Towards net-zero energy and net-zero carbon wastewater treatment

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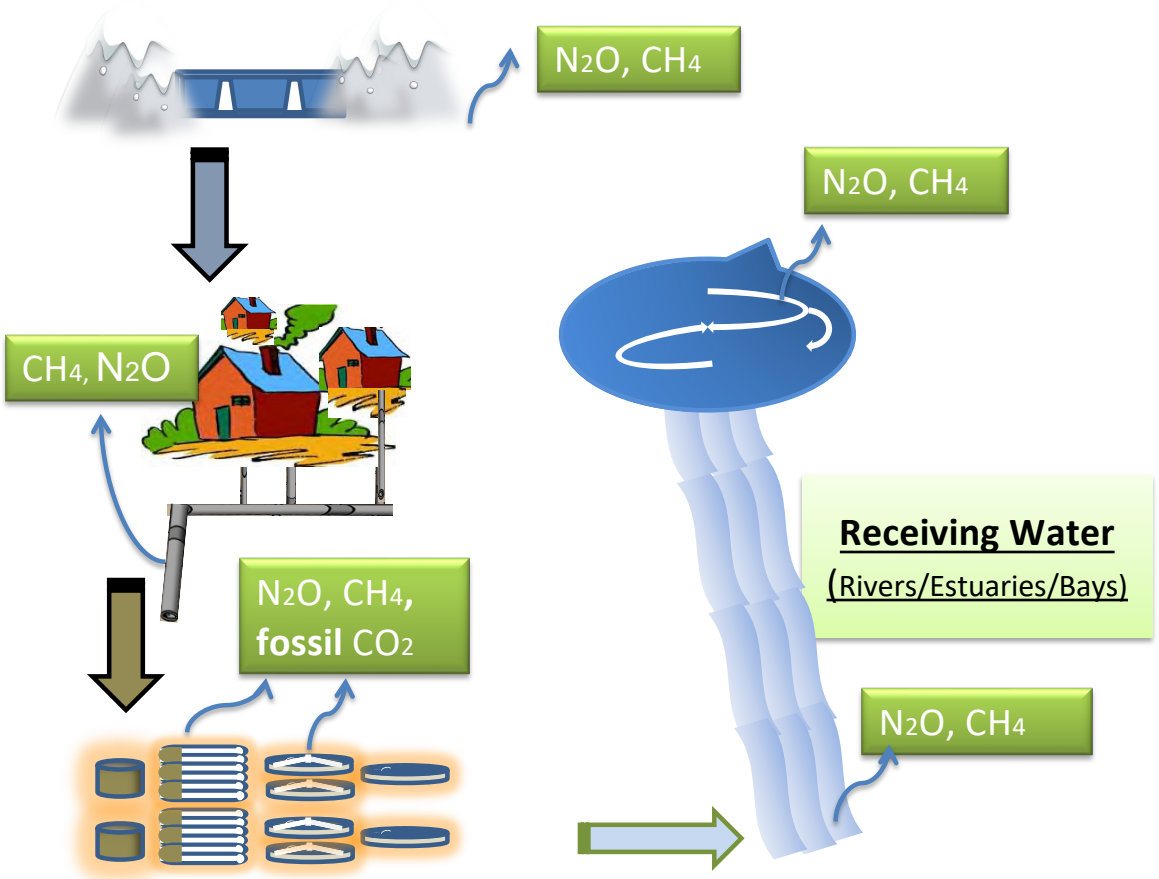
Race to Zero water utilities

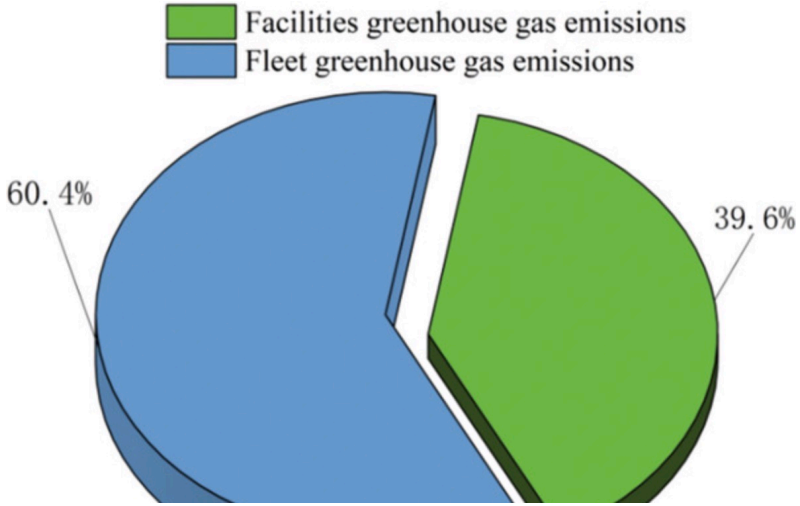
26 Water Utilities from UK, AUS, and NZ pledged net zero by 2025-2050

- **Serve over 72 million population**
- **Including 14 in AUS and NZ serving 18 million population**

WSAA 2021. Water utilities unite to cut emissions in Race to Zero. Water Services Association of Australia: Water utilities unite to cut emissions in Race to Zero.

What does net zero mean?





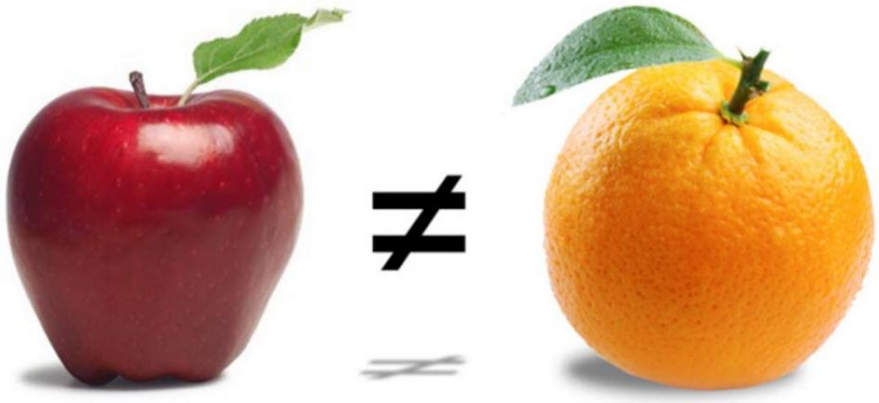
Greenhouse Gases: Science and Technology Volume 12, Issue 5 p. 587-601

A technology roadmap to energy and carbon neutral ~~wastewater~~ sewage ~~management~~ treatment operations

Energy neutrality

energy exported = energy imported

It is not just about megajoules;
types of energy matter;
need to compare apple with apple



A technology roadmap to energy and carbon neutral sewage treatment operations

Carbon neutrality

- Nitrifying bacteria
- Algae
- Some biogas upgrading processes
- …

- Exporting energy/power
- Purchasing carbon credits
- …

carbon emitted = carbon sequestered + offset

- Scope 1: Direct Emissions
- Scope 2: Power consumption

Typical boundary for net zero

- Scope 3: Upstream and downstream emissions

Strategies for net zero

- Scope 1:
  - Reduction in direct emissions
- Scope 2:
  - Reducing energy consumption
  - Generating renewable power & use locally
  - Purchasing renewable energy
- Offset:
  - Energy export (e.g. power, biogas/biomethane)
  - Purchasing carbon credits
  - Planting trees
  - …

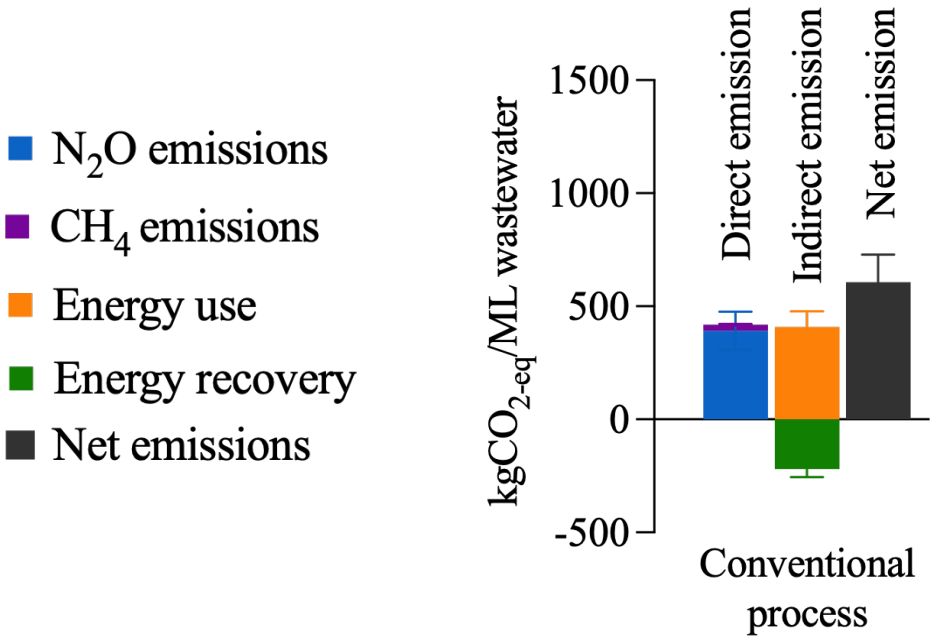
A technology roadmap to energy and carbon neutral sewage treatment operations

Energy neutrality ≠ Carbon neutrality

- Minimising energy consumption
- Maximising energy recovery
- Minimising direct emissions (N_2O and CH_4)

Are these goals consistent? Or can we make these goals consistent?

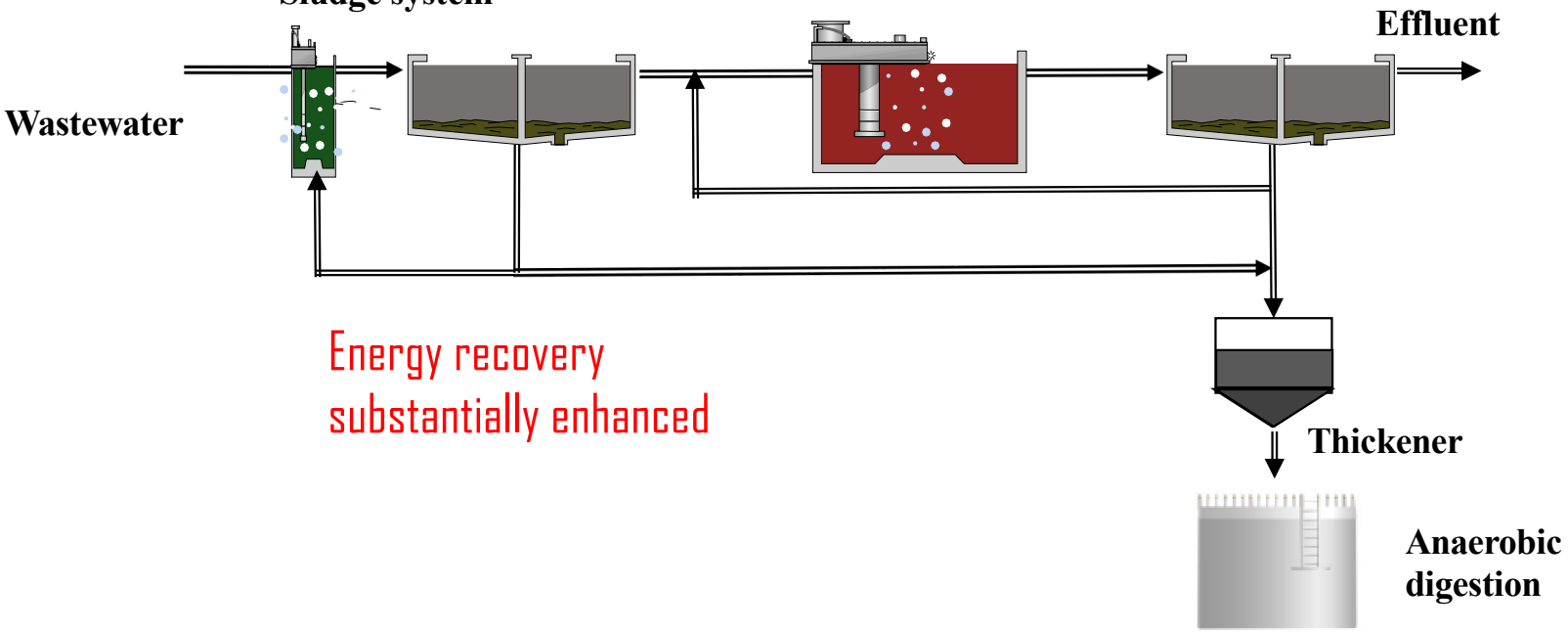
GHG emissions from a conventional process



A HRAS-PNA configuration for energy-positive sewage treatment

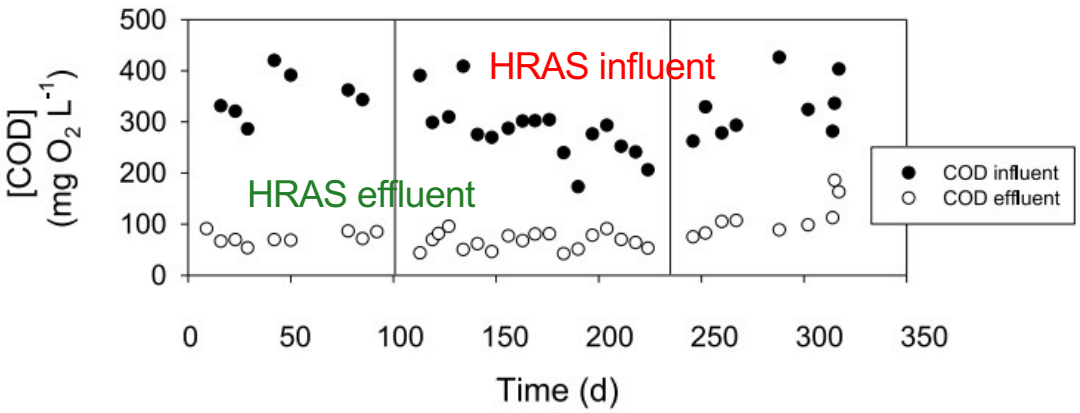
(50%) NH_4^+ → Energy consumption substantially reduced

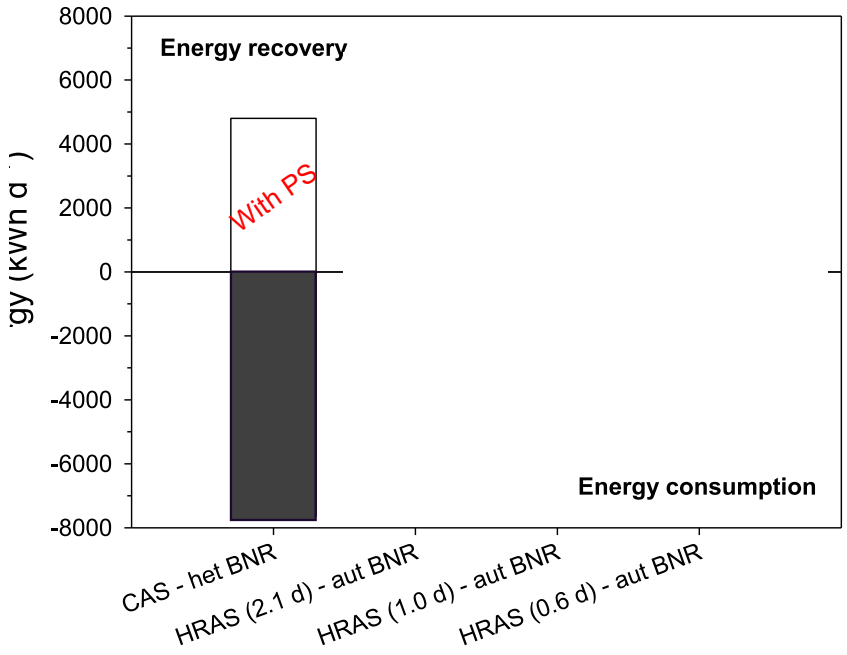
(50%) $NH_4^+ \rightarrow NO_2^- \rightarrow N_2$



HRAS for efficient carbon separation

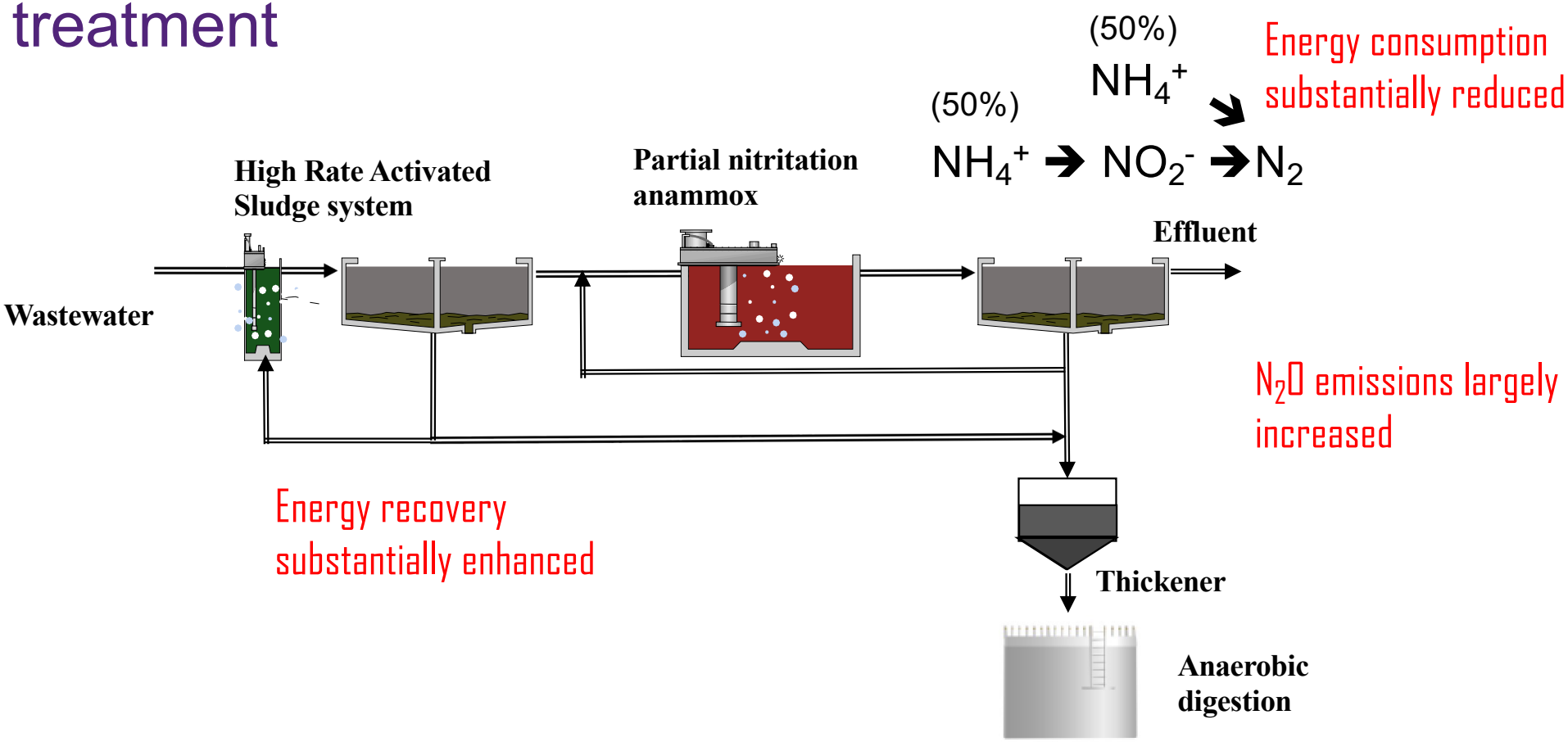
High tCOD removal: 65-79% tCOD removal over 1-year pilot demonstration (Carrera et al 2022)



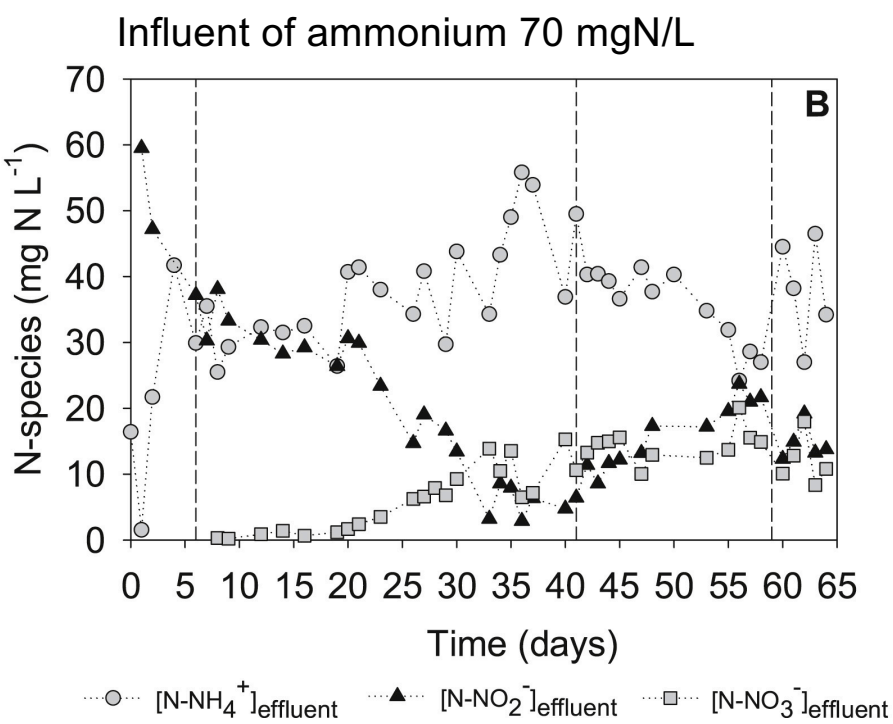


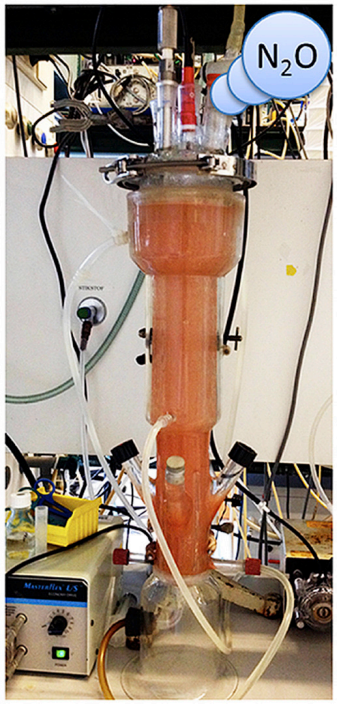
Carrera, Julián, et al. *Journal of Cleaner Production* 354 (2022): 131734.

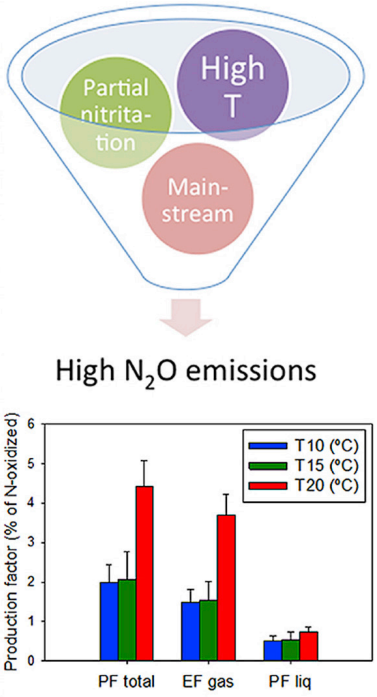
A HRAS-PNA configuration for energy-positive sewage treatment



Mainstream PNA often generates high N_2O emissions







3.7 ± 0.5% of ammonium removed at 20°C was converted to N_2O in a mainstream one-stage PNA reactor

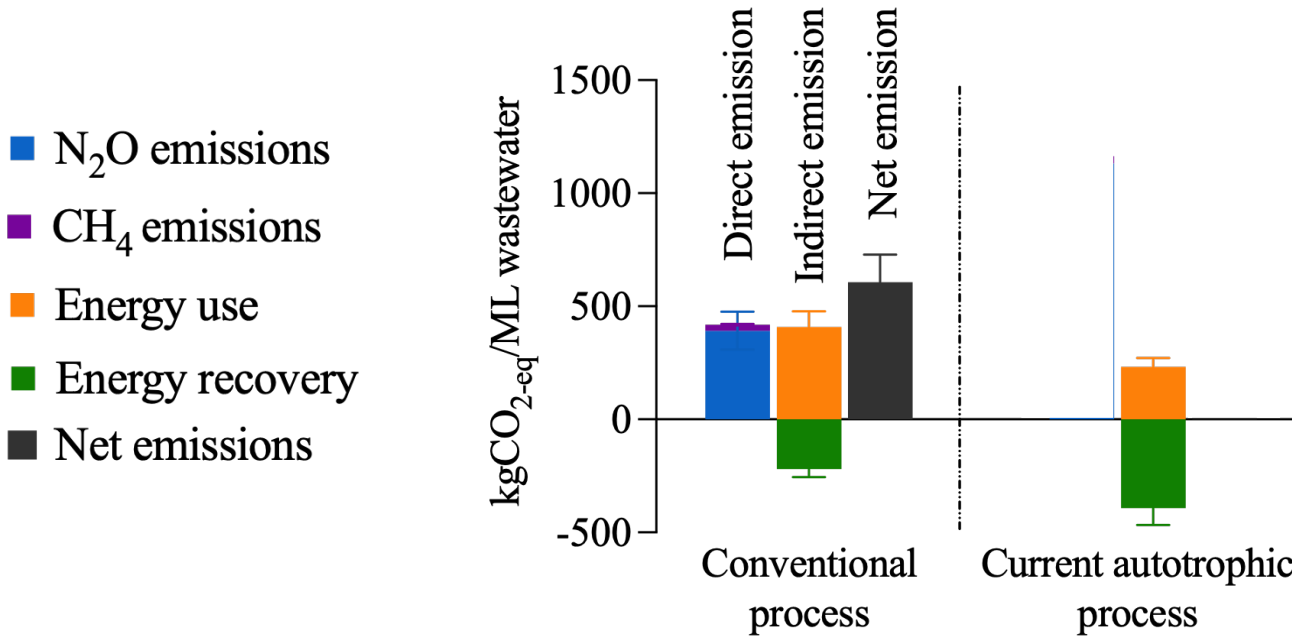
Reino, C., van Loosdrecht, M.C.M., Carrera, J. and Pérez, J. 2017. *Chemosphere* 185, 336-343.

Mainstream PNA often generates high N_2O emissions

Wastewater	Scale	Configuration	N_2O emission	Ref
Potato processing wastewater (264 mgN/L)	Full-scale	Two-stage	5.10%–6.60% of the nitrogen loading in partial nitritation	J. Desloover, H.D. Clippeleir, P. Boeckx, et al., Water Res. 45 (2011) 2811–2821.
Synthetic wastewater (5.8–54 mgN/L)	Lab-scale	Two-stage	4.00 ± 1.50%	S. Okabe, M. Oshiki, Y. Takahashi, et al., Water Res. 45 (2011) 6461–6470.
Synthetic wastewater (70 mgN/L)	Lab-scale	Two-stage	3.70 ± 0.50%	B. Kartal, J.G. Kuenen, M.C.M.V. Loosdrecht, Science 328 (2010) 702–703.
Synthetic wastewater (220 mgN/L)	Lab-scale	Two-stage	1.40%–2.90% of the oxidized NH_4^+	R.M. Rathnayake, M. Oshiki, S. Ishii, et al., Bioresour. Technol. 197 (2015) 15–22.
Synthetic wastewater (28 mgN/L)	Lab	One stage	2.4% of N removal and 2.28% of N loading	Z. Hu, T. Lotti, M. de Kreuk, R. Kleerebezem, M. van Loosdrecht, J. Kruit, M.S.M. Jetten, B. Kartal Appl. Environ. Microbiol., 79 (2013), pp. 2807-2812,
Swine wastewater (52 mgN/L)	Lab	One-stage	11.4% of N removal 8.55% of N loading	E.T. Staunton, M.D. Aitken. Environ. Eng. Sci., 32 (2015), pp. 750-760,
Synthetic wastewater (70 mgN/L)	Lab	One stage	1.6 - 3.3% of N loading	Li, K., Fang, F., Wang, H., Wang, C., Chen, Y., Guo, J., ... & Jiang, F. (2017). Scientific reports, 7(1), 42072.

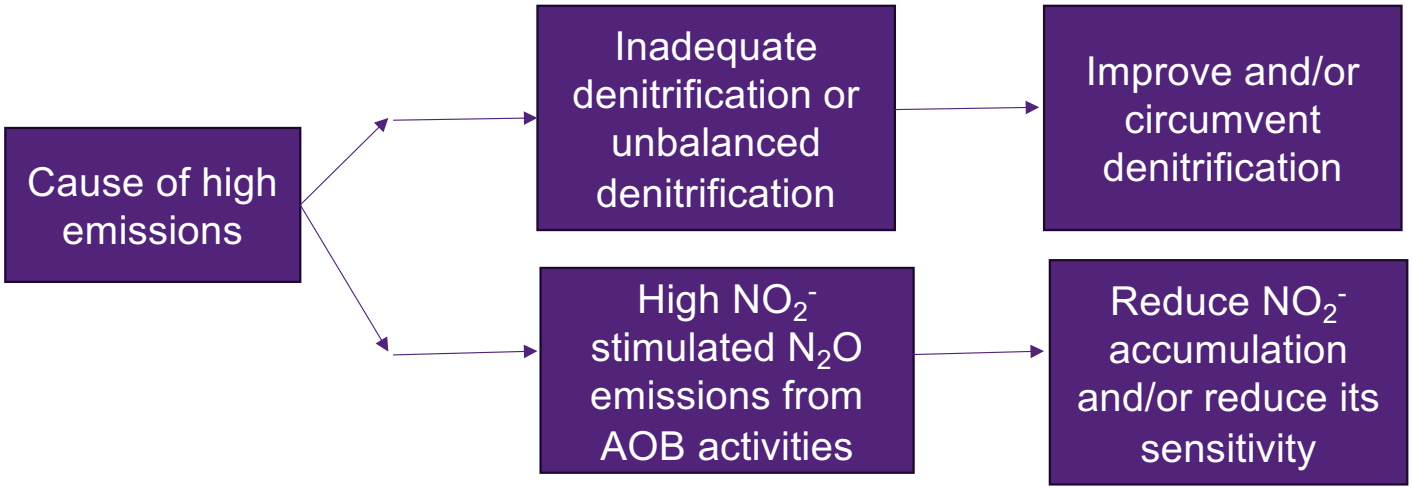
Average N_2O emissions 3.93 ± 1.31% of N loading

GHG emissions from an HRAS-PNA process

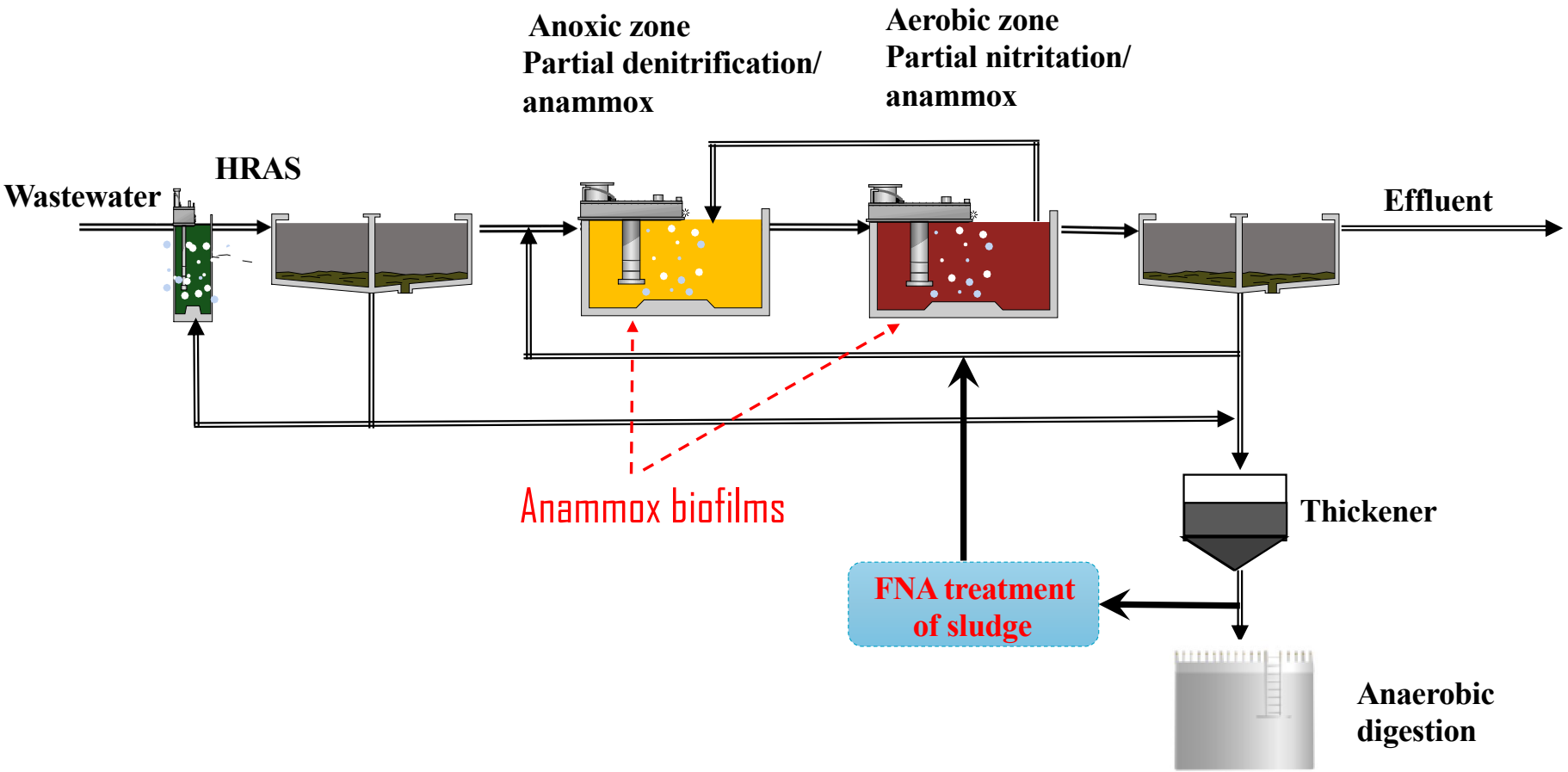


N_2O emission factor = 3.93%
Mean value reported in literature

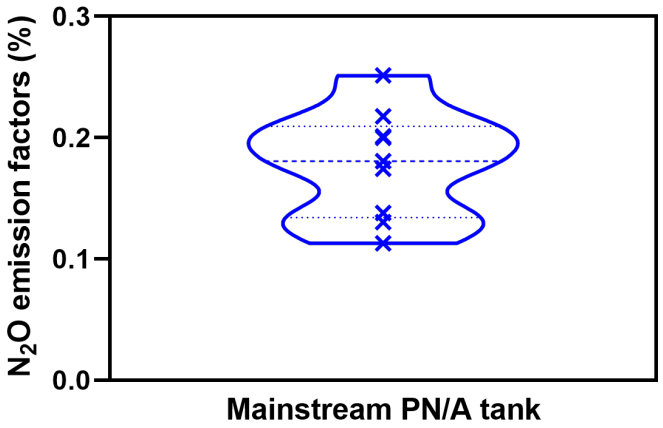
High N_2O emissions from PNA process



A HRAS-PdNA-PNA configuration for energy-positive sewage treatment

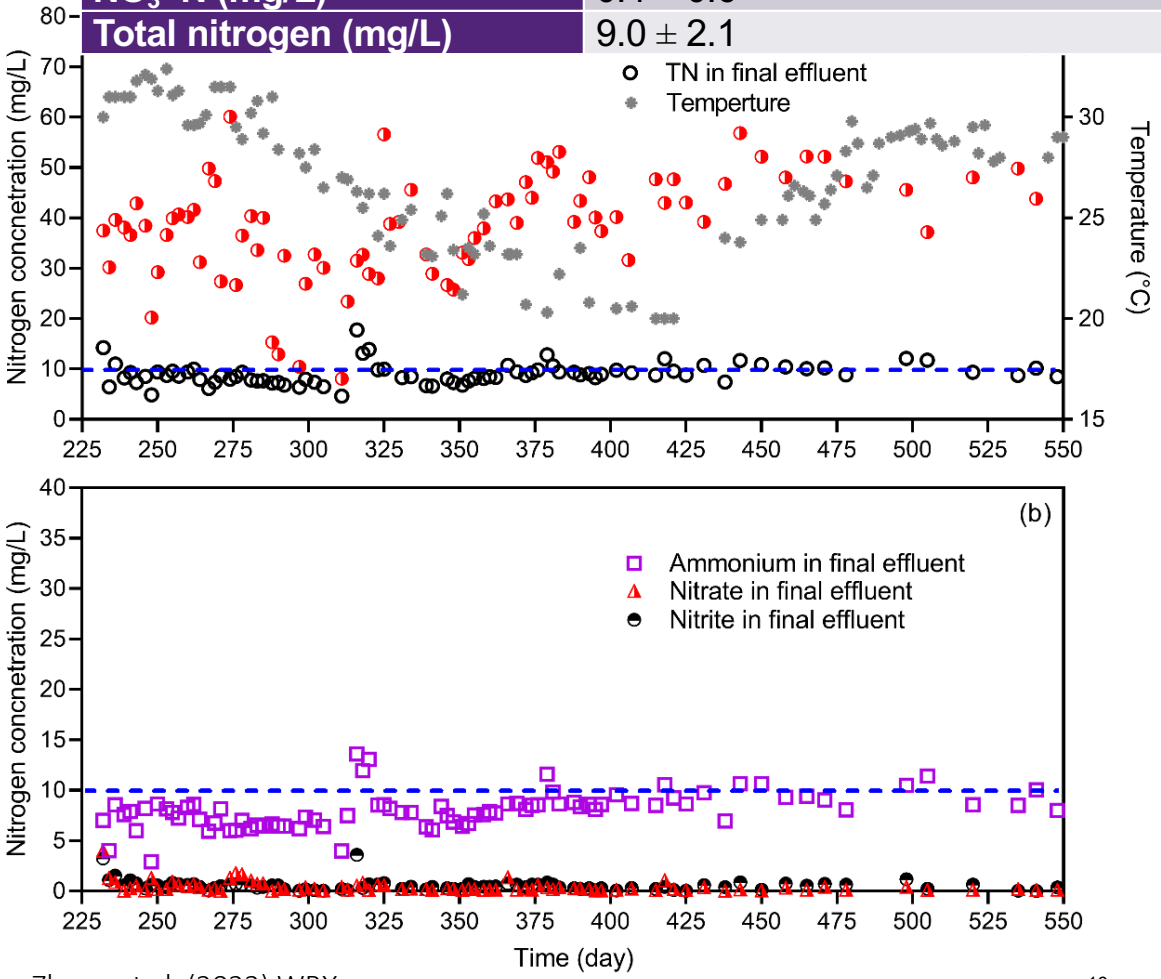


Pilot scale demonstration



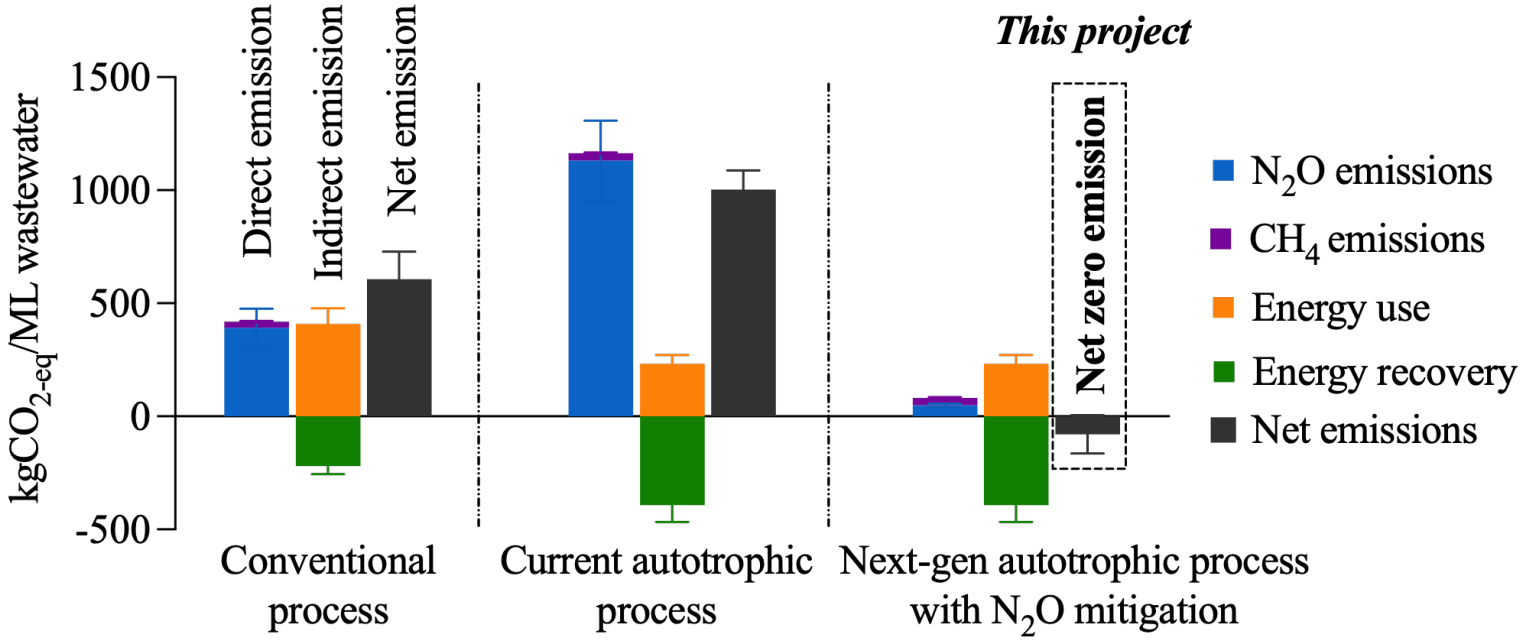
Emission factor: 0.178 ± 0.042 %

Effluent quality	Average value ± standard deviation
NH_4^+-N (mg/L)	8.1 ± 1.8
NO_2^--N (mg/L)	0.5 ± 0.5
NO_3^--N (mg/L)	0.4 ± 0.6
Total nitrogen (mg/L)	9.0 ± 2.1

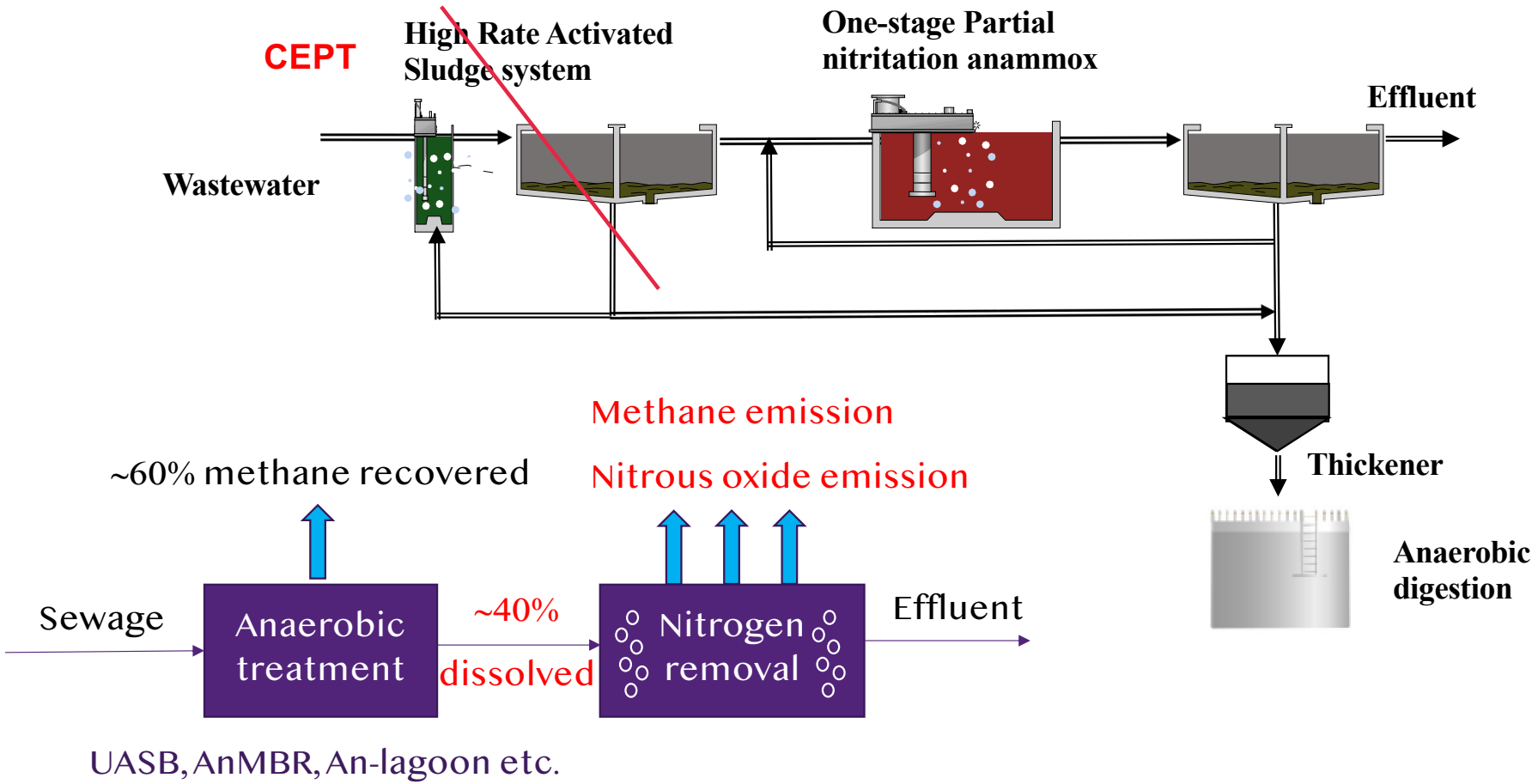


Zheng et al. (2023) WRX

GHG emissions from the HRAS-PdNA-PNA process



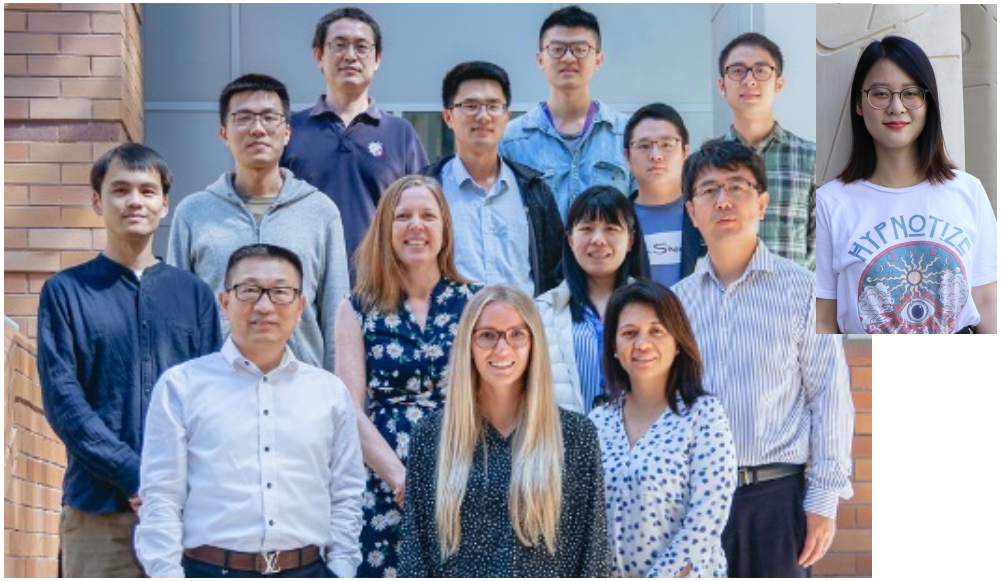
An alternative configuration for energy-positive sewage treatment



Conclusions

- Energy-neutral or even energy positive sewage treatment operations is possible
- Carbon-neutral sewage treatment is also possible
- The key factors:
  - Upfront carbon separation for bioenergy recovery
  - Innovative processes to minimise N_2O and CH_4 emissions in N removal

Acknowledgements



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