Overlooked GHG emissions from waste treatment

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Background

New Zealand GHG emission are legislated to reach net zero by 2050:

- NZ is committed to Paris, limiting warming to <1.5/2.0°C
- The Zero Carbon Act requires that emissions budgets are met through domestic action alone
- Climate Change Commission (CCC) is established and has developed first three GHG emission budgets
- Cabinet has agreed to budgets of:
  - 290MtCO_{2equi} for 2022 – 2025
  - 305MtCO_{2equi} for 2026 – 2030
  - 240MtCO_{2equi} for 2031 – 2035

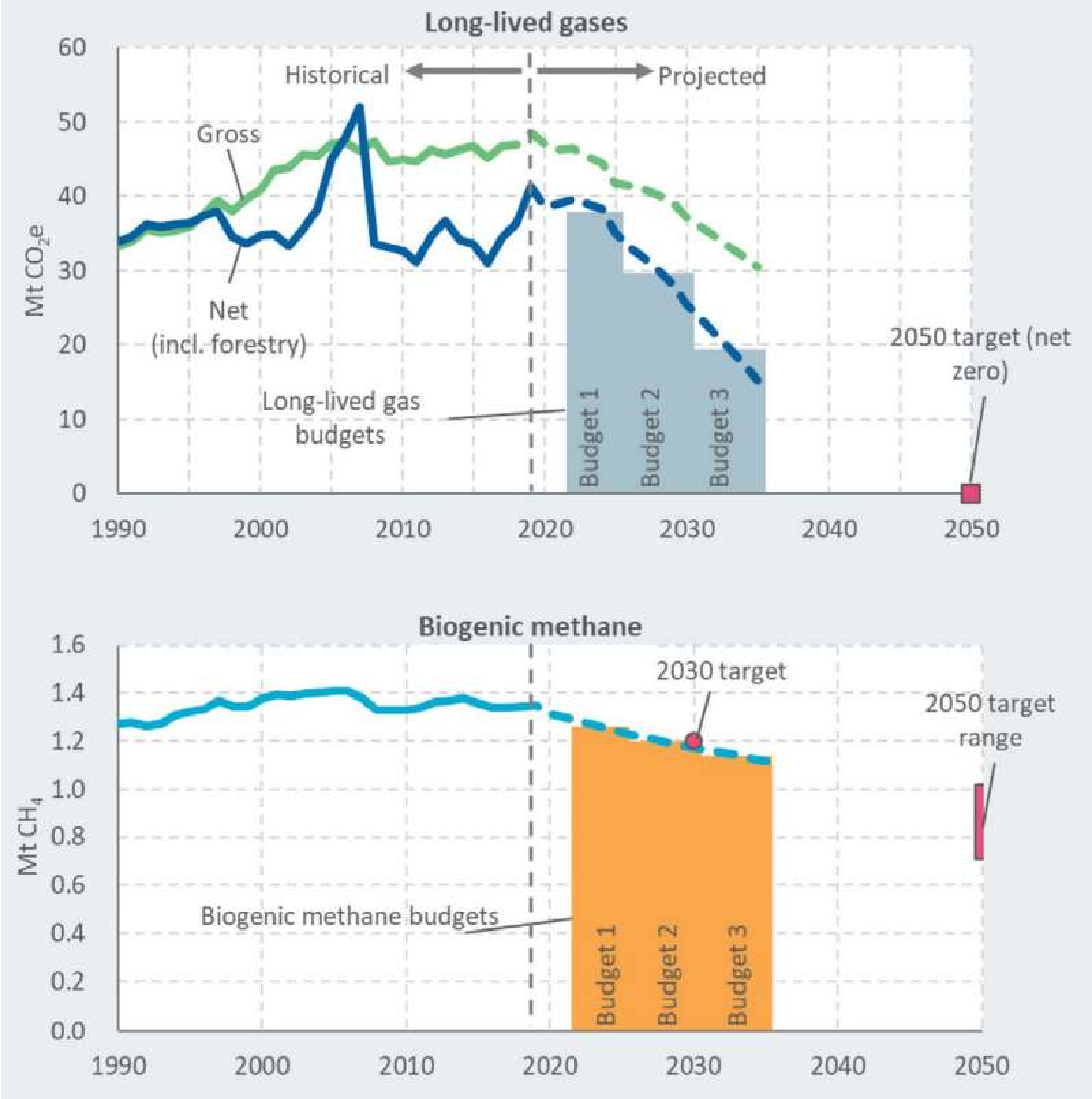
Climate Change Response (Zero Carbon) Amendment Act 2019

Public Act 2019 No 61
Date of assent 13 November 2019

Background

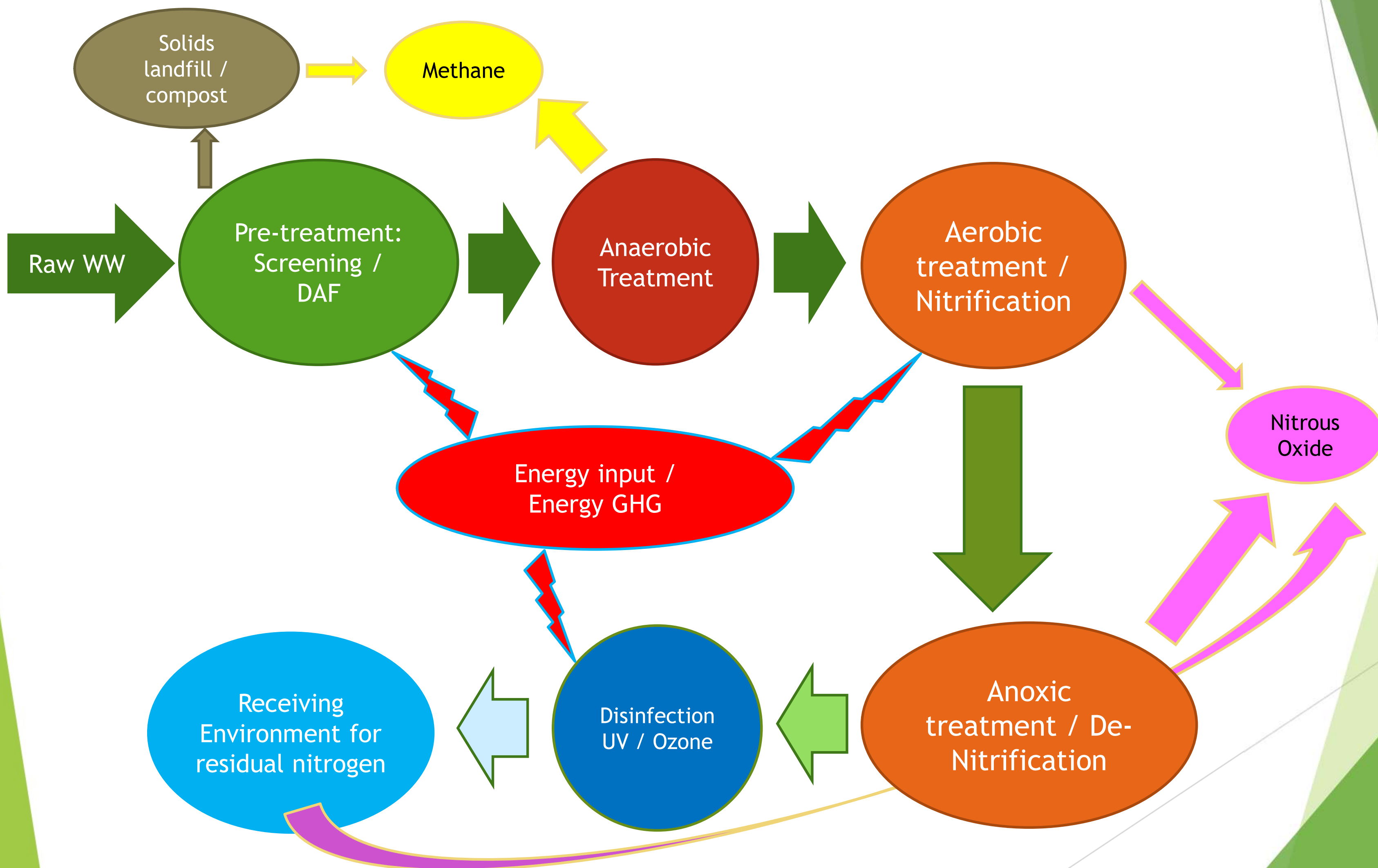
The CCC has adopted a "split gas" approach and developed budgets for long-lived gases as well as biogenic methane:

- The waste sector produces both short- and long-lived gases
- Long lived gases, including N_2O, required to reach 2050 net zero
- NZ total biogenic methane to be reduced by 24-47% by 2050
- Waste sector envisaged to reduce methane faster, e.g. -29% by 2030 vs -11% by 2030 for agriculture



Source: CCC report Ināia tonu nei, Figure 5.3, page 81

Grand Overview – GHG from a WWTP



No issue if it doesn’t cost $?

Wastewater GHG emissions don’t cost $ (yet) :

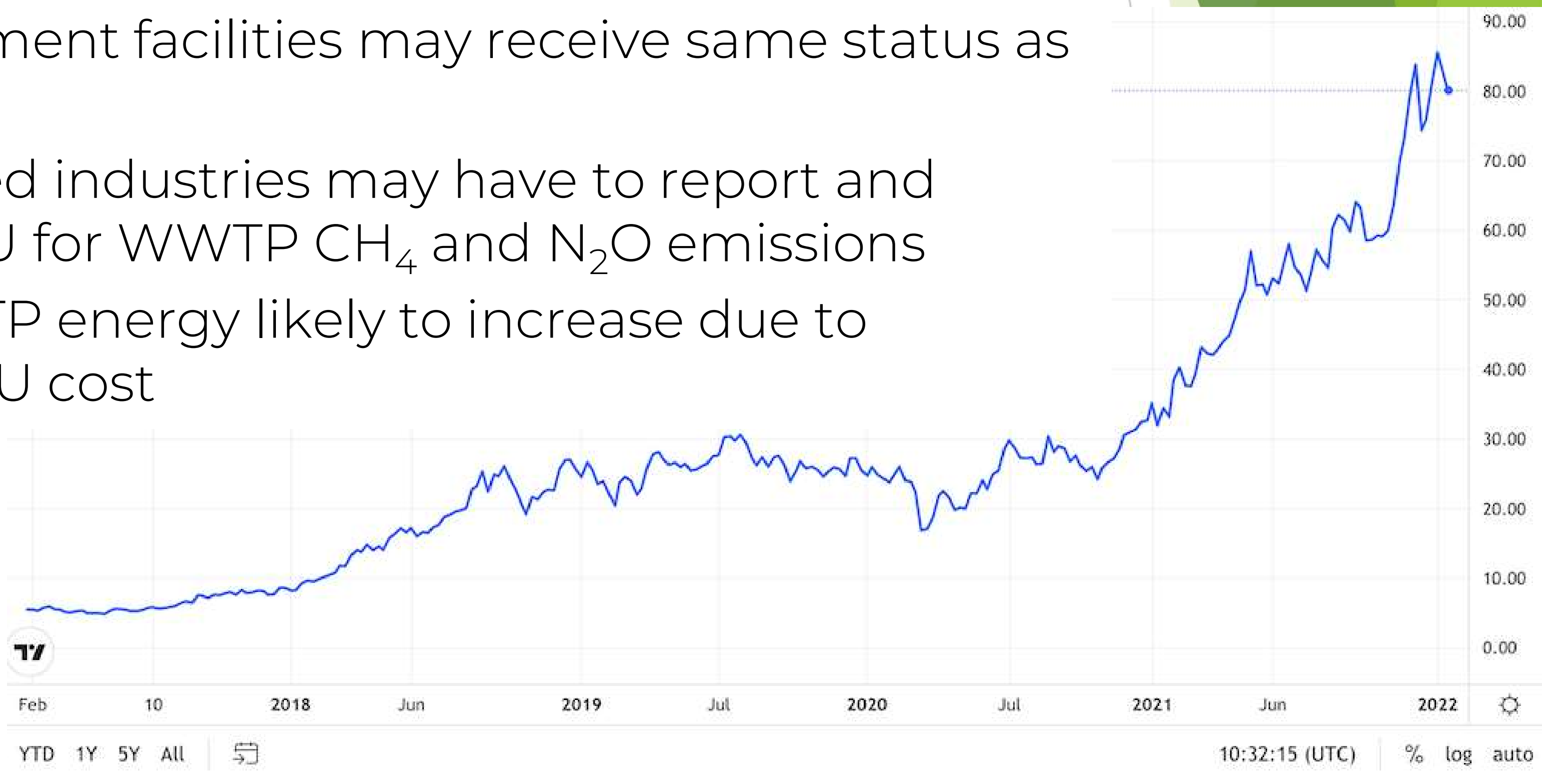
- The ETS it is the primary method for the NZ Government to achieve its long-term commitment to reduce our GHG
- Since 2013, disposal facility operators have had an obligation to report their emissions and surrender New Zealand Units (NZUs) under the ETS:
  - Operators of sewage treatment facilities are not currently ETS participants ➔ Municipal WWTP are exempt (for now).
  - Since 2011, companies carrying out certain agricultural activities have had an obligation:
    - Dairy processing of milk or colostrum, equal to or above 500 tonnes of milk solids per year
    - Slaughtering ruminant animals, pigs, horses, or poultry.
    - ➔ GHG from industrial WWTP in double grey zone.
  - Currently only WWTP energy (cost) covered by ETS

Source: https://www.epa.govt.nz/industry-areas/emissions-trading-scheme/

Issue 1

GHG emissions from the wastewater sector are overlooked because they mostly don't incur any direct costs.

- Exemptions may be temporal and may expire
- Exemptions are sectoral, and boundaries may be redefined
    - Sewage treatment facilities may receive same status as landfills
    - Already obliged industries may have to report and surrender NZU for WWTP CH_4 and N_2O emissions
    - $ cost of WWTP energy likely to increase due to increasing NZU cost



Graph source: https://theconversation.com/theres-a-massive-bubble-in-the-price-of-carbon-and-yet-it-wont-bring-down-emissions-any-faster-174821

Somebody else's problem?

Wastewater solids like screenings, DAF, primary sludge, WAS, etc. are frequently sent to landfill or composting:

- 1.92% of all landfill waste is WW sludge (~65,000t p.a.)
- Methane potential of 1t solids dry matter ~200 – 400m^3CH_4/t
- Average NZ landfill @ 70% recovery ➔ ~1-2tCO_{2equi}/tDM sludge
- Modern NZ landfill @ 90% recovery ➔ ~0.33–0.66tCO2equi/tDM
- Landfill operation pays for WW sector problem
- Composting GHG emission on a 1t sludge DM basis:
    - Methane @ 10kgCH_4/tDM = ~0.25tCO_{2equi}/tDM
    - N_2O @ 0.6kg/tDM = ~0.18tCO_{2equi}/tDM (@2%TN in DM)
    - N_2O @ 1.8kg/tDM = ~0.54tCO_{2equi}/tDM (@6%TN in DM)
    - Composting total: 0.43 - 0.79tCO_{2equi}/tDM sludge
- Composting operations not covered by ETS

Source: NZ GHG inventory 1990 - 2020

Source: IPCC 2006 guidelines waste, Table 4.1

Issue 2

GHG emissions from the wastewater sector are overlooked because they are exported

- Wastewater treatment solids disposal to landfill may become more restricted and/or more expensive not only due to physical limitations (blending ratios), but also because of GHG emission costs
- Composting is no GHG alternative (compared to modern landfill) and may become part of ETS and more costly going forward

Does it exist if it is not in the inventory?

The NZ GHG inventory currently accounts for:

- All WW treatment energy GHG emissions ✓
- Accounts for methane GHG emissions from:
  - Domestic / urban wastewater ✓
  - Meat industry ✓
  - Pulp and paper ✓
  - Wine industry ?
- Does not account for methane GHG emissions from:
  - Dairy processing ✓
  - Wool scouring ✓
  - Leather and skin ✓

Source: NZ GHG inventory 1990 - 2020

Photo credit: nzherald.co.nz

Does it exist if it is not in the inventory?

The NZ GHG inventory currently accounts for:

- Accounts for nitrous oxide GHG emissions from:
  - Meat industry ✓
  - Dairy processing✓
  - Leather and skin ?
  - Domestic WW nitrogen to environment ?
- Does not account for nitrous oxide GHG emissions from:
  - Domestic wastewater treatment ✗
  - Pulp and Paper ✓
  - Wool scouring ✓
  - Wine industry✓

Source: NZ GHG inventory 1990 - 2020

Photo credit: Carolyn Howell

Issue 3

Some GHG emissions from the wastewater sector are overlooked because they are not covered by the NZ GHG inventory:

- Overall, the NZ GHG inventory does a good job identifying and tabulating GHG emissions from the wastewater sector.
- Some moderate adjustments of coverage could improve the wastewater section of the NZ GHG inventory

Is the inventory using correct activity data?

The key calculation input parameters for computing methane and nitrous oxide GHG emissions are TOW (amount of organically degradable material in WW produced annually (tCOD/y)) for methane and associated total nitrogen for N_2O (derived via a N:COD ratio), going to each type of WW treatment:

- TOW for municipal wastewater based on population, fixed factors for COD and TN load, and split of treatment technologies from septic tank to activated sludge system.
- TOW for industrial wastewater based on product output and associated fixed COD and TN factors:
  - Meat industry: carcass t p.a. x 50.0kgCOD/t x 0.09 TN:COD
  - Pulp and paper: P+P t p.a. x 36.0kgCOD/t x 0.0038 TN:COD
  - Leather and skin: product t p.a. x 180kgCOD/t x 0.08TN:COD
  - Dairy processing: product t p.a. x 2.0kgCOD/t x 0.044 TN:COD
- Tyranny of averages starts here!

Source: NZ GHG inventory 1990 – 2020 and Cardno 2015

Is the inventory using correct activity data?

Do the TOW and TN numbers stand up to counter checks:

- For the TOW numbers used for methane emission calculations – domestic wastewater, meat industry, pulp and paper – the TOW totals in the inventory appear generally sound.
- The TN figures in the inventory appear as less accurate, for example dairy processing:
  - Dairy processing TN in effluent 2020: 490 tTN (inventory Table 7.5.4., page 333)
  - Counter check: 2020 raw milk production 21,900,000 t x 3.5% protein x 16% N in protein = 122,640 tTN factory throughput
  - @ 1.5% (1%-5%) loss to WW = 1.840 tTN/y to WW
  - Efficient dairy factories have a higher TN load from cleaning chemicals and HNO_3 than from milk loss, so addition of +10% to + 150% correction factor required.
  - Inventory may underestimate TN in dairy WW by factor 4 to 6

Source:
BPO 2022

Issue 4

Some GHG emissions from the wastewater sector are overlooked because suboptimal activity data is informing the NZ GHG inventory:

- Activity data (TOW) for calculation of methane GHG emission appears as generally sound.
- More uncertainty and discrepancies with TN activity data for N_2O emission calculations:
  - Some industries may require different input factor base
  - Fixed link between TOW and TN can multiply inaccuracies

How adequate are inventory emission factors?

Methane GHG emission calculation is based on an ultimate bio-chemical methane potential (B_o) of 0.25kgCH_4/kgCOD (IPCC 2006) and sector specific methane correction factors (MCF), reflecting an aggregate of sector specific WW treatment systems:

- Methane emissions from domestic wastewater are dominated by septic tank emission from ~ 12% of total population. Aggregate overall emission factor: 0.016kgCH_4/kg COD ✗
- Meat industry: MCF 55% ✗ = 0.036kgCH_4/kgCOD ✗
- Pulp and paper: MCF 80% ✓ = 0.0117kgCH_4/kgCOD ✗
- Wine industry: MCF 10 - 50% ? = 0.0167kgCH_4/kgCOD ?

Source: NZ GHG inventory 1990 – 2020 and Cardno 2015

Table 7-6 2012 Wastewater Treatment Emissions Inventory

Industry	CH_4 Emissions		N_2O Emissions	
	kt p.a	% of total	kt p.a	% of total
Meat Processing (cattle, sheep, lamps, pigs, goat, deer)	2.073	60%	0.0111	42.1%
Poultry Processing	0.298	8.6%	0.0024	9.0%
Dairy Processing	0.000	0.0%	0.0128	48.9%
Pulp and Paper Processing	1.017	29%	0.0000	0.0%
Winemaking	0.068	2.0%	0.0000	0.0%
Total	**3.456**	**100%**	**0.0262**	**100%**

How adequate are inventory emission factors?

Inventory methane emission factors moderately to severely underestimate real world emissions. Example:

- Anonymous, large NZ meat works (beef 500 – 1,000 head/day)
- Annual TOW: 3,000 tCOD/y
- Anaerobic pond COD removal: 90%
- Anaerobic pond conversion to methane (sludge correction): 90%
- (B_o) = 0.25kgCH_4/kgCOD (IPCC 2006)
- Annual CH_4 emissions: 600 tCH_4/y = 29% of NZ total meat industry CH_4 emissions (2,073 tCH_4/y) from a single site!

How adequate are inventory emission factors?

Nitrous oxide emission factors (EF): the real tyranny of averages!

- Default IPCC EF for N_2O emissions from domestic wastewater is 0.5% (0.0005 - 0.25) kg N_2O-N/kg N (IPCC 2006 guidelines) – a 2 order of magnitude range!
- The EF of 0.005 is the same for all NZ industrial wastewater treatment as well as domestic WW discharge to environment.
  - Unclear why EF should be the same if absorption is more dominant process in a natural environment vs. WWTP
  - Unclear why WWTP EF should be only half of EF for N volatilization in agricultural soil category.
- More recently suggested WWTP N_2O EF:
- 1.2% of N removed (Townsend-Small, et al. 2011)
- 1.6% of WWTP TN input (IPCC 2019, refinement of 2006 guidelines)
- 1.1% of WWTP TN input (deHaas and Andrews, 2022)

How adequate are inventory emission factors?

Is it possible to define N_2O emission factors (EF) for nitrification and de-nitrification in WW treatment separately?:

- Evidence from soil science suggests denitrification is the more potent source of N_2O emissions.
- Lab and full-scale studies with WW have both confirmed and contradicted these hypothesis.
- In the absence of better data, assuming a 50/50 split is as much right as it is wrong.
- Other studies, e.g. Gruber et al. (2021), suggest that nitrite (NO_2^-) concentrations are a key parameter for ultimate N_2O emissions from both nitrification and de-nitrification, with observed N_2O emissions varying by > factor 10 from both nitrification and de-nitrification depending on NO_2^- concentration

Issue 5

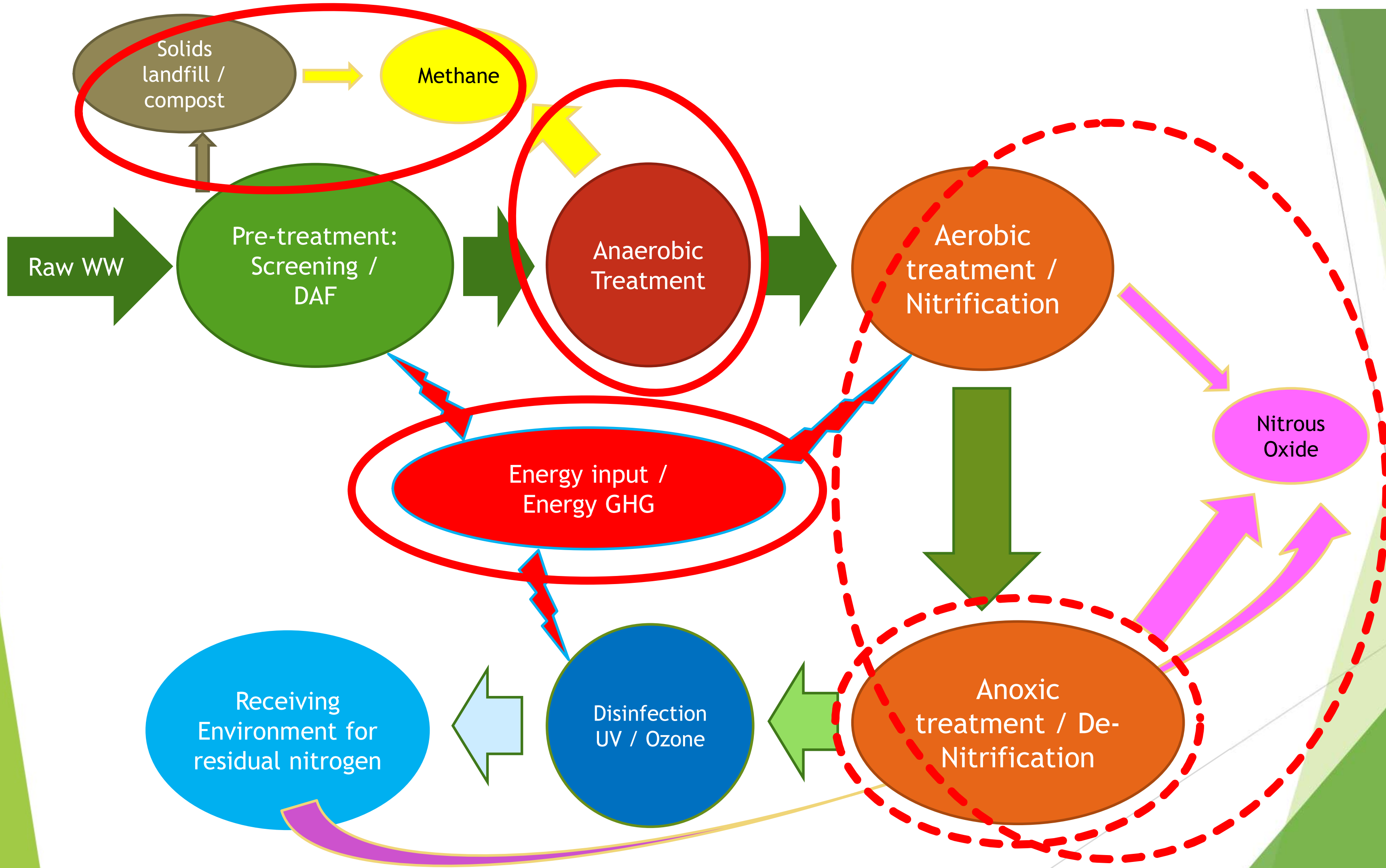
Some GHG emissions from the wastewater sector are overlooked because inadequate emission factors are used for the NZ GHG inventory:

- EF for WW methane too small for several industries
- A survey of the 50 largest industrial sites could provide a lot of clarity regarding industrial WW CH_4
- EF for N_2O emissions from WW treatment as difficult to define as ever.
- Adoption of IPCC 2019 refinement a step in the right direction, even if it isn't a silver bullet

GHG emissions from Wastewater Treatment

In summary: Trouble ahead!

How can the WW sector react to the GHG challenge?



Strategy 1: WWTP sludges and solids

The wastewater sector needs to phase out disposal of sludges and solids to landfill and composting, exporting its GHG liability:

- Increasing costs and bans may drive this, regardless
- The goal needs to be a sludge and solids disposal strategy based on anaerobic digestion, storage, and digestate recycling as a fertilizer on dedicated, non-food producing land (e.g. bio-energy crops).

Strategy 2: AD with CH_4 recovery up-front

Anaerobic solids reduction (or diversion) can reduce treatment energy requirements, methane recovery directly reduces GHG emissions, and reduced TN loads reduce nitrification and denitrification N_2O emissions:

- Existing lagoons need to be covered for CH_4 recovery
- More industries (dairy processing, wine industry, domestic WW, etc.) need to explore full stream AD
- Focus on primary sludge removal, up the pipe diversion, better DAF, etc. to divert solids to separate AD

Photo: Covered anaerobic lagoon at Fonterra Tirau

Source: bioenergy.org.nz

Strategy 3: Reduction of nitrification N_2O

Most strategies are only partial, experimental, or indirect:

- If possible, maximize assimilated TN removal:
  - Maximize primary sludge and DAF TN removal
  - Maximize secondary sludge generation, if disposal pathway exists.
- Direct nitrogen recovery (ammonia blowing, struvite, etc.) - only possible for specialist wastewaters
- Big data – continuous optimization:
  - Can WWTP operators identify patterns in secondary parameters, e.g. ORP, temperature changes, pH, nitrite concentrations, etc. that correlate with high N_2O emissions?
  - Can simple operational changes, like altered aeration times and rates, upfront pH balancing, etc. reduce N_2O spikes (80/20 rule)?

Strategy 4: Reduction of denitrification N_2O

Photo: Lipp GmbH

Most strategies are only partial, experimental, or indirect:

- All strategies reducing nitrification N_2O should also reduce denitrification N_2O.
- Is active N_2O recovery from denitrification an option?
- Physically only possible from SBR reactors with roof
- Example: 1,000 m^3 industrial WW with 500 g/m^3 TN as nitrate and sufficient organic C, 1.1% N_2O yield:
    - 1,478LCO_2 + 314LN_2 + 4LN_2O per m^3
    - 2,357gCO_2 + 494gN_2 + 9gN_2O per m^3
    - 2.7 tCO_{2equi} GHG emissions per 1,000m^3 run
    - 1,800m^3 off-gas per 1,000m^3 run
    - Treatment of 9kg N_2O in 1,800m^3 off-gas very difficult and expensive

Strategy 5: On-site renewable energy

Many domestically and internationally proven options are available:

- Most options can provide GHG savings without alternations to current treatment process.
- Methane capture and utilization, provides double GHG benefit
- Methane is storable energy
- Floating PV on treatment ponds – technology now ready
- Wastewater as heat recovery / heat sink media for district heating and industrial heating and cooling.

Photo credit: stuff.co.nz

Questions?

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