*Final Report*

# Discussion Paper for a Wastewater Treatment Plant Sector Greenhouse Gas Emissions Reporting Protocol

Prepared for

**California Wastewater Climate Change Group**
**and**
**Bay Area Clean Water Agencies**

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# Acronyms and Abbreviations

| | |
|---|---|
| AB | Assembly Bill |
| ASMN | Activated Sludge Model-Nitrogen |
| BOD | biochemical oxygen demand |
| CARB | California Air Resources Board |
| CCAR | California Climate Action Registry |
| CEC | California Energy Commission |
| $CH_4$ | methane |
| $CO_2$ | carbon dioxide |
| CWCCG | California Wastewater Climate Change Group |
| CWNS | Clean Watershed Needs Survey |
| EIIP | Emission Inventory Improvement Program |
| GHG | greenhouse gas |
| IPCC | Intergovernmental Panel on Climate Change |
| kg | kilogram |
| LACSD | Los Angeles County Sanitation Districts |
| N | nitrogen |
| $N_2O$ | nitrous oxide |
| NACWA | National Association of Clean Water Agencies |
| NDN | Nitrification/denitrification |
| USEPA | United States Environmental Protection Agency |
| WWTP | wastewater treatment plant |

# 1.0 Introduction

## 1.1 Background

In 2006 the California legislature established, and the Governor signed, the California Global Warming Solutions Act of 2006 (Assembly Bill 32 [AB 32]). AB 32 mandates that the California Air Resources Board (CARB) adopt rules and regulations to reduce greenhouse gas (GHG) emissions to 1990 levels by the year 2020. As defined in AB 32, GHGs include: carbon monoxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. These are the gases listed as GHGs in the Kyoto Protocol. To meet this goal, CARB must adopt regulations on mandatory emission reporting and verification beginning in January 2008 and must identify emissions reduction measures beginning in 2011. These regulations will become enforceable beginning in 2009 and 2012, respectively.

Based on CARB's initial regulatory concepts, the largest emitters of GHG emissions, such as the cement manufacturing, landfill, power/utility, refiner, and transportation sectors, will be required to report emissions beginning in 2009. Wastewater treatment plants (WWTPs) have not been initially identified as one of the largest emitting sectors. However, many WWTPs generate their power and may be included in the power/utility sector. In addition, California WWTPs anticipate that once CARB regulates the largest sources of emissions, it will then create additional regulations for the next-largest sources of emissions, which will likely include WWTPs. Previous national and state GHG emissions estimates have focused mainly on emissions of $CH_4$ and $N_2O$ from wastewater treatment and have identified wastewater treatment as one of the top ten $CH_4$ and $N_2O$ emitters in the nation and in the state of California.

## 1.2 Project Description

In a proactive approach to meeting future regulatory requirements, California wastewater agencies have formed the California Wastewater Climate Change Group (CWCCG), whose purpose is to respond to climate change and forthcoming regulations and to provide a unified voice for the California wastewater industry. The group, formed in May 2007, currently comprises 40 wastewater agencies and three wastewater organizations (the Bay Area Clean Water Agencies, the Southern California Alliance of Publicly Owned Treatment Works, and the Central Valley Clean Water Agencies). Together this group represents the majority of wastewater treated in the state of California.

The initial goals for this group are to identify the existing methodologies for estimating emissions from municipal WWTP processes and to develop a WWTP sector GHG emissions reporting protocol. This paper summarizes CWCCG's efforts to identify the existing methodologies for estimating emissions from municipal WWTP processes, which includes both domestic and industrial wastewater that is treated by a municipal WWTP. This paper also makes recommendations, which build upon the existing methodologies, for the

development of more accurate and appropriate methods to estimate both facility and statewide WWTP GHG emissions.

## 1.3 Objectives

Wastewater treatment is already recognized as a source of air pollutants and, therefore heavily regulated. The Intergovernmental Panel on Climate Change (IPCC) and others have developed protocols to estimate GHG emissions from wastewater on a gross basis. However, there is no existing protocol to estimate GHG emissions specifically from WWTPs at a facility level. The goal of this discussion paper is to identify the needs for a specific WWTP GHG emissions reporting protocol through the understanding of where California WWTP emissions come from, what estimation methods currently exist, and identifying gaps in existing methods. Initial research conducted by CWCCG members identified both $CH_4$ and $N_2O$ as the main GHG emissions from wastewater treatment. Therefore, this paper focuses mainly on $CH_4$ and $N_2O$ emissions.

Section 2.0 of this discussion paper describes the types of WWTP processes common to California and the expected GHG emissions. Section 3.0 provides an assessment of the existing methodologies to estimate WWTP emissions and where improvements can be made. Finally, Section 4.0 presents recommendations on what emissions should be covered in a WWTP protocol for California and also provides recommendations on methods to characterize facility level and statewide level GHG emissions. WWTPs will eventually be able to use a WWTP-specific emission reporting protocol to characterize facility baseline emissions, which will aid in the development of reduction strategies. A WWTP-specific protocol can also be used to characterize the statewide baseline emissions from WWTPs and will help the CWCCG determine if WWTPs should be a regulated source of GHG emissions.

Based on the findings and recommendations of this paper, the CWCCG intends to work cooperatively with both the California Climate Action Registry (CCAR) and CARB to develop an acceptable WWTP sector GHG emissions reporting protocol that will be recognized as the standard method for estimating WWTP process emissions.

# 2.0 WWTP Emissions

## 2.1 Types of Emissions at a WWTP

There are multiple sources of GHG emissions at a WWTP. CCAR, a non-profit voluntary registry for GHG emissions, categorizes emissions types as: direct, indirect, fugitive, and *de minimus* (CCAR, 2006).

### 2.1.1 Direct Emissions

CCAR defines direct emissions as emissions from sources that are owned or controlled by the reporting organization. Direct emissions result from stationary combustion, mobile combustion, and industrial processes. Stationary sources at WWTPs include boilers, emergency generators, and pumps that emit GHGs such as $CO_2$, $N_2O$, and $CH_4$ as a result of combustion processes. Mobile sources such as automobiles, trucks, off-road vehicles, and construction equipment also release the same types of GHG emissions due to combustion processes. Internationally accepted protocols have been established previously to estimate emissions from stationary and mobile combustion sources. The CCAR outlines methods to estimate direct GHG emissions from mobile and stationary combustion sources in their General Reporting Protocol (CCAR, 2006). Since methodologies for estimating emissions from mobile and stationary combustion sources already exist, these are not further discussed in this paper. However, references to applicable methodologies for estimating these emissions should be included in a WWTP sector GHG emissions reporting protocol.

Emissions from industrial processes are another subcategory of direct emissions. Emissions protocols for specific industrial processes such as the production of iron and steel, cement manufacturing, and the production of semi-conductor wafers are internationally recognized and are available through resources such as the GHG Protocol Initiative, UK Guidelines for the UK Emissions Trading Scheme, and CCAR. However, a protocol for WWTP process emissions has not yet been properly developed.

### 2.1.2 Indirect Emissions

CCAR defines indirect emissions as emissions that are a consequence of the actions of a reporting entity but are produced by sources owned or controlled by another entity. Indirect emissions result from the purchase of electricity, imported steam, district heating or cooling, and production of electricity from a cogeneration plant. Internationally accepted protocols have been established previously to estimate emissions associated with the identified indirect emission sources. For example, the CCAR outlines methods to estimate indirect emissions in its General Reporting Protocol (CCAR, 2006). Since methodologies for estimating emissions from indirect sources have already been developed for indirect emissions related to electricity, steam, heating and cooling, these methodologies are not further discussed in this paper. However, references to applicable methodologies for estimating these emissions should be included in a WWTP sector GHG emissions reporting protocol.

### 2.1.3 Fugitive Emissions

CCAR defines fugitive emissions as "intentional and unintentional releases of GHG emissions from joints, seals, gaskets, etc." Fugitive emissions result from specific industrial processes and can result from WWTP operations. Examples of GHG fugitive emission from WWTP processes are $CH_4$ leaks from digesters and associated equipment for solids handling (e.g., dewatering of anaerobically digested sludge).

### 2.1.4 *De Minimus* Emissions

CCAR defines *de minimus* emissions as a quantity of GHG emissions from a combination of sources and/or gases which, when summed, are considered insignificant (e.g., equal to less than 5 percent of an organization's total emissions). The category of *de minimus* emissions was defined to prevent overly burdensome emissions reporting. *De minimus* emissions are not further discussed in this report as these emissions are defined in detail in the CCAR General Reporting Protocol (CCAR, 2006).

## 2.2 WWTP Industry in California

The United States Environmental Protection Agency's (USEPA's) Office of Wastewater Management conducts the Clean Watershed Needs Survey (CWNS) every 4 years. Based on the most recently available data, in 2000, there were 577 wastewater treatment facilities in California treating approximately 6,600 million gallons per day. Based on the CWNS data, the majority of municipal WWTPs in California have primary sedimentation, followed by an aerobic secondary treatment process (e.g., activated sludge). The resulting primary and secondary sludge at an aerobic WWTP typically is sent to an anaerobic digester, dewatered, and the resulting biosolids are then sent offsite to a landfill or for reuse. Anaerobic treatment of wastewater at a WWTP (e.g., anaerobic lagoons) is also practiced by smaller communities and a few larger facilities. The types of GHG emissions that are expected from these typical wastewater process schemes are discussed in Sections 2.3 through 2.5.

## 2.3 $CO_2$ Emissions

WWTP $CO_2$ emissions, other than those from stationary and mobile combustion sources (discussed in Section 2.1.1), result from the combustion of sludge (i.e., incineration) or digester gas (i.e., flares, turbines, boilers, etc.). Both sludge and digester gas are types of biofuels or renewable energy fuel sources, and their resulting $CO_2$ emissions are generally accepted as "biogenic" carbon-neutral emissions or non-fossil fuel emissions. The general international practice for $CO_2$ emissions from the combustion of wastewater products such as sludge or digester gas is that these emissions should not be reported as GHG emissions and should be kept in a category separate from fossil fuel emissions, which are considered anthropogenic emissions. Based on this general practice, $CO_2$ emissions from WWTPs are not further discussed.

## 2.4 $CH_4$ Emissions

Existing international practice (IPCC, 2006) and CCAR practice recognizes $CH_4$ and $N_2O$ as the only GHG emissions from WWTP processes. Based on IPCC, $CH_4$ emissions from aerobic processes are expected to be limited and are dependent on the design and management of a system. A poorly-managed aerobic system may emit more $CH_4$ emissions than a well-managed system. The majority of wastewater within California is treated centrally through aerobic processes at treatment plants that are well-managed and regulated; therefore, $CH_4$ emissions from aerobic treatment are expected to be very minimal. The larger source of $CH_4$ emissions occurs from open anaerobic wastewater treatment processes, when the $CH_4$ produced is released directly to the atmosphere uncollected, uncontrolled, and without treatment, such as anaerobic lagoons, anaerobic reactors (e.g., digesters), or septic tanks. While $CH_4$ emissions from septic tanks can be significant, these emissions are not considered in this paper for inclusion in a WWTP protocol because septic tanks are not part of municipal WWTP operations.

$CH_4$ emissions also result from fugitive releases from solids handling processes, such as sludge digestion. Typical solids handling processes in California consist of anaerobic digestion of sludge with the capture of $CH_4$ emissions generated during digestion, which are then treated or controlled through flaring or some other combustion process to produce heat or power. Digested sludge is then dewatered before trucking offsite to a landfill or for reuse. Fugitive $CH_4$ emissions are expected to be small and may be considered *de minimus* by CARB and CCAR. Small amounts of direct $CH_4$ emissions may also be released as a result of incomplete combustion of digester gas.

## 2.5 $N_2O$ Emissions

$N_2O$ emissions result from nitrification/denitrification (NDN) processes at a WWTP. $N_2O$, as well as nitric oxide, are normal intermediate byproducts of denitrification, which is a process by which nitrite and nitrate are converted to nitrogen gas. $N_2O$ can also be produced under some nitrifying conditions via nitrifying microorganisms. In addition to the NDN process, $N_2O$ emissions can also result from natural denitrification of nitrogen-containing compounds in treated wastewater discharged to a receiving stream. As wastewater enters a river or other body of water, the remaining nitrogen species in the effluent can naturally be converted and released as $N_2O$. Small amounts of $N_2O$ emissions may also come from the combustion of digester gas.

## 2.6 Summary of WWTP Process Emissions

Based on the typical WWTP processes identified in Section 2.1.4 for California and the discussion above, the expected GHG emissions are $CO_2$, $CH_4$, and $N_2O$. Of these three GHGs, accepted methods already exist to estimate $CO_2$ emissions from direct stationary combustion and indirect sources. In addition, process $CO_2$ emissions from most WWTP processes typically is considered biogenic and is either not reported or is kept separate from other GHG emissions. Therefore, the CWCCG is focusing on development of estimation methods for $CH_4$ and $N_2O$ emissions to be included in a WWTP sector GHG emissions reporting protocol.

When comparing the GHGs emitted at a WWTP, $CH_4$ and $N_2O$ have 100-year global warming potentials of 23 and 296, respectively (IPCC, 2001). The 100-year global warming potential is a measurement of the heat-trapping capacity of a GHG when compared to that of $CO_2$. Therefore, $CH_4$ and $N_2O$ are more potent GHGs. The sources of $CH_4$ and $N_2O$ emissions at a WWTP are summarized in Table 2-1.

**TABLE 2-1**
GHG Emission Sources for WWTP Processes
*Discussion Paper for a Wastewater Treatment Plant Sector Greenhouse Gas Emissions Reporting Protocol*

| Process Step | Expected GHG Emissions |
|---|---|
| Primary Treatment | None expected |
| Secondary Treatment | None expected from well-managed aerobic processes |
| | $CH_4$ from uncollected or uncontrolled anaerobic wastewater treatment processes (e.g., anaerobic lagoons) |
| Advanced Treatment | $N_2O$ emissions from NDN process |
| Solids Handling | Fugitive $CH_4$ emissions from sludge handling processes such as digestion (these emissions may be considered *de minimus*) |
| | $CH_4$ emissions resulting from incomplete combustion of digester gas |
| Effluent Discharge | $N_2O$ emissions from denitrification of nitrogen species originating from wastewater effluent in receiving water |

# 3.0 Review of Existing Protocols

A thorough review of all existing protocols was conducted as part of this effort to identify resources for estimating GHG emissions from WWTP processes. Most current protocols originate from the GHG Protocol Initiative. The GHG Protocol Initiative is a partnership between the World Resources Institute and the World Business Council for Sustainable Development and is internationally recognized as the most widely-used accounting tool for GHG emissions inventories. Some of the protocols used by the CCAR, the California Energy Commission (CEC), and the USEPA originate from the GHG Protocol Initiative. However, the GHG Protocol Initiative does not have a protocol for estimating GHG emissions from WWTP processes.

Other sources of GHG protocols include:

- The Intergovernmental Panel for Climate Change: *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006)
- U.K. Department of Environment, Food, and Rural Affairs: The U.K. Emissions Trading Scheme
- Emission Inventory Improvement Program (EIIP): *Technical Report Series Volume 8: Estimating* Greenhouse *Gas Emissions* (EIIP, 1999)
- CCAR: *General Reporting Protocol* (CCAR, 2006)
- USEPA: *Inventory of U.S. Greenhouse Gas Emissions and Sinks (1990-2005)* (USEPA, 2007)
- CEC: *Inventory of California Greenhouse Gas Emissions and Sinks (1990-2004)* (CEC, 2006)

The IPCC has developed a methodology for estimating emissions from wastewater treatment. EIIP presents a modified version of the IPCC methodology in their report. The USEPA and CEC have conducted national- and state-level estimates of wastewater treatment-related GHG emissions using the IPCC and EIIP as a basis with some modifications. The USEPA Climate Leaders Program is also in the process of developing a wastewater treatment plant protocol, which will also be based on the IPCC methodology. More detailed description of the IPCC, USEPA, and CEC methodologies is provided below.

## 3.1 IPCC Methodology

### 3.1.1 $CH_4$ Emissions

The current IPCC methodology (2006) presents a general, top-down approach to estimating $CH_4$ emissions from domestic wastewater that is generally based on the factors summarized in Table 3-1. The full IPCC methodology is provided in Appendix A.

**TABLE 3-1**
IPCC 2006 Inventory Methodology to Estimate $CH_4$ Emissions from Domestic Wastewater Treatment
*Discussion Paper for a Wastewater Treatment Plant Sector Greenhouse Gas Emissions Reporting Protocol*

| Factor | Value | Units |
|---|---|---|
| Fraction of population based on type | Location-specific: (i.e., rural, urban) | Fraction |
| Degree of utilization of a specific treatment/discharge pathway | Location-specific: (i.e., septic tank, latrine, sewer, other, or none) | Fraction |
| Emission factor for $CH_4$ from BOD | Calculated, or<br>Default: 0.6 kg $CH_4$/kg BOD,<br>0.25 kg $CH_4$/kg COD | kg $CH_4$ per kg BOD or COD |
| • Maximum $CH_4$ producing capacity | Country-specific | kg $CH_4$/kg BOD |
| • $CH_4$ correction factor | Based on treatment system processes (i.e., centralized aerobic treatment, anaerobic digestion, septic system, etc.) | Fraction |
| Total Organically Degradable Material | Calculated | kg BOD/yr |
| • Population | Country-specific | No. people |
| • Per capita BOD | Country-specific: 85 g BOD/person-day for the United States | g BOD/person-day |
| • Correction factor for industrial BOD discharged to sewers | Location-specific: 1.25 for industrial wastewater collection, 1.00 if uncollected | Fraction |
| Removal of organics as sludge | Location-specific | kg BOD/yr |
| Amount of $CH_4$ recovered | Location-specific | kg $CH_4$/yr |

Notes:

BOD = biochemical oxygen demand.
$CH_4$ = methane.
COD = chemical oxygen demand.

The IPCC method can be used to estimate all of the wastewater emissions from a country by summing the emissions associated with specific populations and the specific types of treatment employed. For instance, in the United States, 78 percent of the population is considered "high urban" and, of that population, 95 percent is served by sewer system. Furthermore, the wastewater that flows through a sewer system can be treated by a variety of treatment processes (e.g., a centralized aerobic treatment plant followed by anaerobic digestion, lagoon, etc.). The emissions that result from different subsets of the population and the different subsets of treatment processes are then summed to form an aggregate nationwide estimate of $CH_4$ emissions from ALL wastewater treated, not just wastewater treated at a WWTP.

This method does not account for $CH_4$ emissions resulting from incomplete combustion of digester gas nor does it account for $CH_4$ fugitive emissions (e.g., from digestion or dewatering), which are expected to be small. The emissions from biosolids sent offsite to landfills or incinerators or from biosolids used in agriculture are also not accounted for. However, emissions from biosolids sent offsite are estimated at the downstream point of emission and are included in other protocols (e.g., landfill and agriculture emissions protocols).

This method is a top-down approach that is based on population and assumed contributions of biochemical oxygen demand (BOD) per capita. Influent wastewater BOD concentrations on a plant-by-plant basis are not taken into consideration.

### 3.1.2 $N_2O$ Emissions

The current IPCC methodology (2006) for $N_2O$ also represents a top-down approach. $N_2O$ is estimated from two pathways—emissions from treated wastewater effluent discharged to a receiving water body and emissions from NDN processes. The factors used in estimating $N_2O$ emissions from these two sources are summarized in Table 3-2 and Table 3-3.

**TABLE 3-2**
IPCC 2006 Inventory Methodology to Estimate $N_2O$ Emissions from Domestic Wastewater Treatment
*Discussion Paper for a Wastewater Treatment Plant Sector Greenhouse Gas Emissions Reporting Protocol*

| Factor | Value | Units |
|---|---|---|
| Nitrogen in the effluent discharged to the aquatic environment | Calculate | kg N/yr |
| • Population | Country-specific | No. people |
| • Protein consumption | Country-specific: 42.1 kg/person-yr for U.S. | kg/person-yr |
| • Fraction of nitrogen in protein | Default: 0.16 kg N/kg protein | kg N/kg protein |
| • Factor for non-consumed protein added to wastewater | Country-specific: 1.4 for developed countries | Fraction |
| • Factor for industrial and commercial co-discharge protein into the sewer system | Default: 1.25 | Fraction |
| • Nitrogen removed with sludge | Default: 0 kg N/yr | kg N/yr |
| Emission factor for $N_2O$ from discharged wastewater | Default: 0.005 kg $N_2O$-N/kg N | kg $N_2O$-N/kg N |

**TABLE 3-3**
Factors Used by IPCC to Estimate $N_2O$ Emissions from NDN Processes
*Discussion Paper for a Wastewater Treatment Plant Sector Greenhouse Gas Emissions Reporting Protocol*

| Factor | Value | Units |
|---|---|---|
| Population | Country-specific | No. people |
| Degree of utilization of modern centralized WWTP | Location specific | Percent |
| Fraction of industrial and commercial co-discharged protein | Default: 1.25 | Fraction |
| Emission Factor | Default: 3.2 g $N_2O$/person-year | g $N_2O$/person-yr |

Source: IPCC, 2006.

This method assumes that the majority of $N_2O$ emissions at a WWTP are emissions from treated wastewater discharged to a receiving body, based on a factor of 0.005 kg $N_2O$-N/kg nitrogen in the effluent. The IPCC states that direct emissions from NDN processes at WWTPs may be considered a minor source and that these emissions are typically much

smaller than those from the effluent. Furthermore, direct emissions of $N_2O$ from wastewater processes are predominantly associated with advanced centralized wastewater treatment plants. Despite IPCC's conclusion that process $N_2O$ emissions are small, $N_2O$ emissions from WWTP processes have not been studied extensively to date and may be influenced by process conditions.

If a country is including $N_2O$ from NDN processes in its estimate, then the amount of nitrogen associated with these emissions must be back-calculated and subtracted from the amount of nitrogen in the effluent.

## 3.2 USEPA Methodology

The USEPA has conducted an estimate of emissions for the entire United States. The most recent estimate was published in April 2007 for emissions from 1990 to 2005 (USEPA, 2007). As estimated, wastewater treatment is the seventh highest contributing sector to national $CH_4$ emissions and the sixth highest contributing sector to national $N_2O$ emissions. The method used in the USEPA's inventory is based on the IPCC approach and is provided in Appendix B.

### 3.2.1 $CH_4$ Emissions

The estimate of total national $CH_4$ emissions from domestic wastewater treatment completed by the USEPA accounts for emissions from septic systems, centrally treated aerobic systems, centrally treated anaerobic systems, and anaerobic digesters. The population served by each of these treatment system types and the percent of wastewater treated by each of these treatment system types was determined from data from the United States Census Bureau and the USEPA CWNS. Some of the location-specific factors used by the USEPA are included in Table 3-4.

**TABLE 3-4**
Factors Used by USEPA to Estimate $CH_4$ Emissions from Domestic Wastewater Treatment
*Discussion Paper for a Wastewater Treatment Plant Sector Greenhouse Gas Emissions Reporting Protocol*

| Factor | Value |
|---|---|
| Degree of utilization of a specific treatment/discharge pathway: | |
| • Percent of wastewater treated in septic systems | 21 percent |
| • Percent of wastewater treated centrally aerobically | 74 percent |
| • Percent of wastewater treated centrally anaerobically | 5 percent |
| Emission Factor for $CH_4$ from BOD | Calculated |
| • Maximum $CH_4$ producing capacity | 0.6 kg $CH_4$/kg BOD |
| • $CH_4$ correction factor | -- |
| – Septic systems | 0.5 |
| – Central aerobic treatment | 0.0 or 0.3 |
| – Central anaerobic treatment | 0.8 |

Source: USEPA, 2007 (see Appendix B).

Based on estimates of national GHG emissions from wastewater treatment, conducted by Los Angeles County Sanitation Districts (LACSD), using the data and methodology outlined by the USEPA (2007), there are no expected emissions from centralized aerobic treatment processes (Figure 3-1). The majority of $CH_4$ emissions from wastewater treatment in the United States come from septic tanks (76 percent) which, as previously discussed, are not part of a municipal WWTP. Uncontrolled $CH_4$ emissions from anaerobic wastewater treatment systems, such as anaerobic lagoons, account for 23 percent of the wastewater treatment sector emissions, and $CH_4$ emissions from controlled anaerobic sludge digesters via incomplete combustion of digester gas accounts for only 1 percent. The calculations completed by LACSD are included in Appendix C.

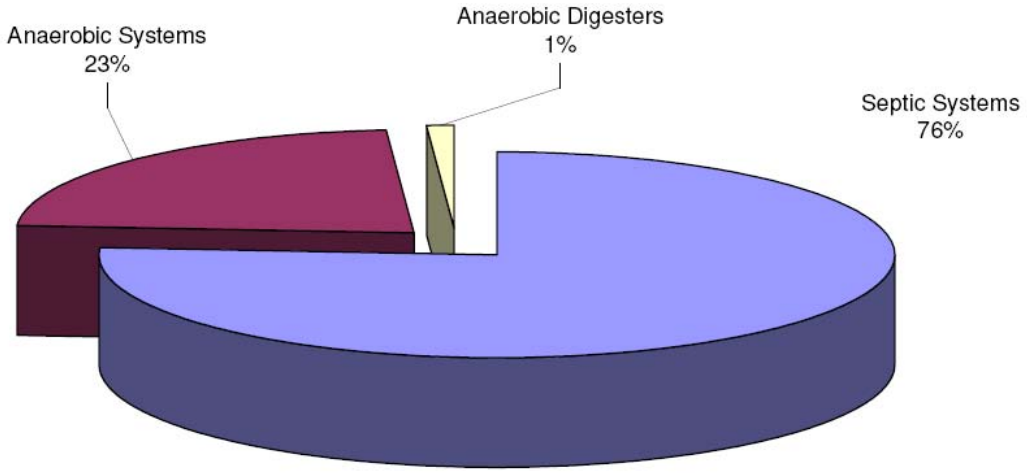



**FIGURE 3-1**
National Wastewater Treatment $CH_4$ Emission Sources

There are several factors used by the USEPA that may be considered overly conservative, resulting in an inflated estimate of $CH_4$ emissions. In January 2007, the National Association of Clean Water Agencies (NACWA) submitted a comment letter to the USEPA with suggestions on where to improve the emissions estimate (attached as Appendix D). NACWA's major comments included the following:

- The USEPA estimated that 5 percent of centrally treated systems are anaerobic systems. NACWA argued that true anaerobic systems are seldom, if ever, used and a more reasonable estimate of 0.5 percent should be used.
- The maximum $CH_4$-producing capacity of 0.6 kg $CH_4$/kg BOD removed is overly conservative and is more accurately calculated to be 0.4 kg $CH_4$/kg BOD removed.
- The calculations assume 100 percent complete removal of all influent BOD. Treatment plants are not 100 percent efficient. A more reasonable estimate of overall performance of 90 percent should be used.

The proposed changes outlined by NACWA results in a more appropriate estimate of national wastewater $CH_4$ emissions and would significantly reduce USEPA's national estimate.

### 3.2.2 $N_2O$ Emissions

The USEPA estimated the total national $N_2O$ emissions from domestic wastewater using the IPCC 2006 methodology described above, also taking into account the nitrogen content in biosolids, which is not available for conversion to $N_2O$. Estimates for $N_2O$ emissions from effluent conversion, NDN processes, and conventional treatment without NDN processes were all conducted.

Based on estimates of national GHG emissions from wastewater treatment conducted by LACSD using the data and methodology outlined by the USEPA (2007), approximately 97.2 percent of $N_2O$ emissions result from the conversion of nitrogen compounds from treated wastewater effluent in a receiving water body (Figure 3-2). Roughly 2.8 percent of emissions come from conventional activated sludge treatment processes, and less than 0.1 percent come from NDN processes. The calculations completed by LACSD are included in Appendix C.

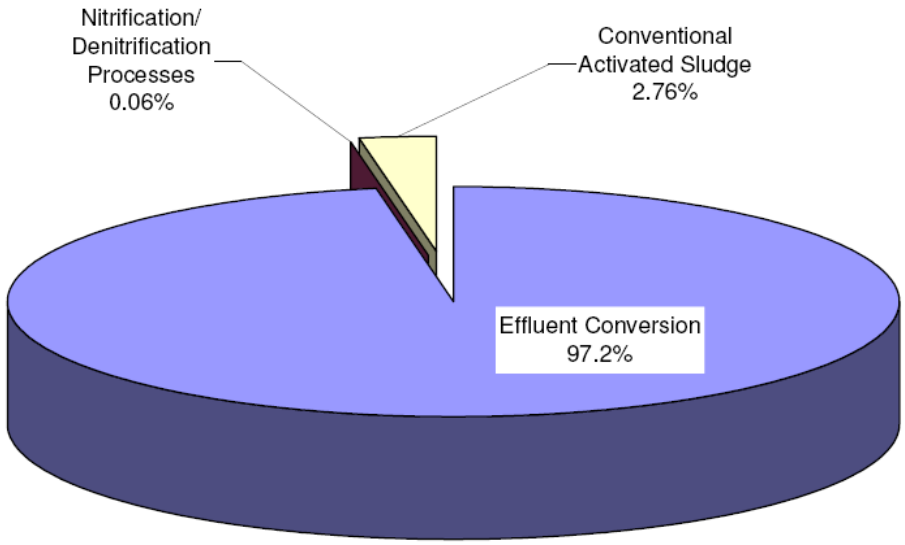



**FIGURE 3-2**
National Wastewater Treatment $N_2O$ Emission Sources

NACWA also reviewed the USEPA's estimation of $N_2O$ and concluded that several overly conservative factors were resulting in overestimation of $N_2O$ emissions:

- In the method used by the USEPA, nitrogen content in wastewater is calculated based on annual protein consumption. This method results in a per capita nitrogen load of 9.43 kg N/person-year. This method is at odds with the per capita nitrogen discharge rate to wastewater from the Metcalf & Eddy standard reference of 5.48 kg N/ person-year.
- The USEPA calculations also include a factor of 1.25 (from the IPCC methodology) to account for industrial discharges. NACWA argues that industrial discharges are inherently accounted for in both the protein consumption approach and in the per capita nitrogen load approach.

The emissions factor used by USEPA to estimate $N_2O$ from effluent conversion should also be further reviewed. The proposed changes outlined by NACWA would result in a significantly lower estimate of $N_2O$ wastewater treatment emissions by roughly 50 percent.

## 3.3 CEC Methodology

The CEC has previously conducted estimates of GHG emissions on a statewide level. The CEC statewide estimate includes emissions from wastewater treatment based on the method outlined by EIIP (1999), which is a simplified version of the IPCC approach. The latest CEC estimate for 2004 (published in 2006) ranks wastewater treatment as the fourth-largest contributing sector to $CH_4$ emissions and the third-largest contribution sector to $N_2O$ emissions in the state of California.

### 3.3.1 $CH_4$ Emissions

$CH_4$ emissions were calculated based on the factors shown in Table 3-5.

**TABLE 3-5**
CEC Inventory Methodology to Estimate $CH_4$ Emissions from Wastewater Treatment
*Discussion Paper for a Wastewater Treatment Plant Sector Greenhouse Gas Emissions Reporting Protocol*

| Factor | Value |
|---|---|
| State Population | No. People |
| Per capita BOD | 65 g BOD/person/day |
| Fraction of BOD that degrades anaerobically | Default: 16.25% |
| Emission Factor | Default: 0.6 kg $CH_4$/kg BOD |

Source: CEC, 2006.

This method does not take into account the varying amount of emissions that result from different treatment processes (i.e., low to no emission from centralized aerobic treatment plants). Further, the CEC method assumes that 16.25 percent of all BOD degrades anaerobically. This default factor accounts for the anaerobic degradation that takes place in septic systems. The emission factor of 0.6 kg $CH_4$/kg BOD also does not take into account any correction factors based on treatment method. For instance, in the USEPA estimate, the emission factor included a 0.0 to 0.3 correction factor for aerobic treatment.

Based on these findings, it is likely that the CEC method overestimates the amount of $CH_4$ emissions from WWTPs in the state of California.

### 3.3.2 $N_2O$ Emissions

The method used by CEC to estimate $N_2O$ emissions is also a more simplified version than that used by USEPA (2007). $N_2O$ emissions were calculated based on the factors shown in Table 3-6.

This method assumes that all $N_2O$ emissions result from discharged wastewater and does not account for $N_2O$ emissions from NDN processes or conventional activated sludge plants. It is unclear whether this estimate includes factors to account for industrial/

commercial and non-consumed protein contributors, such as those included in the USEPA estimate. Finally, the effluent conversion factor of 0.01 kg $N_2O$-N/kg N is an order of magnitude larger than the emission factor used by IPCC and the USEPA (0.005 kg $N_2O$-N/kg N). Based on these findings, it is likely that the CEC estimate of $N_2O$ emissions from wastewater in the state of California is overestimated.

**TABLE 3-6**
CEC Inventory Methodology to Estimate $N_2O$ Emissions from Domestic Wastewater Treatment
*Discussion Paper for a Wastewater Treatment Plant Sector Greenhouse Gas Emissions Reporting Protocol*

| Factor | Value |
|---|---|
| Population | No. people |
| Protein Consumption | 42.1 kg/person-yr |
| Fraction of nitrogen in protein | 0.16 kg N/kg protein |
| Emission factor for $N_2O$ from discharged wastewater | 0.01 kg $N_2O$-N/kg N |

Source: CEC, 2006.

# 3.4 Applicability of Protocols

## 3.4.1 Facility-level Protocols

The IPCC protocol reviewed in Section 3.1 represents the only available methodology to estimate facility-level wastewater treatment GHG emissions. This protocol was developed to estimate national-level emissions from wastewater treatment and has been modified by both the USEPA and CEC in the development of their national- and state-level estimates. Although the IPCC approach may provide a good starting point for facilities to estimate their emissions, for several reasons, the IPCC approach may not be the best possible approach for individual facility estimates.

The IPCC approach is a top-down approach that does not use facility-specific information; rather, it uses general assumptions such as the amount of protein consumed per capita per year and the amount of BOD generated per capita per year. This approach on a facility level will not be as accurate as an approach based on facility-specific data, such as influent nitrogen or BOD concentrations. The IPCC approach was also developed to estimate emissions from a variety of treatment processes. For example, a correction factor is applied in estimating $CH_4$ emissions based on whether the process is a septic tank, a centralized aerobic plant, a centralized anaerobic plant, etc. This approach may not be ideal for a single facility using one type of treatment process (e.g., centralized aerobic treatment). The IPCC approach also does not include all sources of fugitive $CH_4$ emissions on a plant-by-plant basis.

The IPCC estimation method for $N_2O$ emissions from NDN processes may not be accurate. The IPCC states that process $N_2O$ emissions may be considered a minor source and that the emission factor used is uncertain because it is based on the results of only one field test. $N_2O$ emissions are influenced by process conditions and are highly variable. Therefore, an emission factor that considers potential $N_2O$ emissions based on process conditions or a

plant-specific emission factor based on site-specific testing would provide a better estimate. In addition, the IPCC approach and the modified approach used by the USEPA and CEC use overly conservative factors that result in an inflated estimate of $N_2O$ emissions.

### 3.4.2 State-level Protocols

Since facility-level data are not known for every WWTP in California, a top-down approach is more appropriate to estimate the state-level aggregate wastewater treatment GHG emissions. The CEC approach is a top-down approach; however, inconsistencies with the current IPCC approach and the use of overly conservative factors result in the overestimation of wastewater treatment emissions. The CEC approach does not differentiate between types of treatment facilities and processes, which is appropriate for a state-level estimate. The modified approach used by the USEPA may be a more appropriate method to use for the state of California.

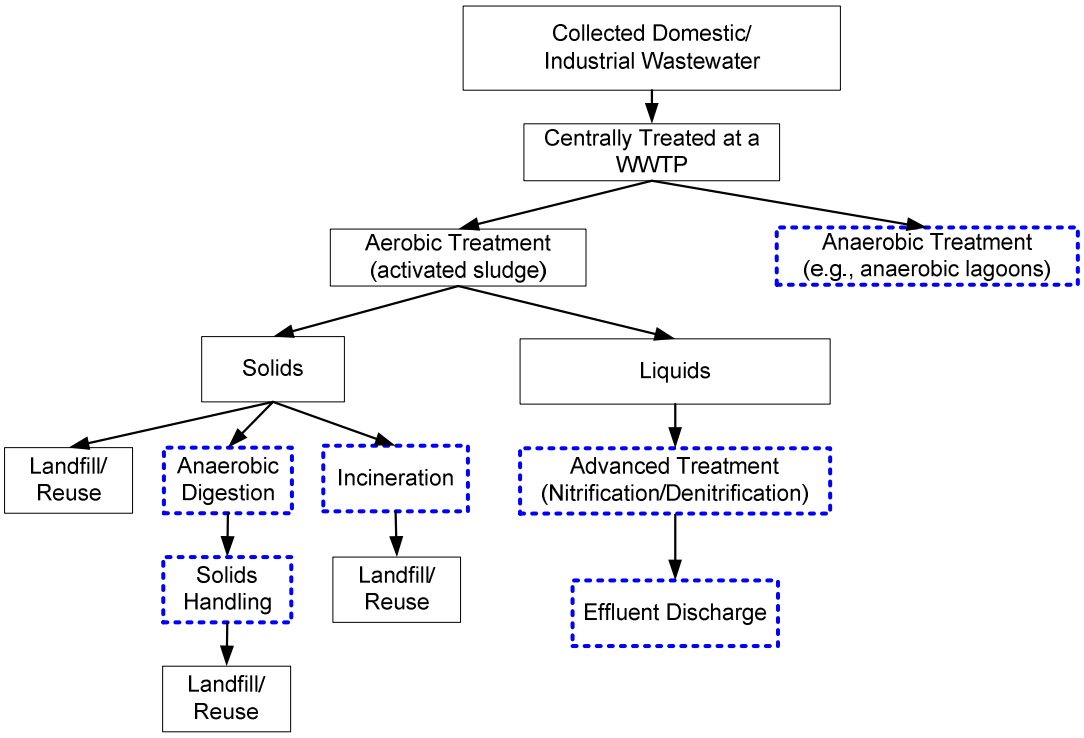
# 4.0 Recommendations

## 4.1 Accounting Boundaries

Figure 4-1 identifies WWTP and discharge pathways for typical California WWTPs and the expected sources of emissions that are recommended to be included in a WWTP protocol. $CH_4$ and $N_2O$ emissions are expected from anaerobic treatment processes, sludge handling processes (anaerobic digestion and incineration), NDN processes, and from the effluent discharged to an aquatic environment.

The protocol boundaries for a WWTP should not include emissions from offsite anaerobic treatment, such as a septic tank, since these systems are not included in municipal WWTP operations. The protocol boundaries also should not include emissions from landfill or use of biosolids. As previously discussed, the emissions from landfill or use of biosolids are accounted for in protocols used by other sectors (e.g., landfill and agriculture). Special precautions against double-counting of emissions from any source category need to be included in a WWTP sector GHG emissions reporting protocol. Emissions from collection systems are not included in the IPCC protocol or in the USEPA or CEC estimates. Based on this precedent, collection system emissions should not be included in a WWTP sector reporting protocol.

**FIGURE 4-1**
California WWTP and Discharge Pathways and Emission Sources




Note: Dashed blue boxes indicate sources of $CH_4$ and $N_2O$ emissions recommended to be included in a WWTP sector GHG emissions reporting protocol.

## 4.2 Characterizing Facility Baseline Emissions

To better estimate the facility specific emissions for all WWTPs in California, it is recommended that the CWCCG develop a protocol with a variety of methodologies to estimate $CH_4$ and $N_2O$ process emissions, which will allow for flexibility in the level of detail and accuracy. Smaller WWTPs with fewer emissions may not need to do a very detailed site-specific evaluation. However, larger WWTPs may want a higher level of detail and accuracy. The protocol should also provide flexibility based on type of treatment process. For example, WWTPs that have a denitrification process may want to use a more site-specific approach. The protocol should provide guidance to WWTPs as to what method is best suited for a particular plant.

### 4.2.1 $CH_4$

Based on the national inventory conducted by the USEPA (2007) and considering the typical WWTP processes used in California (aerobic treatment and anaerobic digestion), $CH_4$ emissions are expected to be very small and may be considered *de minimus* by CCAR and CARB. The majority of $CH_4$ emissions identified in the USEPA inventory come from anaerobic treatment such as lagoons and septic tanks. Septic tanks are not part of a municipal WWTP and should not be included in a WWTP specific emissions reporting protocol. However, emissions from lagoons should be included. Fugitive emissions from digester leaks, dewatering activities, and emissions from incomplete combustion of digester gas should be considered for inclusion in a WWTP protocol.

The following methods are recommended for further development of a WWTP protocol to estimate $CH_4$ emissions:

- **Option 1: USEPA Approach/IPCC Approach**. Smaller wastewater treatment facilities that are not expecting to be required to submit an inventory to CARB may be able to use the existing top-down approach outlined by the USEPA (2007). In such a case, no plant-specific sampling and analysis would be required. It should be noted, however, that this option will result in conservative emissions estimates. Guidance should be provided in the protocol to help determine whether this option is appropriate for a given situation.
- **Option 2**: **USEPA Approach with Updated Default Values**. Recognizing that the approach in Option 1 will lead to conservative emissions estimates, this option would allow a treatment plant to make a more accurate emissions estimate by using more accurate factors. The updates to the USEPA approach should be based on the NACWA findings. This may be more appropriate for large wastewater facilities that use aerobic processes and that want a more accurate estimate.
- **Option 3**: **Complete Emissions Inventory/Sampling-based Approach**. For anaerobic plants, or those with potentially high $CH_4$ emissions, a more site-specific emissions inventory program may be required. This program may consist of source testing and modeling of anaerobic sources and fugitive sources. This approach is a source-specific, bottom-up approach.

### 4.2.2 $N_2O$

Similar to the recommendations for estimating $CH_4$ emissions, a variety of methods should be developed for estimating $N_2O$ emissions. The IPCC method (2006) states that the majority

of $N_2O$ emissions are expected to be from treatment plant effluent and that NDN process emissions should be small. However, as discussed, $N_2O$ process emissions are heavily influenced by process conditions and have not been studied extensively. The top-down approach of estimating $N_2O$ emissions based on protein consumption may not provide an accurate estimate.

Modeling is a potential approach to establishing better $N_2O$ emissions estimates. There is a new modeling tool for estimating $N_2O$ emissions from NDN processes called Activated Sludge Model-Nitrogen (ASMN) developed by Hiatt, et al. (2007a-b). This new model is the only comprehensive model available to calculate $N_2O$ emissions and was built upon previous activated sludge models developed by Grady and Gujer (Grady et al., 1986; Gujer et al., 1999). The input to the model is influent nitrogen concentration. $N_2O$ emissions are estimated based on process kinetics. Combined with a computer solution, this new model can provide a tool to evaluate plant-specific $N_2O$ emissions. Thus far, only lab-scale testing of this model has been performed. The emissions estimated by this model should be calibrated and verified with facility level in-field testing.

Considering the availability of this model, the following methods for estimating $N_2O$ WWTP emissions are recommended for further development in a protocol:

- **Option 1: USEPA Approach/IPCC Approach**. Smaller wastewater treatment facilities that are not expecting to be required to submit an inventory to CARB may be able to use the existing top-down approach outlined by the USEPA (2007). This estimate will use the existing knowledge and will not require plant-specific sampling or further detailed analysis. Guidance should be provided in the protocol to help determine whether this option is appropriate for a given situation.
- **Option 2**: **USEPA Approach with Updated Default Values**. Recognizing that the approach in Option 1 will lead to conservative emissions estimates, this option would provide a treatment plant with a more accurate emissions estimate by using more factors that are not overly conservative. The updates to the existing USEPA approach should be based on the NACWA findings.
- **Option 3: Mass Balance Approach with New Emission Factors**. The new model described above can be used to develop general emissions factors for different classes of WWTPs based on size and treatment schemes. A WWTP could then estimate its emissions using the general emission factor that most closely represents its operations. This approach will require in-field testing at a range of WWTPs to calibrate the model.
- **Option 4: Model and Source Test**. This approach will provide a WWTP with the most site-specific emissions estimate. Using this approach, a facility will conduct source testing at their WWTP and input those results into the model to develop a more accurate estimate of $N_2O$ emissions from their facility.

This proposed approach for protocol development will allow flexibility for treatment plants to develop a more general emissions estimate down to a site-specific estimate dependent on their preference.

## 4.3 Characterizing Statewide Aggregate Emissions

As discussed in Section 3.4.2, a more accurate statewide aggregate emissions estimate can be calculated using a top-down approach with refined factors based on the USEPA approach (2007) rather than the existing CEC approach. The CEC approach is a simplified approach, which may result in overestimation of WWTP emissions.

# 5.0 Summary

GHG emissions from WWTPs in California are expected to be:

- $CO_2$ from combustion sources (to be estimated using existing protocols, as appropriate, such as the CCAR General Reporting Protocol or the CCAR Power/Utility Reporting Protocol).
- $CO_2$ from indirect sources, e.g., purchased electricity (to be estimated using existing protocols, as appropriate such as the CCAR General Reporting Protocol).
- $CH_4$ emissions that are uncollected or controlled from anaerobic secondary wastewater treatment processes.
- $CH_4$ fugitive emissions from solids handling processes (e.g., anaerobic digestion of sludge and sludge dewatering).
- $CH_4$ emissions from the incomplete combustion of digester gas.
- $N_2O$ emissions from NDN processes.
- $N_2O$ emissions from wastewater effluent in receiving aquatic environments.

The IPCC has developed a method for estimating wastewater treatment emissions on a national scale but, as discussed in this paper, this method is not the most appropriate for estimating emissions on an individual facility-by-facility basis. In addition, as discussed in Section 3.0, the IPCC method uses overly conservative values that can lead to overestimation of $N_2O$ emissions and does not account for all fugitive sources of $CH_4$ emissions. In light of coming regulations on emissions inventories, WWTPs need an approach appropriate for individual facilities so that they can better assess their GHG emissions footprint and identify where there is potential to reduce emissions.

The proposed approach for development of $CH_4$ and $N_2O$ estimating methods for WWTPs is to identify multiple methodologies from which a WWTP can choose based on the size of the plant, its treatment processes and its expected emissions. The most conservative estimate can be calculated using the existing top-down approach provided by IPCC and used by USEPA and CEC. Increased accuracy can be achieved by using emission factors that are more specific to individual plant operations.

$CH_4$ emissions are expected to be very minor at most plants in California if a plant is using aerobic secondary treatment processes. If this is the case, emissions can most conservatively be estimated using the first recommended option (Option 1: USEPA Approach/IPCC Approach), which is to estimate emissions using the USEPA method. The second option (Option 2: USEPA Approach with Updated Default Values) is the USEPA method with refined factors, based on the findings of NACWA. The final option, which will result in the most accurate estimate of $CH_4$ emissions, would be to conduct site-specific source testing and modeling (Option 3: Complete Emissions Inventory/Sampling-based Approach). This

option might be preferred for treatment plants using anaerobic processes with uncollected and uncontrolled methane emissions that expect their $CH_4$ emissions to be significant.

The first two recommended options for estimating $N_2O$ emissions are the same as for $CH_4$ emissions using the USEPA approach. These methods are the most conservative. The development of a new model by Hiatt et al. (2007a-b) for estimating $N_2O$ emissions provides a method for more accurate site-specific estimates. As proposed, Option 3: Mass Balance Approach with New Emission Factors, for $N_2O$ emissions estimates would use the new ASMN model to develop general emission factors for different classes of WWTPs. WWTP facilities could then estimate their emissions using the emission factor that most closely represent their operations. The final recommended option for estimating $N_2O$ emissions (Option 4: Model and Source Test) is to develop a site-specific emissions estimate. This option would require a facility to conduct site-specific source testing, followed by modeling to evaluate site-specific emissions.

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# Appendix A
# IPCC Wastewater Treatment Methodology

# CHAPTER 6

# WASTEWATER TREATMENT AND DISCHARGE

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# 6 WASTEWATER TREATMENT AND DISCHARGE

## 6.1 INTRODUCTION

Wastewater can be a source of methane ($CH_4$) when treated or disposed anaerobically. It can also be a source of nitrous oxide ($N_2O$) emissions. Carbon dioxide ($CO_2$) emissions from wastewater are not considered in the *IPCC Guidelines* because these are of biogenic origin and should not be included in national total emissions. Wastewater originates from a variety of domestic, commercial and industrial sources and may be treated on site (uncollected), sewered to a centralized plant (collected) or disposed untreated nearby or via an outfall. Domestic wastewater is defined as wastewater from household water use, while industrial wastewater is from industrial practices only.[1] Treatment and discharge systems can sharply differ between countries. Also, treatment and discharge systems can differ for rural and urban users, and for urban high income and urban low-income users.

Sewers may be open or closed. In urban areas in developing countries and some developed countries, sewer systems may consist of networks of open canals, gutters, and ditches, which are referred to as open sewers. In most developed countries and in high-income urban areas in other countries, sewers are usually closed and underground. Wastewater in closed underground sewers is not believed to be a significant source of $CH_4$. The situation is different for wastewater in open sewers, because it is subject to heating from the sun and the sewers may be stagnant allowing for anaerobic conditions to emit $CH_4$. (Doorn *et al*., 1997).

The most common wastewater treatment methods in developed countries are centralized aerobic wastewater treatment plants and lagoons for both domestic and industrial wastewater. To avoid high discharge fees or to meet regulatory standards, many large industrial facilities pre-treat their wastewater before releasing it into the sewage system. Domestic wastewater may also be treated in on-site septic systems. These are advanced systems that may treat wastewater from one or several households. They consist of an anaerobic underground tank and a drainage field for the treatment of effluent from the tank. Some developed countries continue to dispose of untreated domestic wastewater via an outfall or pipeline into a water body, such as the ocean.

The degree of wastewater treatment varies in most developing countries. In some cases industrial wastewater is discharged directly into bodies of water, while major industrial facilities may have comprehensive in-plant treatment. Domestic wastewater is treated in centralized plants, pit latrines, septic systems or disposed of in unmanaged lagoons or waterways, via open or closed sewers. In some coastal cities domestic wastewater is discharged directly into the ocean. Pit latrines are lined or unlined holes of up to several meters deep, which may be fitted with a toilet for convenience. Figure 6.1 shows different pathways for wastewater treatment and discharge.

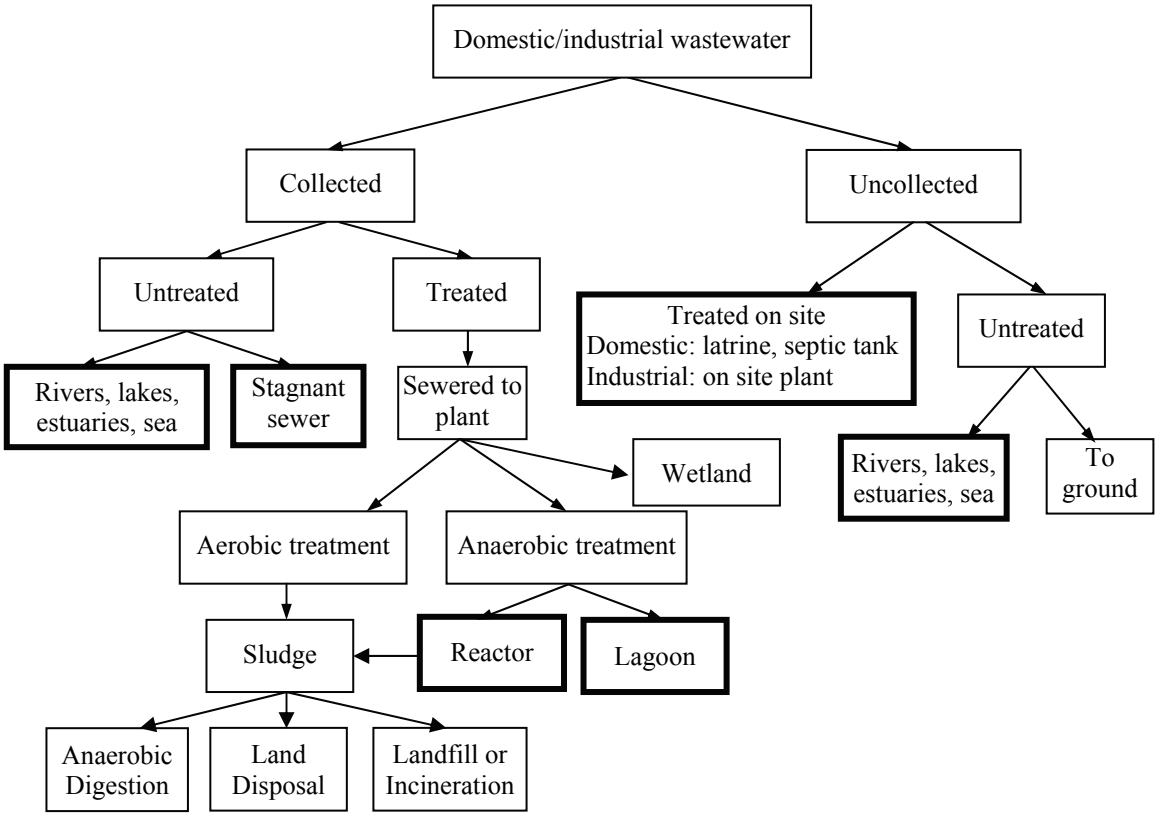
Centralized wastewater treatment methods can be classified as primary, secondary, and tertiary treatment. In primary treatment, physical barriers remove larger solids from the wastewater. Remaining particulates are then allowed to settle. Secondary treatment consists of a combination of biological processes that promote biodegradation by micro-organisms. These may include aerobic stabilisation ponds, trickling filters, and activated sludge processes, as well as anaerobic reactors and lagoons. Tertiary treatment processes are used to further purify the wastewater of pathogens, contaminants, and remaining nutrients such as nitrogen and phosphorus compounds. This is achieved using one or a combination of processes that can include maturation/polishing ponds, biological processes, advanced filtration, carbon adsorption, ion exchange, and disinfection.

Sludge is produced in all of the primary, secondary and tertiary stages of treatment. Sludge that is produced in primary treatment consists of solids that are removed from the wastewater and is not accounted for in this category. Sludge produced in secondary and tertiary treatment results from biological growth in the biomass, as well as the collection of small particles. This sludge must be treated further before it can be safely disposed of. Methods of sludge treatment include aerobic and anaerobic stabilisation (digestion), conditioning, centrifugation, composting, and drying. Land disposal, composting, and incineration of sludge is considered in Volume 5, Section 2.3.2 in Chapter 2, Waste Generation, Composition, and Management Data, Section 3.2 in Chapter 3, Solid Waste Disposal, Section 4.1 in Chapter 4, Biological Treatment and Disposal, and Chapter 5, Incineration and Open Burning of Waste, respectively. Some sludge is incinerated before land disposal. $N_2O$ emissions from sludge and wastewater spread on agricultural land are considered in Section 11.2, $N_2O$ emissions from managed

[1] Because the methodology is on a per person basis, emissions from commercial wastewater are estimated as part of domestic wastewater. To avoid confusion, the term municipal wastewater is not used in this text. Municipal wastewater is a mix of household, commercial and non-hazardous industrial wastewater, treated at wastewater treatment plants.

soils, in Chapter 11, $N_2O$ Emissions from Managed Soils, and $CO_2$ Emissions from Lime and Urea Application, in Volume 4 of the Agriculture, Forestry, and Other Land Use (AFOLU) Sector.

**Figure 6.1 Wastewater treatment systems and discharge pathways**




Note: Emissions from boxes with bold frames are accounted for in this chapter.

### *Methane ($CH_4$)*

Wastewater as well as its sludge components can produce $CH_4$ if it degrades anaerobically. The extent of $CH_4$ production depends primarily on the quantity of degradable organic material in the wastewater, the temperature, and the type of treatment system. With increases in temperature, the rate of $CH_4$ production increases. This is especially important in uncontrolled systems and in warm climates. Below 15°C, significant $CH_4$ production is unlikely because methanogens are not active and the lagoon will serve principally as a sedimentation tank. However, when the temperature rises above 15°C, $CH_4$ production is likely to resume.

The principal factor in determining the $CH_4$ generation potential of wastewater is the amount of degradable organic material in the wastewater. Common parameters used to measure the organic component of the wastewater are the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Under the same conditions, wastewater with higher COD, or BOD concentrations will generally yield more $CH_4$ than wastewater with lower COD (or BOD) concentrations.

The BOD concentration indicates only the amount of carbon that is aerobically biodegradable. The standard measurement for BOD is a 5-day test, denoted as $BOD_5$. The term 'BOD' in this chapter refers to $BOD_5$. The COD measures the total material available for chemical oxidation (both biodegradable and non-biodegradable). [2] Since the BOD is an aerobic parameter, it may be less appropriate for determining the organic components in anaerobic environments. Also, both the type of wastewater and the type of bacteria present in the wastewater influence the BOD concentration of the wastewater. Usually, BOD is more frequently reported for domestic wastewater, while COD is predominantly used for industrial wastewater.

[2] In these guidelines, COD refers to chemical oxygen demand measured using the dichromate method. (American Public Health Association, American Water Works Association and Water Environment Federation, 1998)

### *Nitrous Oxide ($N_2O$)*

Nitrous oxide ($N_2O$) is associated with the degradation of nitrogen components in the wastewater, e.g., urea, nitrate and protein. Domestic wastewater includes human sewage mixed with other household wastewater, which can include effluent from shower drains, sink drains, washing machines, etc. Centralized wastewater treatment systems may include a variety of processes, ranging from lagooning to advanced tertiary treatment technology for removing nitrogen compounds. After being processed, treated effluent is typically discharged to a receiving water environment (e.g., river, lake, estuary, etc.). Direct emissions of $N_2O$ may be generated during both nitrification and denitrification of the nitrogen present. Both processes can occur in the plant and in the water body that is receiving the effluent. Nitrification is an aerobic process converting ammonia and other nitrogen compounds into nitrate ($NO_3^-$), while denitrification occurs under anoxic conditions (without free oxygen), and involves the biological conversion of nitrate into dinitrogen gas ($N_2$). Nitrous oxide can be an intermediate product of both processes, but is more often associated with denitrification.

### *Treatment and Discharge Systems and $CH_4$ and $N_2O$ Generation Potential*

Treatment systems or discharge pathways that provide anaerobic environments will generally produce $CH_4$ whereas systems that provide aerobic environments will normally produce little or no $CH_4$. For example, for lagoons without mixing or aeration, their depth is a critical factor in $CH_4$ production. Shallow lagoons, less than 1 metre in depth, generally provide aerobic conditions and little or no $CH_4$ is likely to be produced. Lagoons deeper than about 2-3 metres will generally provide anaerobic environments and significant $CH_4$ production can be expected.

Table 6.1 presents the main wastewater treatment and discharge systems in developed and developing countries, and their potentials to emit $CH_4$ and $N_2O$.

**TABLE 6.1**
**$CH_4$ AND $N_2O$ EMISSION POTENTIALS FOR WASTEWATER AND SLUDGE TREATMENT AND DISCHARGE SYSTEMS**

| Types of treatment and disposal | | | | $CH_4$ and $N_2O$ emission potentials |
|---|---|---|---|---|
| Collected | Untreated | | River discharge | Stagnant, oxygen-deficient rivers and lakes may allow for anaerobic decomposition to produce $CH_4$.<br>Rivers, lakes and estuaries are likely sources of $N_2O$. |
| | | | Sewers (closed and under ground) | Not a source of $CH_4$/$N_2O$. |
| | | | Sewers (open) | Stagnant, overloaded open collection sewers or ditches/canals are likely significant sources of $CH_4$. |
| | Treated | Aerobic treatment | Centralized aerobic wastewater treatment plants | May produce limited $CH_4$ from anaerobic pockets.<br>Poorly designed or managed aerobic treatment systems produce $CH_4$.<br>Advanced plants with nutrient removal (nitrification and denitrification) are small but distinct sources of $N_2O$. |
| | | | Sludge anaerobic treatment in centralized aerobic wastewater treatment plant | Sludge may be a significant source of $CH_4$ if emitted $CH_4$ is not recovered and flared. |
| | | | Aerobic shallow ponds | Unlikely source of $CH_4$/$N_2O$.<br>Poorly designed or managed aerobic systems produce $CH_4$. |
| | | Anaerobic treatment | Anaerobic lagoons | Likely source of $CH_4$.<br>Not a source of $N_2O$. |
| | | | Anaerobic reactors | May be a significant source of $CH_4$ if emitted $CH_4$ is not recovered and flared. |
| Uncollected | Septic tanks | | | Frequent solids removal reduces $CH_4$ production. |
| | Open pits/Latrines | | | Pits/latrines are likely to produce $CH_4$ when temperature and retention time are favourable. |
| | River discharge | | | See above. |

### 6.1.1 Changes compared to 1996 Guidelines and Good Practice Guidance

*The Revised 1996 IPCC Guidelines* (*1996 Guidelines*, IPCC, 1997) included separate equations to estimate emissions from wastewater and from sludge removed from the wastewater. The distinction has been removed because the $CH_4$ generation capacities for sludge and wastewater with dissolved organics are generally the same, and separated equations are not necessary. The *2006 Guidelines* include a new section to estimate $CH_4$ emissions from uncollected wastewater. Also, guidance has been included to estimate $N_2O$ emissions from advanced wastewater treatment plants. Furthermore, the industrial wastewater section has been simplified by suggesting that only the most significant industrial sources need to be addressed. See Section 6.2.3.

## 6.2 METHANE EMISSIONS FROM WASTEWATER

### 6.2.1 Methodological issues

Emissions are a function of the amount of organic waste generated and an emission factor that characterises the extent to which this waste generates $CH_4$.

Three tier methods for $CH_4$ from this category are summarised below:

The Tier 1 method applies default values for the emission factor and activity parameters. This method is considered *good practice* for countries with limited data.

The Tier 2 method follows the same method as Tier 1 but allows for incorporation of a country specific emission factor and country specific activity data. For example, a specific emission factor for a prominent treatment system based on field measurements could be incorporated under this method. The amount of sludge removed for incineration, landfills, and agricultural land should be taken into consideration.

For a country with good data and advanced methodologies, a country specific method could be applied as a Tier 3 method. A more advanced country-specific method could be based on plant-specific data from large wastewater treatment facilities.

Wastewater treatment facilities can include anaerobic process steps. $CH_4$ generated at such facilities can be recovered and combusted in a flare or energy device. The amount of $CH_4$ that is flared or recovered for energy use should be subtracted from total emissions through the use of a separate $CH_4$ recovery parameter. The amount of $CH_4$ which is recovered is expressed as R in Equation 6.1.

Note that only a few countries may have sludge removal data and $CH_4$ recovery data. The default for sludge removal is zero. The default for $CH_4$ recovery is zero. If a country selects to report $CH_4$ recovery, it is *good practice* to distinguish between flaring and $CH_4$ recovery for energy generation, which should be reported in the Energy Sector taking into account the avoidance of double counting emissions from flaring and energy used.

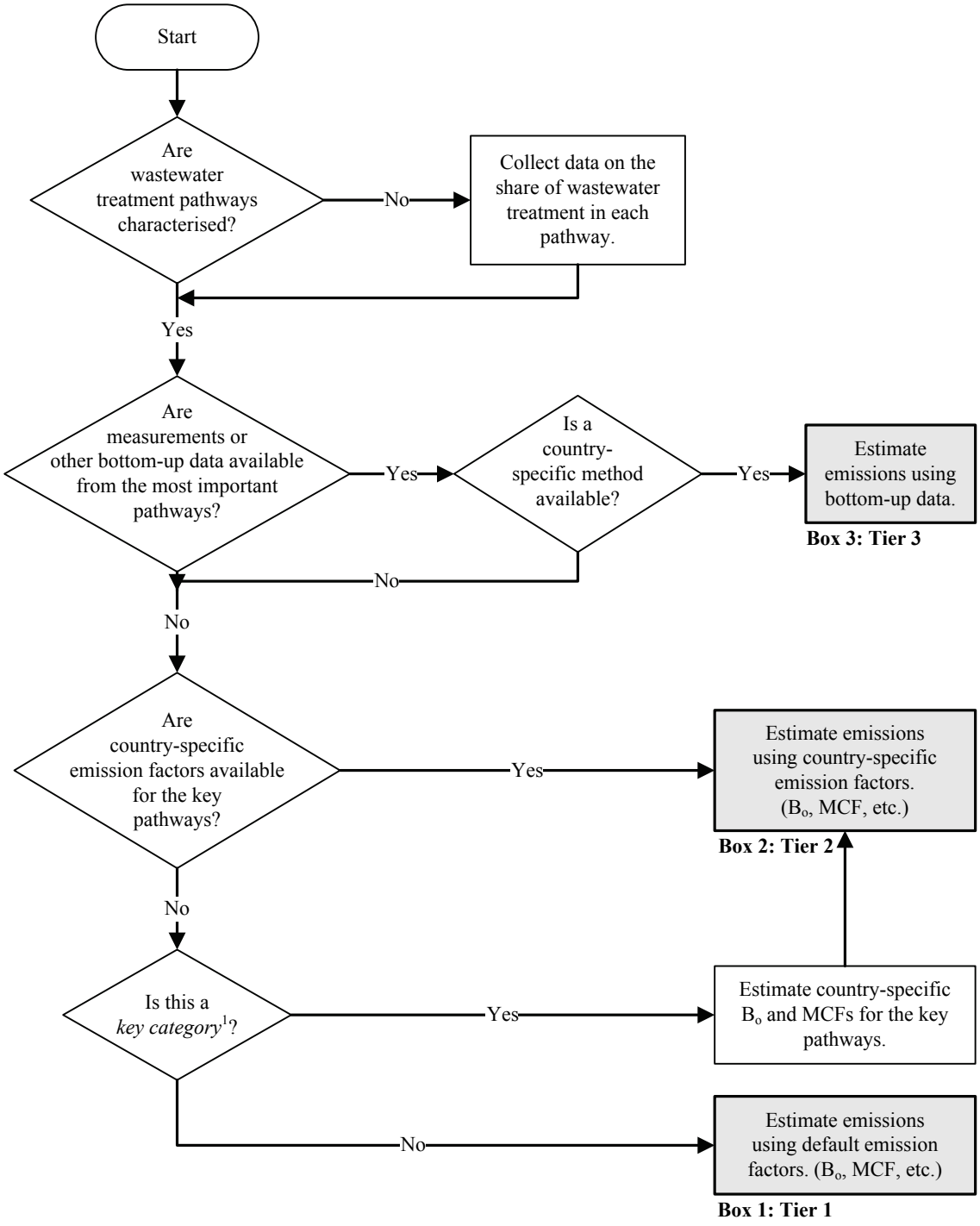
Emissions from flaring are not significant, as the $CO_2$ emissions are of biogenic origin, and the $CH_4$ and $N_2O$ emissions are very small so *good practice* in the Waste Sector does not require their estimation. However, if it is wished to do so these emissions should be reported under the Waste Sector. A discussion of emissions from flares and more detailed information are given in Volume 2, Energy, Chapter 4.2. Emission from flaring is not treated at Tier 1.

## 6.2.2 Domestic wastewater

### 6.2.2.1 CHOICE OF METHOD

A decision tree for domestic wastewater is included in Figure 6.2.

**Figure 6.2 Decision Tree for $CH_4$ emissions from domestic wastewater**




1. See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting Section 4.1.2 on limited resources), for discussion of key categories and use of decision trees.

The steps for *good practice* in inventory preparation for $CH_4$ from domestic wastewater are as follows:

**Step 1:** Use Equation 6.3 to estimate total organically degradable carbon in wastewater (TOW).

**Step 2:** Select the pathway and systems (See Figure 6.1) according to country activity data. Use Equation 6.2 to obtain the emission factor for each domestic wastewater treatment/discharge pathway or system.

**Step 3:** Use Equation 6.1 to estimate emissions, adjust for possible sludge removal and/or $CH_4$ recovery and sum the results for each pathway/system.

As described earlier, the wastewater characterisation will determine the fraction of wastewater treated or disposed of by a particular system. To determine the use of each type of treatment or discharge system, it is *good practice* to refer to national statistics (e.g., from regulatory authorities). If these data are not available, wastewater associations or international organisations such as the World Health Organization (WHO) may have data on the system usage.

Otherwise, consultation with sanitation experts can help, and expert judgement can also be applied (see Chapter 2, Approaches to Data Collection, in Volume 1). Urbanisation statistics may provide a useful tool, e.g., city sizes and income distribution.

If sludge separation is practised and appropriate statistics are available, then this category should be separated out as a subcategory. If default factors are being used, emissions from wastewater and sludge should be estimated together. Regardless of how sludge is treated, it is important that $CH_4$ emissions from sludge sent to landfills, incinerated or used in agriculture are not included in the wastewater treatment and discharge category. If sludge removal data are available, the data should be consistent across the sectors, and categories, amount disposed at SWDS, applied to agricultural land, incinerated or used elsewhere should be equal to the amount organic component removed as sludge in Equation 6.1. Wastewater and sludge that is applied on agricultural land should be considered in Volume 4 for AFOLU Sector, Section 11.2, $N_2O$ emissions from managed soils, in Chapter 11, $N_2O$ Emissions from Managed Soils, and $CO_2$ Emissions from Lime and Urea Application.

Wastewater treatment system/pathway usage often differs for rural and urban residents. Also, in developing countries, there are likely to be differences between urban high-income and urban low-income residents. Hence, a factor U is introduced to express each income group fraction. It is *good practice* to treat the three categories: rural population, urban high income population, and urban low income population separately. It is suggested to use a spreadsheet, as shown in Table 6.5 below.

The general equation to estimate $CH_4$ emissions from domestic wastewater is as follows:

**EQUATION 6.1**
**TOTAL $CH_4$ EMISSIONS FROM DOMESTIC WASTEWATER**

$$CH_4\ Emissions = \left[\sum_{i,j}\left(U_i \bullet T_{i.j} \bullet EF_j\right)\right]\left(TOW - S\right) - R$$

Where:

$CH_4$ Emissions = $CH_4$ emissions in inventory year, kg $CH_4$/yr

TOW = total organics in wastewater in inventory year, kg BOD/yr

S = organic component removed as sludge in inventory year, kg BOD/yr

$U_i$ = fraction of population in income group *i* in inventory year, See Table 6.5.

$T_{i,j}$ = degree of utilisation of treatment/discharge pathway or system, *j*, for each income group fraction *i* in inventory year, See Table 6.5.

i = income group: rural, urban high income and urban low income

j = each treatment/discharge pathway or system

$EF_j$ = emission factor, kg $CH_4$ / kg BOD

R = amount of $CH_4$ recovered in inventory year, kg $CH_4$/yr

### 6.2.2.2 CHOICE OF EMISSION FACTORS

The emission factor for a wastewater treatment and discharge pathway and system (terminal blocks with bold frames in Figure 6.1) is a function of the maximum $CH_4$ producing potential ($B_o$) and the methane correction factor (MCF) for the wastewater treatment and discharge system, as shown in Equation 6.2. The $B_o$ is the maximum amount of $CH_4$ that can be produced from a given quantity of organics (as expressed in BOD or COD) in the wastewater. The MCF indicates the extent to which the $CH_4$ producing capacity ($B_o$) is realised in each type of treatment and discharge pathway and system. Thus, it is an indication of the degree to which the system is anaerobic.

**EQUATION 6.2**
**$CH_4$ EMISSION FACTOR FOR**
**EACH DOMESTIC WASTEWATER TREATMENT/DISCHARGE PATHWAY OR SYSTEM**

$$EF_j = B_o \bullet MCF_j$$

Where:

$EF_j$ = emission factor, kg $CH_4$/kg BOD

j = each treatment/discharge pathway or system

$B_o$ = maximum $CH_4$ producing capacity, kg $CH_4$/kg BOD

$MCF_j$ = methane correction factor (fraction), See Table 6.3.

*Good practice* is to use country-specific data for $B_o$, where available, expressed in terms of kg $CH_4$/kg BOD removed to be consistent with the activity data. If country-specific data are not available, a default value, 0.6 kg $CH_4$/kg BOD can be used. For domestic wastewater, a COD-based value of $B_o$ can be converted into a BOD-based value by multiplying with a factor of 2.4. Table 6.2 includes default maximum $CH_4$ producing capacity ($B_o$) for domestic wastewater.

**TABLE 6.2**
**DEFAULT MAXIMUM $CH_4$ PRODUCING CAPACITY ($B_O$) FOR DOMESTIC WASTEWATER**

| |
|---|
| 0.6 kg $CH_4$/kg BOD |
| 0.25 kg $CH_4$/kg COD |
| Based on expert judgment by lead authors and on Doorn *et al*., (1997) |

Table 6.3 includes default MCF values.

**TABLE 6.3**
**DEFAULT MCF VALUES FOR DOMESTIC WASTEWATER**

| Type of treatment and discharge pathway or system | Comments | MCF [1] | Range |
|---|---|---|---|
| **Untreated system** | | | |
| Sea, river and lake discharge | Rivers with high organics loadings can turn anaerobic. | 0.1 | 0 – 0.2 |
| Stagnant sewer | Open and warm | 0.5 | 0.4 – 0.8 |
| Flowing sewer (open or closed) | Fast moving, clean. (Insignificant amounts of $CH_4$ from pump stations, etc) | 0 | 0 |
| **Treated system** | | | |
| Centralized, aerobic treatment plant | Must be well managed. Some $CH_4$ can be emitted from settling basins and other pockets. | 0 | 0 – 0.1 |
| Centralized, aerobic treatment plant | Not well managed. Overloaded. | 0.3 | 0.2 – 0.4 |
| Anaerobic digester for sludge | $CH_4$ recovery is not considered here. | 0.8 | 0.8 – 1.0 |
| Anaerobic reactor | $CH_4$ recovery is not considered here. | 0.8 | 0.8 – 1.0 |
| Anaerobic shallow lagoon | Depth less than 2 metres, use expert judgment. | 0.2 | 0 – 0.3 |
| Anaerobic deep lagoon | Depth more than 2 metres | 0.8 | 0.8 – 1.0 |
| Septic system | Half of BOD settles in anaerobic tank. | 0.5 | 0.5 |
| Latrine | Dry climate, ground water table lower than latrine, small family (3-5 persons) | 0.1 | 0.05 – 0.15 |
| Latrine | Dry climate, ground water table lower than latrine, communal (many users) | 0.5 | 0.4 – 0.6 |
| Latrine | Wet climate/flush water use, ground water table higher than latrine | 0.7 | 0.7 – 1.0 |
| Latrine | Regular sediment removal for fertilizer | 0.1 | 0.1 |

[1] Based on expert judgment by lead authors of this section.

### 6.2.2.3 CHOICE OF ACTIVITY DATA

The activity data for this source category is the total amount of organically degradable material in the wastewater (TOW). This parameter is a function of human population and BOD generation per person. It is expressed in terms of biochemical oxygen demand (kg BOD/year). The equation for TOW is:

**EQUATION 6.3**
**TOTAL ORGANICALLY DEGRADABLE MATERIAL IN DOMESTIC WASTEWATER**

$$TOW = P \bullet BOD \bullet 0.001 \bullet I \bullet 365$$

Where:

TOW = total organics in wastewater in inventory year, kg BOD/yr

P = country population in inventory year, (person)

BOD = country-specific per capita BOD in inventory year, g/person/day, See Table 6.4.

0.001 = conversion from grams BOD to kg BOD

I = correction factor for additional industrial BOD discharged into sewers (for collected the default is 1.25, for uncollected the default is 1.00.)

The factor *I* values in Equation 6.3 are based on expert judgment by the authors. It expresses the BOD from industries and establishments (e.g., restaurants, butchers or grocery stores) that is co-discharged with domestic wastewater. In some countries, information from industrial discharge permits may be available to improve *I*. Otherwise, expert judgment is recommended. Total population statistics should be readily available from national statistics agencies or international agencies (e.g., United Nations Statistics, see http://esa.un.org/unpp/). Table 6.4 includes BOD default values for selected countries. It is *good practice* to select a BOD default value from a nearby comparable country when country-specific data are not available. The degree of urbanization for a country can be retrieved from various sources, (e.g., Global Environment Outlook, United Nations Environment Programme and World Development Indicators, World Health Organization). The urban high-income and urban-low income fractions can be determined by expert judgment when statistical or other comparable information is not available. Table 6.5 includes default values of $U_i$ and $T_{i,j}$ for selected countries.

**TABLE 6.4**
**ESTIMATED $BOD_5$ VALUES IN DOMESTIC WASTEWATER FOR SELECTED REGIONS AND COUNTRIES**

| Country/Region | $BOD_5$ (g/person/day) | Range | Reference |
|---|---|---|---|
| Africa | 37 | 35 – 45 | 1 |
| Egypt | 34 | 27 – 41 | 1 |
| Asia, Middle East, Latin America | 40 | 35 – 45 | 1 |
| India | 34 | 27 – 41 | 1 |
| West Bank and Gaza Strip (Palestine) | 50 | 32 – 68 | 1 |
| Japan | 42 | 40 – 45 | 1 |
| Brazil | 50 | 45 – 55 | 2 |
| Canada, Europe, Russia, Oceania | 60 | 50 – 70 | 1 |
| Denmark | 62 | 55 – 68 | 1 |
| Germany | 62 | 55 – 68 | 1 |
| Greece | 57 | 55 – 60 | 1 |
| Italy | 60 | 49 – 60 | 3 |
| Sweden | 75 | 68 – 82 | 1 |
| Turkey | 38 | 27 – 50 | 1 |
| United States | 85 | 50 – 120 | 4 |

Note: These values are based on an assessment of the literature. Please use national values, if available.

Reference:

1. Doorn and Liles (1999).
2. Feachem *et al*. (1983).
3. Masotti (1996).
4. Metcalf and Eddy (2003).

**TABLE 6.5**
**SUGGESTED VALUES FOR URBANISATION (U) AND DEGREE OF UTILISATION OF TREATMENT, DISCHARGE PATHWAY OR METHOD ($T_{i,j}$) FOR EACH INCOME GROUP FOR SELECTED COUNTRIES**

| | Urbanization(U) [1] | | | Degree of utilisation of treatment or discharge pathway or method for each income group ($T_{i,j}$)[3] | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fraction of Population | | | U=rural | | | | | U= urban high income | | | | | U=urban low income | | | | |
| Country | Rural | urban-high[2] | urban-low[2] | Septic Tank | Latrine | Other | Sewer[4] | None | Septic Tank | Latrine | Other | Sewer[4] | None | Septic Tank | Latrine | Other | Sewer[4] | None |
| **Africa** | | | | | | | | | | | | | | | | | | |
| Nigeria | 0.52 | 0.10 | 0.38 | 0.02 | 0.28 | 0.04 | 0.10 | 0.56 | 0.32 | 0.31 | 0.00 | 0.37 | 0.00 | 0.17 | 0.24 | 0.05 | 0.34 | 0.20 |
| Egypt | 0.57 | 0.09 | 0.34 | 0.02 | 0.28 | 0.04 | 0.10 | 0.56 | 0.15 | 0.05 | 0.10 | 0.70 | 0.00 | 0.17 | 0.24 | 0.05 | 0.34 | 0.20 |
| Kenya | 0.62 | 0.08 | 0.30 | 0.02 | 0.28 | 0.04 | 0.10 | 0.56 | 0.32 | 0.31 | 0.00 | 0.37 | 0.00 | 0.17 | 0.24 | 0.05 | 0.34 | 0.20 |
| South Africa | 0.39 | 0.12 | 0.49 | 0.10 | 0.28 | 0.04 | 0.10 | 0.48 | 0.15 | 0.15 | 0.00 | 0.70 | 0.00 | 0.17 | 0.24 | 0.05 | 0.34 | 0.20 |
| **Asia** | | | | | | | | | | | | | | | | | | |
| China | 0.59 | 0.12 | 0.29 | 0.00 | 0.47 | 0.50 | 0.00 | 0.3 | 0.18 | 0.08 | 0.07 | 0.67 | 0.00 | 0.14 | 0.10 | 0.03 | 0.68 | 0.05 |
| India | 0.71 | 0.06 | 0.23 | 0.00 | 0.47 | 0.10 | 0.10 | 0.33 | 0.18 | 0.08 | 0.07 | 0.67 | 0.00 | 0.14 | 0.10 | 0.03 | 0.53 | 0.20 |
| Indonesia | 0.54 | 0.12 | 0.34 | 0.00 | 0.47 | 0.00 | 0.10 | 0.43 | 0.18 | 0.08 | 0.00 | 0.74 | 0.00 | 0.14 | 0.10 | 0.03 | 0.53 | 0.20 |
| Pakistan | 0.65 | 0.07 | 0.28 | 0.00 | 0.47 | 0.00 | 0.10 | 0.43 | 0.18 | 0.08 | 0.00 | 0.74 | 0.00 | 0.14 | 0.10 | 0.03 | 0.53 | 0.20 |
| Bangladesh | 0.72 | 0.06 | 0.22 | 0.00 | 0.47 | 0.00 | 0.10 | 0.43 | 0.18 | 0.08 | 0.00 | 0.74 | 0.00 | 0.14 | 0.10 | 0.03 | 0.53 | 0.20 |
| Japan | 0.20 | 0.80 | 0.00 | 0.20 | 0.00 | 0.50 | 0.30 | 0.00 | 0.00 | 0.00 | 0.10 | 0.90 | 0.00 | 0.10 | 0 | 0 | 0.90 | 0 |
| **Europe** | | | | | | | | | | | | | | | | | | |
| Russia | 0.27 | 0.73 | 0.00 | 0.30 | 0.10 | 0.00 | 0.60 | 0.00 | 0.10 | 0.00 | 0.00 | 0.90 | 0.00 | NA | NA | NA | NA | NA |
| Germany[5] | 0.06 | 0.94 | 0.00 | 0.20 | 0.00 | 0.00 | 0.80 | 0.00 | 0.05 | 0.00 | 0.00 | 0.95 | 0.00 | NA | NA | NA | NA | NA |
| United Kingdom | 0.10 | 0.90 | 0.00 | 0.11 | 0.00 | 0.00 | 0.89 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | NA | NA | NA | NA | NA |
| France | 0.24 | 0.76 | 0.00 | 0.37 | 0.00 | 0.00 | 0.63 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | NA | NA | NA | NA | NA |
| Italy | 0.32 | 0.68 | 0.00 | 0.42 | 0.00 | 0.00 | 0.58 | 0.00 | 0.04 | 0.00 | 0.00 | 0.96 | 0.00 | NA | NA | NA | NA | NA |
| **North America** | | | | | | | | | | | | | | | | | | |
| United States | 0.22 | 0.78 | 0.00 | 0.90 | 0.02 | 0.00 | 0.08 | 0.00 | 0.05 | 0.00 | 0.00 | 0.95 | 0.00 | NA | NA | NA | NA | NA |
| Canada | 0.20 | 0.80 | 0.00 | 0.90 | 0.02 | 0.00 | 0.08 | 0.00 | 0.05 | 0.00 | 0.00 | 0.95 | 0.00 | NA | NA | NA | NA | NA |
| **Latin America and Caribbean** | | | | | | | | | | | | | | | | | | |
| Brazil | 0.16 | 0.25 | 0.59 | 0.00 | 0.45 | 0.00 | 0.10 | 0.45 | 0.00 | 0.20 | 0.00 | 0.80 | 0.00 | 0.00 | 0.40 | 0.00 | 0.40 | 0.20 |
| Mexico | 0.25 | 0.19 | 0.56 | 0.00 | 0.45 | 0.00 | 0.10 | 0.45 | 0.00 | 0.20 | 0.00 | 0.80 | 0.00 | 0.00 | 0.40 | 0.00 | 0.40 | 0.20 |
| **Oceania** | | | | | | | | | | | | | | | | | | |
| Australia and New Zealand | 0.08 | 0.92 | 0.00 | 0.90 | 0.02 | 0.00 | 0.08 | 0.00 | 0.05 | 0.00 | 0.00 | 0.95 | 0.00 | NA | NA | NA | NA | NA |

Notes:

1. Urbanization projections for 2005 (United Nations, 2002).
2. Suggested urban-high income and urban low income division. Countries are encouraged to use their own data or best judgment.
3. $T_{i,j}$ values based on expert judgment, (Doorn and Liles, 1999).
4. Sewers may be open or closed, which will govern the choice of MCF, see Table 3.3
5. Destatis, 2001.

Note: These values are from the literature or based on expert judgment. Please use national values, if available.

### Example

Table 6.6 includes an example. Categories with negligible contributions are not shown. Note that the table can easily be expanded with a column for MCF for each category. The degree of urbanization for this country is 65 percent.

**TABLE 6.6**
**EXAMPLE OF THE APPLICATION OF DEFAULT VALUES FOR DEGREES OF TREATMENT UTILIZATION (T) BY INCOME GROUPS**

| Treatment or discharge system or pathway | | T (%) | Notes |
|---|---|---|---|
| Urban high-income | To sea | 10 | No $CH_4$ |
| | To aerobic plant | 20 | Add industrial component |
| | To septic systems | 10 | Uncollected |
| Urban low-income | To sea | 10 | Collected |
| | To pit latrines | 15 | Uncollected |
| Rural | To rivers, lakes, sea | 15 | Uncollected |
| | To pit latrines | 15 | |
| | To septic tanks | 5 | |
| Total | | 100% | Must add up to 100 % |
| Reference: Doorn and Liles (1999) | | | |

## 6.2.2.4 TIME SERIES CONSISTENCY

The same method and data sets should be used for estimating $CH_4$ emissions from wastewater for each year. The MCF for different treatment systems should not change from year to year, unless such a change is justifiable and documented. If the share of wastewater treated in different treatment systems changes over the time period, the reasons for these changes should be documented.

Sludge removal and $CH_4$ recovery should be estimated consistently across years in the time series. Methane recovery should be included only if there are sufficient facility-specific data. The quantity of recovered methane should be subtracted from the methane produced as shown in Equation 6.1.

Because activity data are derived from population data, which is available for all countries and all years, countries should be able to construct an entire time series for uncollected and collected wastewater. If data on the share of uncollected wastewater treated onsite vs. untreated are missing for one or more years, the surrogate data and extrapolation/interpolation splicing techniques described in Chapter 5, Time Series Consistency, of Volume 1, General Guidance and Reporting, can be used to estimate emissions. Emissions from wastewater typically do not fluctuate significantly from year to year.

## 6.2.2.5 UNCERTAINTIES

Chapter 3, Uncertainties, in Volume 1 provides advice on quantifying uncertainties in practice. It includes guidance on eliciting and using expert judgements which in combination with empirical data can provide overall uncertainty estimates. Table 6.7 provides default uncertainty ranges for emission factor and activity data of domestic wastewater. The following parameters are believed to be very uncertain:

- The degrees to which wastewater in developing countries is treated in latrines, septic tanks, or removed by sewer, for urban high, urban low income groups and rural population ($T_{i,,j}$).
- The fraction of sewers that are 'open', as well as the degree to which open sewers in developing countries are anaerobic and will emit $CH_4$. This will depend on retention time and temperature, and on other factors including the presence of a facultative layer and possibly components that are toxic to anaerobic bacteria (e.g., certain industrial wastewater discharges).
- The amount of industrial TOW that is discharged into open or closed domestic sewers for each country is very difficult to quantify.

**TABLE 6.7**
**DEFAULT UNCERTAINTY RANGES FOR DOMESTIC WASTEWATER**

| Parameter | Uncertainty Range |
|---|---|
| **Emission Factor** | |
| Maximum $CH_4$ producing capacity ($B_o$) | ± 30% |
| Fraction treated anaerobically (MCF) | The MCF is technology dependent. See Table 6.3. Thus the uncertainty range is also technology dependent. The uncertainty range should be determined by expert judgement, bearing in mind that MCF is a fraction and must be between 0 and 1. Suggested ranges are provided below.<br>Untreated systems and latrines, ± 50%<br>Lagoons, poorly managed treatment plants± 30%<br>Centralized well managed plant, digester, reactor, ± 10% |
| **Activity Data** | |
| Human population (P) | ± 5% |
| BOD per person | ± 30% |
| Fraction of population income group (U) | Good data on urbanization are available, however, the distinction between urban high income and urban low income may have to be based on expert judgment. ± 15% |
| Degree of utilization of treatment/ discharge pathway or system for each income group ($T_{i,j}$) | Can be as low as ± 3% for countries that have good records and only one or two systems. Can be ± 50% for an individual method/pathway. Verify that total $T_{i,j}$ = 100% |
| Correction factor for additional industrial BOD discharged into sewers (I) | For uncollected, the uncertainty is zero %. For collected the uncertainty is ± 20% |

Source: Judgement by Expert Group (Authors of this section).

### 6.2.2.6 QA/QC, COMPLETENESS, REPORTING AND DOCUMENTATION

It is *good practice* to conduct quality control checks and quality assurance procedures as outlined in Chapter 6, Volume 1. Below, some fundamental QA/QC procedures are included.

#### *Activity Data*

- Characterize all wastewater according to the percentages flowing to different treatment systems (aerobic and anaerobic), and the percentage of untreated wastewater. Make sure that all wastewater is characterized so that the wastewater flows sum to 100 percent of the wastewater generated in the country.
- Inventory compilers should compare country-specific data on BOD in domestic wastewater to IPCC default values. If inventory compilers use country-specific values they should provide documented justification why their country-specific values are more appropriate for their national circumstances.

#### *Emission Factors*

- For domestic wastewater, inventory compilers can compare country-specific values for $B_o$ with the IPCC default value (0.25 kg $CH_4$/kg COD or 0.6 kg $CH_4$/kg BOD). Although there are no IPCC default values for the fraction of wastewater treated anaerobically, inventory compilers are encouraged to compare values for MCFs against those from other countries with similar wastewater handling practices.
- Inventory compilers should confirm the agreement between the units used for degradable carbon in the waste (TOW) with the units for $B_o$. Both parameters should be based on the same units (either BOD or COD) in order to calculate emissions. This same consideration should be taken into account when comparing the emissions.

### *$CH_4$ Recovery and Sludge Removal*

- A carbon balance check can be used to ensure that the carbon contained in the inflow and outflow (effluent BOD, methane emission and methane recovery) are comparable.
- If sludge removal is reported in the wastewater inventory, check for consistency with the estimates for sludge applied to agriculture soils, sludge incinerated, and sludge deposited in solid waste disposal.

### *Comparison of emissions estimates using different approaches*

- For countries that use country-specific parameters, or Tier 2 or higher methods, inventory compilers can cross-check the national estimate with emissions using the IPCC default method and parameters.

### COMPLETENESS

Completeness can be verified on the basis of the degree of utilization of a treatment or discharge system or pathway (T). The sum of T should equal 100 percent. It is a *good practice* to draw a diagram similar to Figure 6.1 for the country to consider all potential anaerobic treatment and discharge systems and pathways, including collected and uncollected, as well as treated and untreated. Any industrial wastewater treated in domestic wastewater treatment facilities should be included in the collected category. If sludge is removed for the purpose of incineration, disposal in landfills or as fertilizer on agricultural lands, the amount of organic material removed as sludge should be consistent with data used in the relevant sectors (see text under Section 6.2.2).

### REPORTING AND DOCUMENTATION

It is *good practice* to document and report a summary of the methods used, activity data and emission factors. Worksheets are provided at the end of this volume. When country-specific methods and/or emission factors are used, the reasoning for the choices as well as references to how the country-specific data (measurements, literature, expert judgement, etc.) have been derived (measurements, literature, expert judgement, etc.) should be documented and included in the reporting.

If sludge is incinerated, landfilled, or spread on agricultural lands, the quantities of sludge, and associated emissions, should be reported in the waste incineration, SWDS, or agricultural categories, respectively.

Where $CH_4$ is recovered for energy use, then the resulting greenhouse gas emissions should be reported under Energy Sector. As discussed in Section 6.2.1, *good practice* in the Waste Sector does not require the estimation of $CH_4$ and $N_2O$ from $CH_4$ recovery and flaring. However, if it is wished to do so emissions from flaring should be reported under the Waste Sector.

More information on reporting and documentation can be found in Volume 1, Chapter 6, Section 6.11 Documentation, archiving and reporting.

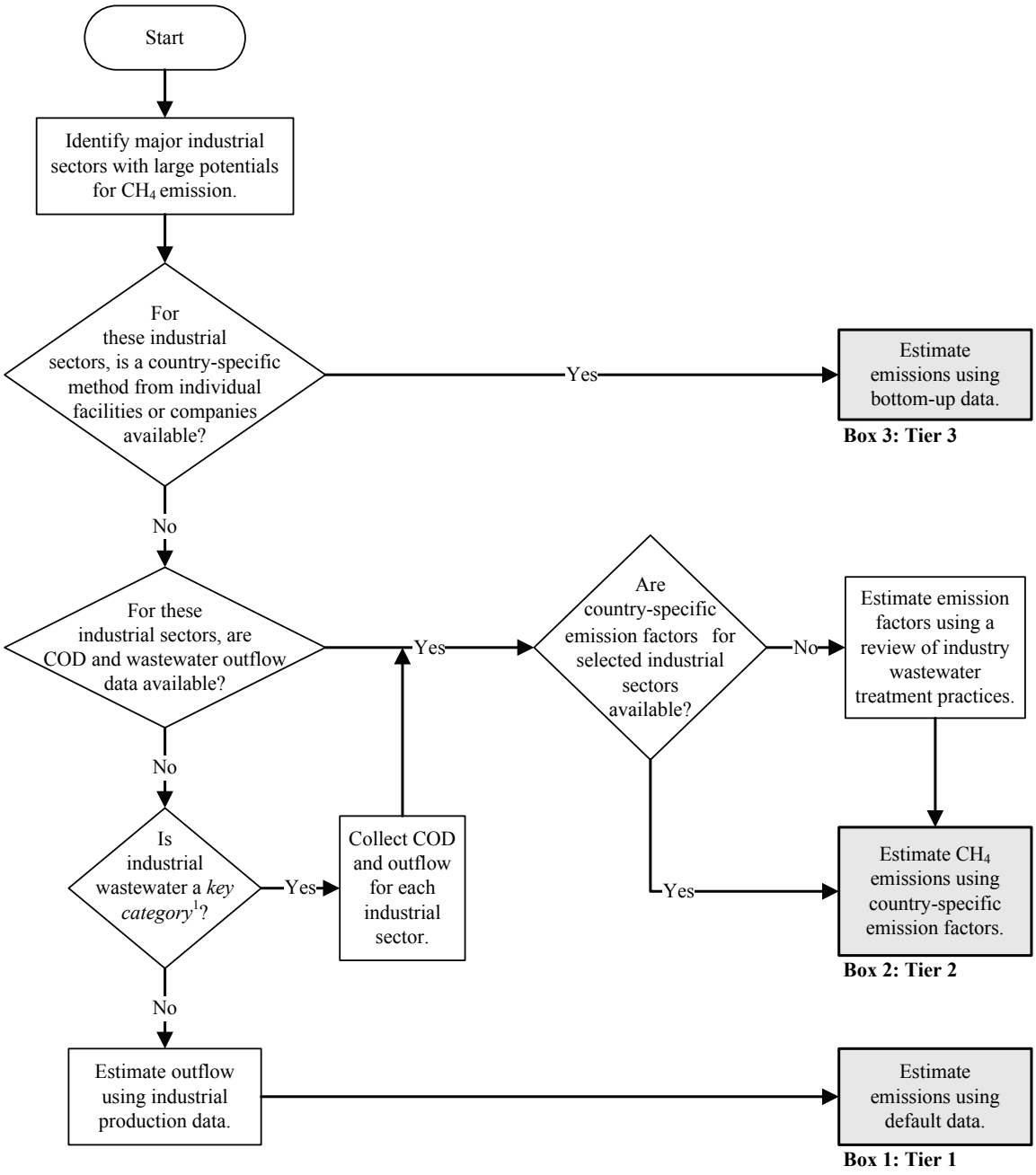
## 6.2.3 Industrial wastewater

Industrial wastewater may be treated on site or released into domestic sewer systems. If it is released into the domestic sewer system, the emissions are to be included with the domestic wastewater emissions. This section deals with estimating $CH_4$ emissions from on-site industrial wastewater treatment. Only industrial wastewater with significant carbon loading that is treated under intended or unintended anaerobic conditions will produce $CH_4$. Organics in industrial wastewater are often expressed in terms of COD, which is used here.

### 6.2.3.1 CHOICE OF METHOD

A decision tree for industrial wastewater is included in Figure 6.3.

**Figure 6.3 Decision Tree for $CH_4$ emissions from industrial wastewater treatment**




1. See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting Section 4.1.2 on limited resources), for discussion of key categories and use of decision trees.

Assessment of $CH_4$ production potential from industrial wastewater streams is based on the concentration of degradable organic matter in the wastewater, the volume of wastewater, and the propensity of the industrial sector to treat their wastewater in anaerobic systems. Using these criteria, major industrial wastewater sources with high $CH_4$ gas production potential can be identified as follows:

- pulp and paper manufacture,
- meat and poultry processing (slaughterhouses),

- alcohol, beer, starch production,
- organic chemicals production,
- other food and drink processing (dairy products, vegetable oil, fruits and vegetables, canneries, juice making, etc.).

Both the pulp and paper industry and the meat and poultry processing industries produce large volumes of wastewater that contain high levels of degradable organics. The meat and poultry processing facilities typically employ anaerobic lagoons to treat their wastewater, while the paper and pulp industry also use lagoons and anaerobic reactors. The non-animal food and beverage industries produce considerable amounts of wastewater with significant organic carbon levels and are also known to use anaerobic processes such as lagoons and anaerobic reactors. Anaerobic reactors treating industrial effluents with biogas facilities are usually linked with recovery of the generated $CH_4$ for energy. Emissions from the combustion process for energy should be reported in the Energy Sector.

The method for estimating emissions from industrial wastewater is similar to the one used for domestic wastewater. See the decision tree in Figure 6.3. The development of emission factors and activity data is more complex because there are many types of wastewater, and many different industries to track. The most accurate estimates of emissions for this source category would be based on measured data from point sources. Due to the high costs of measurements and the potentially large number of point sources, collecting comprehensive measurement data is very difficult. It is suggested that inventory compilers use a top-down approach that includes the following general steps:

**Step 1:** Use Equation 6.6 to estimate total organically degradable carbon in wastewater (TOW) for industrial sector *i*

**Step 2:** Select the pathway and systems (Figure 6.1) according to country activity data. Use Equation 6.5 to obtain emission factor. For each industrial sector estimate the emission factor using maximum methane producing capacity and the average industry-specific methane correction factor.

**Step 3:** Use Equation 6.4 to estimate emissions, adjust for possible sludge removal and or $CH_4$ recovery and sum the results.

The general equation to estimate $CH_4$ emissions from industrial wastewater is as follows:

**EQUATION 6.4**
**TOTAL $CH_4$ EMISSIONS FROM INDUSTRIAL WASTEWATER**

$$CH_4\ Emissions = \sum_i \left[ \left( TOW_i - S_i \right) EF_i - R_i \right]$$

Where:

$CH_4$ Emissions = $CH_4$ emissions in inventory year, kg $CH_4$/yr

$TOW_i$ = total organically degradable material in wastewater from industry *i* in inventory year, kg COD/yr

i = industrial sector

$S_i$ = organic component removed as sludge in inventory year, kg COD/yr

$EF_i$ = emission factor for industry *i*, kg $CH_4$/kg COD for treatment/discharge pathway or system(s) used in inventory year

If more than one treatment practice is used in an industry this factor would need to be a weighted average.

$R_i$ = amount of $CH_4$ recovered in inventory year, kg $CH_4$/yr

The amount of $CH_4$ which is recovered is expressed as R in Equation 6.4. The recovered gas should be treated as described in Section 6.2.1.

### 6.2.3.2 CHOICE OF EMISSION FACTORS

There are significant differences in the $CH_4$ emitting potential of different types of industrial wastewater. To the extent possible, data should be collected to determine the maximum $CH_4$ producing capacity ($B_o$) in each industry. As mentioned before, the MCF indicates the extent to which the $CH_4$ producing potential ($B_o$) is

realised in each type of treatment method. Thus, it is an indication of the degree to which the system is anaerobic. See Equation 6.5.

**EQUATION 6.5**
**$CH_4$ EMISSION FACTOR FOR INDUSTRIAL WASTEWATER**

$$EF_j = B_o \bullet MCF_j$$

Where:

$EF_j$ = emission factor for each treatment/discharge pathway or system, kg $CH_4$/kg COD, (See Table 6.8.)

j = each treatment/discharge pathway or system

$B_o$ = maximum $CH_4$ producing capacity, kg $CH_4$/kg COD

$MCF_j$ = methane correction factor (fraction) (See Table 6.8.)

*Good practice* is to use country and industry sector specific data that may be available from government authorities, industrial organisations, or industrial experts. However, most inventory compilers will find detailed industry sector-specific data unavailable or incomplete. If no country-specific data are available, it is *good practice* to use the IPCC COD-default factor for $B_o$ (0.25 kg $CH_4$/kg COD).

In determining the Methane correction factor (MCF), which is the fraction of waste treated anaerobically, expert judgement is recommended. A peer-reviewed survey of industry wastewater treatment practices is one useful technique for estimating these data. Surveys should be conducted frequently enough to account for major trends in industry practices (i.e., every 3-5 years). Chapter 2, Approaches to Data Collection, in Volume 1, describes how to elicit expert judgement for uncertainty ranges. Similar expert elicitation protocols can be used to obtain the necessary information for other types of data if published data and statistics are not available. Table 6.8 includes default MCF values, which are based on expert judgment.

**TABLE 6.8**
**DEFAULT MCF VALUES FOR INDUSTRIAL WASTEWATER**

| Type of treatment and discharge pathway or system | Comments | MCF [1] | Range |
|---|---|---|---|
| **Untreated** | | | |
| Sea, river and lake discharge | Rivers with high organics loadings may turn anaerobic, however this is not considered here. | 0.1 | 0 – 0.2 |
| **Treated** | | | |
| Aerobic treatment plant | Must be well managed. Some $CH_4$ can be emitted from settling basins and other pockets. | 0 | 0 – 0.1 |
| Aerobic treatment plant | Not well managed. Overloaded | 0.3 | 0.2 – 0.4 |
| Anaerobic digester for sludge | $CH_4$ recovery not considered here | 0.8 | 0.8 – 1.0 |
| Anaerobic reactor (e.g., UASB, Fixed Film Reactor) | $CH_4$ recovery not considered here | 0.8 | 0.8 – 1.0 |
| Anaerobic shallow lagoon | Depth less than 2 metres, use expert judgment | 0.2 | 0 – 0.3 |
| Anaerobic deep lagoon | Depth more than 2 metres | 0.8 | 0.8 – 1.0 |

[1] Based on expert judgment by lead authors of this section

### 6.2.3.3 CHOICE OF ACTIVITY DATA

The activity data for this source category is the amount of organically degradable material in the wastewater (TOW). This parameter is a function of industrial output (product) P (tons/yr), wastewater generation W ($m^3$/ton of product), and degradable organics concentration in the wastewater COD (kg COD/$m^3$). See Equation 6.6. The following steps are required for determination of TOW:

(i) Identify the industrial sectors that generate wastewater with large quantities of organic carbon, by evaluating total industrial product, degradable organics in the wastewater, and wastewater produced.

(ii) Identify industrial sectors that use anaerobic treatment. Include those that may have unintended anaerobic treatment as a result of overloading of the treatment system. Experience has shown that usually three or four industrial sectors are *key*.

For each selected sector estimate total organically degradable carbon (TOW).

**EQUATION 6.6**
**ORGANICALLY DEGRADABLE MATERIAL IN INDUSTRIAL WASTEWATER**

$$TOW_i = P_i \bullet W_i \bullet COD_i$$

Where:

$TOW_i$ = total organically degradable material in wastewater for industry *i*, kg COD/yr

i = industrial sector

$P_i$ = total industrial product for industrial sector *i*, t/yr

$W_i$ = wastewater generated, $m^3/t_{product}$

$COD_i$ = chemical oxygen demand (industrial degradable organic component in wastewater), kg COD/$m^3$

Industrial production data and wastewater outflows may be obtained from national statistics, regulatory agencies, wastewater treatment associations or industry associations. In some cases quantification of the COD loading in the wastewater may require expert judgement. In some countries, COD and total water usage per sector data may be available directly from a regulatory agency. An alternative is to obtain data on industrial output and tonnes COD produced per tonne of product from the literature. Table 6.9 provides examples that could be used as default values. These should be used with caution, because they are industry-, process- and country-specific.

**TABLE 6.9**
**EXAMPLES OF INDUSTRIAL WASTEWATER DATA**

| Industry Type | Wastewater Generation W ($m^3$/ton) | Range for W ($m^3$/ton) | COD (kg/$m^3$) | COD Range (kg/$m^3$) |
|---|---|---|---|---|
| Alcohol Refining | 24 | 16 – 32 | 11 | 5 – 22 |
| Beer & Malt | 6.3 | 5.0 – 9.0 | 2.9 | 2 – 7 |
| Coffee | NA | NA – | 9 | 3 – 15 |
| Dairy Products | 7 | 3 – 10 | 2.7 | 1.5 – 5.2 |
| Fish Processing | NA | 8 – 18 | 2.5 | |
| Meat & Poultry | 13 | 8 – 18 | 4.1 | 2 – 7 |
| Organic Chemicals | 67 | 0 – 400 | 3 | 0.8 – 5 |
| Petroleum Refineries | 0.6 | 0.3 – 1.2 | 1.0 | 0.4 – 1.6 |
| Plastics & Resins | 0.6 | 0.3 – 1.2 | 3.7 | 0.8 – 5 |
| Pulp & Paper (combined) | 162 | 85 – 240 | 9 | 1 – 15 |
| Soap & Detergents | NA | 1.0 – 5.0 | NA | 0.5 – 1.2 |
| Starch Production | 9 | 4 – 18 | 10 | 1.5 – 42 |
| Sugar Refining | NA | 4 – 18 | 3.2 | 1 – 6 |
| Vegetable Oils | 3.1 | 1.0 – 5.0 | NA | 0.5 – 1.2 |
| Vegetables, Fruits & Juices | 20 | 7 – 35 | 5.0 | 2 – 10 |
| Wine & Vinegar | 23 | 11 – 46 | 1.5 | 0.7 – 3.0 |

Notes: NA = Not Available.
Source: Doorn *et al*. (1997).

### 6.2.3.4 TIME SERIES CONSISTENCY

Once an industrial sector is included in the inventory calculation, it should be included for each subsequent year. If the inventory compiler adds a new industrial sector to the calculation, then he or she should re-calculate the

entire time series so that the method is consistent from year to year. General guidance on recalculation of estimates through time series is provided in Volume 1, Chapter 5, Time Series Consistency.

As with domestic wastewater, sludge removal and $CH_4$ recovery should be treated consistently across years in the time series. $CH_4$ recovery should be included only if there are facility-specific data. The quantity of recovered $CH_4$ should be subtracted from the $CH_4$ produced as shown in Equation 6.4.

### 6.2.3.5 UNCERTAINTIES

Uncertainty estimates for $B_o$, MCF, P, W and COD are provided in Table 6.10. The estimates are based on expert judgement.

**TABLE 6.10**
**DEFAULT UNCERTAINTY RANGES FOR INDUSTRIAL WASTEWATER**

| Parameter | Uncertainty Range |
|---|---|
| **Emission Factor** | |
| Maximum $CH_4$ producing capacity ($B_o$) | ± 30% |
| Methane correction factor (MCF) | The uncertainty range should be determined by expert judgement, bearing in mind that this is a fraction and uncertainties cannot take it outside the range of 0 to 1. |
| **Activity Data** | |
| Industrial production (P) | ± 25% Use expert judgement regarding the quality of data source to assign more accurate uncertainty range. |
| Wastewater/unit production (W) | These data can be very uncertain as the same sector might use different waste handling procedures at different plants and in different countries. The product of the parameters (W•COD) is expected to have less uncertainty. An uncertainty value can be attributed directly to kg COD/tonne of product. –50 %, +100% is suggested (i.e., a factor of 2). |
| COD/unit wastewater (COD) | |

Source*:* Judgement by Expert Group (Co-chairs, Editors and Authors of this sector).

### 6.2.3.6 QA/QC, COMPLETENESS, REPORTING AND DOCUMENTATION

It is *good practice* to conduct quality control checks and quality assurance procedures as outlined in Chapter 6, QA/QC and Verification, of Volume 1. Below, some fundamental QA/QC procedures include:

- For industrial wastewater, inventory compilers may review the secondary data sets (e.g., from national statistics, regulatory agencies, wastewater treatment associations or industry associations) , that are used to estimate and rank industrial COD waste output. Some countries may have regulatory control over industrial discharges, in which cases significant QA/QC protocols may already be in place for the development of the wastewater characteristics on an industry basis.
- For industrial wastewater, inventory compilers should cross-check values for MCFs against those from other national inventories with similar wastewater characteristics.
- The inventory compilers should review facility-specific data on $CH_4$ recovery to ensure that it was reported according to criteria on measurements outlined in Chapter 2, Approaches to Data Collection, in Volume 1.
- Use a carbon balance check to ensure that the carbon contained in $CH_4$ recovery is less than the carbon contained in BOD entering the facility that reports $CH_4$ recovery.
- If sludge removal is reported in the wastewater inventory, check for consistency with the estimates for sludge applied to agriculture soils, sludge incinerated, and sludge deposited in solid waste disposal.
- For countries that use country-specific parameters or higher tier methods, inventory compilers should cross-check the national estimates with emissions using the IPCC default method and parameters.

#### COMPLETENESS

Completeness for estimating emissions from industrial wastewater depends on an accurate characterization of industrial sectors that produce organic wastewater. In most countries, approximately 3-4 industrial sectors will account for the majority of the organic wastewater volume, so the inventory compilers should ensure that these sectors are covered. Periodically, the inventory compilers should re-survey industrial sources, particularly if some industries are growing rapidly.

This category should only cover industrial wastewater treated onsite. Emissions from industrial wastewater released into domestic sewer systems should be addressed and included with domestic wastewater.

Some sludge from industrial wastewater treatment may be incinerated or deposited in landfills or on agricultural lands. This constitutes an amount of organic waste that should be subtracted from available TOW. It is *good practice* to be consistent across sectors: the amount of sludge that is removed from TOW should be equal to the amount of sludge disposed at landfills, applied to agricultural soils, incinerated or treated elsewhere.

#### REPORTING AND DOCUMENTATION

It is *good practice* to document and report a summary of the methods used, activity data and emission factors. Worksheets are provided at the end of this volume. When country-specific methods and/or emission factors are used, the reasoning for the choices as well as references to how the country-specific data (measurements, literature, expert judgement, etc.) have been derived (measurements, literature, expert judgement, etc.) should be documented and included in the reporting.

If sludge is incinerated, landfilled, or spread on agricultural lands, the quantities of sludge and associated emissions should be reported in the waste incineration, SWDS, or agricultural categories, respectively.

If $CH_4$ recovery data are available for industrial wastewater treatment, these should be documented for flaring and energy recovery separately. The treatment of recovered $CH_4$ and how to report emissions from flaring should be the same as the guidance for domestic wastewater in Section 6.2.2.6.

More information on reporting and documentation can be found in Volume 1, Chapter 6, Section 6.11 Documentation, archiving and reporting.

# 6.3 NITROUS OXIDE EMISSIONS FROM WASTEWATER

## 6.3.1 Methodological issues

### 6.3.1.1 CHOICE OF METHOD

Nitrous oxide ($N_2O$) emissions can occur as direct emissions from treatment plants or from indirect emissions from wastewater after disposal of effluent into waterways, lakes or the sea. Direct emissions from nitrification and denitrification at wastewater treatment plants may be considered as a minor source and guidance is offered in Box 6.1 to estimate these emissions. Typically, these emissions are much smaller than those from effluent and may only be of interest to countries that predominantly have advanced centralized wastewater treatment plants with nitrification and denitrification steps.

No higher tiers are given, so it is *Good practice* to estimate $N_2O$ from domestic wastewater effluent using the method given here, No decision tree is provided. Direct emissions need to be estimated only for countries that have predominantly advanced centralized wastewater treatment plants with nitrification and denitrification steps.

Accordingly, this section addresses indirect $N_2O$ emissions from wastewater treatment effluent that is discharged into aquatic environments. The methodology for emissions from effluent is similar to that of indirect $N_2O$ emissions explained in Volume 4, Section 11.2.2, in Chapter 11, $N_2O$ Emissions from Managed Soils, and $CO_2$ Emissions from Lime and Urea Application. The simplified general equation is as follows:

**EQUATION 6.7**
**$N_2O$ EMISSIONS FROM WASTEWATER EFFLUENT**

$$N_2O\ Emissions = N_{EFFLUENT} \bullet EF_{EFFLUENT} \bullet 44/28$$

Where:

$N_2O$ emissions = $N_2O$ emissions in inventory year, kg $N_2O$/yr

$N_{EFFLUENT}$ = nitrogen in the effluent discharged to aquatic environments, kg N/yr

$EF_{EFFLUENT}$ = emission factor for $N_2O$ emissions from discharged to wastewater, kg $N_2O$-N/kg N

The factor 44/28 is the conversion of kg $N_2O$-N into kg $N_2O$.

### 6.3.1.2 CHOICE OF EMISSION FACTORS

The default IPCC emission factor for $N_2O$ emissions from domestic wastewater nitrogen effluent is 0.005 (0.0005 - 0.25) kg $N_2O$-N/kg N. This emission factor is based on limited field data and on specific assumptions regarding the occurrence of nitrification and denitrification in rivers and in estuaries. The first assumption is that all nitrogen is discharged with the effluent. The second assumption is that $N_2O$ production in rivers and estuaries is directly related to nitrification and denitrification and, thus, to the nitrogen that is discharged into the river. (See Volume 4, Table 11.3 of Section 11.2.2 in Chapter 11, $N_2O$ Emissions from Managed Soils, and $CO_2$ Emissions from Lime and Urea Application.)

### 6.3.1.3 CHOICE OF ACTIVITY DATA

The activity data that are needed for estimating $N_2O$ emissions are nitrogen content in the wastewater effluent, country population and average annual per capita protein generation (kg/person/yr). Per capita protein generation consists of intake (consumption) which is available from the Food and Agriculture Organization (FAO, 2004), multiplied by factors to account for additional 'non-consumed' protein and for industrial protein discharged into the sewer system. Food (waste) that is not consumed may be washed down the drain (e.g., as result of the use of garbage disposals in some developed countries) and also, bath and laundry water can be expected to contribute to nitrogen loadings. For developed countries using garbage disposals, the default for non-consumed protein discharged to wastewater pathways is 1.4, while for developing countries this fraction is 1.1. Wastewater from industrial or commercial sources that is discharged into the sewer may contain protein (e.g., from grocery stores and butchers). The default for this fraction is 1.25. The total nitrogen in the effluent is estimated as follows:

**EQUATION 6.8**
**TOTAL NITROGEN IN THE EFFLUENT**

$$N_{EFFLUENT} = \left( P \bullet Protein \bullet F_{NPR} \bullet F_{NON-CON} \bullet F_{IND-COM} \right) - N_{SLUDGE}$$

Where:

$N_{EFFLUENT}$ = total annual amount of nitrogen in the wastewater effluent, kg N/yr

P = human population

Protein = annual per capita protein consumption, kg/person/yr

$F_{NPR}$ = fraction of nitrogen in protein, default = 0.16, kg N/kg protein

$F_{NON-CON}$ = factor for non-consumed protein added to the wastewater

$F_{IND-COM}$ = factor for industrial and commercial co-discharged protein into the sewer system

$N_{SLUDGE}$ = nitrogen removed with sludge (default = zero), kg N/yr

**BOX 6.1**
**SUBCATEGORY - EMISSIONS FROM ADVANCED CENTRALISED WASTEWATER TREATMENT PLANTS**

Emissions from advanced centralised wastewater treatment plants are typically much smaller than those from effluent and may only be of interest for countries that have predominantly advanced centralized wastewater treatment plants with controlled nitrification and denitrification steps. The overall emission factor to estimate $N_2O$ emissions from such plants is 3.2 g $N_2O$/person/year. This emission factor was determined during field testing at a domestic wastewater treatment plant in the Northern United States (Czepiel *et al*., 1995). The emission data were obtained at a plant that received only domestic wastewater. This wastewater already included non-consumption protein, but did not include any co-discharged industrial and commercial wastewater. No other country-specific emission factors are available. The emissions from $N_2O$ from centralized wastewater treatment processes are calculated as follows:

**EQUATION 6.9**
**$N_2O$ EMISION FROM**
**CENTRALIZED WASTEWATER TREATMENT PROCESSES**

$$N_2O_{PLANTS} = P \bullet T_{PLANT} \bullet F_{IND-COM} \bullet EF_{PLANT}$$

Where:

$N_2O_{PLANTS}$ = total $N_2O$ emissions from plants in inventory year, kg $N_2O$/yr

P = human population

$T_{PLANT}$ = degree of utilization of modern, centralized WWT plants, %

$F_{IND-COMM}$ = fraction of industrial and commercial co-discharged protein (default = 1.25, based on data in Metcalf & Eddy (2003) and expert judgment)

$EF_{PLANT}$ = emission factor, 3.2 g $N_2O$/person/year

Note: When a country chooses to include $N_2O$ emissions from plants, the amount of nitrogen associated with these emissions ($N_{WWT}$) must be back calculated and subtracted from the $N_{EFFLUENT}$. The $N_{WWT}$ can be calculated by multiplying $N_2O_{PLANTS}$ by 28/44, using the molecular weights.

## 6.3.2 Time series consistency

If a country decides to incorporate plant emissions into the estimate, this change must be made for the entire time series. Potential sludge removal should be treated consistently across years in the time series.

## 6.3.3 Uncertainties

Large uncertainties are associated with the IPCC default emission factors for $N_2O$ from effluent. Currently insufficient field data exist to improve this factor. Also, the $N_2O$ emission factor for plants is uncertain, because it is based on one field test. Table 6.11 below includes uncertainty ranges based on expert judgment.

**TABLE 6.11**
**$N_2O$ METHODOLOGY DEFAULT DATA**

| | Definition | Default Value | Range |
|---|---|---|---|
| **Emission Factor** | | | |
| $EF_{EFFLUENT}$ | Emission factor, (kg $N_2O$-N/kg –N) | 0.005 | 0.0005 – 0.25 |
| $EF_{PLANTS}$ | Emission factor, (g $N_2O$/person/year) | 3.2 | 2 – 8 |
| **Activity Data** | | | |
| P | Number of people in country | Country-specific | ± 10 % |
| Protein | Annual per capita protein consumption | Country-specific | ± 10 % |
| $F_{NPR}$ | Fraction of nitrogen in protein (kg N/kg protein) | 0.16 | 0.15 – 0.17 |
| $T_{plant}$ | Degree of utilization of large WWT plants | Country-specific | ± 20 % |
| $F_{NON-CON}$ | Factor to adjust for non-consumed protein | 1.1 for countries with no garbage disposals, 1.4 for countries with garbage disposals | 1.0 – 1.5 |
| $F_{IND-COM}$ | Factor to allow for co-discharge of industrial nitrogen into sewers. For countries with significant fish processing plants, this factor may be higher. Expert judgment is recommended. | 1.25 | 1.0 – 1.5 |

## 6.3.4 QA/QC, Completeness, Reporting and Documentation

This method makes use of several default parameters. It is recommended to solicit experts' advice in evaluating the appropriateness of the proposed default factors.

### COMPLETENESS

Unless sludge removal data are available, the methodology for estimating emissions from effluent is based on population and on the assumption that all nitrogen associated with consumption and domestic use, as well as nitrogen from co-discharged industrial wastewater, will eventually enter a waterway. As such, this estimate can be seen as conservative estimate and covers the entire source associated with domestic wastewater use.

The methodology does not include $N_2O$ emissions from industrial sources, except for industrial wastewater that is co-discharged with domestic wastewater into the sewer system. The $N_2O$ emissions from industrial sources are believed to be insignificant compared to emissions from domestic wastewater.

Very few countries collect data on wastewater sludge handling. If these data exist, it is suggested to make them available to the appropriate inventory teams.

The emission factor used for $N_2O$ emissions from effluent is the same as the emission factor used for indirect $N_2O$ emissions in the AFOLU Sector.

### REPORTING AND DOCUMENTATION

It is *good practice* to document and report a summary of the methods used, activity data and emission factors. Worksheets are provided at the end of this volume. When country-specific methods and/or emission factors are used, the reasoning for the choices as well as references to how the country-specific data (measurements, literature, expert judgement, etc.) have been derived (measurements, literature, expert judgement, etc.) should be documented and included in the reporting.

If sludge is incinerated, landfilled, or spread on agricultural lands, the associated quantities of sludge should be reported in the waste incineration, SWDS, or agricultural categories, respectively.

More information on reporting and documentation can be found in Volume 1, Chapter 6, Section 6.11 Documentation, archiving and reporting.

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# Appendix B
# USEPA Wastewater Treatment Methodology

# 8. Waste

Waste management and treatment activities are sources of greenhouse gas emissions (see Figure 8-1). Landfills accounted for approximately 24 percent of total U.S. anthropogenic methane ($CH_4$) emissions in 2005,[1] the largest contribution of any $CH_4$ source in the United States. Additionally, wastewater treatment accounts for just under 5 percent of U.S. $CH_4$ emissions. Nitrous oxide ($N_2O$) emissions from the discharge of wastewater treatment effluents into aquatic environments were estimated, as were $N_2O$ emissions from the treatment process itself. Nitrogen oxide ($NO_x$), carbon monoxide (CO), and non-$CH_4$ volatile organic compounds (NMVOCs) are emitted by waste activities, and are addressed separately at the end of this chapter. A summary of greenhouse gas and indirect greenhouse gas emissions from the Waste chapter is presented in Table 8-1 and Table 8-2.

Figure 8-1: 2005 Waste Chapter Greenhouse Gas Sources

Overall, in 2005, waste activities generated emissions of 165.4 Tg $CO_2$ Eq., or just over 2 percent of total U.S. greenhouse gas emissions.

Table 8-1: Emissions from Waste (Tg $CO_2$ Eq.)

| Gas/Source | 1990 | 1995 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|---|
| **$CH_4$** | **185.8** | **182.2** | **158.3** | **153.5** | **156.2** | **160.5** | **157.8** | **157.4** |
| Landfills | 161.0 | 157.1 | 131.9 | 127.6 | 130.4 | 134.9 | 132.1 | 132.0 |
| Wastewater Treatment | 24.8 | 25.1 | 26.4 | 25.9 | 25.8 | 25.6 | 25.7 | 25.4 |
| **$N_2O$** | **6.4** | **6.9** | **7.6** | **7.6** | **7.7** | **7.8** | **7.9** | **8.0** |
| Domestic Wastewater Treatment | 6.4 | 6.9 | 7.6 | 7.6 | 7.7 | 7.8 | 7.9 | 8.0 |
| **Total** | **192.2** | **189.1** | **165.9** | **161.1** | **163.9** | **168.4** | **165.7** | **165.4** |

Note: Totals may not sum due to independent rounding.

Table 8-2: Emissions from Waste (Gg)

| Gas/Source | 1990 | 1995 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|---|
| **$CH_4$** | **8,848** | **8,674** | **7,537** | **7,310** | **7,439** | **7,645** | **7,514** | **7,496** |
| Landfills | 7,668 | 7,479 | 6,280 | 6,078 | 6,210 | 6,425 | 6,292 | 6,286 |
| Wastewater Treatment | 1,180 | 1,195 | 1,257 | 1,232 | 1,229 | 1,220 | 1,222 | 1,210 |
| **$N_2O$** | **21** | **22** | **24** | **25** | **25** | **25** | **26** | **26** |
| Domestic Wastewater Treatment | 21 | 22 | 24 | 25 | 25 | 25 | 26 | 26 |
| **$NO_x$** | **+** | **1** | **2** | **2** | **2** | **2** | **2** | **2** |
| **CO** | **1** | **2** | **8** | **8** | **7** | **7** | **7** | **7** |
| **NMVOCs** | **673** | **731** | **119** | **122** | **116** | **116** | **116** | **116** |

Note: Totals may not sum due to independent rounding.

[1] Landfills also store carbon, due to incomplete degradation of organic materials such as wood products and yard trimmings, as described in the Land Use, Land-Use Change, and Forestry chapter.

## 8.1. Landfills (IPCC Source Category 6A1)

In 2005, landfill $CH_4$ emissions were approximately 132 Tg $CO_2$ Eq. (6,286 Gg), representing the largest source of $CH_4$ emissions in the United States. Emissions from municipal solid waste (MSW) landfills, which received about 64 percent of the total solid waste generated in the United States, accounted for about 89 percent of total landfill emissions, while industrial landfills accounted for the remainder. Approximately 1,800 operational landfills exist in the United States, with the largest landfills receiving most of the waste and generating the majority of the $CH_4$ (BioCycle 2006, adjusted to include missing data from five states).

After being placed in a landfill, waste (such as paper, food scraps, and yard trimmings) is initially decomposed by aerobic bacteria. After the oxygen has been depleted, the remaining waste is available for consumption by anaerobic bacteria, which break down organic matter into substances such as cellulose, amino acids, and sugars. These substances are further broken down through fermentation into gases and short-chain organic compounds that form the substrates for the growth of methanogenic bacteria. These $CH_4$-producing anaerobic bacteria convert the fermentation products into stabilized organic materials and biogas consisting of approximately 50 percent carbon dioxide ($CO_2$) and 50 percent $CH_4$, by volume.[2] Significant $CH_4$ production typically begins one or two years after waste disposal in a landfill and continues for 10 to 60 years.

From 1990 to 2005, net $CH_4$ emissions from landfills decreased by approximately 18 percent (see Table 8-3 and Table 8-4), with small increases occurring in some interim years. This downward trend in overall emissions is the result of increases in the amount of landfill gas collected and combusted,[3] which has more than offset the additional $CH_4$ emissions resulting from an increase in the amount of municipal solid waste landfilled.

Methane emissions from landfills are a function of several factors, including: (1) the total amount of municipal solid waste in landfills, which is related to total municipal solid waste landfilled annually; (2) the characteristics of landfills receiving waste (i.e., composition of waste-in-place, size, climate); (3) the amount of $CH_4$ that is recovered and either flared or used for energy purposes; and (4) the amount of $CH_4$ oxidized in landfills instead of being released into the atmosphere. The estimated annual quantity of waste placed in landfills increased from about 209 Tg in 1990 to 304 Tg in 2005, an increase of 45 percent (see Annex 3.14). During this period, the estimated $CH_4$ recovered and combusted from landfills increased as well. In 1990, for example, approximately 1,079 Gg of $CH_4$ were recovered and combusted (i.e., used for energy or flared) from landfills. In 2005, the estimated quantity of $CH_4$ recovered and combusted increased to 5,668 Gg, a 7 percent increase from 2004 levels.

Over the next several years, the total amount of municipal solid waste generated is expected to increase as the U.S. population continues to grow. The percentage of waste landfilled, however, may decline due to increased recycling and composting practices. In addition, the quantity of $CH_4$ that is recovered and either flared or used for energy purposes is expected to increase as a result of 1996 federal regulations that require large municipal solid waste landfills to collect and combust landfill gas (see 40 CFR Part 60, Subpart Cc 2005 and 40 CFR Part 60, Subpart WWW 2005), voluntary programs encouraging $CH_4$ recovery and use such as EPA's Landfill Methane Outreach Program (LMOP), and federal and state economic incentives.

Table 8-3: $CH_4$ Emissions from Landfills (Tg $CO_2$ Eq.)

| Activity | 1990 | 1995 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|---|
| MSW Landfills | 188.7 | 204.7 | 217.3 | 221.4 | 227.2 | 234.9 | 242.4 | 249.6 |
| Industrial Landfills | 12.9 | 13.9 | 15.4 | 15.6 | 15.7 | 15.9 | 16.0 | 16.1 |
| Recovered | | | | | | | | |

[2] The percentage of $CO_2$ in biogas released from a landfill may be smaller because some $CO_2$ dissolves in landfill water (Bingemer and Crutzen 1987). Additionally, less than 1 percent of landfill gas is typically composed of non-$CH_4$ volatile organic compounds (NMVOCs).

[3] The $CO_2$ produced from combusted landfill $CH_4$ at landfills is not counted in national inventories as it is considered part of the natural C cycle of decomposition.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Gas-to-Energy | (17.6) | (22.3) | (49.0) | (54.3) | (54.4) | (54.9) | (57.1) | (58.6) |
| Flared | (5.0) | (21.8) | (37.1) | (40.8) | (43.7) | (46.0) | (54.4) | (60.4) |
| Oxidized[a] | (17.9) | (17.5) | (14.7) | (14.2) | (14.5) | (15.0) | (14.7) | (14.7) |
| **Total** | **161.0** | **157.1** | **131.9** | **127.6** | **130.4** | **134.9** | **132.1** | **132.0** |

Note: Totals may not sum due to independent rounding. Parentheses indicate negative values.
[a] Includes oxidation at both municipal and industrial landfills.

Table 8-4: $CH_4$ Emissions from Landfills (Gg)

| Activity | 1990 | 1995 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|---|
| MSW Landfills | 8,985 | 9,745 | 10,348 | 10,541 | 10,820 | 11,188 | 11,543 | 11,885 |
| Industrial Landfills | 614 | 664 | 731 | 744 | 749 | 757 | 761 | 767 |
| Recovered | | | | | | | | |
| Gas-to-Energy | (840) | (1,061) | (2,335) | (2,588) | (2,590) | (2,614) | (2,720) | (2,790) |
| Flared | (239) | (1,039) | (1,766) | (1,943) | (2,080) | (2,192) | (2,593) | (2,877) |
| Oxidized[a] | (852) | (831) | (698) | (675) | (690) | (714) | (699) | (698) |
| **Total** | **7,668** | **7,479** | **6,280** | **6,078** | **6,210** | **6,425** | **6,292** | **6,286** |

Note: Totals may not sum due to independent rounding. Parentheses indicate negative values.
[a] Includes oxidation at municipal and industrial landfills.

## Methodology

$CH_4$ emissions from landfills were estimated to equal the $CH_4$ produced from municipal solid waste landfills, plus the $CH_4$ produced by industrial landfills, minus the $CH_4$ recovered and combusted, minus the $CH_4$ oxidized before being released into the atmosphere:

$$CH_{4,\text{Solid Waste}} = [CH_{4,MSW} + CH_{4,ind} - R] - Ox$$

where,

| | |
|---|---|
| $CH_{4,\text{Solid Waste}}$ | = $CH_4$ emissions from solid waste |
| $CH_{4,MSW}$ | = $CH_4$ generation from municipal solid waste landfills, |
| $CH_{4,ind}$ | = $CH_4$ generation from industrial landfills, |
| R | = $CH_4$ recovered and combusted, and |
| Ox | = $CH_4$ oxidized from MSW and industrial landfills before release to the atmosphere. |

The methodology for estimating $CH_4$ emissions from municipal solid waste landfills is based on the first order decay model described by the Intergovernmental Panel on Climate Change (IPCC 2006). Values for the $CH_4$ generation potential ($L_0$) and rate constant (k) were obtained from an analysis of $CH_4$ recovery rates for a database of 52 landfills and from published studies of other landfills (RTI 2004; EPA 1998; SWANA 1998; Peer, Thorneloe, and Epperson 1993). The rate constant was found to increase with average annual rainfall; consequently, values of k were developed for 3 ranges of rainfall. The annual quantity of waste placed in landfills was apportioned to the 3 ranges of rainfall based on the percent of the U.S. population in each of the 3 ranges, and historical census data were used to account for the shift in population to more arid areas over time. For further information, see Annex 3.14.

National landfill waste generation and disposal data for 1989 through 2005 were obtained from *BioCycle* (2006). Because *BioCycle* does not account for waste generated in U.S. territories, waste generation for the territories was estimated using population data obtained from the U.S. Census Bureau (2006) and national per capita solid waste generation from *BioCycle* (2006). Estimates of the annual quantity of waste landfilled for 1960 through 1988 were obtained from EPA's *Anthropogenic Methane Emissions in the United States, Estimates for 1990: Report to Congress* (EPA 1993) and an extensive landfill survey by the EPA's Office of Solid Waste in 1986 (EPA 1988). Although waste placed in landfills in the 1940s and 1950s contributes very little to current $CH_4$ generation, estimates for those years were included in the first order decay model for completeness in accounting for $CH_4$ generation rates and are based on the population in those years and the per capita rate for land disposal for the 1960s.

The estimated landfill gas recovered per year was based on updated data collected from vendors of flaring equipment, a database of landfill gas-to-energy (LFGTE) projects compiled by LMOP (EPA 2006), and a database maintained by the Energy Information Administration (EIA) for the voluntary reporting of greenhouse gases (EIA 2006). The three databases were carefully compared to identify landfills that were in two or all three of the databases to avoid double-counting reductions. Based on the information provided by the EIA and flare vendor databases, the $CH_4$ combusted by flares in operation from 1990 to 2005 was estimated. This quantity likely underestimates flaring because these databases do not have information on all flares in operation. Additionally, the EIA and LMOP databases provided data on landfill gas flow and energy generation for landfills with LFGTE projects. If a landfill in the EIA database was also in the LMOP and/or the flare vendor database, the emissions avoided were based on the EIA data because landfill owners or operators reported the amount recovered based on measurements of gas flow and concentration, and the reporting accounted for changes over time. If both flare data and LMOP recovery data were available for any of the remaining landfills (i.e., not in the EIA database), then the emissions recovery was based on the LMOP data, which provides reported landfill-specific data on gas flow for direct use projects and project capacity (i.e., megawatts) for electricity projects. The flare data, on the other hand, only provided a range of landfill gas flow for a given flare size. Given that each LFGTE project is likely to also have a flare, double counting reductions from flares and LFGTE projects in the LMOP database was avoided by subtracting emissions reductions associated with LFGTE projects for which a flare had not been identified from the emissions reductions associated with flares.

A destruction efficiency of 99 percent was applied to $CH_4$ recovered to estimate $CH_4$ emissions avoided. The value for efficiency was selected based on the range of efficiencies (98 to 100 percent) recommended for flares in EPA's *AP-42 Compilation of Air Pollutant Emission Factors, Chapter 2.4* (EPA 1998) efficiencies used to establish new source performance standards (NSPS) for landfills, and in recommendations for closed flares used in LMOP.

Emissions from industrial landfills were estimated from activity data for industrial production, waste disposal factors, and the first order decay model. The amount of $CH_4$ oxidized by the landfill cover at both municipal and industrial landfills was assumed to be ten percent of the $CH_4$ generated that is not recovered (IPCC 2006, Mancinelli and McKay 1985, Czepiel et al. 1996). To calculate net $CH_4$ emissions, both $CH_4$ recovered and $CH_4$ oxidized were subtracted from $CH_4$ generated at municipal and industrial landfills.

## Uncertainty

Several types of uncertainty are associated with the estimates of $CH_4$ emissions from landfills. The primary uncertainty concerns the characterization of landfills. Information is not available on two fundamental factors affecting $CH_4$ production: the amount and composition of waste placed in every landfill for each year of its operation. The approach used here assumes that the $CH_4$ generation potential and the rate of decay that produces $CH_4$, as determined from several studies of $CH_4$ recovery at landfills, are representative of U.S. landfills.

Additionally, the approach used to estimate the contribution of industrial wastes to total $CH_4$ generation introduces uncertainty. Aside from uncertainty in estimating $CH_4$ generation potential, uncertainty exists in the estimates of oxidation by cover soils. There is also uncertainty in the estimates of methane that is recovered by flaring and energy projects. The IPCC default value of 10 percent for uncertainty in recovery estimates was used in the uncertainty analysis when metering was in place (for about 64 percent of the methane estimated to be recovered). For flaring without metered recovery data (approximately 34 percent of the methane estimated to be recovered), a much higher uncertainty of approximately 50 percent was used (e.g., when recovery was estimated as 50 percent of the flare's design capacity).

$N_2O$ emissions from the application of sewage sludge on landfills are not explicitly modeled as part of greenhouse gas emissions from landfills. $N_2O$ emissions from sewage sludge applied to landfills would be relatively small because the microbial environment in landfills is not very conducive to the nitrification and denitrification processes that result in $N_2O$ emissions. The total nitrogen (N) in sewage sludge increased from 189 to 268 Gg total N between 1990 and 2005, however; the quantity of sewage sludge applied to landfills decreased from 28 to 10 percent from 1990 to 2005.[4]

The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 8-5. Landfill $CH_4$ emissions in 2005 were estimated to be between 80.5 and 174.2 Tg $CO_2$ Eq., which indicates a range of 39 percent below to 32 percent above the actual 2005 emission estimate of 132 Tg $CO_2$ Eq.

Table 8-5. Tier 2 Quantitative Uncertainty Estimates for $CH_4$ Emissions from Landfills (Tg $CO_2$ Eq. and Percent)

| Source | Gas | 2005 Emission Estimate (Tg $CO_2$ Eq.) | Uncertainty Range Relative to Emission Estimate[a] (Tg $CO_2$ Eq.) | | (%) | |
|---|---|---|---|---|---|---|
| | | | Lower Bound | Upper Bound | Lower Bound | Upper Bound |
| Landfills | $CH_4$ | 132.0 | 80.5 | 174.2 | -39% | +32% |

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

## Recalculations Discussion

Two recalculations affected the estimates of $CH_4$ generation from landfills. As recommended in IPCC (2006) for MSW landfills, the more accurate integrated form of the first order decay model was applied (see Annex 3A.1 of IPCC 2006), and a delay time of 6 months was incorporated. The integrated form of the FOD model captures a constantly changing rate of reaction, whereas the previously used method, which was not integrated, instead assumed that the rate of reaction remained constant throughout each year. The 6-month delay represents the time before substantial methane generation begins at a landfill. By recalculating previous emissions estimates using this method, estimates of $CH_4$ generation from MSW landfills were reduced by 4 percent over the time series. The second change was an improvement in the estimate of $CH_4$ generation from industrial landfills, which was based on industrial production, waste disposal factors, and the first order decay model. For previous inventories, the generation rate was estimated as simply 7 percent of $CH_4$ generation from MSW landfills. This change resulted in a decrease of 2 percent in the estimated $CH_4$ generation at industrial landfills relative to the previous inventory.

Another recalculation affecting estimates of $CH_4$ recovery was associated with updating the EIA, LMOP, and flare vendor databases. The estimates of gas recovery by LFGTE projects and flares from 1990 to 2004 increased by 0.7 percent based on changes to the current inventory. This change is due in part to updating the EIA database and identifying additional flares installed in 2004 that were not included in the previous inventory. The EIA database for 2004 did not become available until late in 2005; consequently, the gas recovery rate for 2004 was estimated from the 2003 data. The 2004 update showed that LFGTE projects in the EIA 2003 database reported more gas recovery in 2004 than 2003, and additional landfills were included in the 2004 database, both of which increased the estimate of $CH_4$ recovery. A recalculation that had a minor effect was the application of a destruction efficiency of 99 percent to $CH_4$ recovered to estimate $CH_4$ emissions avoided.

The overall effect of these recalculations was an average decrease of 5 percent in the estimated $CH_4$ emissions from landfills over the 1990 to 2004 time series.

[4] The methodology for estimating the quantity of N in sewage sludge disposed via incineration, land application, surface disposal, landfill, ocean dumping, and other is described in Annex 3.11 Methodology for Estimating $N_2O$ Emissions From Agricultural Soil Management.

## Planned Improvements

For future inventories, additional efforts will be made to improve the estimates of $CH_4$ generation at industrial landfills. Improvements to the flare database will be investigated, and an effort will be made to identify additional landfills that have flares.

[Begin Text Box]

Box 8-1: Biogenic Emissions and Sinks of Carbon

$CO_2$ emissions from the combustion or decomposition of biogenic materials (e.g., paper, wood products, and yard trimmings) grown on a sustainable basis are considered to mimic the closed loop of the natural carbon cycle—that is, they return to the atmosphere $CO_2$ that was originally removed by photosynthesis. In contrast, $CH_4$ emissions from landfilled waste occur due to the man-made anaerobic conditions conducive to $CH_4$ formation that exist in landfills, and are consequently included in this inventory.

Depositing wastes of biogenic origin in landfills causes the removal of carbon from its natural cycle between the atmosphere and biogenic materials. As empirical evidence shows, some of these wastes degrade very slowly in landfills, and the carbon they contain is effectively sequestered in landfills over a period of time (Barlaz 1998, 2005). Estimates of carbon removals from landfilling of forest products, yard trimmings, and food scraps are further described in the Land Use, Land-Use Change, and Forestry chapter, based on methods presented in IPCC (2003) and IPCC (2006).

[End Box]

## *8.2. Wastewater Treatment (IPCC Source Category 6B)*

Wastewater treatment processes can produce anthropogenic $CH_4$ and $N_2O$ emissions. Wastewater from domestic (municipal sewage) and industrial sources is treated to remove soluble organic matter, suspended solids, pathogenic organisms, and chemical contaminants. Treatment may either occur on site, most commonly through septic systems or package plants,[5] or off site at centralized treatment systems. Centralized wastewater treatment systems may include a variety of processes, ranging from lagooning to advanced tertiary treatment technology for removing nutrients. In the United States, approximately 21 percent of domestic wastewater is treated in septic systems or other on-site systems, while the rest is collected and treated centrally (U.S. Census Bureau 2006b).

Soluble organic matter is generally removed using biological processes in which microorganisms consume the organic matter for maintenance and growth. The resulting biomass (sludge) is removed from the effluent prior to discharge to the receiving stream. Microorganisms can biodegrade soluble organic material in wastewater under aerobic or anaerobic conditions, where the latter condition produces $CH_4$. During collection and treatment, wastewater may be accidentally or deliberately managed under anaerobic conditions. In addition, the sludge may be further biodegraded under aerobic or anaerobic conditions. The generation of $N_2O$ may also result from the treatment of domestic wastewater during both nitrification and denitrification of the nitrogen present, usually in the form of urea, ammonia, and proteins. These compounds are converted to nitrate ($NO_3$) through the aerobic process of nitrification. Denitrification occurs under anoxic conditions (without free oxygen), and involves the biological conversion of nitrate into dinitrogen gas ($N_2$). $N_2O$ can be an intermediate product of both processes, but is more often associated with denitrification.

The principal factor in determining the $CH_4$ generation potential of wastewater is the amount of degradable organic

[5] Package plants are treatment plants assembled in a factory, skid mounted, and transported to the treatment site.

material in the wastewater. Common parameters used to measure the organic component of the wastewater are the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Under the same conditions, wastewater with higher COD (or BOD) concentrations will generally yield more $CH_4$ than wastewater with lower COD (or BOD) concentrations. 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). Because BOD is an aerobic parameter, it is preferable to use COD to estimate $CH_4$ production. The principal factor in determining the $N_2O$ generation potential of wastewater is the amount of N in the wastewater.

In 2005, $CH_4$ emissions from domestic wastewater treatment were estimated to be 17.0 Tg $CO_2$ Eq. (809 Gg). Emissions fluctuated from 1990 through 1996, and have decreased since 1997 due to decreasing percentages of wastewater being treated in anaerobic systems, including reduced use of on-site septic systems and central anaerobic treatment systems. In 2005, $CH_4$ emissions from industrial wastewater treatment were estimated to be 8.4 Tg $CO_2$ Eq. (400 Gg). Industrial emission sources have increased across the time series through 1999 and then slightly decreased in keeping with production changes associated with the treatment of wastewater from the pulp and paper, meat and poultry, and the vegetables, fruits and juices processing industries.[6] Table 8-6 and Table 8-7 provide $CH_4$ and $N_2O$ emission estimates from domestic and industrial wastewater treatment. With respect to $N_2O$, the United States identifies two distinct sources for $N_2O$ emissions from domestic wastewater: emissions from centralized wastewater treatment processes, and emissions from effluent from centralized treatment systems that has been discharged into aquatic environments. The 2005 emissions of $N_2O$ from centralized wastewater treatment processes and from effluent were estimated to be 0.2 Tg $CO_2$ Eq. (1 Gg) and 7.8 Tg $CO_2$ Eq. (25 Gg), respectively. Total $N_2O$ emissions from domestic wastewater were estimated to be 8.0 Tg $CO_2$ Eq. (26 Gg). $N_2O$ emissions from wastewater treatment processes gradually increased across the time series as a result of increasing U.S. population and protein consumption.

Table 8-6. $CH_4$ and $N_2O$ Emissions from Domestic and Industrial Wastewater Treatment (Tg $CO_2$ Eq.)

| Activity | 1990 | 1995 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|---|
| **$CH_4$** | **24.8** | **25.1** | **26.4** | **25.9** | **25.8** | **25.6** | **25.7** | **25.4** |
| Domestic | 17.4 | 16.7 | 17.7 | 17.5 | 17.3 | 17.2 | 17.1 | 17.0 |
| Industrial* | 7.4 | 8.4 | 8.7 | 8.4 | 8.5 | 8.4 | 8.5 | 8.4 |
| **$N_2O$** | **6.4** | **6.9** | **7.6** | **7.6** | **7.7** | **7.8** | **7.9** | **8.0** |
| Domestic | 6.4 | 6.9 | 7.6 | 7.6 | 7.7 | 7.8 | 7.9 | 8.0 |
| **Total** | **31.2** | **32.0** | **34.0** | **33.5** | **33.5** | **33.4** | **33.6** | **33.4** |

* Industrial activity includes the pulp and paper, meat and poultry, and the vegetables, fruits and juices processing industries.
Note: Totals may not sum due to independent rounding.

Table 8-7. $CH_4$ and $N_2O$ Emissions from Domestic and Industrial Wastewater Treatment (Gg)

| Activity | 1990 | 1995 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|---|
| **$CH_4$** | **1,180** | **1,195** | **1,257** | **1,232** | **1,229** | **1,220** | **1,222** | **1,210** |
| Domestic | 826 | 797 | 842 | 832 | 826 | 820 | 815 | 809 |
| Industrial* | 354 | 398 | 415 | 400 | 402 | 400 | 407 | 400 |
| **$N_2O$** | **21** | **22** | **24** | **25** | **25** | **25** | **26** | **26** |
| Domestic | 21 | 22 | 24 | 25 | 25 | 25 | 26 | 26 |

* Industrial activity includes the pulp and paper, meat and poultry, and the vegetables, fruits and juices processing industries.
Note: Totals may not sum due to independent rounding.

[6]Emissions associated with refinery wastewater are estimated in Annex 2.3 Methodology for Estimating Carbon Emitted from Non-Energy Uses of Fossil Fuels. Other industrial sectors include organic chemicals, starch production, alcohol refining, creameries, and textiles; however, emissions from these sectors are considered to be insignificant.

## Methodology

### Domestic and Industrial Wastewater $CH_4$ Emission Estimates

Domestic wastewater $CH_4$ emissions originate from both septic systems and from centralized treatment systems, such as publicly owned treatment works (POTWs). Within these centralized systems, $CH_4$ emissions can arise from aerobic systems that are not well managed, anaerobic systems (anaerobic lagoons and facultative lagoons), and from anaerobic digesters when the captured biogas is not completely combusted. $CH_4$ emissions from septic systems were estimated by multiplying the total $BOD_5$ produced in the United States by the percent of wastewater treated in septic systems (21 percent), the maximum $CH_4$ producing capacity for domestic wastewater (0.60 kg $CH_4$/kg BOD), and the $CH_4$ correction factor (MCF) for septic systems (0.5). $CH_4$ emissions from POTWs were estimated by multiplying the total $BOD_5$ produced in the United States by the percent of wastewater treated centrally (79 percent), the relative percentage of wastewater treated by aerobic and anaerobic systems, the maximum $CH_4$-producing capacity of domestic wastewater, and the relative MCFs for aerobic (zero or 0.3) and anaerobic (0.8) systems. $CH_4$ emissions from anaerobic digesters were estimated by multiplying the amount of biogas generated by wastewater sludge treated in anaerobic digesters by the proportion of $CH_4$ in digester biogas, the density of $CH_4$, and the destruction efficiency associated with burning the biogas in an energy/thermal device.[7] The methodological equations are:

*Emissions from Septic Systems = A*
= (% onsite) × (total $BOD_5$ produced) × ($B_o$) × (MCF-septic) × 1/10^6

*Emissions from Centrally Treated Aerobic Systems = B*
= (% collected) × (total $BOD_5$ produced) × (% aerobic) × (% operations not well managed) × ($B_o$) × (MCF-aerobic_not_well_man) × 1/10^6

*Emissions from Centrally Treated Anaerobic Systems = C*
= (% collected) × (total $BOD_5$ produced) × (% anaerobic) × ($B_o$) × (MCF-anaerobic) × 1/10^6

*Emissions from Anaerobic Digesters = D*
= [(POTW_flow_AD) × (digester gas)/ (per capita flow)] × 0.0283 × (FRAC_$CH_4$) × (365.25) × (density of $CH_4$) × (1-DE) × 1/10^9

Total $CH_4$ Emissions (Gg) = A + B + C + D

where,

| | |
|---|---|
| % onsite = | Flow to septic systems / total flow |
| % collected = | Flow to POTWs / total flow |
| % aerobic = | Flow to aerobic systems / total flow to POTWs |
| % anaerobic = | Flow to anaerobic systems / total flow to POTWs |
| % operations not well managed = | Percent of aerobic systems that are not well managed and in which Some anaerobic degradation occurs |
| Total $BOD_5$ produced = | kg BOD/capita/day × U.S. population × 365.25 days/yr |
| $B_o$ = | Maximum $CH_4$-producing capacity for domestic wastewater (0.60 kg $CH_4$/kg BOD) |
| MCF-septic = | $CH_4$ correction factor for septic systems (0.5) |
| 1/10^6 = | Conversion factor, kg to Gg |
| MCF-aerobic_not_well_man. = | $CH_4$ correction factor for aerobic systems that are not well managed |

[7] Anaerobic digesters at wastewater treatment plants generated 799 Gg $CH_4$ in 2005, 791 Gg of which was combusted in flares or energy devices (assuming a 99% destruction efficiency).

| | |
|---|---|
| | (0.3) |
| MCF-anaerobic = | $CH_4$ correction factor for anaerobic systems (0.8) |
| DE = | $CH_4$ destruction efficiency from flaring or burning in engine (0.99 for enclosed flares) |
| POTW_flow_AD = | Wastewater influent flow to POTWs that have anaerobic digesters (gal) |
| digester gas = | Cubic feet of digester gas produced per person per day (1.0 $ft^3$/person/day) (Metcalf and Eddy 1991) |
| per capita flow = | Wastewater flow to POTW per person per day (100 gal/person/day) |
| 0.0283 = | Conversion factor, $ft^3$ to $m^3$ |
| FRAC_$CH_4$ = | Proportion $CH_4$ in biogas (0.65) |
| density of $CH_4$ = | 662 (g $CH_4/m^3$ $CH_4$) |
| 1/10^9 = | Conversion factor, g to Gg |

U.S. population data were taken from the U.S. Census Bureau International Database (U.S. Census 2006a) and include the populations of the United States, American Samoa, Guam, Northern Mariana Islands, Puerto Rico, and the Virgin Islands. Table 8-8 presents U.S. population and total $BOD_5$ produced for 1990 through 2005. The proportions of domestic wastewater treated onsite versus at centralized treatment plants were based on data from the 1993, 1995, 1997, 1999, 2001, 2003, and 2005 American Housing Surveys conducted by the U.S. Census Bureau (U.S. Census 2006b), with data for intervening years obtained by linear interpolation. The wastewater flow to aerobic systems and anaerobic systems, and the wastewater flow to POTWs that have anaerobic digesters were obtained from the 1992, 1996, 2000, and 2004 Clean Watershed Needs Survey, collected by EPA (EPA 1992, 1996, 2000, and 2004a).[8] Data for intervening years were obtained by linear interpolation. The $BOD_5$ production rate per capita (0.09 kg/capita/day) for domestic wastewater was obtained from Metcalf and Eddy (1991and 2003). The $CH_4$ emission factor (0.6 kg $CH_4$/kg $BOD_5$) and the MCF data were taken from IPCC (2006a). The $CH_4$ destruction efficiency, 99 percent, was selected based on the range of efficiencies (98-100 percent) recommended for flares in EPA's "AP-42 Compilation of Air Pollutant Emission Factors, Chapter 2.4," (EPA 1998) efficiencies used to establish new source performance standards (NSPS) for landfills, and in recommendations for closed flares used in the LMOP. The cubic feet of digester gas produced per person per day (1.0 $ft^3$/person/day) and the proportion of $CH_4$ in biogas (0.65) come from Metcalf and Eddy 1991. The wastewater flow to a POTW per person per day (100 gal/person/day) was taken from the Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers, "Recommended Standards for Wastewater Facilities (Ten-State Standards)" (2004).

Table 8-8. U.S. Population (Millions) and Domestic Wastewater $BOD_5$ Produced (Gg)

| Year | Population | $BOD_5$ |
|---|---|---|
| 1990 | 254 | 8,350 |
| | | |
| 1995 | 271 | 8,895 |
| | | |
| 2000 | 287 | 9,419 |
| 2001 | 289 | 9,509 |
| 2002 | 292 | 9,597 |
| 2003 | 295 | 9,685 |
| 2004 | 297 | 9,774 |
| 2005 | 300 | 9,864 |

Source: U.S. Census Bureau (2006a); Metcalf & Eddy 1991 and 2003.

[8] Aerobic and anaerobic treatment were determined based on unit processes in use at the facilities. Because the list of unit processes became more extensive in the 2000 and 2004 surveys, the criteria used to identify aerobic and anaerobic treatment differ slightly across the time series. Once facilities were identified as aerobic or anaerobic, they were separated by whether or not they had anaerobic digestion in place. Once these classifications were determined, the flows associated with facilities in each category were summed.

$CH_4$ emissions estimates from industrial wastewater were developed according to the methodology described in IPCC (2006a). Industry categories that are likely to produce significant $CH_4$ emissions from wastewater treatment were identified. High volumes of wastewater generated and a high organic wastewater load were the main criteria. The top three industries that meet these criteria are pulp and paper manufacturing; meat and poultry processing; and vegetables, fruits, and juices processing. Table 8-9 contains production data for these industries.

Table 8-9. U.S. Pulp and Paper, Meat and Poultry, and Vegetables, Fruits and Juices Production (Tg)

| Year | Pulp and Paper | Meat (Live Weight Killed) | Poultry (Live Weight Killed) | Vegetables, Fruits and Juices |
|---|---|---|---|---|
| 1990 | 128.9 | 27.3 | 14.6 | 40.5 |
| | | | | |
| 1995 | 140.9 | 30.8 | 18.9 | 49.0 |
| | | | | |
| 2000 | 142.8 | 32.1 | 22.2 | 52.7 |
| 2001 | 134.3 | 31.6 | 22.8 | 46.7 |
| 2002 | 132.7 | 32.7 | 23.5 | 49.1 |
| 2003 | 131.9 | 32.3 | 23.7 | 46.2 |
| 2004 | 136.4 | 31.2 | 24.4 | 49.1 |
| 2005 | 131.4 | 31.4 | 25.1 | 43.6 |

$CH_4$ emissions from these categories were estimated by multiplying the annual product output by the average outflow, the organics loading (in COD) in the outflow, the percentage of organic loading assumed to degrade anaerobically, and the emission factor. Ratios of BOD:COD in various industrial wastewaters were obtained from the World Bank (1999) and used to estimate COD loadings. The $B_o$ value used for all industries is the IPCC default value of 0.25 kg $CH_4$/kg COD (IPCC 2006a). The methodological equation is:

$$CH_4 \text{ (industrial wastewater)} = P \times W \times (COD) \times TA \times B_o \times MCF$$

where,

| | |
|---|---|
| $CH_4$ (industrial wastewater) | = Total $CH_4$ emissions from industrial wastewater (kg/year) |
| P | = Industry output (metric tons/year) |
| W | = Wastewater generated ($m^3$/metric ton of product) |
| COD | = Organics loading in wastewater (kg /$m^3$) |
| TA | = Percent of wastewater treated anaerobically on site |
| MCF | = $CH_4$ correction factor, indicating the extent to which the organic content (measured as COD) degrades anaerobically |
| $B_o$ | = Maximum $CH_4$ producing potential of industrial wastewater (default value of 0.25 kg $CH_4$/kg COD) |

Wastewater treatment for the pulp and paper industry typically includes neutralization, screening, sedimentation, and flotation/hydrocycloning to remove solids (World Bank 1999, Nemerow and Dasgupta 1991). Secondary treatment (storage, settling, and biological treatment) mainly consists of lagooning. In determining the percent that degrades anaerobically, both primary and secondary treatment were considered. Primary treatment lagoons are aerated to reduce anaerobic activity. However, the lagoons are large and zones of anaerobic activity may occur and, consequently, the primary lagoons are assumed to be 1.4 percent anaerobic (based on expert judgment). Approximately 42 percent of the BOD passes on to secondary treatment, which is less likely to be aerated (EPA 1993a,b). Twenty-five percent of the BOD in secondary treatment lagoons was assumed to degrade anaerobically, while 10 percent passes through to be discharged with the effluent (EPA 1997a). Consequently, the overall percentage of wastewater organics that degrade anaerobically was determined to be 10.3 percent (i.e., 58 percent × 1.4 percent + 42 percent × 90 percent × 25 percent). A time series of $CH_4$ emissions for 1990 through 2001 was developed based on production figures reported in the Lockwood-Post Directory (Lockwood-Post 2002). Published data from the American Forest and Paper Association (AF&PA) and data published by Paper Loop were used to estimate production for 2002 through 2005 (Pulp and Paper 2005, 2006 and monthly reports from 2003–2006). The

overall wastewater outflow was estimated to be 85 $m^3$/metric ton, and the average BOD loading entering the secondary treatment lagoons was estimated to be 0.4 gram BOD/liter (EPA 1997b, EPA 1993a,b, World Bank 1999).

The meat and poultry processing industry makes extensive use of anaerobic lagoons in sequence with screening, fat traps and dissolved air flotation when treating wastewater on site. About 33 percent of meat processing operations (EPA 2002) and 25 percent of poultry processing operations (U.S. Poultry 2006) perform on-site treatment in anaerobic lagoons. The IPCC default $B_o$ of 0.25 kg COD/kg $CH_4$ and default MCF of 0.8 for anaerobic lagoons were used to estimate the $CH_4$ produced from these on-site treatment systems. Production data, in carcass weight and live weight killed for the meat and poultry industry, were obtained from the USDA Agricultural Statistics Database and the Agricultural Statistics Annual Reports (USDA 2006). Data collected by EPA's Office of Water provided estimates for wastewater flows into anaerobic lagoons: 5.3 and 12.5 $m^3$/metric ton for meat and poultry production (live weight killed), respectively (EPA 2002). The loadings are 2.8 and 1.5 g BOD/liter for meat and poultry, respectively.

Treatment of wastewater from fruits, vegetables, and juices processing includes screening, coagulation/settling and biological treatment (lagooning). The flows are frequently seasonal, and robust treatment systems are preferred for on-site treatment. Effluent is suitable for discharge to the sewer. This industry is likely to use lagoons intended for aerobic operation, but the large seasonal loadings may develop limited anaerobic zones. In addition, some anaerobic lagoons may also be used (Nemerow and Dasgupta 1991). Consequently, 5 percent of these wastewater organics are assumed to degrade anaerobically. EPA used the IPCC default $B_o$ of 0.25 kg COD/kg $CH_4$ and default MCF of 0.8 for anaerobic treatment to estimate the $CH_4$ produced from these on-site treatment systems. The USDA National Agricultural Statistics Service (USDA 2006) provided production data for potatoes, other vegetables, citrus fruit, non-citrus fruit, and grapes processed for wine. Outflow and BOD data, presented in Table 8-10, were obtained from EPA (1974) for potato, citrus fruit, and apple processing, and from the World Bank (1999) for all other sectors.

Table 8-10. Wastewater Flow ($m^3$/ton) and BOD Production (g/L) for U.S. Vegetables, Fruits and Juices Production

| Commodity | Wastewater Outflow ($m^3$/ton) | BOD (g/L) |
|---|---|---|
| **Vegetables** | | |
| Potatoes | 10.27 | 1.765 |
| Other Vegetables | 8.64 | 0.817 |
| **Fruit** | | |
| Apples | 3.66 | 1.317 |
| Citrus | 10.11 | 0.317 |
| Non-citrus | 11.7 | 0.982 |
| Grapes (for wine) | 1.53 | 2.346 |

### Domestic Wastewater $N_2O$ Emission Estimates

$N_2O$ emissions from domestic wastewater (wastewater treatment) were estimated using the updated IPCC (2006) methodology, including calculations that take into account N removal with sewage sludge, non-consumption and industrial wastewater N, and emissions from advanced centralized wastewater treatment plants:

- In the United States, a certain amount of N is removed with sewage sludge, which is applied to land, incinerated or landfilled ($N_{SLUDGE}$). The N disposal into aquatic environments is reduced to account for the sewage sludge application.[9]

[9] The methodology for estimating the quantity of sewage sludge N not entering aquatic environments is described in Annex 3.11

- The IPCC methodology uses annual, per capita protein consumption (kg protein/[person-year]). This number is likely to underestimate the amount of protein entering the sewer or septic system. Food (waste) that is not consumed is often washed down the drain, as a result of the use of garbage disposals. Also, bath and laundry water can be expected to contribute to N loadings. As a result, a factor of 1.4 for non-consumption N is introduced for each year in the Inventory.[10] Furthermore, a significant quantity of industrial wastewater (N) is co-discharged with domestic wastewater. To account for this, a factor of 1.25 is used.[11]
- Small amounts of gaseous nitrogen oxides are formed as by-products in the conversion of nitrate to N gas in anoxic biological treatment systems. Approximately 7 grams $N_2O$ is generated per capita per year if wastewater treatment includes nitrification and denitrification (Scheehle and Doorn 2001). Analysis of the 2000 CWNS shows 88 treatment plants in the United States, serving a population of 2,636,668 persons, with denitrification as one of their unit operations. Based on an emission factor of 7 grams/capita/year, approximately 17.5 metric tons of additional $N_2O$ may have been emitted via denitrification in 2000. Similar analysis was done for each year in the Inventory using data from CWNS on the amount of wastewater in centralized systems treated in denitrification units.

With the modifications described above, $N_2O$ emissions from domestic wastewater were estimated using the following methodology:

$$N_2O_{TOTAL} = N_2O_{PLANT} + N_2O_{EFFLUENT}$$

$$N_2O_{PLANT} = N_2O_{NIT/DENIT} + N_2O_{WOUT\ NIT/DENIT}$$

$$N_2O_{NIT/DENIT} = [(US_{POPND}) \times EF_2] \times 1/10\text{^}9$$

$$N_2O_{WOUT\ NIT/DENIT} = \{[(US_{POP} \times WWTP) - US_{POPND}] \times EF_1\} \times 1/10\text{^}9$$

$$N_2O_{EFFLUENT} = \{[(US_{POP} \times Protein \times F_{NPR} \times F_{NON\text{-}CON} \times F_{IND\text{-}COM}) - N_{SLUDGE}] \times EF_3 \times 44/28\} \times 1/10\text{^}6$$

where,

| | |
|---|---|
| $N_2O_{TOTAL}$ = | Annual emissions of $N_2O$ |
| $N_2O_{PLANT}$ = | $N_2O$ emissions from centralized wastewater treatment plants |
| $N_2O_{NIT/DENIT}$ = | $N_2O$ emissions from centralized wastewater treatment plants with nitrification/denitrification |
| $N_2O_{WOUT\ NIT/DENIT}$ = | $N_2O$ emissions from centralized wastewater treatment plants without nitrification/denitrification |
| $N_2O_{EFFLUENT}$ = | $N_2O$ emissions from wastewater effluent discharged to aquatic environments |
| $US_{POP}$ = | U.S. population |
| $US_{POPND}$ = | U.S. population that is served by biological denitrification (from CWNS) |
| WWTP = | Fraction of population using WWTP (as opposed to septic systems) |
| $EF_1$ = | Emission factor (3.2 g $N_2O$/person-year) |

[10] Metcalf & Eddy (1991) provide a typical influent nitrogen concentration of 40 mg/L Total Kjeldahl Nitrogen (TKN) for average wastewater from residences, which includes bathwater, laundry, and the use of garbage disposals. The factor for non-consumptive protein was estimated based on wastewater treated in 1990, the percent of population serviced by centralized treatment systems, and the per capita TKN loading, resulting in a factor of 1.4.

[11] The type, composition, and quantity of this co-discharged wastewater vary greatly between municipalities. Metcalf & Eddy (1991) provide a range of influent nitrogen concentrations of 20 to 85 mg/L TKN (average 55) for combined residential and industrial wastewater, while residential wastewater loading was roughly estimated at 40 mg TKN/liter (see previous footnote). Until better data become available, the amount of N in wastewater is increased by 10 mg/L to account for industrial co-discharge (factor of 1.25).

| | |
|---|---|
| $EF_2$ = | Emission factor (7 g $N_2O$/person-year) |
| Protein = | Annual per capita protein consumption (kg/person/year) |
| $F_{NPR}$ = | Fraction of N in protein, default = 0.16 (kg N/kg protein) |
| $F_{NON-CON}$ = | Factor for non-consumed protein added to wastewater |
| $F_{IND-COM}$ = | Factor for industrial and commercial co-discharged protein into the sewer system |
| $N_{SLUDGE}$ = | N removed with sludge, kg N/yr |
| $EF_3$ = | Emission factor (0.005 kg $N_2O$ -N/kg sewage-N produced) |
| 44/28 = | Molecular weight ratio of $N_2O$ to $N_2$ |

U.S. population data were taken from the U.S. Census Bureau International Database (U.S. Census 2006a) and include the populations of the United States, American Samoa, Guam, Northern Mariana Islands, Puerto Rico, and the Virgin Islands. The fraction of the U.S. population using wastewater treatment plants is based on data from the 1993, 1995, 1997, 1999, 2001, and 2003 American Housing Survey (U.S. Census 2006b). Data for intervening years were obtained by linear interpolation. The emission factor ($EF_1$) to estimate emissions from wastewater treatment was taken from IPCC (2006a). Data on annual per capita protein intake were provided by the United Nations Food and Agriculture Organization for the 1990 to 2003 time frame (FAO 2006). Protein consumption data for 2004 and 2005 were extrapolated from data for 1990 through 2003. Table 8-11 presents the data for U.S. population and average protein intake. An emission factor to estimate emissions from effluent ($EF_3$) has not been specifically estimated for the United States, thus the newly-revised default IPCC value (0.005 kg $N_2O$-N/kg sewage-N produced) was applied. The fraction of N in protein (0.16 kg N/kg protein) was also obtained from IPCC (2006). An estimate for the nitrogen removed as sludge ($N_{SLUDGE}$) was obtained by determining the amount of sludge disposed by incineration, by land application (agriculture or other), through surface disposal, in landfills, or through ocean dumping.

Table 8-11. U.S. Population (Millions) and Average Protein Intake [kg/(person-year)]

| Year | Population | Protein |
|---|---|---|
| 1990 | 254 | 39.2 |
| 1995 | 271 | 40.0 |
| 2000 | 287 | 41.6 |
| 2001 | 289 | 41.3 |
| 2002 | 292 | 41.3 |
| 2003 | 295 | 41.7 |
| 2004 | 297 | 41.9 |
| 2005 | 300 | 42.1 |

Source: U.S. Census Bureau 2006a, FAO 2006.

## Uncertainty

The overall uncertainty associated with both the 2005 $CH_4$ and $N_2O$ emissions estimates from wastewater treatment and discharge was calculated using the IPCC *Good Practice Guidance* Tier 2 methodology (2000). Uncertainty associated with the parameters used to estimate $CH_4$ emissions included that of numerous input variables used to model emissions from domestic wastewater, and wastewater from the pulp and paper industry, meat and poultry processing, as well as from fruits, vegetables and juices processing. Uncertainty associated with the parameters used to estimate $N_2O$ emissions included that of sewage sludge disposal, total U.S. population, average protein consumed per person, fraction of N in protein, non-consumption nitrogen factor, emission factors per capita and per mass of sewage-N, and for the percentage of total population using centralized wastewater treatment plants.

The results of this Tier 2 quantitative uncertainty analysis are summarized in Table 8-12. $CH_4$ emissions from wastewater treatment were estimated to be between 15.8 and 37.3 Tg $CO_2$ Eq. at the 95 percent confidence level (or in 19 out of 20 Monte Carlo Stochastic Simulations). This indicates a range of approximately 38 percent below to 47 percent above the 2005 emissions estimate of 25.4 Tg $CO_2$ Eq. $N_2O$ emissions from wastewater treatment were estimated to be between 1.7 and 15.4 Tg $CO_2$ Eq., which indicates a range of approximately 79 percent below to 93

percent above the actual 2005 emissions estimate of 8.0 Tg $CO_2$ Eq.

Table 8-12. Tier 2 Quantitative Uncertainty Estimates for $CH_4$ Emissions from Wastewater Treatment (Tg $CO_2$ Eq. and Percent)

| Source | Gas | 2005 Emission Estimate (Tg $CO_2$ Eq.) | Uncertainty Range Relative to Emission Estimate[a] (Tg $CO_2$ Eq.) | | (%) | |
|---|---|---|---|---|---|---|
| | | | Lower Bound | Upper Bound | Lower Bound | Upper Bound |
| Wastewater Treatment | $CH_4$ | 25.4 | 15.8 | 37.3 | -38% | +47% |
| Domestic | $CH_4$ | 17.0 | 8.6 | 28.2 | -49% | +66% |
| Industrial | $CH_4$ | 8.4 | 4.6 | 13.5 | -45% | +60% |
| Domestic Wastewater Treatment | $N_2O$ | 8.0 | 1.7 | 15.4 | -79% | +93% |

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

## Recalculations Discussion

The 2005 estimates for $CH_4$ emissions from domestic wastewater include two major methodological refinements and one major data change. First, $CH_4$ emissions were estimated from four distinct source categories (septic systems, centrally treated aerobic systems, centrally treated anaerobic systems, and anaerobic digesters) rather than calculating an overall percentage of wastewater treated anaerobically from which to calculate emissions. Calculating emissions from anaerobic digesters constitutes the second methodological refinement to the inventory. Emissions from anaerobic digesters were included to account for the increasing number of facilities that produce and use digester biogas. The major data adjustment for the current inventory estimates involves the BOD per capita rate. In previous inventories, the BOD per capita rate varied across the time series. However, the 2005 estimates employ a standard value for the BOD per capita rate (0.09 kg/capita/day). This change resulted in varying differences in emissions estimates over time, ranging from an increase of 52 percent (1990) to a decrease of 15 percent (2004).

For industrial wastewater , production data for the entire time series were updated and other factors, such as wastewater outflow, BOD, and percent of waste treated anaerobically, were revised. Production data for potato processing, which accounts for about 45 percent of all vegetable processing in the United States, and about 25 percent of all fruit and vegetable processing, had not been included in previous inventories. However, the increase in industrial wastewater emissions due to the inclusion of potatoes was offset by other changes made to the inventory. Flow and BOD data for fruits and vegetable processing wastewater were updated to reflect commodity-specific data, which resulted in a decrease in emissions. In addition, the amount of meat and poultry processing wastewater treated on site anaerobically was substantially revised. Previously, it was assumed that all wastewater from meat and poultry processing was treated anaerobically. However, data from EPA's Office of Water and from U.S. Poultry and Egg Association became available to show that indirect dischargers do not treat wastewater anaerobically. Therefore, the percent of waste treated anaerobically was reduced (to 33 percent for meat processors and 25 percent for poultry processors), which resulted in a significant decrease in emission estimates. These changes resulted in overall decreases of industrial wastewater emissions between 45 and 50 percent across the time series.

Overall, the $CH_4$ emission estimates for wastewater treatment are on average 17 percent lower than the previous inventory.

For $N_2O$ emissions from domestic wastewater, minor changes were made to the time series to include more specific estimates of the percent of U.S. population using centralized wastewater treatment, and a factor was introduced to account for the amount of biological denitrification occurring at centralized treatment plants. The calculation estimates for protein consumed were updated for the entire time series. These improvements resulted in minor decreases to the emission estimates across the time series, from 3 to 4 percent.

Finally, the default factor for $N_2O$ emissions from N in effluent discharged to aquatic environments was updated from 0.01 to 0.005 kg $N_2O$ -N/kg sewage-N, which resulted in a decrease of approximately 50 percent in emission estimates over the time series compared to the previous inventory. The effect of all changes was an overall decrease in emission estimates from 50.1 to 51.4 percent across the time series.

Overall, emissions from wastewater treatment and discharge ($CH_4$ and $N_2O$) decreased by an average of 28 percent from the previous inventory.

### Planned Improvements Discussion

The methodology to estimate $CH_4$ emissions from domestic wastewater treatment currently utilizes estimates for the percentage of centrally treated wastewater that is treated by aerobic systems and anaerobic systems. These data come from the 1992, 1996, 2000, and 2004 CWNS. The designation of systems as aerobic or anaerobic could be further refined to differentiate aerobic systems with the potential to generate small amounts of $CH_4$ (aerobic lagoons) versus other types of aerobic systems, and to differentiate between anaerobic systems to allow for the use of different MCFs for different types of anaerobic treatment systems. Currently it is assumed that all aerobic systems are well managed and produce no $CH_4$, and that all anaerobic systems have an MCF of 0.8. Efforts to obtain better data are currently being pursued.

Currently, BOD removal is not explicitly included in inventory calculations. The appropriateness of including a factor to account for BOD that is not removed through treatment and therefore does not contribute to $CH_4$ emissions is being investigated.

The methodology to estimate emissions for industrial wastewater currently accounts for pulp and paper, meat and poultry processing, and fruits and vegetables processing wastewater treatment. Information is currently being collected on ethanol production in the United States to determine if this should be included in future Inventories.

With respect to estimating $N_2O$ emissions, the default emission factor for $N_2O$ from wastewater effluent has a high uncertainty. The IPCC recently updated this factor; however, future research may identify new studies that include updated data. The factor that accounts for non-sewage nitrogen in wastewater (bath, laundry, kitchen, industrial components) also has a high uncertainty. Obtaining data on the changes in average influent nitrogen concentrations to centralized treatment systems over the time series would improve the estimate of total N entering the system, which would reduce or eliminate the need for other factors for non-consumed protein or industrial flow. In addition, more research may be conducted to update the protein consumption data.

## *8.3. Waste Sources of Indirect Greenhouse Gases*

In addition to the main greenhouse gases addressed above, waste generating and handling processes are also sources of indirect greenhouse gas emissions. Total emissions of $NO_x$, CO, and NMVOCs from waste sources for the years 1990 through 2005 are provided in Table 8-13.

Table 8-13: Emissions of $NO_x$, CO, and NMVOC from Waste (Gg)

| Gas/Source | 1990 | 1995 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|---|
| **$NO_x$** | **+** | **1** | **2** | **2** | **2** | **2** | **2** | **2** |
| Landfills | + | 1 | 2 | 2 | 2 | 2 | 2 | 2 |
| Wastewater Treatment | + | + | + | + | + | + | + | + |
| Miscellaneous[a] | + | 1 | + | + | + | + | + | + |
| **CO** | **1** | **2** | **8** | **8** | **7** | **7** | **7** | **7** |
| Landfills | 1 | 2 | 7 | 7 | 6 | 6 | 6 | 7 |
| Wastewater Treatment | + | + | 1 | 1 | + | + | + | + |
| Miscellaneous[a] | + | 1 | + | + | + | + | + | + |
| **NMVOCs** | **673** | **731** | **119** | **122** | **116** | **116** | **116** | **116** |
| Wastewater Treatment | 57 | 61 | 51 | 53 | 50 | 50 | 50 | 50 |
| Miscellaneous[a] | 558 | 602 | 46 | 46 | 44 | 44 | 44 | 44 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Landfills | 58 | 68 | 23 | 23 | 22 | 22 | 22 | 22 |

[a] Miscellaneous includes TSDFs (Treatment, Storage, and Disposal Facilities under the Resource Conservation and Recovery Act [42 U.S.C. § 6924, SWDA § 3004]) and other waste categories.
Note: Totals may not sum due to independent rounding.
+ Does not exceed 0.5 Gg.

## Methodology

These emission estimates were obtained from preliminary data (EPA 2006), and disaggregated based on EPA (2003), which, in its final iteration, will be published on the National Emission Inventory (NEI) Air Pollutant Emission Trends web site. Emission estimates of these gases were provided by sector, using a "top down" estimating procedure—emissions were calculated either for individual sources or for many sources combined, using basic activity data (e.g., the amount of raw material processed) as an indicator of emissions. National activity data were collected for individual source categories from various agencies. Depending on the source category, these basic activity data may include data on production, fuel deliveries, raw material processed, etc.

Activity data were used in conjunction with emission factors, which relate the quantity of emissions to the activity. Emission factors are generally available from the EPA's *Compilation of Air Pollutant Emission Factors, AP-42* (EPA 1997). The EPA currently derives the overall emission control efficiency of a source category from a variety of information sources, including published reports, the 1985 National Acid Precipitation and Assessment Program emissions inventory, and other EPA databases.

## Uncertainty

No quantitative estimates of uncertainty were calculated for this source category. Uncertainties in these estimates, however, are primarily due to the accuracy of the emission factors used and accurate estimates of activity data.

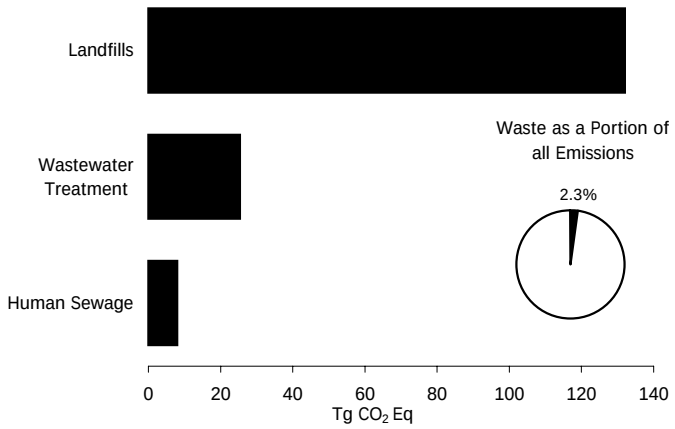


Figure 8-1: 2005 Waste Chapter Greenhouse Gas Sources

# Appendix C
# National Wastewater Treatment Emission Calculations

# Table C-1: EPA 2005 Methane Emissions

| Factor | Value | Units | Source/Comments |
|---|---|---|---|
| **Septic Systems** | | | |
| % BOD Directed to Septic Systems | 21 | % | American Housing Survey - U.S. Census Bureau |
| per Capita BOD Production Rate | 0.09 | kg/cap./day | Metcalf & Eddy 1991 & 2003 |
| U. S. Population for 2005 | 300.0 | millions | Table 8-8, EPA Inventory, 2005 |
| Domestic Wastewater BOD Produced | 9864.0 | Gg | = (?) 300 million x 0.09 kg BOD/capita/day x 365.25 days |
| Default Max $CH_4$ Producing Capacity | 0.6 | kg $CH_4$/kg BOD | IPCC Guidelines, Table 6.2 |
| MCF-septic | 0.5 | unitless | IPCC Guidelines, Table 6.3, 1/2 of BOD settles in septic tank |
| **Septic Systems Emissions** | **621.4** | **Gg $CH_4$** | =21% x 9864 Gg BOD x 0.6 kg $CH_4$/kg BOD x 0.5 |
| **Centrally Treated "Aerobic" Systems** | | | |
| % BOD Directed to Collection Systems | 79 | % | American Housing Survey - U.S. Census Bureau |
| per Capita BOD Production Rate | 0.09 | kg/cap./day | Metcalf & Eddy 1991 & 2003 |
| U. S. Population for 2005 | 300.0 | millions | Table 8-8, EPA Inventory, p. 8-9, 2005 |
| Domestic Wastewater BOD Produced | 9864.0 | Gg | = (?) 300 million x 0.09 kg BOD/capita/day x 365.25 days |
| Default Max $CH_4$ Producing Capacity | 0.6 | kg $CH_4$/kg BOD | IPCC Guidelines, Table 6.2 |
| Flow to Aerobic / Total Collected Flow | 0.95 | unitless | Clean Watershed Needs Survey - EPA |
| % Operations **NOT** Well Managed | **0** | unitless | IPCC Guidelines, Table 6.3 |
| MCF-Operations Not Well Managed | 0.3 | unitless | IPCC Guidelines, Table 6.3 |
| **Centrally Treated "Aerobic" Systems** | **0** | **Gg $CH_4$** | =79% x 9864 Gg BOD x 0.6 kg $CH_4$/kg BOD x 0.95 x **0** x 0.3 |
| **Centrally Treated "Anaerobic" Systems** | | | |
| % BOD Directed to Collection Systems | 79 | % | American Housing Survey - U.S. Census Bureau |
| per Capita BOD Production Rate | 0.09 | kg/cap./day | Metcalf & Eddy 1991 & 2003 |
| U. S. Population for 2005 | 300.0 | millions | Table 8-8, EPA Inventory, 2005 |
| Domestic Wastewater BOD Produced | 9864.0 | Gg | = (?) 300 million x 0.09 kg BOD/capita/day x 365.25 days |
| Default Max $CH_4$ Producing Capacity | 0.6 | kg $CH_4$/kg BOD | IPCC Guidelines, Table 6.2 |
| Flow to **An**aerobic / Total Collected Flow | 0.05 | unitless | Clean Watershed Needs Survey - EPA |
| MCF-Anaerobic Systems | 0.8 | unitless | IPCC Guidelines, Table 6.3 |
| **Centrally Treated "Anaerobic" Systems** | **187.0** | **Gg $CH_4$** | =79% x 9864 Gg BOD x 0.6 kg $CH_4$/kg BOD x 0.05 x 0.8 |

## Table C-1: EPA 2005 Methane Emissions

| Factor | Value | Units | Source/Comments |
|---|---|---|---|
| **Emissions from Anaerobic Digesters** | | | |
| Methane Generated by Anaerobic Digesters | 799 | Gg | Footnote 7 in EPA Inventory, p. 8-8, 2005 |
| Assumed Destruction Efficiency | 99 | % | AP-42, Compilation of Air Pollutant Emission Factors, Chapter 2.4, EPA, 1998 |
| **Emissions from Anaerobic Digesters** | **8.0** | **Gg $CH_4$** | =799*(1-99/100) |
| **TOTAL METHANE EMISSIONS** | **816.4**<br>**17.1** | **Gg $CH_4$**<br>**Tg $CO_2$ eq.** | = 816.4 Gg $CH_4$ x 21 Gg $CO_2$ equivalent / Gg $CH_4$ x 1 Tg / 1000 Gg |
| **EPA 2005 Inventory "Wastewater Treatment" Percentage Breakdown for Methane** | | | |
| **Septic Systems Emissions** | **76.1%** | | |
| **Centrally Treated "Aerobic" Systems** | **0.0%** | | |
| **Centrally Treated "Anaerobic" Systems** | **22.9%** | | |
| **Emissions from Anaerobic Digesters** | **1.0%** | | |
| **Percentage of Wastewater Emissions Attributable to POTWs Without Lagoons** | **1.0%** | | |
| **EPA 2005 Inventory ALL Methane Sources** | | | |
| **All Sources Combined** | **539.3** | **Tg $CO_2$ eq.** | Table ES-2, EPA Inventory, p. ES-5, 2005 |
| **Landfills** | **132** | | |
| **Enteric Fermentation** | **112.1** | | |
| **Natural Gas Systems** | **111.1** | | |
| **Coal Mining** | **52.4** | | |
| **Manure Management** | **41.3** | | |
| **Petroleum Systems** | **28.5** | | |
| **Wastewater Treatment** | **25.4** | | Table ES-2, Includes 8.4 Tg $CO_2$ eq. From Industrial Activity |
| **Forest Land** | **11.6** | | Table ES-2, EPA Inventory, p. ES-5, 2005 |
| **Everything Else** | **24.9** | | |

## Table C-2: EPA 2005 Nitrous Oxide Emissions

| Factor | Value | Units | Source/Comments |
|---|---|---|---|
| **Nitrification/Denitrification Systems - In Plant Generation** | | | |
| Population Served by NDN Systems | 2,636,668 | persons | EPA Inventory text, p. 8-12, 2005 |
| Generation per Person | 7 | g/person | EPA Inventory text, p. 8-12 and 8-13, 2005 |
| **NDN Systems - In Plant Generation** | **0.0185** | **Gg $N_2O$** | =2,636,668 persons*7 g/person*1 Gg/1,000,000,000 g |
| **Conventional Activated Sludge Systems - In Plant Generation** | | | |
| U. S. Population for 2005 | 300.0 | millions | Table 8-8, EPA Inventory, p. 8-9, 2005 |
| % BOD Directed to Collection Systems | 79 | % | American Housing Survey - U.S. Census Bureau |
| Population served by NDN Systems | 2,636,668 | persons | EPA Inventory text, p. 8-12, 2005 |
| Generation per Person | 3.2 | g/person | 2006 IPCC Guidelines, p. 6.26, Box 6.1 |
| **Conventional Treatment Systems** | **0.750** | **Gg $N_2O$** | =(300,000,000 *0.79-2,636,668) persons*3.2 g/person*1 Gg/1,000,000,000 g |
| **Effluent Conversion - Post Treatment** | | | |
| **Factor** | **Value** | **Units** | **Source/Comments** |
| U. S. Population for 2005 | 300.0 | millions | Table 8-8, EPA Inventory, p. 8-9, 2005 |
| Annual per Capita Protein Consumption | 42.1 | kg/(person-year) | Table 8-11, EPA Inventory, p. 8-13, 2005 |
| Fraction of Nitrogen in Protein | 0.16 | kg N/kg protein | 2006 IPCC Guidelines, p. 6.25 |
| Additional Non-Consumed Protein | 1.4 | unitless | 2006 IPCC Guidelines, p. 6.25, developed country value |
| Industrial/Commercial Protein | 1.25 | unitless | 2006 IPCC Guidelines, p. 6.25 |
| Possible Nitrogen "Loading" to Environment | 3536 | Gg N | =300 MMpersons*42.1 kg/per./yr*0.16 kg N/kg pro.*1.4*1.25*1 Gg/1MMkg |
| Nitrogen Sequestered in Biosolids | 179 | Gg N | Table A-181, EPA Inventory, Annex 3.11, p.A-207 |
| Actual Nitrogen "Loading" to Environment | 3357 | Gg N | =3536 - 179 |
| Default Effluent N Conversion to $N_2O$ | 0.005 | kg $N_2O$/kg N | 2006 IPCC Guidelines, p 6.25 |
| Molecular Weight Conversion | 1.57 | unitless | = 44/28 (mol. Wt. $N_2O$ / mol. Wt. $N_2$) |
| **Effluent Conversion - Post Treatment** | **26.38** | **Gg $N_2O$** | =(300,000,000 *0.79-2,636,668) persons*3.2 g/person*1 Gg/1,000,000,000 g |
| **TOTAL NITROUS OXIDE EMISSIONS** | **27.1**<br>**8.42** | **Gg $N_2O$**<br>**Tg $CO_2$ eq.** | = 27.1 Gg $N_2O$ x 310 Gg $CO_2$ equivalent / Gg $N_2O$ $_x$ 1 Tg / 1000 Gg |

## Table C-2: EPA 2005 Nitrous Oxide Emissions

| Factor | Value | Units | Source/Comments |
|---|---|---|---|
| **EPA 2005 Inventory "Wastewater Treatment" Percentage Breakdown for Nitrous Oxide** | | | |
| **NDN Systems - In Plant Generation** | **0.1%** | | |
| **Conventional Treatment - In Plant** | **2.8%** | | |
| **Effluent Conversion - Post Treatment** | **97.2%** | | |
| **EPA 2005 Inventory ALL Nitrous Oxide Sources** | | | |
| **All Sources Combined** | **468.6** | **Tg $CO_2$ eq.** | Table ES-2, EPA Inventory, p. ES-5, 2005 |
| **Ag Soil Management** | **365.1** | | |
| **Mobile Combustion** | **38** | | |
| **Nitric Acid Production** | **15.7** | | |
| **Stationary Combustion** | **13.8** | | |
| **Manure Management** | **9.5** | | |
| **Wastewater Treatment** | **8.4** | | |
| **Adipic Acid Production** | **6** | | |
| **Settlements** | **5.8** | | |
| **Everything Else** | **6.3** | | |

# Appendix D
# NACWA Comment Letter on USEPA Wastewater Treatment Emissions Estimates

NACWA
A Clear Commitment to America's Waters



January 10, 2007

Leif Hockstad
Climate Change Division, Office of Atmospheric Programs
U.S. Environmental Protection Agency
1200 Pennsylvania Ave, NW (6207J)
Washington DC 20460

**Re: NACWA Comments on Wastewater Treatment Emissions Estimates in EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005, Draft for Expert Review***

Dear Mr. Hockstad:

As requested in your December 15, 2006 letter, the National Association of Clean Water Agencies (NACWA) has completed a review of the U.S. Environmental Protection Agency's draft *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005, Draft for Expert Review* (*Draft Inventory*). NACWA represents the interests of nearly 300 publicly owned wastewater treatment agencies nationwide. NACWA's members serve the majority of the sewered population in the United States, and collectively treat and reclaim more than 18 billion gallons of wastewater each day. NACWA members are very much aware of the growing importance of global climate change and are already engaged in efforts to reduce greenhouse gas emissions. As more state-wide and national efforts are launched to curb levels of greenhouse gases, EPA's *Inventory* will certainly take on added significance. NACWA appreciates the opportunity to weigh in on these important estimates.

Our review of Section 8.2, *Wastewater Treatment*, of the *Draft Inventory* indicates that the estimates for emissions from wastewater treatment have been over-estimated. Our comments, which are attached, provide explanations for specific factors that are too conservative or require correction. We also provide an analysis of the impact that changing the factors would have on the emissions estimates. These changes would result in a more accurate estimate of actual greenhouse gas emissions from wastewater treatment plants, which would provide a better expected value on which to base the uncertainty analysis for the estimate.

Again, thank you for the opportunity to participate in the expert review of the *Draft Inventory*. Please contact me at 202/296-9836 or *cfinley@nacwa.org* if you have any questions about our review.

Sincerely,

Cynthia A. Finley

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Director, Regulatory Affairs

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NACWA

A Clear Commitment to America's Waters

# Comments on EPA *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005, Draft for Expert Review*

The National Association of Clean Water Agencies (NACWA) has reviewed the wastewater treatment greenhouse gas emission estimates contained in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005, Draft for Expert Review* (*Draft Inventory*). Overall, we find that a series of conservative or incorrect factors led to a significant over-estimation of the greenhouse gas emissions from this source. We recognize that uncertainty exists in calculations of this type; however, the objective should be to use "mid-range" estimates so that a "best estimate" of emissions is developed, rather than one which is inherently biased to over-estimate the actual emissions. The *Draft Inventory* also estimates uncertainty assuming that the computed emissions are a reasonable assessment. NACWA believes that conservative assumptions should be considered in the uncertainty analysis, rather than preemptively embedded directly in the base calculation as it appears was done in the *Draft Inventory*.

NACWA's specific comments on the estimates are provided below. The impact of using more "mid-range" assumptions on the greenhouse gas emissions from the domestic wastewater treatment source is also characterized.

## Comments on $CH_4$ Emissions

1. The factor used to convert $BOD_5$ removed to $CH_4$ [methane] produced neglects important, well-known phenomena, and over-estimates the $CH_4$ produced. The development of this discussion is based on process fundamentals presented in several standard textbooks. The standard reference by Grady, Daigger, and Lim[1] will be used as the basis for this development.

   To begin with, a fundamental relationship exists between $CH_4$ produced and the biodegradable COD [Chemical Oxygen Demand] converted to $CH_4$. This well known relationship is 0.25 kg $CH_4$/kg biodegradable COD converted to $CH_4$. The first correction that must be made is that in any biological process, some of the biodegradable COD removed in the process must be converted into biomass (the bacteria that are responsible for the biochemical conversions). In a typical anaerobic process, about 10% of the COD is converted into anaerobic biomass and 90% is converted into $CH_4$. While this factor is often neglected from a conservative approach, we will include it in our calculations as we are trying to accurately estimate emissions. Since only 90% of the biodegradable COD removed in the process is converted to $CH_4$, the correction is as follows:

   0.25 kg $CH_4$/kg COD converted to $CH_4$ x
   0.9 kg COD converted to $CH_4$/kg biodegradable COD removed
   = 0.225 kg $CH_4$/kg biodegradable COD removed

   Next, biodegradable COD must be converted to $BOD_5$ [Biochemical Oxygen Demand]. For municipal wastewaters the COD/$BOD_5$ ratio typically is in the range of 2.2 to 2.4. However, the total COD includes both biodegradable and non-biodegradable components. Thus, a different factor that targets only the biodegradable COD must be used. The conversion between biodegradable COD and $BOD_5$ is presented in Section 8.6 of Grady, Daigger, and Lim where it is shown that, for municipal wastewater, a typical

[1] Grady, C. P. L., Jr., G. T. Daigger, and H. C. Lim, *Biological Wastewater Treatment*, 2nd Edition, Marcel Dekker, NY, 1999.

value would be 1.7 kg biodegradable COD/kg $BOD_5$. Using this factor, the $CH_4$ produced from the $BOD_5$ removed can be calculated as follows:

0.225 kg $CH_4$/kg biodegradable COD removed x 1.7 kg biodegradable COD/kg $BOD_5$ = 0.3825 kg $CH_4$/kg $BOD_5$ removed

This compares with the factor of 0.6 kg $CH_4$/kg $BOD_5$, which was apparently computed as 0.25 kg $CH_4$/kg COD x 2.4 kg COD/kg $BOD_5$. Use of this conservatively high factor results in an over-estimate of $CH_4$ production from these sources by 0.6 ÷ 0.3825 or 1.57. Even rounding the true $CH_4$ production factor to a convenient value of 0.4 kg $CH_4$/kg $BOD_5$ removed, it is seen that use of the conservative value of 0.6 kg $CH_4$/kg $BOD_5$ removed results in an overestimate of $CH_4$ production by these sources by 50%.

In conclusion, a more appropriate factor to calculate $CH_4$ emissions from wastewater treated anaerobically is 0.4 kg $CH_4$/kg $BOD_5$ removed.

2. The *Draft Inventory* assumes that "anaerobic systems" are used to treat roughly 5% of the domestic wastewater. To our knowledge, true anaerobic systems are seldom, if ever, used in the United States and its territories. In fact, EPA's Clean Water Needs Survey (CWNS) from 2000 shows that the nation's anaerobic lagoons treat less than 1.0 million gallons per day (MGD) as a whole. The *Draft Inventory* includes facultative lagoons, ponds, wetlands, and other natural treatment systems in this "anaerobic" category as well. These facultative systems are not fully anaerobic, and incorporate a combination of aerobic and anaerobic stabilization. An MCF-anaerobic factor of 0.8 is used in the calculation, apparently to reflect the fact that all $BOD_5$ is removed by anaerobic metabolism in these systems. This unduly conservative approach is perhaps appropriate if uncertainty is included, but inappropriate for a "mid-range" calculation. Typical facultative systems remove about half of the $BOD_5$ aerobically (through the action of algae that grow in the system), and about half is removed anaerobically. In fact, some carbon is immobilized in these systems through its incorporation into algae. However, neglecting this, a more reasonable value of 0.5 should be used for the MCF-anaerobic factor.

3. For aerobic systems, it is assumed that a significant fraction is "not well managed." We are uncertain of the basis for this assumption, but it should be recognized that the vast majority of the municipal wastewater treatment plants in this country are consistently in compliance with their discharge standards. Furthermore, it is assumed that in these "not well managed" plants, 30% of the influent $BOD_5$ is stabilized anaerobically. Again, we are unsure of the basis for this estimate, but it is clearly excessive as it would represent a wastewater treatment plant consistently in non-compliance with its discharge requirements. Since such consistent non-compliance would likely result in severe enforcement/regulatory action that will force correction, use of this value is inappropriate. At most, we would think that less than 10% of the plants are "not well managed." This results in a more reasonable, and perhaps still conservative, estimate that 10% of the influent $BOD_5$ is stabilized anaerobically.

4. The calculations assume complete removal of all influent $BOD_5$. While from a water quality perspective we wish that this were the case, no treatment plant is 100% efficient. Secondary treatment requires 85% removal and, as mentioned immediately above, the vast majority of the treatment plants in the U.S. are generally in compliance with their $BOD_5$ discharge requirements. We suggest that 90% is a more reasonable estimate of overall removal performance.

5. A more straightforward calculation of the $CH_4$ emissions from anaerobic digesters could be made. The present methodology depends heavily on the assumption of 100 gal/person/day for wastewater generation. The CWNS provides estimates of both the total wastewater flow treated at plants with anaerobic digesters and of the total wastewater flow centrally treated in aerobic systems. Using these data, the population served by central plants with anaerobic digesters could be calculated as:

Population served by central plants with anaerobic digesters =
(Flow to central plants with anaerobic digesters ÷ Flow to central plants)
x Population served by central plants

6. The calculation of emissions from anaerobic digesters appears to be missing two necessary unit conversion factors. One is to convert $ft^3$ of digester gas to $m^3$. The other is to convert g to Gg. We assume that these conversion factors have actually been included, but if they have not, they are necessary to include. Furthermore, it appears that although the data necessary to calculate these emissions are displayed in a footnote on page 8-7, these emissions were neglected by EPA in the total emissions results in Table 8-7.

## Impacts on Estimated $CH_4$ Emissions

The impact of incorporating the comments presented above on estimated $CH_4$ emissions from the domestic wastewater treatment source would be quite significant, as follows:

1. The impact of using the more appropriate $B_o$ factor of 0.4 kg $CH_4$/kg $BOD_5$, rather than the default value of 0.6 kg $CH_4$/kg $BOD_5$, will be to reduce total $CH_4$ emissions from septic tanks by one-third (i.e., actual emissions are 67 percent of those estimated using the inappropriate $B_o$ value).

2. The combined impact of the comments concerning emissions from the centrally treated aerobic systems source is to reduce emissions from this source to less than 10 percent of those estimated using the highly conservative (and in some cases incorrect) assumptions used for this source.

3. The combined impact of the comments concerning emissions from the centrally treated anaerobic systems source is to reduce emissions from this source to just over one-third of those estimated using the highly conservative (and in some cases incorrect) assumptions used for this source.

4. We assume that the "units" comments made on the emissions from anaerobic digesters source have already been made and just not documented in the reported methodology. Consequently, they will have no effect on the estimated $CH_4$ emissions from this source.

5. Overall, we estimate that the composite impact of these corrections would be to reduce estimated $CH_4$ from domestic wastewater treatment by more than 50%. Due to the significance of their impact, NACWA believes these corrections should be made before the *Draft Inventory* is released for public comment.

## Comments on $N_2O$ Emissions

Given the timeframe, we have not been able to carefully examine the emission factors for this category of emissions. However, we do have significant comments on the method used to estimate the quantity of nitrogen discharged to wastewater treatment plants, as follows:

1. The draft report estimates nitrogen discharges to wastewater treatment based on reported annual protein consumption. Expressed as nitrogen, the estimate for the domestic sources is as follows:

42.1 kg protein/person/year x 0.16 kg N/kg protein x 1.4 Factor for Non-Consumption = 9.43 kg N/person/year

This is at odds with per-capita wastewater discharge rates as presented in standard references such as Metcalf & Eddy[2]. Metcalf & Eddy report per capita nitrogen discharge rates to wastewater of 0.015 kg N/person/day. This is converted to a yearly value as follows:

0.015 kg N/person/day x 365 days/year = 5.48 kg N/person/year

The factors presented in the Metcalf & Eddy standard reference, as well as others, are based on actual data, rather than a more tenuous calculation. Thus, they are considered more reliable. Moreover, the use of standard per-capita values for nitrogen discharges would be consistent with the approach used for $BOD_5$, with which we agree. Use of the more appropriate value based on actual data is a reduction of more than 40%.

2. In the draft document it is assumed that nitrogen discharges to domestic wastewater treatment plants must be increased by 25% (a 1.25 factor) to account for industrial discharges. It is unclear whether this factor is actually needed given the very conservative approach used to estimate direct domestic nitrogen discharges (see Comment 1 immediately above), or whether it is already included in the standard per-capita nitrogen discharges taken from standard references (such as Metcalf & Eddy). As a practical matter, it is impossible to separate the commercial contribution from domestic sewages, whichever methodology is used. Using the protein consumption approach, discharges to both "domestic" and "commercial" sources are inherently considered. Likewise, the values presented in Metcalf & Eddy inherently consider both "domestic" and "commercial" discharges. EPA should be aware that further work is needed to better define nitrogen loadings to domestic wastewater treatment plants.

## Impacts on Estimated $N_2O$ Emissions

As with estimated $CH_4$ emissions, the impacts of the comments presented above on $N_2O$ [nitrous oxide] emissions from domestic wastewater treatment plants are significant, as follows:

1. Using a data-based per-capita nitrogen loading of 0.015 kg/person/day (corresponding to 5.48 kg/person/year) will reduce $N_2O$ emission estimates from effluent discharges by more than 40%.

2. Further reducing wastewater nitrogen loadings by reducing and/or eliminating the correction factor for commercial and industrial discharges would reduce $N_2O$ emission estimates from effluent discharges by 20%.

Thank you for the opportunity to participate in the expert review of the *Draft Inventory*. Please contact Cynthia Finley at 202/296-9836 or *cfinley@nacwa.org* if you have any questions about NACWA's comments.

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[2] Tchobanoglous, G., F.L. Burton, and H.D. Stensel, *Wastewater Engineering: Treatment and Reuse, Metcalf & Eddy, Inc.* 4th Edition, McGraw-Hill, New York, 2003.