markets to develop partnerships in promoting methane emissions mitigation in wastewater management.

6.1.1 *Water Environment Federation*

The Water Environment Federation (WEF), a not for profit organization, has been dedicated to preserving and enhancing the global water environment for the last 80 years. In addition to providing technical advice and assistance, WEF is also deeply dedicated to education and sets up seminars around the nation on selected topics. Under an umbrella of member organizations located in the Americas, Europe, Africa, Asia, and the Middle East, WEF's impact is far and widespread.

Across the United States, WEF organizes information sessions geared toward topics such as wastewater treatment, sustainable utility management, and membrane technology. In terms of policy and technical standards, WEF has prepared reports on topics such as high-performance anaerobic digester design and adoption of methane recovery facilities by municipal wastewater treatment centers. With its member organizations, WEF promotes easy-to-use methane mitigation technology and advice to communities around the world. One such example is the Anaerobic Sludge Processes Division of the Water Institute of Southern Africa, a partner group of the WEF. The Anaerobic Sludge Division provides a communication forum for researchers, engineers, and practitioners working in the anaerobic technology field. It also improves awareness and knowledge of the anaerobic processes in the municipal and industrial sectors and encourages anaerobic technology transfer.

WEF offers a solid technology capability, as well as worldwide reach, especially through its local member organizations.

6.1.2 *International Water Association*

The International Water Association (IWA) resulted from the 1999 merging of two longstanding groups—the International Water Supply Association and the International Water Quality Association. IWA is a member-based organization that strives to connect water professionals worldwide to lead the development of effective and sustainable approaches to water management. IWA is committed to organizing conferences, publishing resources, facilitating the collaboration of groups, and providing global development solutions.

IWA's main focus is organizing conferences and workshops. In 2007, IWA organized a conference in Australia to gather specialists on anaerobic digestion from around the world. IWA's hands-on annual workshops in developing areas teach practical knowledge and implementation of methane recovery systems. One such workshop was the recent 10th Latin American Workshop and Symposium on

Anaerobic Digestion. This event attracted researchers, waste managers, consultants, representatives of private and public sectors, environmental engineers, and other professionals. It addressed topics related to large- and small-scale digesters, private and public systems, and industrial and municipal wastes. In addition to conferences and workshops, IWA also seeks to mitigate methane emissions from wastewater by publishing documentation providing advice on to the benefits of methane recovery and anaerobic digestion.

Like WEF, the IWA offers an excellent venue for research and information exchange.

6.1.3 *Global Water Partnership*

The Global Water Partnership (GWP) was founded in 1996 by the World Bank, the United Nations Development Program (UNDP), and the Swedish International Development Agency (SIDA). Its goal is to foster integrated water resource management (IWRM) and to ensure the coordinated development and management of water, land, and related resources by maximizing economic and social welfare without compromising the sustainability of vital environmental systems. The network of GWP affiliates spreads to over 70 countries.

GWP is actively involved in financing partnerships and has worked with the Organization for Economic Cooperation and Development (OECD) and the European Water Initiative (EUWI) to provide adequate financing for water sanitation projects around the world. Instead of having local partners, GWP has regional affiliates who provide funding and oversight for regional projects. However, most GWP projects have a national focus, rather than local, and although the organization claims to have funded methane reduction projects, these have likely been part of larger projects and detailed information is not readily available.

6.1.4 *Water Supply and Sanitation Collaborative Council*

Created in 1990, in line with a United Nations General Assembly Resolution, the Water Supply and Sanitation Collaborative Council (WSSCC) aims to continue the work of the International Drinking Supply and Sanitation Decade (1981–1990). As a partnership program of the World Health Organization (WHO), the WSSCC has wide influence.

To implement their programs, WSSCC partners with local grassroots organizations. This means that it has widespread influence focused almost exclusively at the local level. The primary tool of WSSCC is a sanitation and hygiene grants program (titled the Global Sanitation Fund), which provides a well-informed financing channel to deliver funds efficiently to competent organizations in selected countries, thus accelerating their work in sanitation and hygiene.

Unlike the previous organizations described, the WSSCC works primarily with community sanitation projects rather than centralized water treatment. Its work in India has improved sanitation and reduced methane emissions for more than 10 million people.

6.2 Key Efforts of the Multilateral Development Banks

In the developing world, wastewater infrastructure projects are primarily financed by large multilateral banks and other international donor organizations. Similar to the situation described above with water organizations, many of the projects financed include methane mitigation options, but few focus explicitly on this objective. The reach of multilateral banks and their commitments to environmentally sustainable projects, makes them good potential partners to promote methane reduction projects internationally, even more so because of their in-country offices around the world and their lending to country governments and local project implementers. The following sections provide some examples of efforts by the key multilateral banks to improve wastewater management practices and, in some cases, reduce emissions.

6.2.1 *The World Bank*

The World Bank has been active in water treatment projects as part of its contribution to the Millennium Development Goal of cutting in half the number of people without sustainable access to drinking water and basic sanitation. These projects typically are investments on the order of $300,000 to $25 million and are located in the Middle East, Europe, South America, and Asia. Examples include:

- A $279 million project in Iran to improve water supply and access to sanitation, while improving environmental, hygiene, and health conditions and strengthening/developing the capacities of local wastewater treatment companies (expected completion September 2009).
- A $275 million project in Turkey to support environmental improvements at the municipal level by financing the development of the water, wastewater, and solid waste sectors and providing technical assistance (expected completion June 2010).
- A $230 million project in Azerbaijan to improve the availability, quality, reliability, and sustainability of water supply and sanitation services, including the financing of wastewater and septic sludge facilities (expected completion January 2012).

While the bulk of these investments include wastewater collection infrastructure, an estimated 15-20 percent of the project investment is for water treatment. In addition, three recent World Bank projects focus specifically on methane emissions reduction:

- A $9.9 million composting project in Santiago, Chile. This plant will use anaerobic digestion to treat urban wastewater. This large-scale project eventually hopes to process at least 20 percent of the organic waste generated in metropolitan Santiago.
- $300,000 of the $11 million Colombia Rio Frio Carbon Offset Project aims to reduce greenhouse gas emissions from the wastewater treatment plant in Giron, Colombia, resulting in methane and nitrous oxide emissions reduction and improved effluent quality.
- The $5 million Bolivia Urban Wastewater Methane Gas Capture project is to cover the primary anaerobic treatment lagoons at all four of the facilities at SAGUAPAC in Santa Cruz with a high-density polyethylene (HDPE) ‘geo-membrane’ sheet supported by a system of floats and supporting tubes. Gas captured will be sent to flare.

The World Bank is also a leader in investment in greenhouse gas mitigation projects. Its Carbon Finance Unit is focused on identifying and developing projects with creditable carbon reductions, and is a logical point of contact for potential partnership with the Methane to Markets program.

6.2.2 *African Development Bank*

Since 1964, the African Development Bank (AfDB) has been a key institution in unifying and uniting Africa. The AfDB serves as a giant financer for Africa, with the goal of reducing poverty and promoting sustainable development. Many of the AfDB’s projects are large-scale, national investments, such as the $70 billion highway development project in Senegal. A few projects, however, focus on small-scale development. Projects related to wastewater treatment include:

- A $24 million project in northern Uganda to improve water access and sanitation in seven small towns (ongoing).
- A $69 million project in Nigeria to increase access to potable water and sustainable sanitation to 90 percent of the population by 2015 and 100 percent by 2020 (ongoing).
- A $1.1 million project in Ziguinchor, Senegal, to provide better sanitation (ongoing).

The AfDB recently organized a new division called the Clean Energy Investment Framework, where potential participation in wastewater methane emissions reduction and recovery may be of interest.

6.2.3 *Asian Development Bank*

While the ADB sponsors many projects seeking to improve sanitation, very few of them attempt to recover and use the methane from wastewater treatment. The majority of plants funded by the ADB are preoccupied with the goal of providing adequate sanitation to lacking regions. In addition, the vast majority of projects undertaken by the ADB in the wastewater sector are concentrated in China. Example projects include:

- A $82.36 million project in the province of Heibei in China, with the goals of reducing water pollution, protecting water resources, promoting sustainable economic development, and improving the environment (ongoing).
- A $150 million project to provide modern, efficient wastewater collection and treatment for the urban and industrial population in the Samut Prakarn Province in Thailand (ongoing).

The ADB established the Asia-Pacific Carbon Fund as part of its Carbon Market Initiative, which offers technical and financial support for carbon-reduction projects, and could be a point of contact for potential collaboration with Methane to Markets.

6.2.4 *Inter-American Development Bank*

The IDB currently has a large portfolio of infrastructure projects in the sanitation sector. A sampling of these includes:

- A $95 million project dedicated to providing better sanitation, wastewater treatment, and health for the residents of Goiania, Brazil.
- A $1.8 million project to provide sustainable solutions to the sanitation and wastewater problems facing the San Pedro and Guayllabamba rivers in Mexico.
- A $82 million project to construct a wastewater removal and treatment system for the city of Ciudad de la Costa in Uruguay.
- A $200 million project with the goal of providing water treatment, infrastructure, and access to rural Chile (ongoing).
- A $29 million project that finances mid-sized wastewater treatment facilities in Honduras (ongoing).

The IDB also seeks to provide innovative methods of distributing funds for critical water and sanitation projects. One of its newest mechanisms for disbursing funds to projects is AquaFund, created to help finance the implementation of the IDB's Water and Sanitation Initiative and contribute to achieving the water-related Millennium Development Goals in IDB-borrowing member countries. Through the AquaFund, the IDB expects to facilitate investment in water and sanitation (including solid waste) and guarantee sustainable and high-quality access to these services. The IDB has limited experience in financing methane capture projects, mostly in the agro-industrial sector. However, a relatively new unit within the bank, the Sustainable Energy and Climate Change Initiative (SECCI) focuses specifically on the development and promotion of GHG emissions reduction projects, and may be interested in Methane to Markets-supported approach to methane emissions reduction in wastewater.

6.3 Wastewater Within the UN Framework Convention on Climate Change

Under the Kyoto Protocol, 183 nations agreed to reduce greenhouse gas emissions 5.2 percent from 1990 levels between 2008 and 2012. To allow a country to receive credit for reducing greenhouse gas emissions in a flexible manner, the protocol created three flexibility mechanisms: emissions trading, joint implementation (JI), and the clean development mechanism (CDM). With regard to reducing methane emissions from wastewater, JI and CDM projects are of particular interest.

Joint Implementation is the mechanism that allows countries to receive carbon reduction credits for projects funded in other countries with emissions reduction targets under the Kyoto Protocol (Annex I countries). Project participants under joint implementation may apply methodologies for baselines and monitoring, including methodologies for small-scale project activities, approved by the Executive Board of the CDM, as appropriate. There are no current wastewater projects under the JI mechanism. One project, "Methane gas capture and electricity production at Kubratovo Wastewater Treatment in Sofia Bulgaria," is pending decision. Another project, "Combined Vodokanal Wastewater Sludge Incinerator Projects, St. Petersburg," was rejected due to a variety of reasons.

CDM is the mechanism through which countries with emissions targets can receive carbon credits for funding projects in countries without emissions targets under the protocol (non-Annex I). Project participants willing to validate or register a CDM project activity must use a methodology previously approved by the Executive Board or propose a new methodology to the Executive Board for consideration and approval. Currently the following approved methodologies pertain directly to wastewater projects:

- AM0080: Mitigation of greenhouse gases emissions with treatment of wastewater in aerobic wastewater treatment plants.
- ACM0014: Mitigation of greenhouse gas emissions from treatment of industrial wastewater.
- AMS-III.H - Methane recovery in wastewater treatment.
- AMS-III.I - Avoidance of methane production in wastewater treatment through replacement of anaerobic systems by aerobic systems.
- AMS-III.Y - Methane avoidance through separation of solids from wastewater or manure treatment systems.

The CDM has had much more activity in the wastewater sector than JI. Currently, 26 registered projects in the UNFCCC CDM database pertain to wastewater. These projects are located across the world in Mexico, India, the Philippines, Brazil, Malaysia, Indonesia, and Thailand. Every one of these projects, however, involves the treatment of industrial or agro-industrial wastewater, and none pertains directly to municipal wastewater treatment. The nations investing in these projects include the United Kingdom, the Netherlands, Japan, Switzerland, and Austria.

Of the projects seeking registration, only one is directly related to municipal wastewater treatment, an electric generator addition to an existing wastewater treatment plant in Colombia that runs on biogas. This project is expected to reduce emission levels by 25.1 $MtCO_2e$ over its 10-year crediting period.

6.4 Opportunities for Methane to Markets to Leverage Existing Efforts and Capabilities to Build a Wastewater Methane Emissions Reduction Program

Opportunities for Methane to Markets to leverage existing efforts worldwide will depend on the main objective of the institutions involved in the sector. A possible approach is as follows.

First, Methane to Markets could approach WEF, and IWA, and possibly GWP, to explore partnerships in promoting methane emissions reductions in wastewater treatment. Specific activities to undertake together with these institutions might include:

- Organizing data on system designs, costs, and most importantly, actual installation experiences to date.
- Participating in pilot installations, possibly sharing costs of measurement and documentation of performance.

- Promoting anaerobic digestion in the sector. Methane to Markets could access its already established network of water and sanitation professionals, local institutions, utilities, and others to transfer knowledge and technologies.
- Facilitating policy and regulatory reform where required, as well as developing national standards and norms for anaerobic digestion in the wastewater sector.
- Facilitating the retrofitting of current wastewater treatment facilities through its affiliates and networks.

Similarly, Methane to Markets could meet with the multilateral banks, especially The World Bank, ADB, and IDB, to understand the extent of their lending and project development in the wastewater sector, as well as to explore their understanding of GHG reduction projects. Meetings could be held both in the Carbon Finance Unit, and in the regional divisions, where large wastewater projects are designed. Specific activities to undertake together with these institutions might include:

- Providing programmatic and technology expertise to include anaerobic digestion in future infrastructure investments.
- Developing wastewater methane reduction efforts as climate change projects.
- Participating in pilot installations and sharing costs and data.
- Providing technical advice on potential impacts of anaerobic digestion at local, national, and regional levels.
- Serving as a repository of data on wastewater emissions reduction projects, technologies, applications and experiences
- Providing a forum for the coordination of investment programs and donor assistance at the country level.

7.0 Examples of Global Wastewater Methane Project Development

Throughout the world, there are examples of successful projects to reduce, capture, and use methane at wastewater treatment facilities. This section provides case studies of wastewater methane project development from India, Mexico, the United States, China, Brazil, and Bolivia as examples of successful methane mitigation projects.

7.1 India

Chennai Metro Water

The Chennai Metro Water plant in India sets a high standard for the rest of Indian wastewater treatment. Chennai is a city on the southeast coast of India and is the fifth most populous city in India. Metro Water provides water and sanitation to the majority of residents within and around the city. During 2005–2006, Chennai Metro Water commissioned four new sewage treatment plants to bring the total system capacity to 486 million liters per day. These four plants were designed to treat 264 million liters per day.

The facility utilizes anaerobic digesters with an energy recovery system to generate electricity and heat from the biogas. In total, the four plants have an installed capacity of 3,222 kilowatts and generate 1,185,000 kilowatt-hours of electricity per month. The power is used locally, and the savings in electricity are in excess of $80,000 a month. The treatment plants that implemented biogas recovery and use are self-supporting and do not need to purchase electricity from the grid.

Tirupur Area Development Project

In 2006, the Tirupur water system—the first public-private partnership project in the history of India's water sector—was completed. Tirupur is located in Tamil Nadu state and is India's largest producer of cotton knitwear. With more than 2,500 textile businesses located within a 25-mile radius, the region is one of India's fastest growing, and one of the most economically important, earning $1 billion U.S. dollars annually.

The municipal area of Tirupur previously lacked an organized system of drainage, sewage collection or treatment. The development project addressed both wastewater treatment for and the delivery of potable water for more than 1.6 million residents in Tirupur and the region's surrounding rural towns, villages, and settlements. Completed in February of 2006, the wastewater treatment plant was initially built with a capacity of 15 MLD, but its design allows expansion to double that volume when the sewer network is extended to the remaining 15 of the town's 52 wards.

Once fully operational, the system will service both the industrial areas and 88 of the city's designated slum areas. The wastewater facility takes domestic sewage only and uses an activated sludge system to achieve secondary treatment standards. Estimated cost of the project was $220 million U.S. dollars. The wastewater plant discharges into Noyyal River.

7.2 Mexico

Dulces Nombres Wastewater Treatment Plant

Built from 1994 to 1995 by Burns & McDonnell, the Dulces Nombres Plant near Monterrey, Mexico, is the largest wastewater treatment plant in Mexico and one of the largest in Latin America. It treats wastewater from part of the Monterrey metropolitan area, which has a population of approximately 1.8 million. On a daily basis, the plant treats approximately 432 MLD and has the capacity to be upgraded to treat 1,640 MLD. Anaerobic digestion is used at the site to treat the wastewater, and the resulting methane is collected. In total the plant produces 9,000 tons of methane per year.

The biogas was originally combined with natural gas to fuel eight generators, for a total of 9.2 megawatts. Currently, however, the plant is only capturing and flaring the methane. The plant stopped generating electricity due to significant government budget cuts, which affected the O&M budget of the plant. The plant recently conducted a feasibility study to justify the rehabilitation of the system to continue generating electricity for its own use.

The Dulces Nombres Plant represents one of the first efforts by Mexico to reduce methane emissions from wastewater.

7.3 United States

City of Albert Lea Wastewater Treatment Facility, Minnesota
In the summer of 2003, the city of Albert Lea, Minnesota, installed a 120-kilowatt (kW) CHP system at its wastewater treatment facility. The CHP system integrates four 30-kW microturbines and utilizes the recovered heat (28 million British thermal units [MMBtu] per day) from the turbines to maintain proper operating temperature of the anaerobic digester and provide a portion of the facility's space heating requirements. With funding from the Minnesota Department of Commerce's Conservation Improvement Program and the local utility, the CHP system provides 120 kW of backup power to operate critical systems during a utility power outage. The CHP system also saves the facility 800,000 kilowatt-hours per year (kWh/year), or 25 percent of its energy use. The CHP system has a payback period of approximately 4 to 6 years. In addition to representing a successful partnership among municipal, utility, and state entities, the project successfully integrates a CHP system utilizing a renewable fuel, generates energy and cost savings for the municipality, and results in reduced air emissions.

Palmdale Water Reclamation Plant, California
In 2004, the Los Angeles County Sanitation District (LACSD) began operating a 250-kW fuel cell CHP system at the Palmdale Water Reclamation Plant. With the CHP system, 70 to 80 percent of the digester gas produced by the facility's anaerobic digesters is utilized in the fuel cell. The system produces 225 kW for use on site, while waste heat from the fuel cell exhaust is used to maintain proper temperature for digester operation. LACSD chose the use of biogas coupled with CHP to conserve fossil fuel, reduce air emissions, and save money. The CHP system reduces annual CO_2 and nitrogen oxide emissions by 778 tons and 0.58 tons, respectively, and saves LACSD approximately $227,000 per year in energy costs.

7.4 China

Chongqing Wastewater Project
With a population of 32 million, Chongqing is China's largest municipality and is located on the Yangtze River. Chongqing's urban environment project included plans for a radical improvement to the treatment of both domestic and industrial wastewaters. This project, which will see 20 wastewater treatment plants built in the area, is part of a series of initiatives to address pollution in the region. In June 2000, the World Bank approved a loan to fund half of the $500 million (U.S.) dollar cost in building the 20 wastewater treatment plants; the remaining $250 million was financed by the Chinese government and the China State Development Bank.

By the beginning of June 2006, Chongqing's wastewater project had gained greater urgency with the early completion of the Three Gorges Dam. At that time, more than 3,000 factories discharged approximately 1 billion tons of effluent per year, and Chongqing discharged almost another billion tons of wastewater, 80 percent of which was untreated, to the Yangtze River. With the completion of the dam causing an inevitable decrease in the river's flow rate, pollution concentrations – previously flushed out by the fast-moving water – began to increase.

The first two wastewater treatment plants were successfully completed in metropolitan Chongqing at a cost of $375 million. The first plant, in the Beipei district of the city, was designed to provide primary treatment to 55 MLD and uses UV disinfection to avoid adding further chemicals to the waters of the Yangtze. The region's remaining 18 plants (with a total budget of $262 million) are either nearing completion or under construction. As a result, the Chongqing has sufficient capacity to treat 60 percent of its wastewater, with the rest of the reservoir area approaching 70 percent capability.

7.5 Brazil

Barueri, Brazil
The wastewater treatment plant at Barueri is an example of the state of Sao Paulo's dedication to not only providing sanitation to its residents, but also doing so in a sustainable way. The plant is one of the largest in South America. Studies have been done to estimate the feasibility of utilizing the methane produced during the treatment process to provide energy to the site, but it is unclear whether these have been implemented. The studies estimate that the plant produces 24,000 cubic meters of biogas per day, enough to fuel several 30 KW turbines.

7.6 Bolivia

Community Development Carbon Funded Project in Santa Cruz de la Sierra, Bolivia
An emissions reductions purchase agreement partnered the Community Development Carbon Fund (CDCF)—managed by the World Bank—and SAGUAPAC, a Bolivian sanitation and waste water treatment cooperative for an emissions reduction and wastewater improvement project in Santa Cruz de la Sierra, the largest city in Bolivia.

According to the agreement, the CDCF will buy 200,000 tons of carbon dioxide equivalents by 2015. Part of the revenues from this purchase will be used to improve sewage services in some of the poorest areas of Santa Cruz de la Sierra. A premium price was paid for the emission reductions as the price of each ton of carbon dioxide equivalent was increased by $1 U.S. dollar as part of this CDCF project. In addition SAGUAPAC contributed an additional $150,000 U.S. dollars for the project.

SAGUAPAC has served the city for more than twenty years and is characterized as one of the best managed cooperatives in Latin America. Sanitation services in Santa Cruz de la Sierra are provided by 10 cooperatives of which SAGUAPAC is the largest, serving 65 percent of the city's area. Sewerage coverage in SAGUAPAC's service area is about 50 percent, giving Santa Cruz an overall level of sewerage coverage of about 30 percent. The project installed covering systems on existing anaerobic lagoons at the four wastewater treatment plants in Santa Cruz de la Sierra constructed and operated by SAGUAPAC. This system allows for the capture and flare of the methane generated. It is expected that the Santa Cruz project could be replicated in other cities around Bolivia and the Latin American region.

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Appendix A: Definition of Regional Groupings

Africa
- Algeria
- Democratic Republic of Congo (Kinshasa)
- Egypt
- Ethiopia
- Nigeria
- Senegal
- South Africa
- Uganda
- Rest of Africa*,**

China/Central Asia
- Cambodia
- China
- Laos
- Mongolia
- North Korea
- Viet Nam
- Rest of China/CPA*,**

Latin America
- Argentina
- Bolivia
- Brazil
- Chile
- Colombia
- Ecuador
- Mexico
- Peru
- Uruguay
- Venezuela
- Rest of Latin America*,**

Middle East
- Iran
- Iraq
- Israel
- Jordan
- Kuwait
- Saudi Arabia
- United Arab Emirates
- Rest of Middle East*,**

Non-EU Eastern Europe
- Albania
- Croatia
- Macedonia
- Rest of Non-EU Eastern Europe*,**

Non-EU Former Soviet Union
- Armenia
- Azerbaijan
- Belarus
- Georgia
- Kazakhstan
- Kyrgyzstan
- Moldova
- Russian Federation (Russia)
- Tajikistan
- Turkmenistan
- Ukraine
- Uzbekistan

South & Southeast Asia
- Bangladesh
- India
- Indonesia
- Myanmar
- Nepal
- Pakistan
- Philippines
- Singapore
- South Korea
- Thailand
- Rest of South & Southeast Asia*,**

OECD1990 & EU
- Australia
- Austria
- Belgium
- Bulgaria
- Canada
- Czech Republic
- Denmark
- Estonia
- Finland
- France
- Germany
- Greece
- Hungary
- Iceland
- Ireland
- Italy
- Japan
- Latvia
- Liechtenstein
- Lithuania
- Luxembourg
- Monaco
- Netherlands
- New Zealand
- Norway
- Poland
- Portugal
- Romania
- Slovak Republic
- Slovenia
- Spain
- Sweden
- Switzerland
- Turkey
- United Kingdom (UK)
- United States (U.S.)
- Rest of OECD*,**

Source: *Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990-2020, EPA, 2006.*

*The complete list of countries included in the "Rest of" groupings can be found in Appendix H of *Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990-2020,* EPA, 2006.

** In this report, when emission totals are presented for a region, the regional sum includes the estimates for all of the individually reported countries AND the aggregated value for the "Rest of" countries.

Appendix B: Methane Emissions from Wastewater (by Country)

- **Countries highlighted in blue are Methane to Markets Partners**
- **Countries are sorted based on 2005 emissions (highest to lowest)**

		MtCO$_2$eq							
Country	**Ranking**	**1990**	**1995**	**2000**	**2005**	**2005 % of Total from Wastewater**	**2010**	**2015**	**2020**
China	1	94.4	99.65	104.25	108.04	12.66%	111.73	115.34	118.29
India	2	81.77	89.73	97.65	105.36	19.24%	112.66	119.09	124.98
United States	3	24.85	29.89	34.34	35.21	6.76%	36.13	36.99	37.84
Indonesia	4	18.01	19.51	20.94	22.25	12.15%	23.47	24.69	25.85
Brazil	5	17.95	19.35	20.67	21.97	5.65%	23.23	24.43	25.55
Pakistan	6	10.88	12.25	13.99	15.89	16.25%	17.97	20.24	22.57
Bangladesh	7	10.44	11.73	13.04	14.48	27.03%	15.94	17.38	18.76
Mexico	8	10.02	10.98	11.91	12.78	6.92%	13.59	14.35	15.05
Nigeria	9	6.8	7.85	9.01	10.26	6.82%	11.63	13.08	14.58
Russian Federation	10	9.44	9.43	9.26	8.97	2.85%	8.72	8.49	8.26
Viet Nam	11	6.74	7.43	7.97	8.51	12.41%	9.05	9.63	10.23
Philippines	12	6.23	6.97	7.72	8.47	20.58%	9.17	9.78	10.35
Iran	13	5.96	6.59	7.18	7.69	8.04%	8.25	8.89	9.54
Turkey	14	5.72	6.27	6.8	7.27	6.90%	7.67	8.06	8.46
Thailand	15	5.59	5.99	6.41	6.79	7.41%	7.11	7.4	7.66
Ethiopia	16	3.88	4.52	5.13	5.79	10.66%	6.52	7.32	8.24
Colombia	17	4.24	4.68	5.11	5.53	8.87%	5.96	6.39	6.79
Egypt	18	4.18	4.61	5.05	5.49	14.46%	5.89	6.28	6.67
Myanmar	19	4.13	4.53	4.87	5.16	6.89%	5.41	5.64	5.89
South Korea	20	4.37	4.59	4.77	4.93	14.75%	5.06	5.17	5.25
Democratic Republic of Congo (Kinshasa)	21	3.02	3.66	4.16	4.91	8.46%	5.82	6.86	8.05
Argentina	22	3.95	4.22	4.49	4.77	5.01%	5.03	5.28	5.5
South Africa	23	3.36	3.69	4	4.15	7.51%	4.17	4.12	4.06
Peru	24	2.62	2.86	3.11	3.37	16.38%	3.63	3.87	4.1
Venezuela	25	2.37	2.65	2.93	3.21	3.83%	3.48	3.75	3.99
Uzbekistan	26	2.09	2.33	2.54	2.72	5.06%	2.91	3.12	3.32
Algeria	27	2.03	2.26	2.47	2.7	9.79%	2.91	3.1	3.3
Iraq	28	1.76	2.05	2.34	2.69	20.46%	3.05	3.42	3.78
Australia	29	2.27	2.4	2.55	2.68	2.08%	2.8	2.92	3.03
Nepal	30	1.85	2.09	2.35	2.64	10.32%	2.95	3.28	3.62
Saudi Arabia	31	1.57	1.74	2.08	2.43	8.75%	2.82	3.24	3.68
North Korea	32	2.04	2.18	2.27	2.35	6.98%	2.42	2.49	2.57
Uganda	33	1.41	1.64	1.9	2.23	16.63%	2.66	3.16	3.74
Chile	34	1.59	1.72	1.85	1.96	13.23%	2.06	2.17	2.28
Spain	35	1.25	1.48	1.8	1.8	4.92%	1.79	1.76	1.73

		MtCO$_2$eq							
Country	**Ranking**	**1990**	**1995**	**2000**	**2005**	**2005 % of Total from Wastewater**	**2010**	**2015**	**2020**
Ecuador	36	1.25	1.39	1.53	1.67	10.83%	1.81	1.93	2.05
Romania	37	1.6	1.81	1.68	1.66	6.24%	1.64	1.61	1.58
Kazakhstan	38	1.71	1.7	1.65	1.62	6.03%	1.61	1.63	1.64
Poland	39	2.93	1.86	1.6	1.59	3.43%	1.58	1.57	1.56
Cambodia	40	0.98	1.16	1.34	1.51	11.17%	1.7	1.9	2.09
Greece	41	2.36	2.09	1.45	1.45	14.93%	1.44	1.43	1.41
Italy	42	1.34	1.39	1.43	1.38	3.98%	1.38	1.35	1.33
France	43	0.71	0.95	1.15	1.17	1.92%	1.19	1.2	1.21
Bolivia	44	0.8	0.9	1.01	1.13	3.40%	1.24	1.36	1.48
Hungary	45	1.25	1.15	1.11	1.08	9.98%	1.06	1.03	1.01
Japan	46	1.1	1.03	1.03	1.04	4.99%	1.05	1.05	1.04
Senegal	47	0.6	0.68	0.77	0.87	9.54%	0.98	1.1	1.23
Azerbaijan	48	0.73	0.78	0.82	0.85	6.04%	0.87	0.89	0.91
United Kingdom	49	0.7	0.72	0.77	0.78	1.69%	0.79	0.79	0.79
Slovak Republic	50	1.01	0.85	0.74	0.75	16.11%	0.65	0.6	0.58
Belarus	51	0.72	0.72	0.71	0.7	5.06%	0.68	0.67	0.66
Israel	52	0.46	0.55	0.62	0.68	5.90%	0.74	0.79	0.83
Tajikistan	53	0.54	0.59	0.62	0.64	21.75%	0.68	0.72	0.78
Bulgaria	54	1.4	1.04	0.59	0.62	6.05%	0.85	1.04	1.22
Laos	55	0.42	0.48	0.54	0.6	4.73%	0.67	0.75	0.82
Jordan	56	0.33	0.43	0.5	0.58	26.70%	0.66	0.73	0.81
Czech Republic	57	0.83	0.65	0.58	0.57	5.45%	0.57	0.56	0.56
Kyrgyzstan	58	0.45	0.47	0.5	0.53	14.48%	0.56	0.6	0.63
Turkmenistan	59	0.37	0.43	0.48	0.53	1.08%	0.58	0.62	0.66
Georgia	60	0.56	0.55	0.54	0.52	14.79%	0.51	0.49	0.47
Portugal	61	0.87	0.9	0.82	0.52	6.09%	0.23	0.23	0.23
Singapore	62	0.31	0.35	0.41	0.45	26.66%	0.47	0.49	0.5
Uruguay	63	0.38	0.39	0.4	0.42	2.11%	0.43	0.45	0.46
Canada	64	0.36	0.38	0.4	0.41	0.40%	0.43	0.44	0.46
Ukraine	65	0.63	0.63	0.39	0.37	0.24%	0.36	0.34	0.33
Lithuania	66	0.08	0.12	0.33	0.33	8.28%	0.33	0.33	0.33
Croatia	67	0.31	0.32	0.32	0.33	7.90%	0.32	0.32	0.32
Moldova	68	0.3	0.3	0.3	0.3	10.95%	0.29	0.29	0.29
Austria	69	0.29	0.3	0.3	0.29	3.64%	0.25	0.22	0.2
United Arab Emirates	70	0.21	0.24	0.27	0.29	0.70%	0.31	0.33	0.34
Ireland	71	0.25	0.25	0.27	0.28	2.35%	0.29	0.31	0.32
Mongolia	72	0.23	0.25	0.26	0.27	3.64%	0.29	0.31	0.34
Netherlands	73	0.32	0.28	0.26	0.27	1.54%	0.27	0.28	0.28
Armenia	74	0.25	0.26	0.26	0.26	9.85%	0.27	0.27	0.26
Albania	75	0.23	0.22	0.22	0.23	7.68%	0.23	0.24	0.25
Kuwait	76	0.22	0.17	0.2	0.22	2.27%	0.25	0.28	0.31

		MtCO$_2$eq							
Country	**Ranking**	**1990**	**1995**	**2000**	**2005**	**2005 % of Total from Wastewater**	**2010**	**2015**	**2020**
Denmark	77	0.2	0.22	0.22	0.22	3.93%	0.22	0.22	0.22
Estonia	78	0.19	0.13	0.22	0.21	8.25%	0.2	0.19	0.18
Latvia	79	0.35	0.2	0.2	0.19	10.35%	0.19	0.18	0.18
Germany	80	2.23	0.89	0.17	0.17	0.25%	0.17	0.17	0.17
Slovenia	81	0.19	0.14	0.18	0.17	8.50%	0.17	0.17	0.17
New Zealand	82	0.16	0.16	0.16	0.17	0.62%	0.17	0.18	0.18
Macedonia	83	0.13	0.14	0.14	0.14	7.29%	0.14	0.14	0.14
Finland	84	0.15	0.15	0.13	0.13	2.53%	0.13	0.13	0.13
Belgium	85	0.08	0.08	0.08	0.06	0.67%	0.04	0.03	0.02
Luxembourg	86	0.03	0.03	0.03	0.03	5.81%	0.03	0.04	0.04
Switzerland	87	0.03	0.03	0.03	0.03	0.88%	0.03	0.03	0.03
Norway	88	0.02	0.02	0.02	0.02	0.39%	0.02	0.02	0.02
Iceland	89	0.02	0.02	0.02	0.02	3.96%	0.02	0.02	0.02
Monaco	90	0	0	0	0	74.89%	0	0	0
Liechtenstein	91	0	0	0	0	5.88%	0	0	0
Rest of Africa		24.88	27.92	31.81	35.78	8.00%	40.1	44.77	49.71
Rest of Latin America		7.63	8.38	9.15	9.95	11.63%	10.76	11.56	12.33
Rest of SE Asia		6.13	7.12	8.19	9.07	8.72%	10.07	10.95	11.85
Rest of Middle East		3.22	3.89	4.59	5.38	7.48%	6.28	7.29	8.4
Rest of Non-EU Eastern Europe		1.01	0.97	1.01	1.03	5.64%	1.03	1.02	1.02
Rest of OECD90 & EU		0.08	0.08	0.09	0.09	9.56%	0.1	0.1	0.1
SE Asia	**1**	149.72	164.86	180.35	195.48	15.58%	210.27	224.1	237.27
China/CPA	**2**	104.81	111.15	116.63	121.29	12.26%	125.86	130.42	134.33
Africa	**3**	50.15	56.83	64.29	72.19	8.46%	80.66	89.79	99.56
Latin America	**4**	52.78	57.51	62.17	66.76	6.65%	71.23	75.54	79.58
OECD90 & EU	**5**	55.2	57.97	61.56	62.71	4.60%	63.89	65.27	66.62
Middle East	**6**	13.74	15.67	17.76	19.96	7.30%	22.36	24.97	27.69
Non-EU FSU	**7**	17.8	18.18	18.08	18.02	2.81%	18.03	18.12	18.2
Non-EU Eastern Europe	**8**	1.69	1.66	1.7	1.72	6.32%	1.73	1.73	1.73
World Totals		445.87	483.82	522.54	558.11	8.71%	594.04	629.93	664.97

Source: *Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990-2020, EPA, 2006.*