TAKING ACTION TO REDUCE SCOPE 1 EMISSIONS – WHERE TO START, PROGRESS AND EXCEL?

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ABSTRACT

Water Authorities globally, including in New Zealand, are increasingly setting Net Zero greenhouse gas (GHG) emission targets. With the use of renewable energy the reduction in Scope 1 GHG emissions (predominately Nitrous Oxide (N2O) and Methane) is critical to achieving Net Zero GHG emissions without significant off-sets.

This paper provides:

- An overview of the key sources of N20 and Methane emissions
- Practical approaches to monitoring emissions
- Practical tips for reducing emissions from existing infrastructure
- A case study presenting a semi-quantitative assessment of water and wastewater treatment technologies to review net zero technologies for consideration in plant upgrades and augmentations

N2O is a potent GHG with global warming potential (GWP) of 265. N2O can be generated during biological nitrogen removal (BNR) processes and emitted from wastewater treatment plants and can contribute up to 75 percent of the GHG footprint of WRRFs, especially in locations where the energy grid is primarily from renewable sources. Methane is a potent GHG with a GWP of 28. Methane is generated in anaerobic conditions and emitted from wastewater treatment plants, particularly from sludge and biosolids treatment processes.

This paper considers impacts on GHG emissions across the whole wastewater treatment site, as well as the impact on site energy demands.

This paper summarises experience in investigating and undertaking leading research into N2O emission monitoring and reductions globally, as well as design of low methane emission sludge treatment processes. This includes an outline to approaches to monitoring N2O and methane emissions, challenges and issues in monitoring and considerations and practical tips for implementing an N2O and Methane emission reduction program. The paper also presents a summary of successful projects globally which have reported material reductions in N2O and

Methane emissions from Water Authorities taking proactive actions to reducing site GHG emissions.

Practical mitigation measures can be effective in minimising fugitive methane emissions at biogas plants. Globally leading case studies from national monitoring programmes and long term methane mitigation schemes in Europe have shown that technical design and operational measures are required to be addressed. Technical measures, including construction of enclosed assets with biogas valorised or flared; (sealing, using best practice in design phase); operational measures include proactive facility management, adoption of leak detection and repair / 'find and fix' methods plus third party quantification to show progress year on year in conjunction with (ongoing) measurements and maintenance. In addition, it is likely that indirect measures (knowledge transfer to plant operators) can also develop new approaches and cultures which will support reducing fugitive methane emissions.

The paper reviews approaches to prioritise and act including the recent review of net zero technologies for Ofwat. The review used a semi-quantitative assessment of water and wastewater treatment technologies to assess alignment with net zero targets and make recommendations for focus over the 2025 – 2030 investment period.

Decarbonising in line with national interim and final targets on net zero is not without its challenges, however it also presents significant opportunities for the water sector.

KEYWORDS

Wastewater, N2O emissions, Methane emissions, Net Zero

PRESENTER PROFILE

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INTRODUCTION

Water Authorities globally, including in New Zealand, are increasingly setting Net Zero greenhouse gas (GHG) emission targets. With the increasing use of renewable energy, the reduction in Scope 1 GHG emissions (predominately Nitrous Oxide (N2O) and Methane) is critical to achieving Net Zero GHG emissions without significant off-sets.

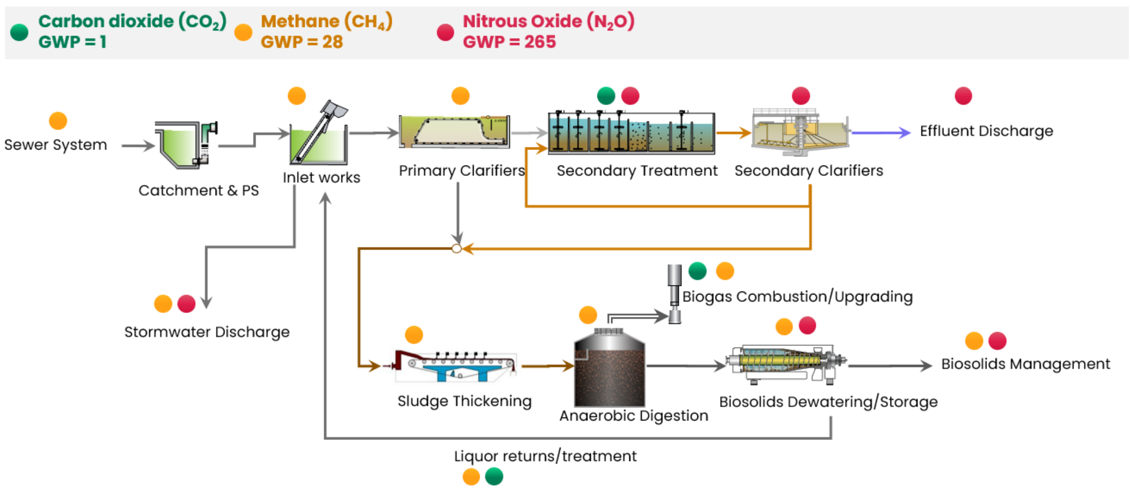
N2O is a potent greenhouse gas with global warming potential of 265. N2O can be generated during biological nitrogen removal (BNR) processes and emitted from WRRF and can contribute up to 75 percent of the GHG footprint of WRRFs, especially in locations where the energy grid is primarily from renewable sources.

Anaerobic digestion is widely applied in medium to large water resource recovery facilities (WRRFs) for sludge stabilization. In anaerobic sludge treatment, fugitive methane emissions can occur from digesters (due to aging infrastructure), downstream storage, from associated pressure relief valves and pipework, and also due to methane slip through combined heat and power (CHP) engines and biogas upgrading. In addition, long-term sludge drying (e.g., in lagoons) is commonly applied in many countries, such as Australia, due to its ease of operation and low operational costs. Methane generated from sludge drying lagoons is typically not captured and can be a significant greenhouse gas (GHG) emission source.

In the US, a country-wide standard methodology for quantifying GHG emissions from the wastewater sector does not exist. Among the available reporting protocols, methodologies for quantifying fugitive methane emissions from sludge treatment and biogas handling are limited to combustion of biomass and biogas, which essentially assumes zero methane emissions from anaerobic digestion and biosolids dewatering processes. The 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines state that unintentional methane leakage during process disturbances or other unexpected events will generate between 0 and 10 percent of the amount of methane generated in biogas, and the average of 5 percent should be used in the absence of other information (Pipatti et al., 2006); this chapter of IPCC guidelines was not updated in the 2019 IPCC Refinement. Recent studies suggest sector-wide underestimation of methane emissions from WRRFs, where the current available methodologies only account for ¼ to ½ of measured plant-wide methane emissions in the US (Moore et al., 2023, Song et al., 2023). The lack of consistent methodology and lack of facility level measurement result in significant risk to facilities in the estimation of their fugitive methane emissions through the sludge treatment and biogas handling processes.

OVERVIEW OF SCOPE 1 EMISSION SOURCES

An overview of N2O, methane, and carbon dioxide emission points from wastewater treatment plants is shown in Figure 1.



GWP: Global Warming Potential
Adapted from WEF Factsheet "GHG Sources and Sinks for WRRFs" (2021)

Figure 1: Process Emissions at Wastewater Treatment Plants

NITROUS OXIDE (N2O) EMISSION SOURCES

The primary areas of focus for N2O emissions from wastewater treatment plants are emissions from wastewater treatment, sludge processing and effluent discharge. Refer to Figure 1 for more details.

METHANE EMISSION SOURCES

Table 1 provides a summary of key methane emissions from sludge treatment and biogas handling processes, based on global case studies including both those which directly monitor methane emissions and those which use various alternative GHG accounting methodologies, generally aligned with Tier 2 level approaches.

Table 1: Methane Emissions from Sludge Treatment and Biogas Handling Processes – Global Case Studies

Process/Area	Emissions (% of Total Methane Produced, unless otherwise specified)	Source
Anaerobic digester manholes	4%	IWA 2022
Anaerobic digester pressure relief valves	0.06-1.7%	IWA 2022
Dissolved methane bubbles in anaerobically digested biosolids	0.4-1%	IWA 2022
Unburned methane in CHP	1.5-1.8%	IWA 2022
Incomplete combustion due to flaring	2%	IWA 2022
Dewatering and digestate storage	2-4.5%	IWA 2022
Anaerobic digestion plants	4.6%	IWA 2022
Sludge drying pans	43% COD in sludge converted to CH_4 emissions	IWA 2022
Loss via annular space of floating roof digesters	2.5%	UKWIR 2020
Venting due to ignition failure and downtime at flare stacks	0.21%	UKWIR 2020
Incomplete combustion	1%	UKWIR 2020
Fugitive emissions	3.8%	UKWIR 2020
Secondary digestion	5.9%	UKWIR 2020
Thermal hydrolysis pre-treatment	2%	UKWIR 2020
Acid phase digestion	3%	UKWIR 2020
Emissions from biogas to grid	1-15% (technology specific)	UKWIR 2020
Methane losses from anaerobic digestion plants	0-10% (5% in absence of other information)	IPCC (Pipatti et al., 2006)
Methane losses from anaerobic digestion plants	2.1%	ECCC 2022

In the absence of global full scale monitoring data to estimate fugitive methane emissions, existing methodology estimates may be beneficial for benchmarking emissions from sludge treatment and biogas handling processes. However, Tier 3 level facility monitoring is required to accurately estimate methane emissions and to validate any mitigation efforts.

PRACTICAL APPROACHES TO MONITORING EMISSIONS

NITROUS OXIDE (N2O) EMISSIONS

There are many approaches in monitoring and quantifying N2O emissions at plant-level and at unit process level. This paper draws together experience in investigating and undertaking leading research into N2O emission monitoring and reductions globally. Generally, three key methods to N2O monitoring have been adopted across a range of studies:

1. Off-gas hood N2O monitoring: This method requires hoods to be installed in the water surface of representative locations of the bioreactor with the off-gas tested and an emission calculated from the estimated or measured air flow through the hood area.
2. Liquid phase dissolved N2O monitoring: N2O probes are installed in representative bioreactor locations and the instantaneous dissolved N2O concentration is monitored – with the air emission factor calculated based on an empirical equation and temperature correction.
3. Mobile tracer gas dispersion method (MTDM): MTDM involves controlled release of a tracer gas using gas cylinders with calibrated flowmeters, and measurement of the atmospheric gas concentrations downwind of the target area using a mobile measurement platform (e.g., vehicle equipped with fast-responding gas analyzers and a global navigation satellite system for recording measurement locations). The tracer gas has long atmospheric lifetimes to maintain a constant concentration ratio during transportation and mixing in the atmosphere, therefore, allowing the N2O emission rate to be calculated in real-time by relating the measured plume traverse concentrations of N2O and the tracer gas.

In general, plant-wide quantification is often used for GHG inventories or reporting, or to characterize and prioritize sites, while process unit GHG quantification is essential to characterize process specific emissions (e.g., for calibration of mechanistic models or to link emissions to the operating conditions) and to develop mitigation measures for specific emission sources. The selection of a suitable method is often case specific, affected by the typology of the targeted process unit and the target GHG, as well as local factors such as the site topography, process design (e.g., aeration type, tank configuration) and operation (e.g., aeration control, whether sludge tank mixers are on), staff and equipment availability, analytical capacity, and costs.

A number of studies have used both methods, examples being ongoing work in Denmark, the Netherlands and UK (liquid phase focused) and work in Australia, Austria, Switzerland and Finland (gas phase focused). These studies report good correlation between the estimated emissions from the dissolved N2O concentrations and the off-gas testing estimating – though work remains undergoing in developing and improving methodologies for both.

METHANE EMISSIONS

No international standards exist for the measurement of fugitive and diffused CH4 emissions from WRRFs, although a number of handbooks exist for measuring CH4 emissions at digestion and biogas facilities, such as the DBFZ (Deutsches Biomasseforschungszentrum) Report No.33 'Recommendations for reliable methane emission rate quantification at biogas plants' (DBFZ, 2019) and Avfall Sverige (Swedish Waste Management) Handbook (Holmgren, 2016).

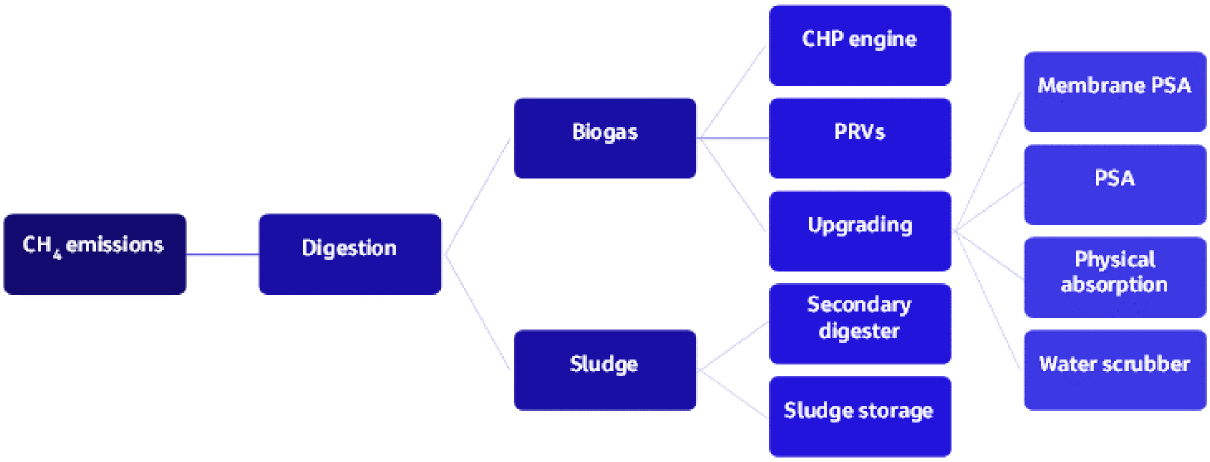


Figure 2: Potential Sources of CH4 Emissions from WRRFs with Anaerobic Digestion

FACILITY-WIDE MONITORING OF METHANE EMISSIONS

Ground-based remote sensing methods can be used for facility-wide quantification of fugitive CH4 emissions, such as MTDM, IDMM and DIAL. These methods calculate the emission rate of the target gas (e.g., CH4) through two main steps: 1) describing the plume generated by the target area and 2) defining the atmospheric dispersion that the target gas undergoes travelling downwind from the target area.

Most recently, some emerging methods offer promising alternatives for facility-wide monitoring of process emissions, such as drone-based systems and Open-Path Laser Absorption Spectrometer (LAS) (Zaccheo and Dobler, 2020). However, these emerging techniques have not been widely applied, therefore are not discussed in this paper.

Mobile Tracer Gas Dispersion Method

MTDM is the most common method that has been implemented for quantifying CH4 emissions at wastewater facilities (IWA, 2022). MTDM involves controlled release of a tracer gas using gas cylinders with calibrated flowmeters, and measurement of the atmospheric gas concentrations downwind of the target area using a mobile measurement platform (e.g., vehicle equipped with fast-responding gas analyzers and a global navigation satellite system for recording measurement locations). The tracer gas has long atmospheric lifetimes to maintain a constant concentration ratio during transportation and mixing in the atmosphere, therefore, allowing the CH4 emission rate to be calculated in real-time by relating the measured plume traverse concentrations of CH4 and the tracer gas. Acetylene (C2H2) is often used as a tracer gas because of there being very few possible interfering sources and its long atmospheric lifetime.

The MTDM has been applied at several full-scale wastewater facilities located in Denmark, Sweden and France (Delre, 2018; Samuelsson, et al., 2018; Yoshida et al., 2014). It should be noted that MTDM offers a site-wide perspective, but it is unlikely to provide understanding of production or emissions specific to process or to support mitigation in the same way process-level monitoring will.

The statistic tracer gas dispersion method (STDM), a static version of the MTDM, can be applied where process units are enclosed and the indoor air is collected in a ventilation system. The STDM has been successfully applied for quantifying CH4 (and N2O) emission rates from ventilated duct in a building that houses sludge thickening and dewatering processes at a wastewater treatment plant (Samuelsson, et al., 2018).

Inverse Dispersion Modelling Method

IDMM refers to deriving emission source strength from measured concentrations at points upwind and downwind from the source combined with meteorological data using a dispersion model. There are many available models for dispersion modelling. The choice of the best appropriate model to be used depends on a range of factors: general application of the model, open source or license model, level of expertise of the user, nature of the available input information (location and terrain, building configuration, source configuration, meteorological data, etc.), practical consideration (accuracy of the results, temporal and spatial resolution etc.). Some of the recommended dispersion models for quantifying methane emission rates at biogas plants include the forward Lagrange Simulation of Aerosol Transport (LASAT) model and Windtrax backward Lagrangian stochastic model (DBFZ, 2019).

IDMM offers a non-intrusive approach for quantifying long-term methane emissions with a small number of measurements. IDMM with OP-TDLAS can be applied to determine emissions from several component sources simultaneously using appropriate instrument setup and a sufficient number of measurement paths. Based on recent work (Fredenslund et al., 2023), it is best suited for long term site-level monitoring, and less appropriate/accurate for short-term campaigns where MTDM and DIAL are considered more appropriate. Measurement equipment and modelling skills currently remain in academics.

Differential Absorption Lidar (DIAL)

DIAL is an optical remote sensing method capable of measuring concentration of a target gas along the path of a laser beam transmitted into the atmosphere. It combines the use of light detection and ranging (lidar) to measure backscattered light from the atmosphere and the targeted species dependent differential absorption of two known, pre-selected, wavelengths of light. One of these (λon) is strongly absorbed by the species of interest while the second pulse (λoff) is at a wavelength that has a much weaker absorption. The difference in the absorption of the two wavelengths allows the concentration of the gas to be calculated along the optical path (Beer-Lambert law). Spatial resolution is obtained by pulsing the laser beam allowing both the location and concentration of emission sources to be determined. In the usual emission rate measurement, a series of DIAL scans are performed at different elevation angles to obtain a vertical cross-sectional plane of concentration data downwind of the source area of interest. Integrating the product of this concentration plane with the wind vector through it gives an emission rate through the area of interest.

DIAL is a well-established technology and has been used worldwide for over 20 years at different industrial facilities for regulatory monitoring. The scanner unit can rotate 360 °C allowing different line-of-sight measurements to be taken from the same location. Although it does not provide data in the first 50 m to 100 m from the DIAL, this is also one of the main advantages because it is carried out remotely and is non-intrusive, offering high data capture rate and fast quantification of whole-site emissions. Compared with other outdoor optical techniques, DIAL measurements are not restricted to weather conditions, but the accuracy is affected by wind speed and direction. However, because DIAL systems are typically mounted on a vehicle, it can be quickly redeployed to a different location to respond to the change of wind direction. It is a complex technique and therefore is relatively expensive. Currently only very few service providers are available.

PROCESS UNIT MONITORING OF METHANE EMISSIONS

Process unit detection and monitoring is critical to help understand the process, locations, and emission rates, and identify mitigation strategies accordingly. The following sections provide established good practice method for process unit monitoring of CH4 at WRRFs.

Flux Chambers

Flux chambers, also known as floating hoods, are upturned chambers which are placed a few centimetres into the surface of open fluids or onto soils. The enclosed space of the flux chamber collects the exhaust gases and with the known surface area under the chamber, the specific flux (mass per area per time) of the gaseous compounds can be determined. The flux chamber method has been applied to many different process units, such as pumping stations, aeration tanks, clarifiers, as well as sludge and biosolids storage tanks.

Some process units are covered with the off gas captured and treated prior to its release into the environment, for example, fully covered plants. Such configuration makes it suitable to perform long-term measurements. Typically, a portion of the off-gas stream can be withdrawn and fed to an online gas analyzer. It has been successfully applied for long-term CH4 (and N2O) monitoring at the the Kralingseveer WWTP in the Netherlands (Daelman et al 2015). This approach cannot measure the spatial variability within a tank, therefore may not provide sufficient evidence to support understanding of production and emission and therefore mitigation. Besides the analytical determination of the CH4 concentration in the off-gas, the accurate measurement of the off-gas flow rate in the venting pipes is essential. Proper calibration and probe positioning inside the off-gas pipe during the measurement are critical.

Hi-Flow Sampler

The High-Flow sampler is a mobile leak detection equipment that can be used to identify biogas leaks. Leak gases are drawn through a nozzle which is attached to combustibles sensor on a backpack. By calculating the flow rate, gas concentration, and background concentration, the leak rate can be determined. The results are displayed on a local screen and can also be stored locally.

The equipment does not require permanent fixtures and can be taken directly to the source of a leak, therefore reducing the amount of equipment needed on site. These unit can operate for several hours, which would cover a large portion of a shift without needing to change them out. An additional battery can be carried if extra time is needed.

The High-Flow sampler relies on knowing where the leak is coming from before a full measurement can be taken at the source. Given the operators proximity to the source of the leak, additional protective gear may be needed for protection, especially in confined locations.

Thermal Infrared (IR) Imaging Camera

Passive thermal IR spectroscopy uses the difference in heat radiation between the target and the background. When a handheld thermal IR camera is used for inspection around leaked gases, the sensor will pick up signals when there is a temperature difference between the target and the surroundings. The sensor comes in a self-contained unit and will not require any additional equipment.

Thermal IR imaging camera provides real time detection, and the location of leaks is not needed to be known beforehand. However, it cannot be used to calculate a quantitative CH_4 concentration or emission and is mainly used to find possible leaks for follow-up measurements using other methods. If the temperature of the leak is similar to the atmosphere, it will be difficult to detect. Detection capability is also weather dependant (weather conditions have an influence on the visibility of the emissions).

Optical Gas Imaging (OGI) Camera

An OGI camera is a thermal IR imaging camera containing an optical filter tuned to the absorption band of the target gas. Similarly, by using temperature difference between the gases and the environment (typically >2 °C), CH_4 leakage can be detected from equipment and pipes using an OGI camera. Some OGI cameras can quantify emissions as both concentration and mass emission rate; others provide a qualitative image only. The OGI camera can detect CH_4 (and other compounds) by displaying these invisible streams as clouds of smoke on a display.

OGI cameras have become one of the most common methods used for leak detection, due to their ease of use and ability to detect leaks in real time whilst keeping personnel away from hazardous fumes. The locations of leaks do not need to be known beforehand and operators do not need to be directly next to equipment. These cameras are portable and can be easily stored or moved to another site when required. Some OGI cameras (which are more costly) allow quantification of emissions as concentration and mass flow, although they generally have not been applied in the wastewater sector to date.

Headspace Sampling of Dissolved CH_4 in Liquid Phase

When salt is added to a liquid in a closed recipient in a sufficiently high concentration, the dissolved CH_4 escape from the liquid to the headspace (salting-out effect). Concentration of CH_4 in the headspace is obtained by drawing a sample from the headspace of the serum bottle with a gas syringe and measure it with a gas chromatography with flame ionization detector (GC-FID). Besides salting-out the dissolved gas, the high salt concentration also ceases any microbial activity that may lead to production or consumption of dissolved CH4 after the sample is taken. Daelman et al. 2012 adapted the method from Gal'chenko et al. 2004 for use in wastewater and sludge treatment.

The salting-out method has proven to be accurate for liquids with low (influent, effluent, settled wastewater) and high (digested sludge, thickened sludge) solids content. No toxic compounds are used for stopping the biological consumption or production of CH4. In addition to the biogas leakage, it can also be used to identify sources of CH4 emissions from other solids handling processes such as thickeners and biosolids storage tanks, as well as influent of the WRRFs and sewer systems (Daleman et al., 2012). However, it cannot be used to estimate CH4 emissions; only concentration and mass flow in the liquid-phase are measured. It is more time consuming and does not offer real-time measurements.

SITE AND PROCESS UNIT PRIORITIZATION

Facility-level monitoring can be used to identify key sites with highest emissions and for subsequent action. To date industry experience has focused on process unit monitoring across individual sites in Europe, with some research focused on characterizing emissions across multiple sites. Process unit monitoring has been used widely in Sweden, Denmark, and Germany to assess point source CH4 emissions and to evaluate mitigation opportunities, while site level monitoring has been most widely undertaken in Denmark.

For WRRFs with anaerobic digestion, practical work in Europe (Netherlands, Sweden, Denmark and Germany) shows that sludge storage contributes significantly to the fugitive CH4 emissions as digested sludge has a significant residual CH4 potential (Daelman et al., 2012). Pressure relief values (PRVs), open tanks (e.g., open secondary digesters) and CHP engine leaks have been identified as key sources from the 14-year monitoring work in Sweden (Liebetrau et al., 2017). Methane slip can also occur during biogas upgrading (e.g., to biomethane); the same monitoring work in Sweden reported highest methane slip for membrane pressure swing adsorption (PSA), followed by PSA, physical absorption, and water scrubber (Liebetrau et al., 2017).

It should be noted that the methane emission rates are not necessarily linked to the size of the plant, therefore, it is important to inspect common methane leak locations such as ventilation systems, digesters, storage tanks, and off-gas in CHP and/or upgrading plants.

PRACTICAL TIPS TO REDUCING EMISSIONS FROM EXISTING INFRASTRUCTURE

NITROUS OXIDE (N2O) EMISSIONS

Where N2O emissions have been monitored, studies have reported that N2O emissions typically vary over the day and over the seasons. With an understanding of the key process conditions contributing to the periods of higher N2O emissions, alternative process controls have been developed to adjust the operating conditions to reduce the N2O emissions.

Multiple factors can lead to increased N2O emissions from BNR processes. Emissions are often reported with a focus on the wastewater treatment process, e.g. MLE, IDEA, Step Feed. This can lead to a perception that certain processes have higher emissions than others. The multiple factors which lead to increased emissions may be highly site-specific, linked to operational conditions, and spatially and seasonally variables. Generally, process instability or imbalance leads to conditions likely to generate N2O; process stability and balancing of loads to treatment and avoiding variable process conditions is likely to contribute to lower emissions. It should be noted that it is often the combinations of operating conditions (rather than single operating condition, or single mainstream liquid treatment process type) that affect N2O emissions. Known possible triggers for N2O emissions include high ammonia loading (e.g., if advanced digestion process results in high ammonia loading sidestream returning to the mainstream), high DO in denitrification zones, low DO in aerobic zones (unplanned condition as opposed to established low DO operations which may offer mitigation potential through enhanced simultaneous nitrification denitrification), carbon deficiency (for denitrification), and other operating conditions that could result in incomplete nitrification and accumulation of nitrite.

A summary of projects that provide examples of successful programs to monitor and reduce N2O emissions through simple process control changes in existing plants is provided in Table 2. Importantly, the reductions in N2O emissions were made with process control changes and, where required, minor works (for example to redistribute loads). The plants are reported to have continued to achieve the effluent quality requirements, and in some cases to have reduced plant energy use.

Table 2: Example Successful N2O Emission Reduction Projects and Monitoring methods

Reference	Approach to N2O emissions reduction	Results
Denmark	N2O online sensor signals used for optimisation and control of DO.	Liquid phase monitoring focus 30 to 80% reduction in N2O, and 50% reduction in sidestream Deammonification process.
Netherlands	Data-based approach to analysing N2O emissions at two treatment works, with optimised DO control to minimise N2O production.	Short term trials have resulted in overall GHG emission reduction for the WWTP of 70%.
SA Water	Reducing DO levels	35% N2O emission reduction was achieved with 20% less operational cost.
UK water sector	Liquid phase monitoring methodologies	Seasonal and spatial variation highlighted as relevant; progressive utilities have rebaselined emissions from 12 month campaigns to date.
Global evidence base – review of all recent full scale N2O work	Summary from 2019 review N2O monitoring – methods and considerations.	Duration of studies highlights larger emission factors for longer term studies.

METHANE EMISSIONS

Practical examples of programmes for monitoring and mitigation across European countries show the criticality of direct methane emissions monitoring, and operational approaches to mitigate methane emissions through regular survey, proactive leak detection and repair and independent certification. Some operational approaches to mitigate methane emissions at WRRFs could include:

1. Prevention of methane emissions
2. Capture and utilisation of methane emissions
3. Capture and treatment of methane emissions

These approaches have been further discussed in the sections below. Whilst these are not all established 'Good Practice' authors consider that they could form good practice if drivers existed to address methane emissions because enough is known about methane emissions and abatement and there is likely to be low hanging fruit. An implication of good practice does not imply this is most cost beneficial. Good practice for estimating mitigation would be considering actual measured data versus assumed data.

PREVENTION OF METHANE EMISSIONS

Table 3 summarizes some of the key sources and (limited) mitigation approaches to reduce CH4 emissions at WRRFs from work to date.

Table 1: Key Source of Methane Emissions and Example Mitigation Approaches

Source of Methane Emission	Available Mitigation Approaches
Digester storage	• Gas tight covers and gas utilization • Treatment to halt methanogenesis
Pressure relief valves and flares	• Use of enclosed flare • Automatic flare operation and management of filling levels to allow flaring before PRV losses and accurate level measurement • Adequate sizing of pipes, blowers and controllable air pressure in air inflated roofs to achieve balanced fill and management • PRV monitoring to allow for number and duration of release events
CHP exhaust (due to incomplete combustion)	• Control and maintenance • Post combustion of exhaust gas (currently not practical; further investigation required) • Selective catalytic reduction (SCR), allowing operating at lower air to fuel ratio leading to lower CH_4 emission
Biogas upgrade emissions (varying depending on technology used)	• Exhaustion treatment in the case of significant emissions • Frequent function control and monitoring of performance required
Pipeline leaks	• Replace worn internals in valves and seals around manhole covers

Source of Methane Emission	Available Mitigation Approaches
Sludge digestion	• Designing the digester to have an a relatively high sludge retention time (SRT) of preferably at least 14 days with a normal operating volume of 75%. • Ensure optimal digestion process conditions including sufficient sludge mixing, optimal temperature, constant feed (amount and composition). • Clean digesters frequently (dependent on grit accumulation rates, but at least ones every 8 years) to removed collected grit from the bottom and increase the working volume.

CAPTURE AND UTILIZATION OF METHANE EMISSIONS

Covering tanks that may generate conditions for methanogenesis such as sludge storage tank, digested sludge storage tanks including open secondary digesters.

Vacuum extraction technology. The technology enables capture additional biogas that cannot be captured within the standard anaerobic digestion process. Vacuum pump withdraws the gas present in dissolved form and as bubbles entrained in digested biosolids prior to dewatering. Biogas can be directed to CHP or passed into an existing gas line (e.g., to biogas boilers). Figure 4 shows the schematic and location of a vacuum degassing technology developed by Elovac. This system is currently being pilot tested at the Ejby Mølle WRRF in Odense, Denmark.

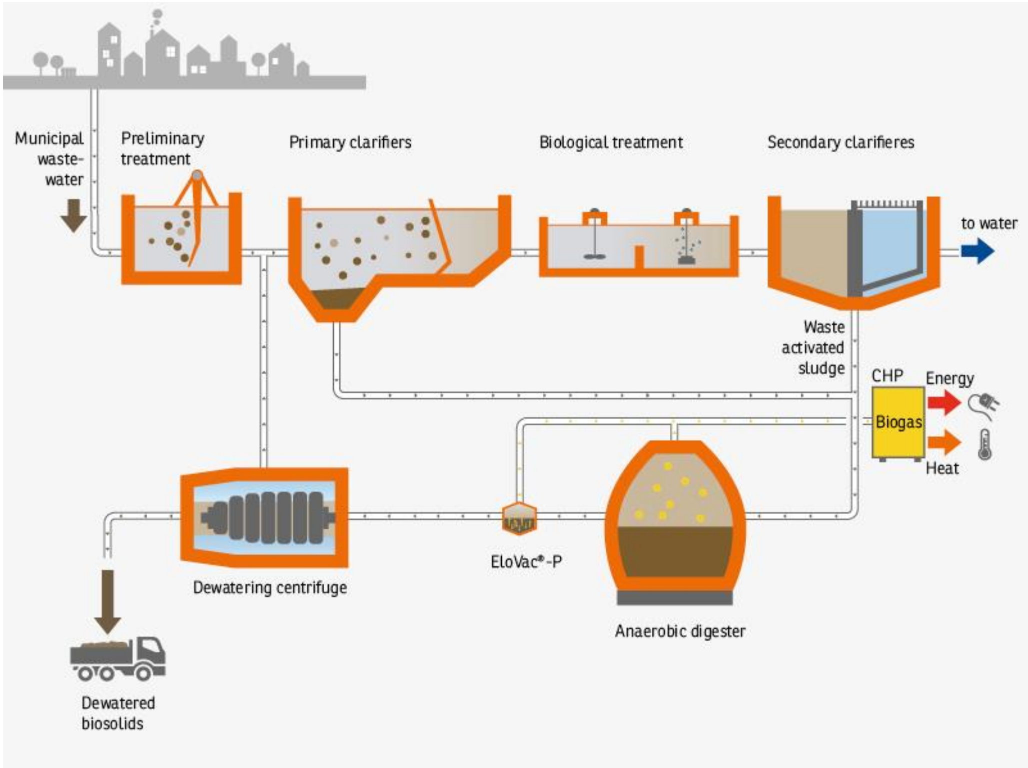


Figure 4: Process flow diagram of a typical WRRF that includes vacuum extraction technology for capturing methane from the digested sludge (credit: ELIQUO)

Capture and Treatment of Methane Emissions (Emerging Approach)

There are several processes that can convert methane into CO_2 and these processes should be considered if the emissions cannot be prevented or cannot be used for energy generation. Processes such as aerobic methane oxidation, anaerobic methane oxidation, and chemical oxidation have been studied (Hu & Tang, 2018). However, these technologies will require modification of the typical processes involved at WRRFs. Some of the promising processes include:

- Post-aerobic digestion (PAD). Management of biosolids to keep products aerobic offers mitigation potential. PAD involves adding an aerobic digester following the anaerobic digesters; existing secondary digesters or sludge storage tanks can be retrofitted as PAD tanks. Introducing air to further decompose the organic material prevents methanogenesis and could potentially also oxidize solubilised methane in the digested biosolids and address some nitrous oxide challenges of intensive sidestream liquors treatment (Xiang, et al. 2022). PAD is a well-established technology and has been used at scale globally (including US) for about twenty years, though not specifically to address methane emissions.

- Thermal oxidation. Fugitive methane emissions can be captured by actively ventilating the covered digestate tank headspace and direct the ventilation air as 'combustion air' to a CHP engine or gas utilisation system (utility boiler, flare). When methane is completely oxidized to carbon dioxide, the contribution to global warming is significantly reduced. About 90% of the impact on the greenhouse effect is reduced when methane is converted to CO_2 as methane is considered about 28 times more potent on mass basis over 100 years, but only about 9 times more potent on a molar basis.

- Biological oxidation. Fugitive methane emissions can be captured by actively ventilating the covered digestate tank headspace and direct the ventilation air to a suitable biological abatement system (e.g., a dedicated biofilter for methane oxidation, especially with sufficient gas contact time). Biological oxidation is performed by Methanotrophs, which are micro-organisms capable of metabolizing methane as their only source of carbon and energy. They can grow aerobically or anaerobically and require single-carbon compounds to survive. Under aerobic conditions, they combine oxygen and methane to form methanol using the mono-oxygenase enzymatic reaction and using a methanol dehydrogenase enzymatic reaction to form formaldehyde, which is then incorporated into organic compounds. Biofilters designed for methane oxidation have demonstrated good purification performance for a wide range of methane concentrations, but require long gas contact times, much longer than typical biofilter designed for odour control.

CASE STUDY ON NET ZERO TECHNOLOGIES FOR CONSIDERATION IN PLANT UPGRADES AND AUGMENTATIONS

Whilst net zero is a term used widely, the definition of net zero alignment and specifically interventions through water and wastewater treatment technology choices that are 'net zero aligned' is not clear, nor are issues around technology readiness, scalability, cost and resource requirements, synergies and potential conflicts with other decarbonisation solutions or pressures. This Net Zero Technologies Case Study addresses the lack of evidence around net zero technologies alignment for water and wastewater treatment and evaluates near term solutions which can be implemented by the water sector, key opportunities and challenges.

METHODOLOGY OF ASSESSMENT

A long list of current and emerging technologies or solutions was developed, based on a literature review, conversations with subject matter experts, and our team's experience of working alongside UK and international water companies and research bodies on the topics of net zero and circular economy. The review also drew on Ofwat's knowledge of technologies and referred to recent Ofwat innovation competition entries, identifying approximately one hundred distinct technologies and solutions in a long list which were considered potentially net zero aligned.

Technologies and solutions underwent coarse screening based on expert knowledge and technology readiness level of 6 or below. In a small number of exceptional cases, technologies that might have a nominal Technology Readiness Level (TRL) below 7 but were subject to significant sector interest and rapid acceleration through the TRLs were also progressed for further consideration. The focus was for technologies and solutions available for the 2025-2030 investment period for the water sector.

Using a workshop approach, technologies were evaluated across nine metrics designed to identify those likely to offer greatest benefit if included in PR24 business plans. Metrics included assessment of feasibility and scalability, representing fundamental considerations such as technical readiness and footprint but also represented integration with established ways of works, regulatory alignment, risk of stranding assets and asset write-off, implications for resilient operations (including resilience of supply chains) and relevant timelines for implementation. A multi-criteria analysis (MCA) was undertaken with a semi-quantitative scoring methodology. This allowed the team to further shortlist technologies and formed the basis the final review.

The shortlist of technologies is shown in Table 4.

Technologies were then tested through a series of scenarios or lenses that allowed the technologies to be viewed from different perspectives by weighting the base scores differently, thereby evaluating changing emphasis. This included different weightings towards absolute decarbonisation potential, value, practical and regulatory disruption in the sector and level of confidence in supporting data. A deep dive was undertaken on shortlisted technologies – and these were described in detail along with available evidence for net zero alignment and the scoring they were given. We also considered the synergies and conflicts with other net zero solutions and we undertook a high-level ranking exercise to categorise technologies in terms of their Net Zero potential and likely cost (see Figure 5 and Figure 6).

Technology or solution	Description	Applicability within sector	Activity
Water efficiency across urban water cycle	Reduced losses of treated water in networks	WaSCs & WoCs	Treated water distribution
Pump efficiency	Refurbish and optimise pumps.	WaSCs & WoCs	Treated water distribution
Power Purchase Agreements (PPAs)	Onsite, behind the meter renewables, or private wire or corporate PPAs for offsite renewables	WaSCs & WoCs	Applicable to all
CH_4 monitoring & mitigation	Site wide monitoring and proactive methane mitigation.	WaSCs	Sewage treatment
Membrane aerated biofilm reactor (MABR)	Membrane aerated biofilm reactor (MABR) for secondary wastewater treatment.	WaSCs	Sewage treatment
Conversion to nitrifying/ denitrifying	Conversion of secondary nitrifying treatment to nitrifying/denitrifying	WaSCs	Sewage treatment
N_2O setpoint optimisation	Process set point optimisation for N_2O	WaSCs	Sewage treatment
Real-time N_2O control	Real time control for optimisation of nitrous oxide.	WaSCs	Sewage treatment
AAD THP	Advanced AD - thermal hydrolysis	WaSCs	Sludge treatment
AAD EH or APD	Advanced AD - enzymatic hydrolysis	WaSCs	Sludge treatment
ITHP	Intermediate thermal hydrolysis (ITHP)	WaSCs	Sludge treatment
Codigestion	Codigestion of sewage sludge with other organic materials	WaSCs	Sludge treatment
Gasification/pyrolysis (sludge)	Thermal treatment of sludge or biosolids by gasification or pyrolysis	WaSCs	Sludge disposal
Biodrying (sludge)	Biodrying of sludge or biosolids	WaSCs	Sludge treatment
Low-energy drying (sludge)	Other low energy drying methods for sludge or biosolids	WaSCs	Sludge treatment
N stripping (liquors)	Stripping ammonia from sludge liquors	WaSCs	Sludge treatment
Tanker (biomethane)	Heavy transport (e.g. sludge tanker) fuelled by biomethane	WaSCs	Sewage collection/ sludge disposal
Heat recovery (onsite)	Heat recovery from onsite influents/effluents	WaSCs	Sewage treatment
Biomethane to grid	Biomethane to grid (where this does not increase import of fossil gas)	WaSCs	Sludge treatment
Stormwater separation & treatment with NBS	Stormwater separation and treatment with nature based solutions (e.g. SuDS).	WaSCs	Sewage collection/ sewage treatment

Table 4: Table Short list of Net Zero technologies

OUTCOMES OF ASSESSMENT

Technologies and interventions focused on the improved monitoring and mitigation of process emissions, in particular nitrous oxide and methane, have the potential to reduce overall greenhouse gas emissions the most and global experience from leading utilities is providing insights into the most cost-effective pathways to process emissions mitigation and key gaps for further work. After mitigation of process emissions, other technologies which scored highly in the MCA included renewable electricity procurement through Power Purchase Agreements (PPAs, used here as shorthand to group behind-the-meter and private-wire renewables and corporate PPAs via the grid), pump efficiency, vacuum methane recovery, advanced digestion technologies with energy recovery, low energy sludge drying and leakage and water efficiency measures.

Where companies embrace resource recovery solutions which offset rather than reduce their own emissions, they will need to show alignment with Net Zero principles and carbon reduction hierarchies through the use of life cycle carbon assessment and substantiate and verify claimed emissions reductions. Offsetting to achieve Net Zero may not be aligned with Net Zero principles but the carbon benefits of resource recovery (e.g. biomethane, heat recovery from final effluent, nitrogen stripping and recovery) may offer the opportunity to reduce emissions in agriculture or industry (e.g. nitrogen recovery to substitute fossil-based fertilisers or heat recovery to substitute fossil gas derived heating). Strong cross-sector collaboration will support development of associated technologies and solutions. Key barriers exist in the near term but innovation remains ongoing.

The review offered key lessons for water utilities globally – whilst context specific factors will exist, the underlying challenges for net zero around process emissions and resource recovery offer many opportunities for common learning and collaboration, along with the importance of global water sector adoption of science-based net zero definitions and understanding.

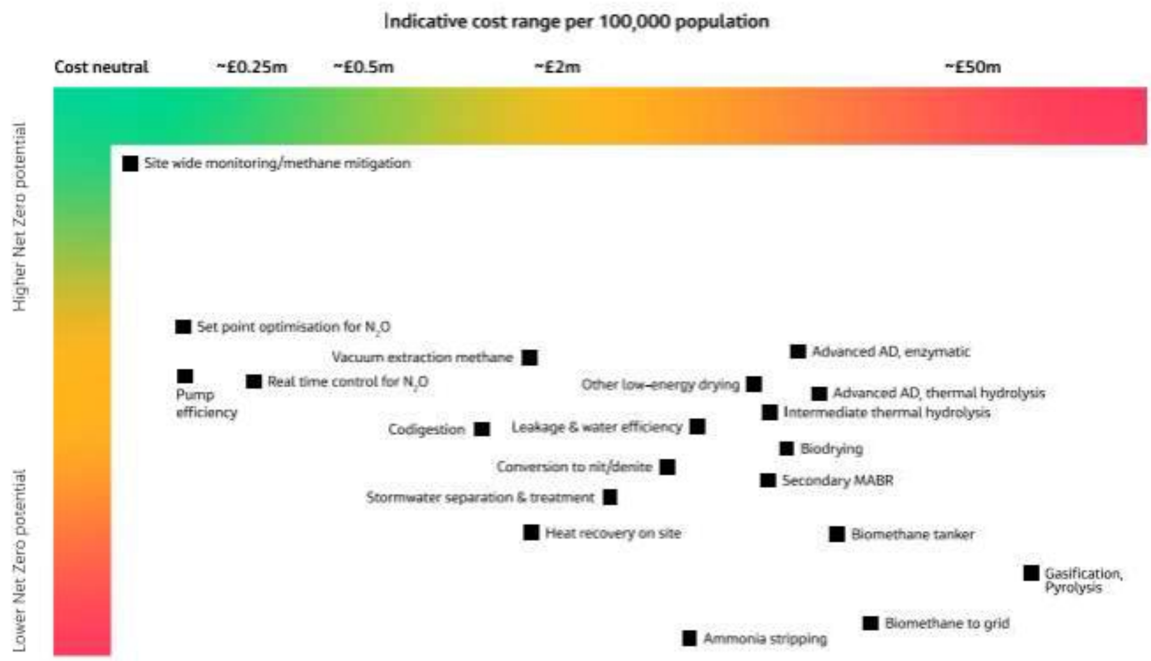


Figure 5: Indicative cost and carbon impacts

CONCLUSIONS

This paper presents key Scope 1 emissions sources (for methane and N2O) and provides practical approaches to monitoring emissions. The paper discusses existing and emerging methods for monitoring, including facility-wide and process unit specific methods for methane monitoring. Practical tips for reducing emissions from existing infrastructure are discussed. A case study on net zero technologies for consideration in plant upgrades and augmentations puts these lessons into practice.

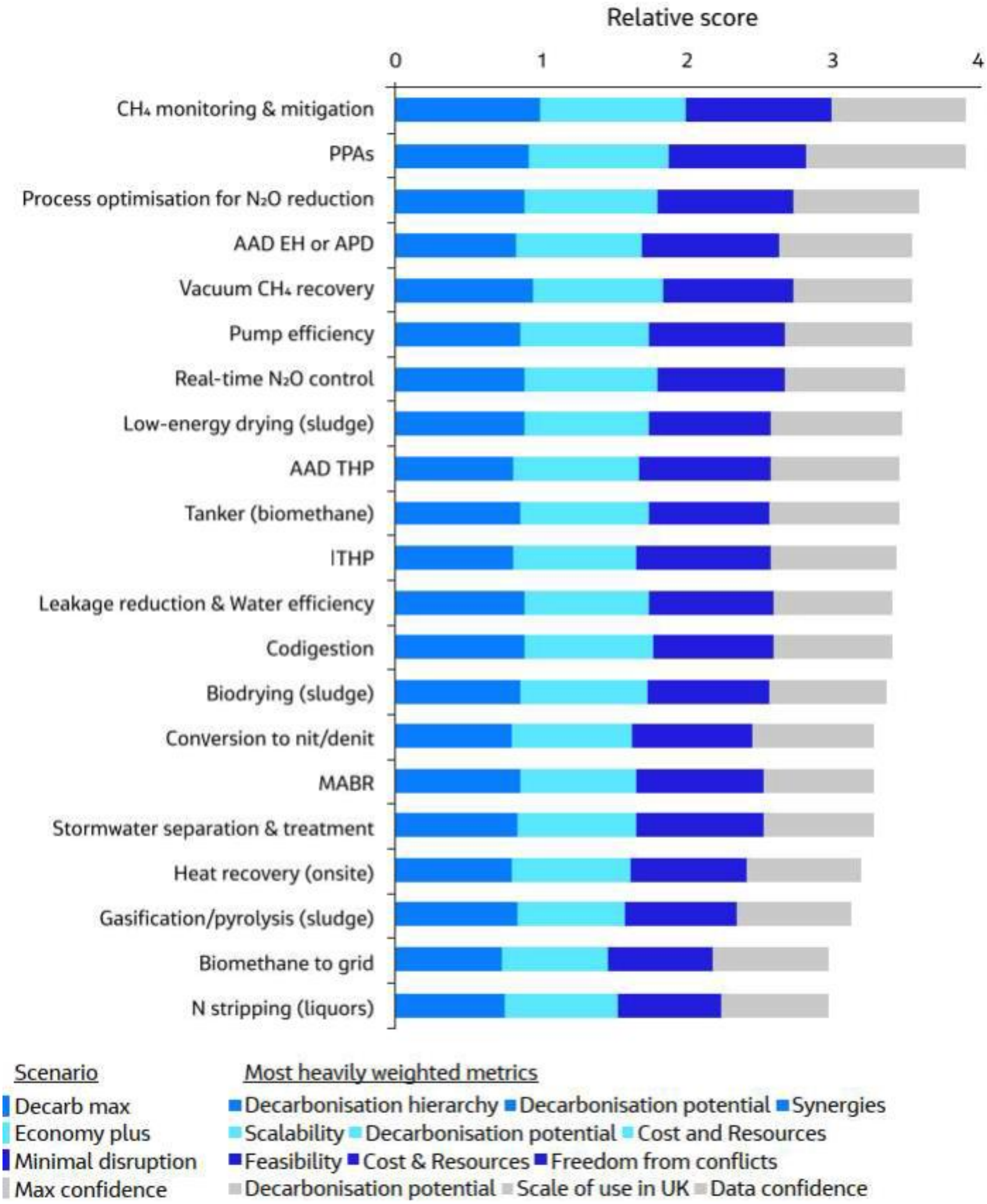


Figure 6: Net Zero technologies evaluation

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