

Final Knowledge Sharing Report Loganholme Wastewater Treatment Plant Gasification Facility Demonstration Project

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Acronyms and Abbreviations

10:2 FTS	Sodium 1H,1H,2H,2H-perfluorododecane sulfonic acid
4:2 FTSA	Sodium 1H,1H,2H,2H-perfluorohexane sulfonic acid
6:2 FTSA	Sodium 1H,1H,2H,2H- perfluorooctane sulfonic acid
8:2 FTS	Sodium 1H,1H,2H,2H-perfluorodecane sulfonic acid
ARENA	Australian Renewable Energy Agency
As	Arsenic
At	Astatine
B	Boron
BHC	Benzene hexachloride
Br	Bromine
Ca	Calcium
Cd	Cadmium
CEMS	Continuous Emissions Monitoring Systems
Cl	Chlorine
CLBAR	Contaminant limiting biosolids application rate
CO	Carbon monoxide
CO ₂	Carbon dioxide
Cr	Chromium
Cu	Copper
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DESI	Department of Environment, Science and Innovation (Queensland)
DS	Dry solids
EA	Environmental Authority
EoW	End of Waste
EPA	Environment Protection Authority
ESP	Electrostatic Precipitator
F	Fluorine
Fe	Iron
GHG	Greenhouse gas
H ₂ SO ₄	Sulfuric acid
HBDC	Hexabromocyclododecane
HCB	Hexachlorobenzene
HCl	Hydrogen Chloride
HEPA	Heads of EPA of Australia and New Zealand
HF	Hydrogen fluoride
Hg	Mercury
I	Iodine
K	Potassium
MASCC	Maximum allowable soil concentration criterion
Mg	Magnesium
Mg(OH) ₂	Magnesium hydroxide
ML	Megalitre
Mn	Manganese

Mo	Molybdenum
N	Nitrogen
NATA	National Association of Testing Authorities
NEMP	PFAS National Environmental Management Plan
N-EtFOSA	N-ethylperfluoro-1-octanesulfonamide
NEtFOSAA	N-ethylperfluoro-1-octanesulfonamido acetic acid
N-EtFOSE	2-(N-ethylperfluoro-1-octane sulfon amido)-Ethanol
N-MeFOSA	N-methylperfluoro-1-octanesulfonamide
N-MeFOSAA	N-methylperfluoro-1-octanesulfon amidoacetic acid
N-MeFOSE	2-(N-methylperfluoro-1octanesulfon)-Ethanol
NO	Nitric oxide
NO ₂	Nitrogen dioxide
NO _x	Nitrogen oxides
NSW	New South Wales
O ₂	Oxygen
P	Phosphorus
Pb	Lead
PBDE	Polybrominated diphenyl esters
PCB	Polychlorinated biphenyls
PFAA	Total perfluoro alkyl acids
PFAS	Per- and poly-fluoroalkyl substances
PFBA	Perfluorobutanoic acid
PFBS	Perfluorobutanesulfonic acid
PFDA	Perfluorodecanoic acid
PFDoA	Perfluorododecanoic acid
PFDS	Perfluorodecanesulfonic acid
PFHpA	Perfluoroheptanoic acid
PFHpS	Perfluoroheptanesulfonic acid
PFHxA	Perfluorohexanoic acid
PFHxS	Perfluorohexane sulfonate
PFHxS	Perfluorohexanesulfonic acid
PFNA	Perfluorononanoic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctanesulfonic acid
PFOSA	Perfluorooctane sulfonamide
PFPeA	Perfluoropentanoic acid
PFPeS	Perfluoropentanesulfonic acid
PFTeDA	Perfluorotetradecanoic acid
PFTrDA	Perfluorotridecanoic acid
PFUdA	Perfluoroundecanoic acid
PHA	Polyhydroxyalkanoates
PM	Particulate matter
PM2.5	Particulate matter particles with a fraction with a diameter of 2.5 µm or less. These are fine inhalable particles and can be drawn into the body with every breath.
PM5	Particulate matter particles with a fraction with a diameter of 5 µm or less. These are fine inhalable particles and can be drawn into the body with every breath.
POEO	Protection of the Environment Operations

POPs	Persistent organic pollutants
PPCPs	Pharmaceuticals and personal care products
S	Sulphur
SO ₂	Sulphur Dioxide
SO _x	Sulphur oxides
TOF	Total organic fluorine
TOPA	Total Oxidable Precursor Assay
TPA	Tonnes per Annum
Ts	Tennessine
TSP	Total Solids Particulates
w/w	Weight to weight
WWTP	Wastewater Treatment Plant
Zn	Zinc

Executive Summary

Logan Water has developed Australia's first biosolids gasification facility. Constructed at the Loganholme wastewater treatment plant (WWTP), this facility transforms biosolids into a renewable energy source and environmentally friendly product, called biochar. Through the utilisation of heat capture, renewable energy is employed to run the drying operation, contributing to a carbon-neutral facility. The gasification facility has assisted in the reduction in carbon emissions by about 4,800tpa compared to traditional biosolids treatment and disposal methods.

Biochar is the carbonised product of biosolids that have undergone gasification via thermal treatment in an oxygen deficient environment. This pellet-like material is a Grade A pathogen-stabilised product, where gasification has destroyed most persistent organic pollutants (POPs) and micro and nano-plastics. While most contaminants and pollutants contained within the biosolids are destroyed, the biochar retains phosphorus in a plant-available form, thereby making the material a potential fertiliser under 'beneficial re-use' programs. Biochar also hosts long term carbon sequestration capacity that occurs on a millennium timescale and thus reduces greenhouse gas (GHG) emissions from both waste management and agricultural practices following soil application.

The Gasification Demonstration Plant (2021) (1) informed the design parameters and provided insight into the performance of these cutting-edge processes for the commissioning of the full-scale Gasification Facility (2022-2023). The demonstration plant confirmed that the production of biochar from biosolids via gasification is a viable technology and that the process could meet the proposed environmental license requirements set out by the Department of Environment, Science and Innovation (DESI) (formerly the Department of Environment and Science).

Initially verified by the demonstration plant and subsequently proven by the full-scale facility, Logan Water's biosolids gasification facility achieves the following objectives:

- reduces carbon emissions by about 4,800tpa compared to traditional biosolids treatment and disposal methods;
- reduces the volume of biosolids for disposal by approximately 90%;
- eliminates POPs such as polyfluoroalkyl substances (PFAS) to below detection or within trigger values;
- reduces the concentration of micro and nano-plastics in biosolids by an average of 82%; and
- approaches energy neutral operations, with self-generation of 80% of the heat energy requirements.

This report fulfils the obligations under ARENA's funding agreement and includes details of the gasification operations up to July 2023.

Air Emissions

Air emission regulations provided by DESI are outlined in the Environmental Authority (EA) (EPPR00867913) (LGN-A1 to LGN A-12) (2), relating to exhaust emissions from the facility stacks. The stacks allow the point release of the facility's emissions in accordance with Condition LGN-A2 and allow the monitoring of contaminants outlined in the EA. An online Continuous Emissions Monitoring Systems (CEMS) unit is utilised to measure the basic air emissions including CO, SO₂, NO₂ and O₂. Emissions are controlled via a variety of methods, including chemical dosing with urea used for the control of NO_x, while magnesium hydroxide is used to control SO_x emissions.

Stack monitoring is conducted by an external third party that holds National Association of Testing Authorities (NATA) accreditation. Full air emissions were undertaken during initial performance testing and will be undertaken on an annual basis, or as required by DESI. This analysis includes all required parameters including those measured by the CEMS. The gasification facility predominantly meets the conditions set out in the EA and is being optimised to ensure full compliance in consultation with DESI.

Over the facility's projected 20-year life span, the greenhouse gas (GHG) emissions from Loganholme WWTP are forecast to be reduced by 129,301 tonnes, or 54%, compared to the previous biosolids management strategy.

Biosolids and Biochar Characterisation

Biosolids from Loganholme WWTP are dewatered to a dry solids content of around 22% via centrifuges. The biosolids are further dried to a dry solids content of around 90% (moisture content of 10%) through thermal belt drying. These are then carbonised in a gasifier, producing biogas and biochar. The biosolids (average net dry calorific value of 17.3 MJ/kg) produces a substantial amount of heat waste during gasification, which is captured via a heat recovery system and utilised to power the drying component of the facility.

The final biochar product is held for storage, and is a sterile, odourless, and stable material. The gasification process results in a 90% reduction of biosolids volume and product handling compared to traditional biosolids treatment, thereby reducing transport costs. There are ongoing discussions with DESI on the finalisation of an End of Waste (EoW) Code for Biochar that are anticipated to improve the potential reuse applications and thus value of the product.

Emerging Contaminants of Concern

The removal of POPs, such as PFAS, and micro and nano-plastics is critical for the continued beneficial use of biosolids following concerns of contaminant uptake by the soil and plants, where these contaminants may enter the food chain.

Following the gasification process, PFAS concentrations were reduced following the volatilisation of these compounds, with non-detectable limits (<0.1 ug/kg) identified for PFAS TOPA (%) in Loganholme biochar material. PFAS concentrations in biochar from the Loganholme WWTP do not exceed the guidelines and pass the trigger values for restricted use soil application.

Total microplastics were found to be reduced by an average of 82% following the gasification process, with greater destruction rates achieved for smaller microparticles. An 83% and 80% destruction rate for microplastics in the size range of 20-100 µm and 100-200 µm respectively was achieved, while the larger particle range (200-500 µm) saw the destruction of 50% of microplastics. This is a significant improvement compared to rates achieved during the demonstration plant (average 60%), achieved through facility optimisation.

Heat Balance

The Loganholme WWTP gasification facility has been designed to achieve a heat balance without the need for supplementary fuel. The heat balance is predominantly influenced by the calorific value of the biosolids, the biosolids dewatering performance, the thermal efficiency of the dryer, and the operating temperature of the dryer. There have been some limitations with the amount of calorific value and with the heat capture with the result that additional supplementary heat has been required to meet the heat demand of the dryers. Remedial works to further reduce the requirement for supplementary heat are ongoing.

Operating Costs

The operating costs of the facility are dominated by the consumption of process additives (chemicals) for equipment protection and emissions control, LPG gas for supplementary heating as well as operation and maintenance costs.

1. Introduction

1.1 The Need for Gasification

Logan Water operates as part of Logan City Council, and currently operates four wastewater treatment plants (WWTP). The largest of these is Loganholme, accounting for the treatment of 45 megalitres (ML) of wastewater per day and generating 34,000 dry tonnes of biosolids annually. Biosolids are a by-product of the wastewater treatment process. Wastewater treatment produces sewage sludge, which is then treated and partially dewatered to create biosolids. Biosolids are primarily composed of water and organic matter.

A significant proportion of Loganholme's WWTP operation and maintenance costs (~30%) are associated with biosolids treatment and disposal. Mainstream biosolids treatment in Australia commonly involves mechanical dewatering and the subsequent application as fertiliser under 'beneficial re-use' programs as a source of nitrogen, phosphorus, and organic material. This method of disposal for Loganholme's dewatered biosolids involves their application to agricultural lands 300 km away in the Darling Downs, seeing the transportation of approximately 34,000 tonnes annually. At the time of developing the business case for gasification, haulage costs were approximately \$1.8M per annum, however since 2019, haulage costs have increased by 300%, resulting in a projected cost for haulage of dewatered biosolids of \$5.4M by mid-2024.

In recent years, this method of biosolids treatment and disposal has become increasingly unsustainable due to rising costs, increasing impacts on communities via truck movements, fumes and odours, noise, and greenhouse gas (GHG) emissions. Additionally, the tightening of environmental requirements associated with the disposal of biosolids, carbon reduction, and the management of persistent organic pollutants (POPs) and micro and nano-plastics are making the use and disposal of dewatered biosolids an increasingly unsuitable management method.



Figure 1: Loganholme WWTP Permanent Gasification Facility

Emerging threats to existing biosolids land application pertain to the lack of destruction that dewatering alone achieves in biosolids, allowing for the continued presence of organic micro-pollutants, POPs and micro and nano plastics. POPs are non-biodegradable, toxic chemicals that accumulate within soils and sludge and can biomagnify up the food chain. Examples of POPs include polybrominated diphenyl esters (PBDEs), hexabromocyclododecane (HBCD), and per- and poly-

fluorinated alkyl substances, known as PFAS. PFAS are an emerging contaminant of concern, encompassing over 4,700 different chemical compounds. These compounds have been deemed 'forever chemicals' due to their high stability and persistence in the environment and their ability to bioaccumulate and travel up the food chain. PFAS are also highly mobile and may leach through soils, leading to groundwater contamination.

The largest sources of micro and nano plastics that enter the wastewater network and become enmeshed in the biosolids include tyres, synthetic textiles, personal care products, city dust, and industrial processes. Treatment via anaerobic or aerobic digestion processes does not destroy microplastics, POPs, or PFAS. Therefore, rising concerns over these pollutants' ability to enter the terrestrial food chain following biosolids application to agricultural lands are growing.

In Queensland, the land application of biosolids is regulated by the Department of Environment, Science and Innovation (DESI). The End of Waste (EoW) Code for Biosolids (3) requires operators to meet both contamination limits and stabilisation quality criteria which dictate land application use and rates. In 2019, DESI placed new triggers on POPs to control their release into the environment, reducing the chemicals' detectable limits in biosolids intended for land application. These limits are expected to tighten further to align with the release of the Australian Government's PFAS National Environmental Management Plan (NEMP) 3.0 (4) which is currently being finalised.

In response to these increasing restrictions and the unsustainable nature of the current biosolids management processes, Logan Water sought to find an alternative method for managing biosolids. The result is a nation-first, biosolids gasification facility. The gasification process destroys most organic pollutants (95% POPs, 82% micro and nano-plastics) and reduces the volume of biosolids by around 90%, significantly reducing disposal volumes and truck movements, making it a timely solution to these compounding risks and rising costs.

In the agricultural market, the value of biosolids is determined by its nutrient content. This value is enhanced in biochar, which is rich in essential macro and micronutrients for crop growth, such as nitrogen and phosphorus. Additionally, biochar has a significant cation exchange capacity (5) (6).

Based on this, the biochar produced in the gasification facility presents a potential valuable additional income stream for Logan Water, which will help offset treatment costs and will ultimately benefit the community through carbon sequestration and soil conditioning capacities. Loganholme WWTP biochar production is currently approximately 3,000 tonnes per year.

1.2 Gasification Technology

Gasification is the process of converting organic, carbon-rich biomass into char and biogas through exposure to high temperatures under oxygen-limited conditions. This is considered a form of incomplete combustion and thus emits gases that retain combustion potential for further utilisation. Gasification also maintains the agronomic value of the biosolids, through the preservation of phosphorus in a plant-available form, thereby producing a potentially ideal material for soil conditioning, known as biochar. As a potent ameliorant for the bioremediation of degraded soil and a low-grade form of activated carbon, biochar is also sparking the interest of land care and construction industries. These emerging applications include biofuel for industrial combustors, bricks and pavers, a metallurgical reductant, and an alternative to activated carbon for industrial and odour control applications. Therefore, by reducing haulage costs as well as producing a saleable product, biosolids gasification has been determined to be the most cost-effective solution for Loganholme WWTP biosolids management.

Logan Water obtained an AUD \$6.2 million grant from the Australian Renewable Energy Agency (ARENA) as part of ARENA's Advancing Renewables Program for the Loganholme WWTP gasification facility demonstration project in 2020. The demonstration plant had over 450 hours of run time on two sources of biosolids during 2020, demonstrating its performance. Logan Water was able to utilise the results from the demonstration plant to inform project risks associated with the design and construction of a full-scale gasification facility. The Loganholme WWTP Gasification Facility (full-scale) underwent construction and pre-commissioning in 2021 – 2022 and has been processing biosolids and undergoing commissioning and optimisation since early 2023. This report includes details of the gasification operations up to July 2023.



Figure 2: Loganholme WWTP Demonstration Plant

The Loganholme Gasification Facility supports the circular economy through the capture and reuse of biosolids, and the recycling of renewable heat energy via biogas production. The thermal treatment of biosolids and the production of biochar results in a Grade A pathogen-stabilised product that meets the criteria for agricultural application set in the EoW Code for Biosolids (3). The final product is a sterile, odourless and stable biochar that is not subject to restricted storage time prior to application (biosolids storage ranges from 24 hours – 2 years), thereby avoiding material degradation during storage.

Logan Water's demonstration plant (2020) (7) confirmed that the gasification of biosolids is a credible alternative process for a WWTP. Each of the objectives set for the demonstration plant in terms of reliability, air emissions, POPs, heat balance, and operating costs were achieved. The construction and optimisation of the full-scale facility at Loganholme WWTP has further confirmed that gasification results in the destruction of POPs in biochar while producing a high quality 'soil conditioner'. The gasification facility also contributes to Council's environmental credentials, following Council's ongoing certification of carbon neutrality by the Australian Government's Climate Active initiative, first achieved in 2022. Over the facility's projected 20-year life span, the GHG emissions from the Loganholme WWTP are forecast to be reduced by 129,301 tonnes or 54%, compared to the previous biosolids management strategy. Additionally, biochar acts as a sink for carbon, sequestering carbon

in the soil on a millennial timescale, thus, increasing the capacity of Australia to meet its international GHG reduction targets (6).

1.3 Components of the Gasification Facility

The full-scale gasification facility was designed based on learnings from the demonstration plant, which was instrumental in informing the facility's design and reducing project risk. The full-scale facility incorporates a mixture of conventional and advanced technologies including centrifuge dewatering, thermal belt drying and gasification.

The gasification facility consists of a number of key components, as illustrated in Figure 3, including the biosolids supply, biosolids dewatering and drying systems, hearth, thermal oxidiser, heat recovery system, wet scrubber, wet electrostatic precipitator and point release air stream exhaust stack.

Biosolids dewatering is conducted by centrifuges, where a dewatered biosolids cake, with a dry solids content of around 22%, is produced. The dewatered biosolids are then transferred to the thermal belt dryer, with an optimised airflow rate to achieve 90% dry biosolids (10% moisture content). The carbonisation stage is performed in the hearth and produces biochar and biogas. The biochar is then transferred to and held in a storage bin, while the biogas undergoes heat capture via the heat recovery system and purification before release.

The oxidiser is fed biogas containing hazardous gases following the gasification of dried biosolids where sufficient turbulence, retention time, oxygen content and temperature ensures the destruction of gases and POPs. This provides supplementary heat captured into the heat recovery circuit and is utilised for the drying process. Following the oxidisers the gas is directed into flue gas heat exchangers for more heat recovery and then onto the wet scrubber, where these gases and remaining solid particulates are transferred into a liquid for pollutant removal. A wet electrostatic precipitator (ESP) is then utilised to collect and remove remaining particulates from the air stream before being discharged via the point release air stream exhaust stack.

1.4 Objectives

Based on learnings from the demonstration plant, the full-scale gasification facility aimed to achieve the following objectives:

- **Air emissions:** to maintain compliance with DESI requirements.
- **Persistent organic pollutants (POPs):** to measure the quality of the biochar product and confirm the destruction of POPs in line with relevant regulations.
- **Heat balance:** to confirm the heat balance for an integrated drying facility.
- **Operating costs:** to optimise and reduce the overall operating costs of the facility.
- **Commercialisation:** investigate market opportunities and develop a tendering process for purchasers of biochar.

BIOSOLIDS GASIFICATION PROCESS

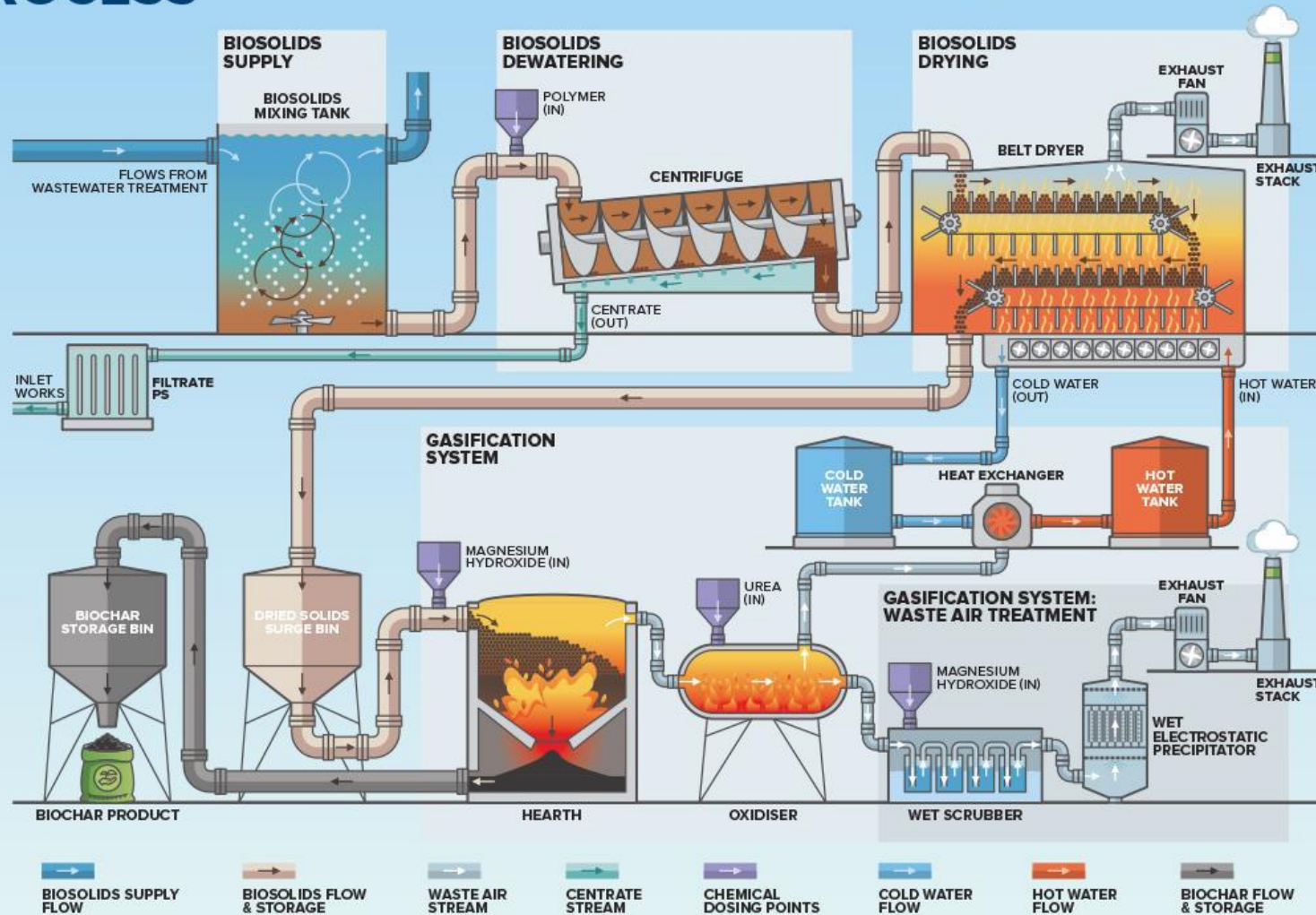


Figure 3: Loganholme WWTP Gasification Facility Process Flow Diagram

2. Air Emissions

2.1 Background

Gasification technology generally has lower air emissions than a typical incineration plant, with studies showing that the overall environmental performance of a gasification system is better than incineration (8). Some of this improved performance is attributable to the incomplete combustion of material and the separate management of volatile and non-volatile fractions under conditions present in gasification. The volatile fraction represents 40-60% of the total dry mass, and during gasification, this is removed and treated, while the non-volatile fraction is carbonised.

The Environmental Authority (EA) (EPPR00867913) (2) conditions for air emissions (LGN-A1 to LGN—A12) were informed by data from the demonstration plant, and these conditions set strict limits for the facility's emissions. Biogas purification equipment makes up 75% of the facility's footprint, and air emissions from the gasifier are controlled by a combination of methods, namely:

- A thermal oxidiser to destroy hazardous gases and POPs;
- A wet scrubber to remove liquid and solid particulate pollutants from the gas stream;
- A wet ESP which removes the remaining particulate matter (PM) and Polyhydroxyalkanoates (PHAs) of the PM_{2.5} range (particles with a diameter of 2.5 µm or less) from the flue gas before discharge via the exhaust stack.

Within the thermal oxidiser, biogas, feed from the hearth, has a residence time of 2 seconds, at temperatures between 800–850°C. This residence time and temperature have been proven to sufficiently exceed 99% destruction of the organic matter passed through the oxidiser¹. Urea dosing is added to the thermal oxidiser to control nitrogen oxide (NO_x) emissions

After the thermal oxidiser, the biogas passes through a flue gas heat exchanger to capture as much heat as possible. Thereafter the gas flows through a venturi device and a wet scrubber. The scrubber is a spray absorber with extended residence time for particulate-seeded condensation capture of the PM₁₀ fraction. This allows rapid quenching of the gas to reduce the temperature, thereby avoiding the dioxin reformation temperature range of 200–600°C (9). The gas-liquid contact allows acid gases and other species to be physically or chemically captured (10). The fine mist that carries over in the exit gas is captured in a wire mesh mist eliminator and recirculated to the scrubber sump.

During the demonstration plant trials, some lime (~25% of dosing) was added to the biosolids feed for conditioning and prolonging the life of the hearth. Most of the lime was dosed in the wet scrubber to primarily control SO_x emissions.

The application of lime was replaced by magnesium hydroxide (Mg(OH)₂) in early May 2020 for SO_x control due to the accelerated fouling of the wet scrubber and handling issues with lime. This is dosed at the inlet of the hearth and the wet scrubber.

In addition, a venturi device is fixed at the entrance of the wet scrubber to assist in the capture of residual particulate matter (PM₅). This maintains PM capture without the use of filter elements, which experienced frequent blockages due to dusty feedstocks. The wet ESP is utilised to cater for the removal of the high PM_{2.5} loads that the biosolids release into the flue gas. Flue gases are then drawn into an induced draft fan and discharged into the atmosphere via the exhaust stack.

2.2 Regulation Requirements

Point source air quality emission monitoring is conducted for three release sites, namely the gasification facility stack and the two dryer stacks. Point source release limits are set by the EA (EPPR00867913) (2), as per

Table 1 below. These limits were derived from a joint review of the New South Wales (NSW) Protection of the Environment Operations (POEO) Act 1997 and the European Commission Directive Waste Incineration Directive (WI Directive) (14), which are included in

Table 1 for comparison.

Table 1: Point source air release limits

Contaminant	EA Target limits (mg/Nm ³ (dry) at 11% O ₂)	POEO Act (mg/Nm ³ (dry)) (see Note 3)	WI Directive (mg/Nm ³ (dry)) (see Note 4)
Total Solids Particulates (TSP)	30	50	30
Carbon Monoxide (CO)	100	125	-
Oxides of Nitrogen (as NO ₂)	400	350	400
Sulphur Dioxide (SO ₂)	200	-	200
Hydrogen Chloride (HCl)	60	-	60
Total fluoride (as HF)	4	50	4
Volatile Organic Compounds (VOCs)	20	20	20
Cadmium and its compounds	0.05	0.2	0.05
Mercury and its compounds	0.05	0.2	0.05
Total Heavy Metals (see Note 1)	0.5	1	0.5
Dioxins and furans (I-TEQ for PCDDs and PCDFs including half LOD)	0.1	0.1 ng/Sm ³ (dry) at 11% O ₂	0.1 ng/Sm ³ (dry)
PFAS (see Note 2)	-	-	-
Carbon tetrafluoride (CF ₄)	2.1	-	-

Table notes:

Note 1: Total heavy metals limit is for the total of antimony, arsenic, cadmium, lead, mercury, beryllium, chromium, cobalt, manganese, nickel, selenium, and vanadium and their compounds.

Note 2: Per- and poly- fluoroalkyl substances (PFAS) – refer to Condition LGN - A5 for monitoring requirements for all PFAS monitoring. Refer to conditions LGN - A6, LGN - A7, and LGN - A8 for monitoring requirements, release limits, and calculation requirements for the gasifier plant stack. No limit is applied to the dryer stacks.

Note 3: The concentrations limits for solid waste incineration refer to 7% O₂, except dioxins that refers to 11% O₂.

Note 4: All concentration limits (100% compliance) refer to 11% O₂ reference level and average over the sample period of 30 minutes.

2.3 Air Pollution Control Equipment

An online CEMS unit was installed and designed to measure CO, SO₂, NO₂ and O₂ as well as stack gas temperature. The demonstration plant experienced several issues with the chosen CEMS unit including blockages due to the high moisture environment, as well as the use of a gravity-head drain. Although these issues did not interfere with the continuous monitoring performance, they resulted in labour intensive corrections and the unit was deemed unsuitable for the full-scale permanent facility.

For the full-scale facility, a better suited CEMS extractive monitoring system was installed which can withstand a high moisture environment. This is possible since each component of the system, including the analyser, is heated above the dew point temperature, negating the need for a condenser. This modification has eliminated the blockages previously experienced.

Two types of air emissions analysis are undertaken for the gasification facility to demonstrate compliance:

- **Basic air emissions:** This analysis is performed by the CEMS unit continually monitoring and recording and includes CO, SO₂, NO₂ and O₂.
- **Full air emissions:** This grab sample analysis includes all parameters including particulates, heavy metals and emerging contaminants of concern.

Stack monitoring has been conducted by an external third-party holding a current accreditation through the National Association of Testing Authorities (NATA).

2.4 Air Emission Results

Stack monitoring was undertaken on two separate occasions in May 2023, with results given in Table 2. In addition, continuous monitoring of the exhaust emissions is conducted, with adjustments made to the chemical dosing (urea for NO₂ and Mg(OH)₂ for SO₂) to ensure compliance with licenced air emission limits. To guarantee the complete destruction of contaminants, the thermal oxidiser is maintained at temperatures over 800°C, and in instances of instability, a backup diesel burner can be activated to sustain the required temperature. There have been challenges in compliance with some parameters, namely the online CEMS monitoring of CO and NO₂, as well as being able to prove the full PFAS destruction requirements, however, these challenges are actively being addressed and discussed with DESI.

Table 2: Average point source air release results for May 2023

Contaminant	EA Conditions: Maximum release at 11% O ₂ (mg/Nm ³ (dry))	LWWTP Stack Emissions (mg/Nm ³ (dry))
Total Solids Particulates (TSP)	30	26.50
Carbon Monoxide (CO)	100	14.05
Oxides of Nitrogen (as NO ₂)	400	110.00
Sulphur Dioxide (SO ₂)	200	15.00
Hydrogen Chloride (HCl)	60	1.20
Total fluoride (as HF)	4	1.90
Volatile Organic Compounds (VOCs)	20	1.05
Cadmium and its compounds	0.05	0.00
Mercury and its compounds	0.05	0.06
Total Heavy Metals (see Note 1)	0.5	0.15
Dioxins and furans (I-TEQ for PCDDs and PCDFs including half LOD)	0.1	0.00
PFAS (see Note 2)	see Note 2	145.50
Carbon tetrafluoride (CF ₄)	0.1	0.00

Table notes:

Note 1: Total heavy metals limit is for the total of antimony, arsenic, cadmium, lead, mercury, beryllium, chromium, cobalt, manganese, nickel, selenium, and vanadium and their compounds.

Note 2: Per- and poly- fluoroalkyl substances (PFAS) – refer to Condition LGN - A5 for monitoring requirements for all PFAS monitoring. Refer to conditions LGN - A6, LGN -A7, and LGN - A8 for monitoring requirements, release limits, and calculation requirements for the gasifier plant stack. No limit is applied to the dryer stacks.

The requirements referenced for PFAS destruction are provided in LGN – A7: The mass of any PFAS released into the atmosphere through the gasification plant stack must not exceed 0.01% of the mass of PFAS measured in the duct connecting the gasifier and the thermal oxidiser prior to its release. This applies to measurements of single PFAS compounds, and to total PFAS measured.

Over the facility's projected 20-year life span, the greenhouse gas (GHG) emissions from the Loganholme WWTP are forecast to be reduced by 129,301 tonnes or 54%, compared to the previous biosolids treatment and disposal management strategy. This was assessed through a lifecycle assessment based on the ARENA guidance document for bioenergy projects (15).

3. Biosolids and Biochar Characterisation

3.1 Biosolids

Biosolids are mainly a mix of water and organic matter and may contain:

- Macronutrients, such as nitrogen (N), phosphorus (P), potassium (K), and sulphur (S)
- Micronutrients, such as copper (Cu), zinc (Zn), calcium (Ca), magnesium (Mg), iron (Fe), boron (B), molybdenum (Mo), and manganese (Mn).

Biosolids may also contain traces of synthetic organic compounds and metals, including arsenic, cadmium, chromium, lead, mercury, nickel, and selenium. These trace compounds can limit the uses for biosolids depending on their concentration, with all potential uses regulated in Queensland by the EoW Code for Biosolids (3).

3.1.1 Biosolids Process

Biosolids are treated prior to gasification to remove water. Drying biosolids concentrates their energy and increases their gross calorific value, turning them into a combustible material. Several factors influence the drying process, including humidity, air velocity, the origin of the biosolids, and their physical transformation after dewatering. Among these, temperature is the most influential. It affects the drying time, rheological properties, thermal stability, and physicochemical characteristics of the biosolids, such as their calorific value and nutrient content.

Centrifuges dewater the biosolids into a biosolids cake to achieve a dry solids content of 22%, and the dewatered biosolids are then dried via the thermal belt dryer to remove remaining moisture and achieve 90% dry solids which is optimal for effective gasification. The belt dryers also ensure the production of a crumb rather than pellet-shaped material which ensures complete carbonisation of the biosolids.

The Eliquo Stultz low-temperature dryer (maximum drying inlet: 120°C) was selected for the full-scale facility due to its production of biosolids at a dryness of 88% weight to weight (w/w) and material sizing output ideally ranging from 3-10 mm. This size is deemed optimal for the rotating plates within the hearth, improving energy capture efficiency. Additionally, the use of low-temperature dryers allows hot water to run the belt dryer rather than thermal oil or steam. The waste heat produced by the gasification process is captured and transferred into a hot water tank through an integrated heat recovery circuit. This hot water is then used as the heat source for the belt dryer. This further contributes to the optimisation of the heat-energy balance and the reduction of long-term operational costs.

To prevent the thermally dried biosolids from degrading during storage, they are immediately transferred from the belt dryers to the gasification unit.

3.1.2 Biosolids Analysis

Calorific Value

The energy recovery (calorific value) from biosolids depends on their composition, which includes organic (volatile) matter, inorganic (inert) material, and water. Since the composition of biosolids can vary, the proportion of volatile solids is a key factor in determining heat energy recovery. To optimise energy recovery and produce the desired energy products, the characteristics of the biosolids must be considered. At Loganholme WWTP, the biosolids typically contain 80% volatile solids, with an average net dry calorific value of 17.3 MJ/kg. This calorific value has been found to be too low to

enable a fully heat neutral outcome at this time and hence additional heating using LPG gas has been required to supplement the shortfall.

Contaminant Analysis

Laboratory analysis of Loganholme WWTP biosolids was conducted by NATA accredited external third parties between August 2022 and July 2023, for a total of 11 samples. Results are presented in Figure 4 (trace metals) and Figure 5 (heavy metals) below.

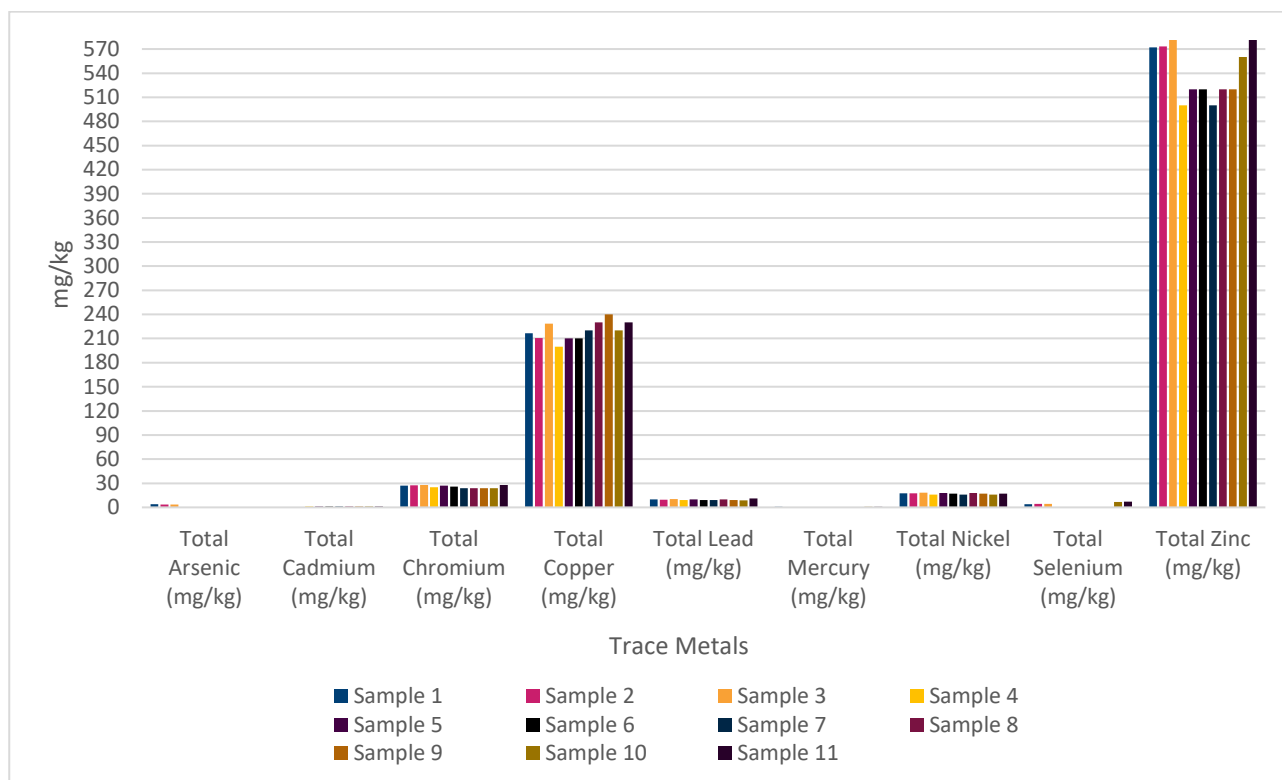


Figure 4: Trace metals present in Loganholme WWTP biosolids

Higher micronutrient concentrations of Zn and Cu are expected in sewage sludge due to the ubiquitous nature of these elements in domestic sources (16), as shown in Figure 4. While there is concern over these concentrations due to the adverse effects these micronutrients exert over the biota and sediments of receiving soil and waters, these trace elements are of high value to the Australian agricultural sector. This deficiency in Australian soils reveals a benefit that has been undervalued in Logan Water’s previous Biosolids Management Strategy.

The heavy metal concentration of biosolids should be taken into consideration as these elements are concentrated in biochar and may contribute to consumer exposure and adverse effects on soil fertility and crop production when applied to agricultural lands in excess. A comparison of the average heavy metal concentrations in Loganholme biosolids against the EoW Code for Biosolids (3) grading concentrations is shown in Figure 5. Data are for 11 samples from August 2022 to May 2023. Provided that the biosolids meet the contamination and pathogen reduction requirements specified in the EoW Code for Biosolids (3), the biosolids are not considered to be a waste, but rather a resource that can be reused for agricultural purposes. This demonstrates that Loganholme biosolids fit within Grade C biosolids, with high results for Cu and Zn.

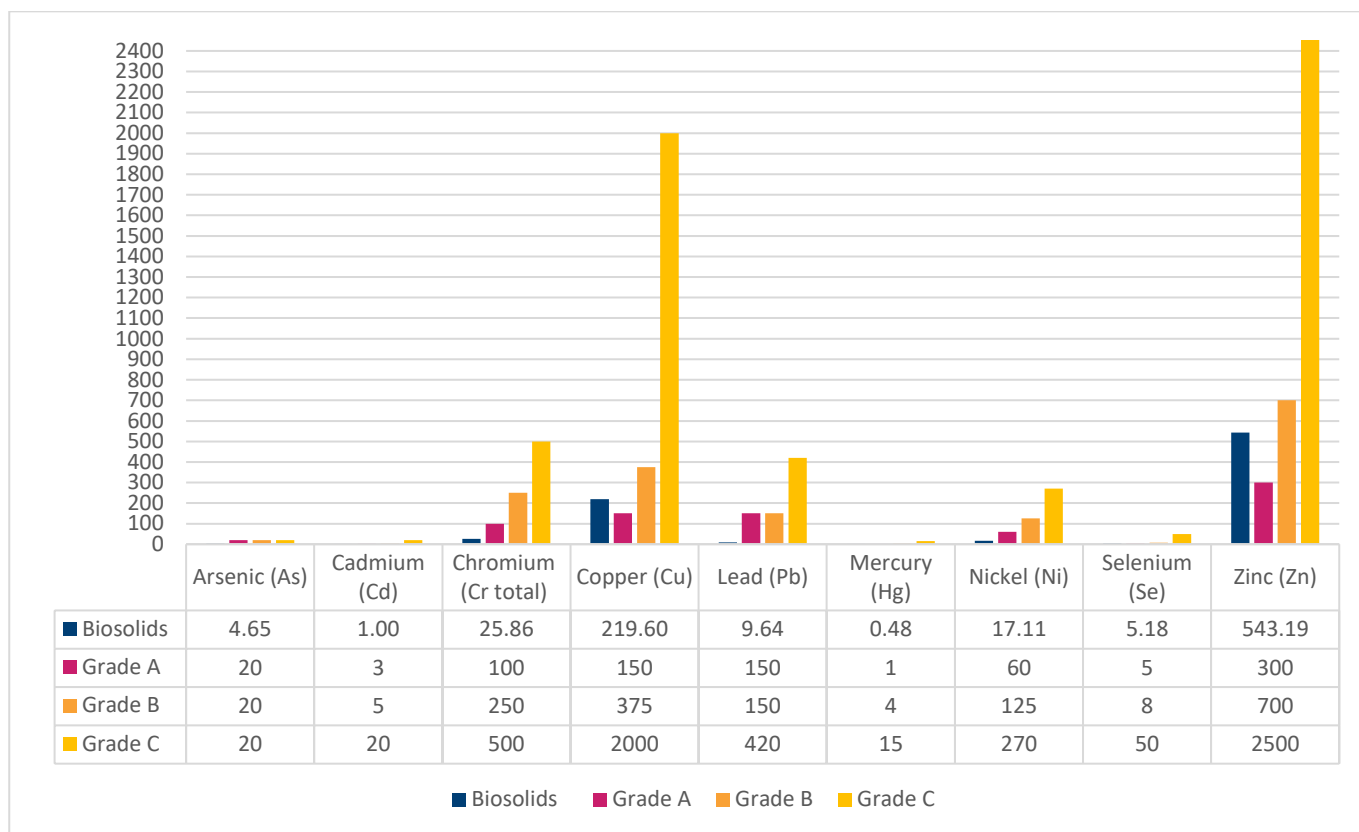


Figure 5: Comparison of the average heavy metals in Loganholme WWTP biosolids against the EoW Code for Biosolids

Limits for the organic contaminants including aldrin, dieldrin, chlordane, heptachlor, hexachlorobenzene (HCB), lindane, benzene hexachloride (BHC), dichlorodiphenyltrichloroethane (DDT), dichlorodiphenyldichloroethylene (DDE), dichlorodiphenyldichloroethane (DDD), and polychlorinated biphenyls (PCB) were below detection and thus adhere to Grade A biosolid guidelines.

3.2 Biochar Analysis

The gasification process produces a carbonised material known as biochar. Biochar is a form of charcoal, derived from combusted organic material in low oxygen conditions at temperatures between 600 and 750°C. The production of biochar sourced from 100% biosolids is an emerging medium, however, initial data has found that heavy metal leachability from biochar is reduced for both Cu and Cr, while Zn is marginally higher (with no clear effect of rate) in soils applied with biochar compared to biosolids (17).

The application of biochar to agricultural lands is expected to provide similar agronomic benefits as biosolids application, improving soil biological and physical properties, such as structure, infiltration, water holding capacity, porosity, cation-exchange capacity, and carbon sequestration (18). The carbon sequestration capacity of biochar occurs on a millennium timescale, reducing GHG emissions from both soils and waste management practices⁷. Biochar properties depend on the feedstock and thermal treatment during gasification. As such, Winchell (19) report that Zn concentrations increase with high temperature processing, while S and N volatilisation is increased by as much as 40% under high temperatures. Plant available forms of P and K become increasingly concentrated in biochar, with low levels of available N due to volatilisation. Despite this, long-term N retention in soils

conditioned with biochar provides a comparable product to slow-release fertilisers, with a reduction of ammonium and nitrate leaching following biochar amendment (20) (21).

A comparison of the average trace metal concentrations in biosolids and biochar for 11 samples from August 2022 to May 2023 is given in Table 3, including the contaminant grading under the EoW Code for Biosolids. Biochar will be managed under the EoW Code for Biosolids until an EoW Code for Biochar is published.

Table 3: Analysis of biosolids and biochar processed through the gasification facility

Parameter	Biosolids (mg/kg)	Biochar (mg/kg)	Difference (mg/kg)	Contaminant Grading		
				Grade A	Grade B	Grade C
Arsenic (As)	4.65	5.09	0.44	20	20	20
Cadmium (Cd)	1.00	1.41	0.41	3	5	20
Chromium (Cr)	25.86	59.39	33.53	100	250	500
Copper (Cu)	219.60	389.19	169.59	150	375	2000
Lead (Pb)	9.64	21.86	12.22	150	150	420
Mercury (Hg)	0.48	0.19	- 0.29	1	4	15
Nickel (Ni)	17.11	31.78	14.67	60	125	270
Selenium (Se)	5.18	4.96	- 0.22	5	8	50
Zinc (Zn)	543.19	1248.96	705.77	300	700	2500
DDT/DDD/DDE (sum)	<0.02	<0.02		0.5	0.5	1
Aldrin	<0.02	<0.02		0.02	0.2	0.5
Dieldrin	<0.02	<0.02		0.02	0.2	0.5
Chlordane (sum)	<0.02	<0.02		0.02	0.2	0.5
Heptachlor (sum)	<0.02	<0.02		0.02	0.2	0.5
HCB	<0.02	<0.02		0.02	0.2	0.5
Lindane	<0.02	<0.02		0.02	0.2	0.5
BHC (sum)	<0.02	<0.02		0.02	0.2	0.5
PCB total (sum of Aroclors)	<0.1	0.1		<0.1	0.3	1

These results demonstrate that, as expected, gasification increases the concentration of trace metals present in biosolids (excluding As, Hg, and Se). The reduction of As, Hg, and Se concentrations in biochar relates to the metals' low boiling points, where hearth processing results in their volatilisation and accumulation in the biogas stream.

The greatest increase in concentrations is found for Zn, Cu, and Cr, as expected following the demonstration plant's material analysis. It is important to note, that while trace metal concentrations increase, the gasification process makes metals such as Ni, Zn, Cu, Cd, and Pb as well as PAHs less mobile and available for plant uptake as well as reducing their tendency to leach (19). Therefore, soil application of biochar is not expected to increase metal concentrations of the surrounding soil or bioaccumulate in crops.

Under the EoW Code for Biosolids (3), the biochar produced from the Loganholme WWTP would be classified as a Grade C due to the high Zn and Cu levels. As pathogen reduction is achieved by

thermal treatment and the contaminate limits are considered Grade C, the biochar would thus be classified as Restricted Use 2. This means that the biochar may be utilised for:

- agriculture
- forestry
- soil and site rehabilitation.

These applications fit the current view that biochar would make a useful soil ameliorant, specifically in Australia, where soils are depleted of Zn and Cu and would thus be sought after by farmers, making the biochar more valuable as a product (5). Therefore, the value of biochar can be derived from the market price for Cu and zinc sulphate, given they are the most common metals applied to land and are the most concentrated metals in biochar.

The commercialisation of biochar for agricultural purposes is based on its ability to sequester carbon and improve soil health by retaining nutrients and water. However, to open other areas of marketability for biochar, the development of an EoW Code for Biochar is necessary (22). The draft EoW Code for Biochar (EOWC010002177) is currently under development by DESI.

Laboratory analysis has indicated that the process of gasification and pyrolysis bind heavy metals to the material via several mechanisms, including surface binding to the functional groups of the biochar, ion exchange reactions between the biochar and the soil solution, the electrostatic attraction of heavy metals, and the precipitation of the metals (6). Thus, it is important that the EoW Code for Biochar considers the metal bioavailability contamination levels for the biochar. This would allow for the maximum commercialisation potential for biochar as a resource for an array of purposes.

4. Persistent Organic Pollutants

The removal of contaminants of concern such as POPs and micro and nano-plastics is critical for the continued beneficial use of biosolids. Loganholme WWTP has ensured the quality of the biochar through the destruction of POPs and other contaminants of concern - removal efficiency is directly tied to processing temperature and residence time, with temperatures of at least 800°C found to effectively reduce pollutants including PPCPs, steroids, hormones, and other emerging pollutants to below detection levels (19). These are discussed in greater detail below.

4.1 Background

Per- and Polyfluoroalkyl Substances (PFAS) are manufactured chemicals that have been used in a wide range of everyday items since the mid-1900s. The application of PFAS allows products to be non-stick, water-repellent, as well as fire, weather, and stain resistant. Thus, this chemical has been applied to a variety of products, from food packaging, non-stick cookware (Teflon), cosmetics, clothing, and carpets, as well as firefighting foams and pesticides. Due to its ubiquitous nature, PFAS is highly prevalent in the built environment, with its mobile nature expanding the pollutant's footprint (23). PFAS analyte detection via total oxidable precursor assay (TOPA) analysis is required for biosolids and biochar as all waste and wastewater treatment plants are considered potential PFAS contamination sites (24). TOPA is the most robust method of PFAS detection, ensuring minimum environmental harm as the assay estimates the worst-case scenario of long-term contamination of PFAS and the potential toxicity of degradation products and secondary PFAS compounds.

With over 4,700 known PFAS chemical types, variation exists concerning their behaviour in the environment, however, PFAS principally have the following characteristics: high stability,

persistence, aversion to biodegradation in the environment, high solubility and high mobility. These characteristics allow PFAS to readily leach from soils and into surface and ground waters where they may travel long distances and move up the food chain via bioaccumulation.

In Queensland, PFAS monitoring has been included in the EoW Code for Biosolids (3). Table 4 presents the trigger limits for a range of PFAS compounds that may be detectable in soil following biosolids land application. Monitoring of PFAS must be conducted for at least every 120 dry tonnes of biosolids to be used, including a minimum of C4-C14 perfluoroalkyl carboxylic acids, C4 –C10 perfluoroalkyl sulfonic acids, perfluoroalkyl sulphonamides and n:2 fluorotelomer sulfonic acids and total organic fluorine (TOF) testing.

Table 4: Trigger values for PFAS in soil after the application to land

Contaminant	Trigger Value
PFHxS	0.003 mg/kg
PFOA	0.004 mg/kg
PFBA, PFPeA, PFHxA	0.001 mg/kg
Sum C9 -C14 Perfluoroalkyl carboxylic acids	0.01 mg/kg
Perfluoroalkyl sulfonamides	0.001 mg/kg
N:2 Fluorotelomer sulfonic acids	0.004 mg/kg

The NEMP 3.0 (draft) is currently under development by the Heads of EPA of Australia and New Zealand (HEPA) (4). This document will provide nationally standardised guidance and standards on the investigation, assessment, and management of PFAS wastes and contamination in the environment. Based on the NEMP 3.0 (draft) issued for consultation, it is likely that maximum allowable soil concentration criterion (MASCC) and contaminant limiting biosolids application rate (CLBAR) will be developed. These criteria consider a range of pathways and end points for PFAS biosolids in amended soils and reflect the newly developed human health exposure guidelines for the consumption of drinking water, crops, meat, and its derived products from agricultural lands that have been amended with biosolids. Future amendments to the restriction of biosolids application may be introduced following the determination of long-term bioaccumulation risks in biosolids land application, however, agreed-upon guideline values have not yet been reached.

There is a suite of analytical methods to test for PFAS presence, and these, together with their limitations, are outlined in Table 5.

Table 5: PFAS standard methods of analysis

Method	Use	Sample matrices	Limitations	Analytes
USEPA Method EPA-821-R-11-007 Draft Procedure for Analysis of Perfluorinated Carboxylic Acids & Sulfonic Acids in Sewage Sludge & Biosolids by HPLC/MS/MS (December 2011)	Specific analytes in sewage sludge & biosolids	Sewage sludge & biosolids	Only analyses for specific PFAS Further details in the reference	PFBA, PFPA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFTriDA, PFTeDA, PFBS, PFHxS, PFHpS, PFOS, PFOSA, NMeFOSA, NEtFOSA, NMeFOSE, NEtFOSE
Total Oxidisable Precursor (TOP) Assay	Can be used in conjunction with a USEPA method to estimate the total PFAS, and sometimes the approximate end point PFAS Can help inform risk assessment	Water samples & extracts including soil, biota, firefighting foam products & wastes	Cannot be used to target exact PFAS precursors, as it is a semi quantitative P69FP69F 1PP method. Allows for some inferences as to precursor chain length	Total PFAS chains (C4- C14)
Total Organic Fluorine (TOF) Assay as combustion ion chromatography (most common method available)	Can be used in conjunction with a USEPA method to understand the total presence of organic fluorine in a sample and compare this to the organic fluorine equivalent detected by the USEPA method	Water samples and extracts including soil, biota, firefighting foam products & wastes	Cannot be used to target exact PFAS precursor compounds	Total organic fluoride corrected to remove inorganic forms

The accredited method TOP assay, originally published by Houtz and Sedlak (25), is widely used as an estimate of the total perfluoroalkyl acids (PFAA) content of a sample, particularly in wastewater and biosolids matrices. This method has been utilised for analysis of the Loganholme biosolids and biochar.

4.2 PFAS - Biosolids

An overview of the average PFAS concentrations found in the Loganholme WWTP biosolids from February to May 2023 is given in Table 6. Non-detectable limits (<0.1 ug/kg) were identified for PFAS TOPA (%). PFAS concentrations do not exceed guidelines for restricted use soil application and pass the trigger values for application to residential lands with garden/accessible soil. Where samples are below the level of detection, these are reported as '0'.

Table 6: Biosolids average PFAS analyte values (February to May 2023)

PFAS Analyte (ug/mg)	Average Value (Feb – May 2023)
Perfluorobutanoic acid (PFBA)	0.58
Perfluoropentanoic acid (PFPeA)	0
Perfluorohexanoic acid (PFHxA)	0.50
Perfluoroheptanoic acid (PFHpA)	0
Perfluorooctanoic acid (PFOA)	0
Perfluorononanoic acid (PFNA)	0
Perfluorodecanoic acid (PFDA)	0
Perfluoroundecanoic acid (PFUdA)	0
Perfluorododecanoic acid (PFDoA)	0
Perfluorotridecanoic acid (PFTrDA)	0
Perfluorotetradecanoic acid (PFTeDA)	0
Perfluorooctane sulfonamide (FOSA)	0
N-methylperfluoro-1-octanesulfonamide (N-MeFOSA)	0
N-ethylperfluoro-1-octanesulfonamide (N-EtFOSA)	0
2-(N-methylperfluoro-1-octanesulfon)-Ethanol (N-MeFOSE)	0
2-(N-ethylperfluoro-1-octane sulfon amido)-Ethanol (N-EtFOSE)	0
N-ethylperfluoro-1-octanesulfonamido acetic acid (NEtFOSAA)	0
N-methylperfluoro-1-octanesulfon amidoacetic acid (N-MeFOSAA)	0.75
Perfluorobutanesulfonic acid (PFBS)	0
Perfluoropentanesulfonic acid (PFPeS)	0
Perfluorohexanesulfonic acid (PFHxS)	0
Perfluoroheptanesulfonic acid (PFHpS)	0
Perfluorodecanesulfonic acid (PFDS)	0
Sodium 1H,1H,2H,2H-perfluorohexane sulfonic acid (4:2 FTSA)	0
Sodium 1H,1H,2H,2H- perfluorooctane sulfonic acid (6:2 FTSA)	0
Sodium 1H,1H,2H,2H-perfluorodecane sulfonic acid (8:2 FTS)	0
Sodium 1H,1H,2H,2H-perfluorododecane sulfonic acid (10:2 FTS)	0

4.3 PFAS - Biochar

After the gasification process, PFAS concentrations were reduced following the volatilisation of these compounds, with non-detectable limits (<0.1 ug/kg) identified for all PFAS TOPA (%) in Loganholme biochar material (February to May 2023). While data suggests that some PFAS is retained within biochar following gasification, these are most often present below detection limits as the gasification process causes the volatilisation of PFAS compounds within the hearth (19). The thermal decomposition of PFAS in oxygen deficient conditions at temperatures of at least 600°C (in the hearth) incites the off-gas formation of by-products and transformed PFAS compounds which require higher temperatures for direct combustion. To achieve this, gas residence time and temperature in the thermal oxidiser is 2 seconds at 800–850°C (in the oxidiser), seeing the destruction of PFAS within the airstream.

4.4 Microplastics

Microplastics are plastics that are smaller than 5 mm, encompassing two main types:

- Primary - intentionally produced plastics, for example, microbeads from toothpaste or glitter from cosmetics.
- Secondary - resulting plastics from the weathering of larger plastics that may cause adverse effects in organisms and ecosystems.

In Australia, between 2,800 and 19,000 tonnes of microplastics are applied to agroecosystems each year via biosolids application (26). The thermal treatment of biosolids via pyrolysis or gasification at temperatures exceeding 500°C has been proven to drastically reduce microplastic abundance in biochar and thus prevent this pollutant from entering the environment (8).

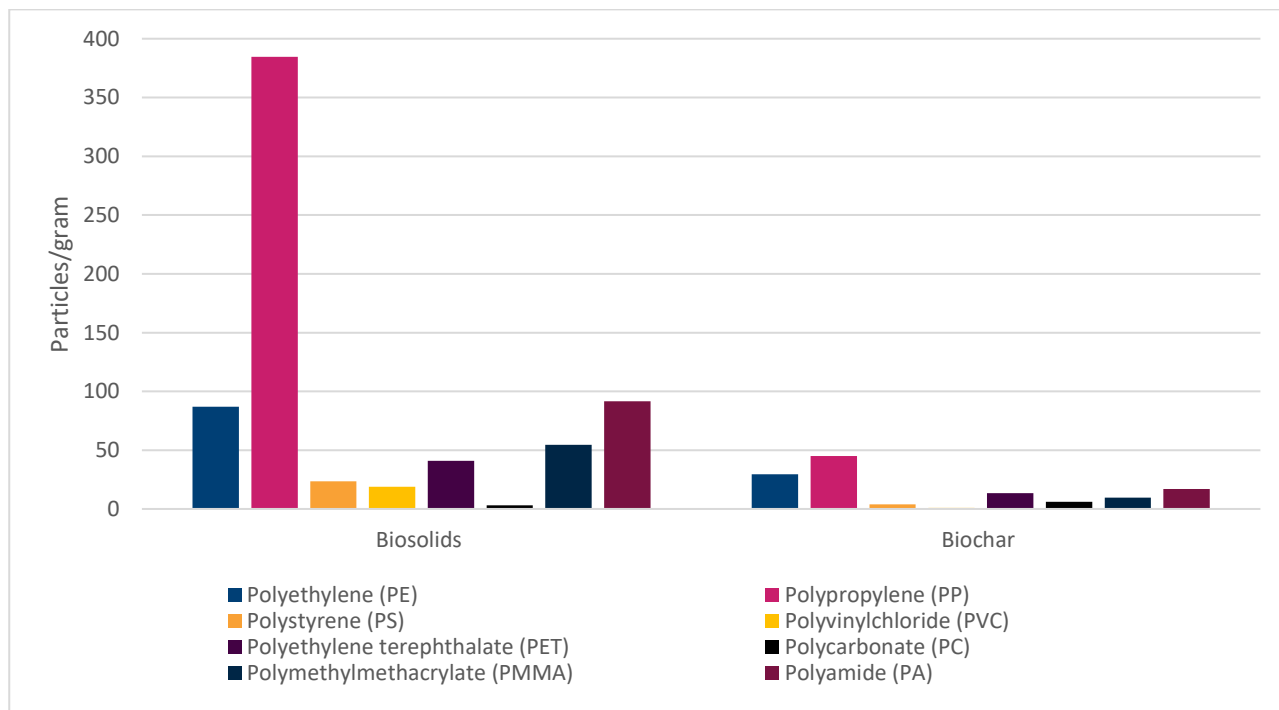


Figure 6: Types of microplastics in the biosolids and biochar

Figure 6 shows that polypropylene was the most common microplastic, with biosolids averaging 385 particles per gram of biosolids. This also demonstrates that the gasification process reduced

microplastic concentration across all polymer types, with polypropylene concentrations reduced by 88%, to 45 particles per gram of biochar.

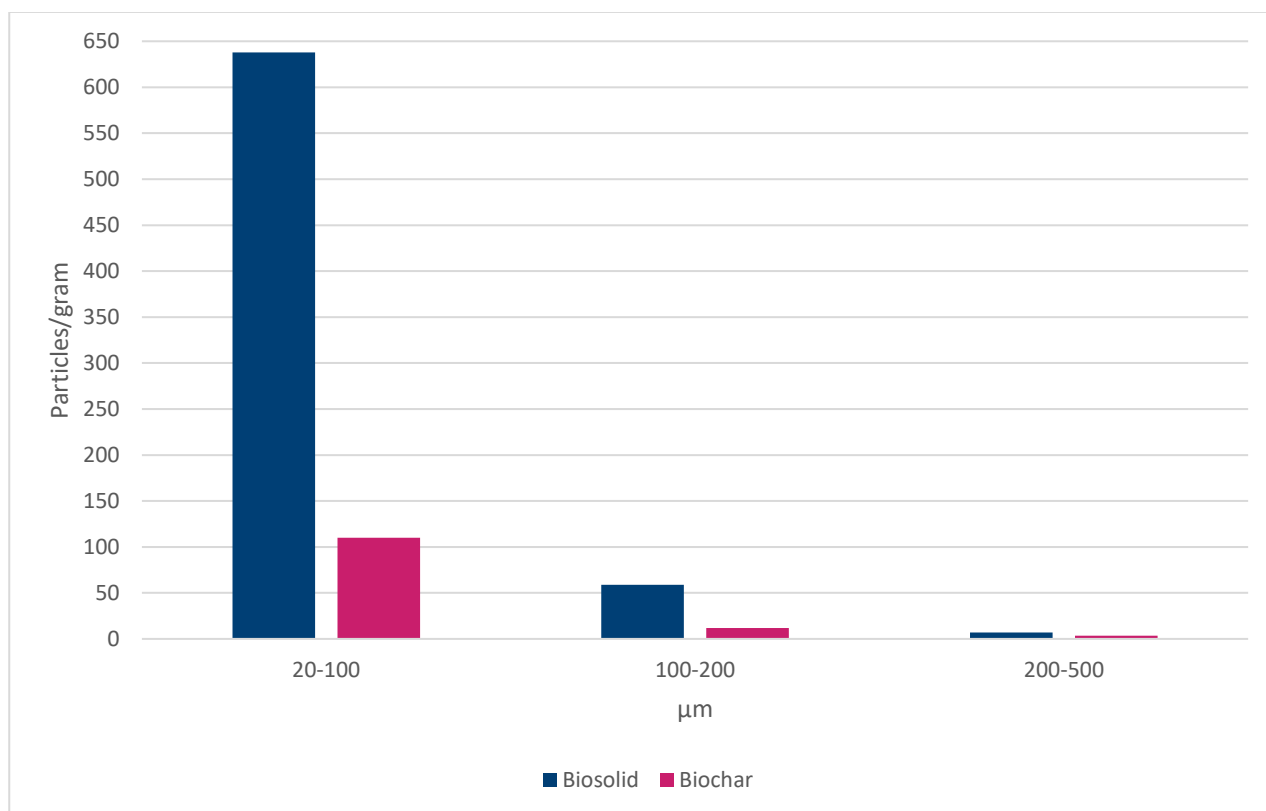


Figure 7: Microplastic sizes in biosolids and biochar

Figure 7 illustrates that gasification destroys a large proportion of microplastics with greater reductions observed in the smaller fragments. An 83% destruction rate for microplastics in the size range of 20-100 µm was observed, while 80% destruction for 100-200 µm sized plastics and the destruction of 50% of microplastics in the largest size range of 200-500 µm was achieved. Therefore, the current gasification process for Loganholme biosolids averages the destruction of 82% of all detectable microplastics, which is a significant improvement compared to rates achieved during the demonstration plant, which averaged 60% destruction. This can be attributed to particle size improvement of the biosolids after passing through the belt driers in the Loganholme gasification facility rather than the sludge and drum dryers used for outsourced biosolids and the paddle dryers used for the Loganholme biosolids in the demonstration plant (1).

5. Heat Balance

The Loganholme WWTP gasification system is designed to achieve a heat balance without the need for supplementary fuel during normal operation (i.e. heat energy neutral). This should be achieved by capturing the heat energy generated during the gasification process to provide the energy required for thermally drying the dewatered biosolids. Excess heat from gasification is captured and used in a hot water generator, which then feeds into an integrated heat recovery unit. The water is heated to 90-95°C and serves as the heat source for belt dryer operations. Water is then returned at 70–75°C.

The heat balance of the overall integrated drying–gasification process is predominantly influenced by four parameters:

- **Calorific value of the biosolids:** This is related to the volatile solids content of the biosolids, which is inherent to the treatment plant and therefore, is not able to be adjusted in design or operation.
- **Biosolids dewatering performance:** Mechanical removal of water via centrifugal dewatering is more efficient than evaporation and significantly impacts the heat required for drying. The initial dewatering step is designed to achieve 22% w/w dry solids (target) with a 20% w/w minimum.
- **Thermal efficiency of the dryer:** Measured as kW of heat input per tonne of water evaporated, a lower figure represents higher efficiency. This is a fundamental characteristic of the type of dryer. A drier feedstock reduces the thermal heat energy required to dry biosolids within the belt dryers, improving efficiencies through the reduction of internal energy loss to dry the material prior to gasification. Therefore, excess energy can be utilised by the thermal oxidiser for subsequent heat recovery.
- **Heat recovery performance:** The heat recovery system includes two heat exchangers and over time these incur efficiency reductions due to fouling, culminating in reduced heat capture. When the performance reduction is too great the facility is taken offline for cleaning.

Several improvements were identified throughout the commissioning and optimisation of the facility to ensure the heat balance requirements are met. These are detailed below:

- **Regular cleaning:** During commissioning of the facility, it was discovered that the flue gas heat exchanger was fouling with particulates at a higher rate than expected and this caused inefficiencies in the heat recovery system. The initial heat exchanger design incorporated an online cleaning method, involving periodic use of compressed air, referred to as a 'soot blow,' to eliminate fouling and particulate build-up. However, this soot blowing process proved disruptive, impacting airflow and the hearth draft pressure control critical to the hearth's operation. To address this issue, a trial was conducted using a sonic horn, also known as an acoustic cleaner, to dislodge fine particles from the heat exchanger. This approach proved effective in reducing fouling rates and extending the heat exchanger's operational cycle before offline cleaning (achieved through water flushing) becomes necessary. These improvements have positively impacted the gasification system's operation, and the optimisation of heat recovery. Issues remain with the heat exchangers and the amount of fouling and therefore cleaning that is required. There are further investigations underway on this with likely modifications required to obtain better performance.
- **Oxygen input:** Biochar yield is determined by the amount of carbonisation which has occurred within the gasification of biosolids. An increase in carbonisation is facilitated by additional oxygen added to the bottom chamber of the hearth to increase the temperatures above 700°C lowering to 600°C in the top chamber of the hearth. The additional carbonisation of the biosolids increases the energy yield of the produced syngas which culminates in more energy produced via combustion within the thermal oxidiser. This heat energy is then captured within the radiant and flue gas heat exchangers.

- **Improved insulation:** Additional insulation was applied to the hot-and cold-water tanks, exposed ducts, pipe flanges and the dryer heat exchanger housings. The insulation reduced heat loss to the environment and therefore improved overall efficiency of the heat recovery circuit.
- **Additional Supplementary Heat Required:** There has been a shortfall of heat generated and captured by the system and a gas heating system was required to be added to “supplement” the heat shortfall of approximately 20%. There is a desire to reduce the reliance on LPG as a supplemental heat source with a number of investigations and optimisations being undertaken.

The heat balance achieved in the gasification facility for the Loganholme biosolids is summarised in Table 7, with an average net dry calorific value of 17.3 MJ/kg.

Table 7: Summary of unit operations performance of the gasification facility

Parameter	Value
Biosolids feed rate	627 kg/hr
Heat recovered kW/kg	2.16
Heat recovered at radiant heat exchanger (Integrated with the Thermal Oxidiser)	422 kW
Heat recovered from flue gas heat exchanger	774 kW

As mentioned above there are further efficiency improvements being explored including replacing the radiant and flue gas heat exchangers with units less susceptible to fouling and continuing to optimise the oxidiser and hearth operations to maximise the performance, heat generation and heat capture.

6. Operating Costs and Optimisation Opportunities

The first year’s operational cost summary for the gasification facility is presented in Table 8. The raw operating costs of the facility were dominated by the consumption of chemical additives for emissions control and equipment protection, LPG usage for supplementary heat and operations and maintenance costs. A continuous improvement approach was adopted to each of these costs, to identify opportunities for efficiencies and optimisation.

It should be noted that Table 8 shows the projected first year of operating costs and does not consider the CAPEX expended and associated interest and depreciation costs. Further capital investment is being undertaken to improve facility’s performance and reduce the operating costs.

Table 8: Estimated Annual Cost Summary – Gasification facility first year

Component	First Year Cost
Biosolids Haulage (when gasification is offline)	\$ 590,000
Polymer	\$ 415,000
Urea	\$ 250,000
Magnesium Hydroxide	\$ 215,000
LPG	\$ 500,000
Diesel	\$ 30,000
Power (electricity)	\$ 73,000
Operations	\$ 350,000
Maintenance	\$1,200,000
Compliance Testing	\$ 100,000
Total	\$ 3,723,000

Based on a nominal 50 ML/day inflow

6.1 Chemical Additives - Urea and Magnesium Hydroxide Dosing

Urea is used as an ammonia source for NO_x reduction within the thermal oxidiser utilising the selective non-catalytic reduction method of control. Magnesium hydroxide is an alkali, used for SO_x and metals capture, as well as hot corrosion control. The dosing and concentration rates of urea and Mg(OH)₂ for emissions control have undergone extensive monitoring and optimisation testing since the demonstration plant trials, with the optimised dosing rates to maintain emission limits presented in Table 9.

Table 9: Urea and Magnesium hydroxide dosing rates (full scale plant)

Parameters	Units	Urea	Magnesium hydroxide
Dosing Location	-	Thermal oxidiser	Hearth (25%) Wet scrubber (75%)
Dosing rate initial (%w/w)	% w/w	4.5	2
Initial dose flow rate (full scale)	L/day	1,095	777
Optimised (current) dose rate (%w/w)	% w/w	3.075	1.5
Optimised dose rate	L/day	748	583
Approximate cost saving	\$/year	100,000 – 130,000	60,000-70,000

Based on a nominal 50 ML/day inflow

6.2 Chemical Additives - Polymer Dosing for Dewatering

Polymer is used in the dewatering process with dosing in the feed to the centrifuges. Polymer assists in achieving the 22% dry solids. Polymer dosing rates are presented in Table 10.

Table 10: Polymer dosing rates

Parameters	Units	Initial Polymer	Optimised Polymer
Dosing rate (%w/w)	kg/tDS	15	11
Daily consumption	L/day	430	315
Approximate cost saving	\$/year	150,000 – 170,000	

Based on a nominal 50 ML/day inflow

6.3 LPG

There have been challenges with the current heat exchangers at the gasification facility. These are currently being investigated and will likely be replaced with an improved technology heat exchanger that consistently captures more heat and requires less cleaning and downtime. In addition to the heat exchangers, the oxidisers are also being evaluated for potential optimisation.

To ensure stability of the heat balance, an LPG gas heater has been installed to provide additional heat for the thermal dryer heat circuit. The usage has been optimised and will continue to improve as modifications are investigated and implemented. Annual usage is currently between 200kW and 400kW, depending on the overall performance of the facility. The projected annual cost of LPG is expected to range between \$250,000 and \$500,000.

6.4 Operation and Maintenance

The reliability of the facility has been lower than planned and expected. The initial expectation was that limited redundancy, similar to a standard dewatering facility, would be appropriate. However, this has found to be incorrect. The facility needs to be treated as a production plant, focussing on minimising downtime to reduce costs. The first year of commissioning and optimisation has seen significant operations and maintenance costs, requiring more personnel and unexpected component replacements.

As a result, additional redundant equipment and critical spare parts are being reviewed and added to improve availability. It is anticipated that the different heat exchanger technology will significantly improve the reliability of the facility and processing units.

6.5 Diesel

Diesel is used at the facility to initiate start-up of the gasifier. On average around 100L of diesel per full gasification unit (train) start-up is consumed. The current facility observes around 12 start-ups per month. Yearly consumption of diesel on the facility is around 12,000 to 18,000 litres. When the heat exchangers and associated modifications are completed, the number of starts is expected to reduce by up to 75%, to 3-4 starts per month.

In addition, a backup diesel burner is available to sustain the required temperature within the thermal oxidiser for PFAS destruction. However, this is a risk-mitigation measure for periods of process instability, which is a non-standard operating condition and as such is not included in usage or cost estimate.

6.6 Electricity

Electrical power usage of the gasification facility has been projected to be within the range of 1,700,000 to 1,900,000 kWh per year. It should be noted that power generated by a 1.1MW solar array on the Loganholme site indirectly offsets the annual electricity usage of the gasification facility.

7. Commercialisation

A key objective of the full-scale gasification facility was to understand the commercial benefits of the gasification of biosolids, specifically around the marketability of the biochar produced from the process. Market investigations have provided valuable information and have highlighted a keen interest in the biochar from the agricultural and composting industry, with testing on biochar properties confirming its value (refer to Section 2.3).

Although the market has shown a keen interest in the biochar product, the regulatory framework to support the market and enable the utilisation of biochar as a resource, distinct from biosolids, is still in development through an EoW Code for Biochar. This is potentially limiting the uptake of the product and its reuse applications. However, since the wider market for biochar is still developing, this is not anticipated to impact the value of the product in the long-term.

8. Conclusion

Through the demonstration plant and now the full-scale facility at Loganholme, Logan Water has proven the biosolids gasification facility to be an innovative solution to the growing issues facing service providers associated with the management of biosolids, particularly due to increasing costs and challenges around emerging contaminants of concern. In addition, the objectives for the full-scale gasification facility have been achieved, as highlighted below:

1. **Air Emissions:** to maintain compliance with environmental requirements.

The gasification facility predominantly meets the conditions set out in the environmental conditions, and this was achieved through the list below. There have been some challenges with full compliance to the current requirements for which we are optimising the system and in discussions with the regulator.

- A thermal oxidiser to destroy hazardous gases and POPs;
- A wet scrubber to remove liquid and solid particulate pollutants from the gas stream;
- A wet Electrostatic precipitator which removes the remaining PM and PHAs of the PM2.5 range from the flue gas before discharge via the exhaust stack;
- The dosing of urea for NO_x emissions, and Mg(OH)₂ for SO_x emissions; and
- The maintenance of the thermal oxidiser at temperatures greater than 800°C.

2. **Persistent Organic Pollutants:** to measure the quality of the biochar product and confirm the destruction of POPs in line with relevant regulations.

By maintaining gasifier temperatures of at least 600°C in the hearth, PFAS TOPA has been reduced to non-detectable limits in the biochar, with the resultant off-gas treated via the thermal oxidiser at temperatures greater than 800 °C. This has a demonstrated destruction of PFAS identified in the exhaust airstream. Microplastics have also been shown to reduce by an average of 82% through the gasification process.

3. **Energy Balance:** to confirm the electrical and heat energy balance for the facility.

The full-scale facility electricity usage is offset by a 1.1MW solar array generation at the WWTP. The gasification facility has been designed to achieve a heat balance without the need for supplementary fuel. The heat balance is predominantly influenced by four parameters, namely the calorific value of the biosolids, the biosolids dewatering performance, the thermal efficiency of the dryer, and the performance of the heat recovery system (i.e. the heat exchangers). The

full-scale facility is approaching heat-energy neutral operations, with ongoing efforts focussed on improving efficiencies and the use of supplementary LPG gas for the shortfall.

4. **Operating Costs:** to optimise the operating costs of the facility.

The operating costs of the facility are dominated by the consumption of chemical additives for emissions control and equipment protection, LPG gas usage for the heat shortfall and Operation and Maintenance costs. A continuous improvement approach was adopted to identify opportunities for efficiencies and optimisation. There are a number of modifications and optimisation areas that have been identified and capital investment is ongoing to realise these and reduce operating costs.

5. **Commercialisation:** investigate market opportunities and develop a tendering process for purchasers of biochar.

Market investigations for biochar have highlighted particular interest in the product from the agricultural and composting industry. The analysis of biochar properties confirms its agronomic value, with Logan Water engaging with customers who have previously purchased dewatered biosolids for soil application. It is expected that with the finalisation of the EoW Code for Biochar, there will be expanded market opportunities for the product in a range of industries.

The facility has further confirmed that the gasification of biosolids is a process that can be incorporated into a WWTP with the correct planning, design, implementation, commissioning, optimisation, and operation and maintenance. Most of the heat is self-generated, and further improvements are being developed to work towards a heat energy neutral facility.

The gasification facility has predominantly achieved compliance with Environmental Authority (EA) (EPPR00867913) (3) Condition LGN-A1-12: air contaminants and has reduced persistent organic pollutants and metals detectable in the biochar. The facility has also attained a carbon neutral through solar array generation of equivalent power requirements and the majority of the heat balance through the application of heat energy capture. A number of components, including online CEMS monitoring of CO and NO_x remain challenges, along with demonstration of PFAS destruction requirements. Optimisation of the facility is ongoing, and compliance will continue to be monitored, improved and reported as required.

An independent review of the reuse of Loganholme's biochar in the agricultural sector as a blended soil supplement has been determined to offer optimum financial returns and the best environmental outcomes for the utilisation of this commodity (1). Investigations into market opportunities and tendering processes for purchasers of biochar are underway, pending the completion of the EoW Code for Biochar.

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