Greenhouse Gas Emissions From Wastewater Treatment – A Comprehensive Review

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Objectives

- Municipal wastewater and residuals (solids) treatment operations
- Greenhouse gases (GHGs) of relevance
- Energy usage and potential at the municipal wastewater treatment plants
- Estimation of GHG emissions of wastewater and biosolids operations
- Use of GHG Emissions Data

Municipal Wastewater and Residuals' Processing

- **The liquid treatment train (traditional)**
  - Preliminary: headworks (screening, grit removal)
  - Primary: clarification of settleable solids
  - Secondary: BOD and NH_3 removal, and NO_3
  - Tertiary: filtration. . .
  - Disinfection
- **The solids treatment train (traditional)**
  - Thickening of sludges
  - Stabilization of sludges (aerobic, anaerobic)
  - Sludge dewatering
  - Dewatered Solids-incineration
  - Dewatered Solids-composting
  - Land Application of solids
  - Landfilling of dewatered solids

Greenhouse Gases of WWTP

- CO_2
- CH_4
- N_2O

- Other, as applicable

- Global anthropogenic GHG contribution
  - Waste and wastewater category – 2.8%

(IPCC, 2007)

Global Warming Potentials (100-yr)

• CO_2	1
• CH_4	25
• N_2O	298
• HFC-134 ($C_2H_2F_4$), and 134a (CH_2FCF_3)	1,100; 1,430
• SF_6	22,800

- Other, if applicable (look up in Table A-1, 40CFR Part 98)

Municipal WWTPs

- More than 15,000 POTWs are in operation.

- Water and wastewater utilities account for 40% of the electric power used in some cities.

- 437 MW power production capacity is in-place by the 133 WWTP-CHP sites in 30 states.

(USEPA, 2011)

Municipal WWTPs

- The 1,351 WWTPs at >1.0 MGD with anaerobic-digesters has potential to generate power at 411 MW and a thermal potential of 37,908 MMBtu/d.
- This in effect can reduce the CO_2 emission of 3.35 MM-tons/yr (at approx. 1,860 lb CO_2/MWh).

    (USEPA, 2011)

- High rate algae systems may provide energy surplus at a WWTP.

    (Woertz et al., 2009)

Energy Usage on Municipal Water Supply & Wastewater Treatment

Raw Water Pumping & Treatment	350 kWh/MG (an approx.)
Pumping to Distribution System	1150 kWh/MG (an approx.)
Pumping to WWTP	150 kWh/MG (an approx.)
Wastewater Treatment	2300 kWh/MG (an approx.)

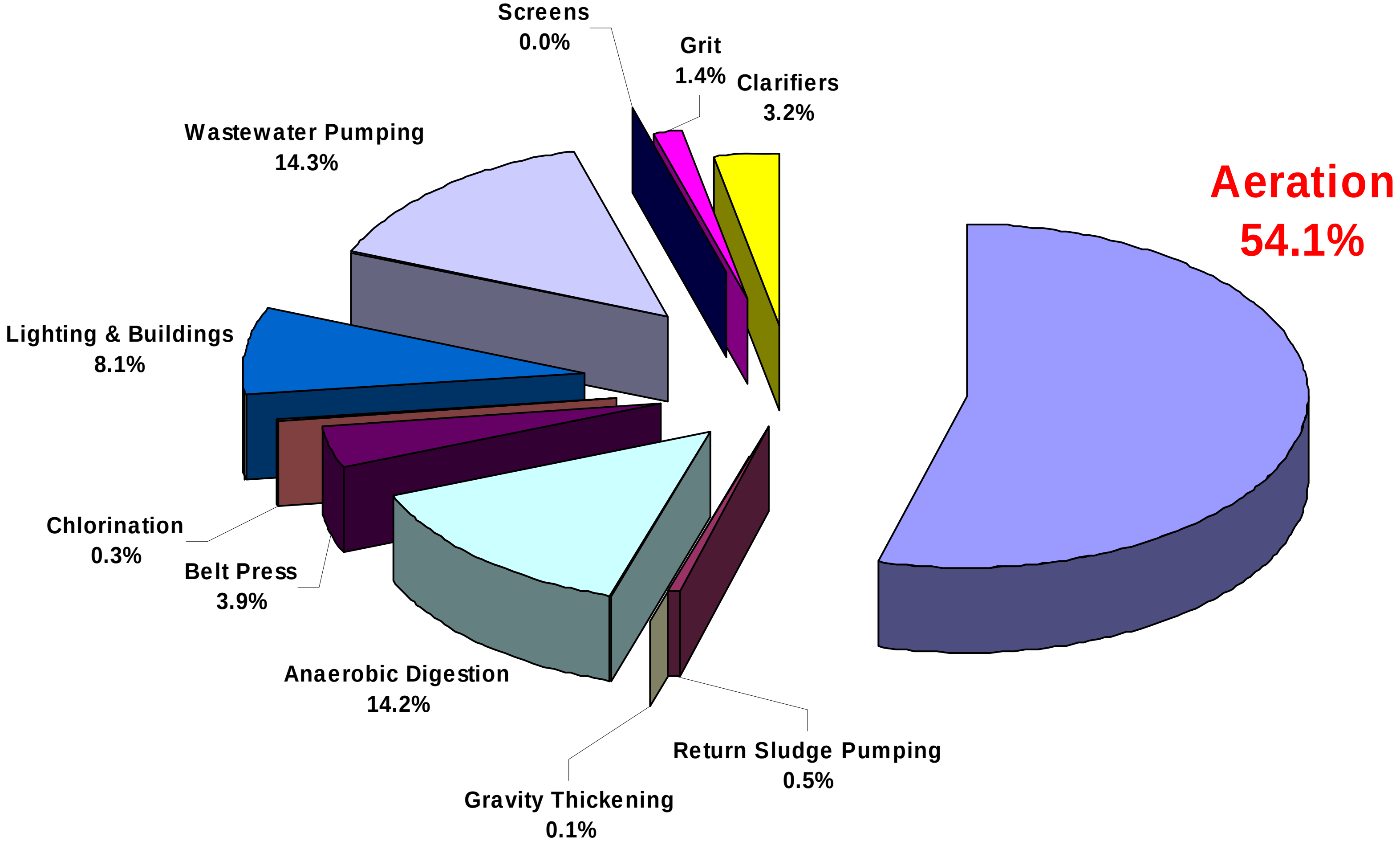
An average of 5,000 kWh/MG, from water-intake to stream-return

US Energy Usage on Wastewater Treatment = 56 bil.kWh/yr
i.e., equivalent to 26.7 MMT CO_2e of methane/yr.

[Ref: EPRI, EESI (2009), GAO, Chitikela (2014)]

WWTP Energy Usage

Energy consumed among a variety of processes and equipment



Ref. Derived from the data from Water Environment Energy Conservation Task Force – *Energy Conservation in Wastewater Treatment*

GHG Emission Estimation

CH_4 Emissions = $[S_{i,j}(U_i)(T_{i,j})(EF_j)](TOW-S)-R$

Where,

TOW = total organics in wastewater, kg BOD/yr

S = organic component removed as sludge

U_i = fraction of population in income group ‘i’

$T_{i,j}$ = degree of utilization of treatment/discharge pathway or system, j, for each income group

R = amount of CH_4 recovered, kg CH_4/yr

EF_j = emission factor, kg CH_4/kg BOD

(IPCC, 2006)

GHG Emission Estimation$_{contd.}$

$$N_2O \text{ Emissions} = N_{Effluent} \times EF_{Effluent} \times 44/28$$

where,

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

$EF_{Effluent}$ = emission factor for N_2O emissions from discharged to wastewater-N, kg N_2O -N/kg N; default factor is 0.005.

(IPCC, 2006)

GHG Emission Estimation$_{\text{contd.}}$

N_2O emission from centralized WWTPs:

$$\mathbf{N_2O\ plants = P \times T_{plant} \times F_{IND\text{-}COM} \times EF_{plant}}$$

where,

P = human population

T_{plant} = degree of utilization of plants, %

$F_{IND\text{-}COM}$ = fraction of industrial and commercial co-discharged protein (1.25, default)

EF_{plant} = emission factor, *3.2 g N_2O /person/yr* (without intentional nitrification and denitrification); *7 g N_2O /person/yr* (with intentional nitrification and denitrification)

GHG Emission Estimation contd.

- **2011, GHG Emission of municipal WWTPs –**

  CH4 7.6 Tg CO_2e

  N2O 5.2 Tg CO_2e

(USEPA, 2013)

- **GHG Emissions of Composting Operations:**

$$E_i = M \times EF_i$$

E_i = CH_4 or N_2O emissions from composting, Gg CH_4 or N_2O

M = mass of organic waste composted, in Gg

EFi = emission factor for composting – 4 g CH_4 per kg of waste treated (wet basis) and 0.3 g N_2O per kg of waste treated (wet basis)

i = designates either CH_4 or N_2O

(IPCC, 2006)

GHG Emission Estimation$_{\text{contd.}}$

- Composting Feedstocks and GHG Emission
  - If C/N ratio is <30 and moisture content is below 55%, GHG emissions potential is reduced.
  - Feedstocks rich in nutrients and wet material has the potential for GHG emissions.
  - If a bulking agent is used to adjust C/N ratio to < 30 and moisture content to < 55%, GHG emissions can be reduced.

(Ritter and Chitikela, 2013)

GHG Emission Estimation contd.

- N_2O Emissions from nitrates and ammonia residuals conversion from the discharged effluents into the water courses, are critical, as well.

- Sludge combustors/incinerators (SSIs) – Emission Factors:
  - CH_4 at 6.4 and 7.8E-01 lb/ton, scrubber-controlled – multiple-hearth
  - CH_4 at 3.2 and 8.0E-01 lb/ton, scrubber-controlled – fluidized bed

GHG Emission Estimation$_{\text{contd.}}$

- Land application of biosolids will increase the soil carbon and gain C credits for sequestering C.
- Land application also reduces fertilizer application so additional GHG emission credits from replacing commercial fertilizer could be obtained

- Reported Emissions: Sludge or biosolids land application--
  - N_2O emissions were 0.6 Tg CO_2e from grass land application

Vs.

  - 0.1 Tg CO_2e for managed manure, and 2.1 Tg CO_2e for the fertilizer applications

(Ritter and Chitikela, 2013, and USEPA, 2013)

GHG Emission Estimation contd.

- And, GHG Emissions from fossil-fuel and digester gas combustion operations on-site:
  - Emergency generators
  - Boilers, and other heat exchangers
  - 2-stroke, 4-stroke engines
  - Stationary gas turbines
  - Other, Heat-exchangers
- AP-42 and other emission factors available (incomplete though).
- Several other modelers have estimated GHG emissions of WWTP operations.

Conclusions

- The global GHG contribution from waste and wastewater operations were reported at 2.8% of the total GHG emissions.
- Wastewater treatment plants in the U.S. reported to be used 56 bil.kWh/yr of electricity, and the equivalent GHG emissions were at 26.7 $MMTCO_{2eq}$ methane/yr.
- There is potential to reduce GHGs of WWTPs.
- Estimation of GHGs includes a level of uncertainty.
- An appropriate and a comprehensive estimation of GHG emissions would be necessary, at the plant level.
- Land application of biosolids has positive effects with respect to GHG emissions.

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Thank You!

Questions?

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