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 NH₃ removal, and NO₃
  – 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$_2$O

- 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$_2$O 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

<table>
<thead>
<tr>
<th>Process</th>
<th>Energy Usage (kWh/MG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Water Pumping &amp; Treatment</td>
<td>350 (an approx.)</td>
</tr>
<tr>
<td>Pumping to Distribution System</td>
<td>1150 (an approx.)</td>
</tr>
<tr>
<td>Pumping to WWTP</td>
<td>150 (an approx.)</td>
</tr>
<tr>
<td>Wastewater Treatment</td>
<td>2300 (an approx.)</td>
</tr>
</tbody>
</table>

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 CO₂e of methane/yr.

[Ref: EPRI, EESI (2009), GAO, Chitikela (2014)]
Energy consumed among a variety of processes and equipment

- Wastewater Pumping: 14.3%
- Chlorination: 0.3%
- Belt Press: 3.9%
- Clarifiers: 3.2%
- Grit: 1.4%
- Screens: 0.0%
- Gravity Thickening: 0.1%
- Return Sludge Pumping: 0.5%
- Anaerobic Digestion: 14.2%
- Lighting & Buildings: 8.1%
- Aeration: 54.1%

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\textsubscript{contd.}

\begin{equation}
\text{N}_2\text{O Emissions} = N_{\text{Effluent}} \times EF_{\text{Effluent}} \times \frac{44}{28}
\end{equation}

where,

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

$EF_{\text{Effluent}}$ = emission factor for N$_2$O emissions from discharged to wastewater-N, kg N$_2$O -N/kg N; default factor is 0.005.

(IPCC, 2006)
GHG Emission Estimation \textit{cont'd.}

\( N_2O \) emission from centralized WWTPs:

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

where,

- \( P \) = human population
- \( T_{\text{plant}} \) = degree of utilization of plants, \%
- \( F_{\text{IND-COM}} \) = fraction of industrial and commercial co-discharged protein (1.25, default)
- \( EF_{\text{plant}} \) = 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 \text{contd.}

- **2011, GHG Emission of municipal WWTPs –**
  - CH4 \( 7.6 \text{ Tg CO}_2\text{e} \)
  - N2O \( 5.2 \text{ Tg CO}_2\text{e} \)
  
  (USEPA, 2013)

- **GHG Emissions of Composting Operations:**
  \[ E_i = M \times EF_i \]

  \( E_i = \text{CH}_4 \) or \( \text{N}_2\text{O} \) emissions from composting, Gg \( \text{CH}_4 \) or \( \text{N}_2\text{O} \)
  
  \( M = \text{mass of organic waste composted, in Gg} \)
  
  \( EF_i = \text{emission factor for composting} - 4 \text{ g CH}_4 \) per kg of waste treated (wet basis) and 0.3 g \( \text{N}_2\text{O} \) per kg of waste treated (wet basis)
  
  \( i = \text{designates either CH}_4 \) or \( \text{N}_2\text{O} \)
  
  (IPCC, 2006)
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\textsubscript{contd.}

- \(\text{N}_2\text{O}\) 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:
  - \(\text{CH}_4\) at 6.4 and 7.8E-01 lb/ton, scrubber-controlled – multiple-hearth
  - \(\text{CH}_4\) at 3.2 and 8.0E-01 lb/ton, scrubber-controlled – fluidized bed
GHG Emission Estimation 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—
  - N₂O emissions were 0.6 Tg CO₂e from grass land application vs.
  - 0.1 Tg CO₂e for managed manure, and 2.1 Tg CO₂e for the fertilizer applications
(Ritter and Chitikela, 2013, and USEPA, 2013)
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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Ohio WEA-AWWA

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Thank You!

Questions?

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