BIOSOLID GASIFICATION DEMONSTRATION PLANT RESULTS AND APPLICABILITY TO NEW ZEALAND’S LANDFILL LOVING PROBLEM

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ABSTRACT

Biosolids generated from wastewater treatment plants can be beneficially reused as an effective soil conditioner for agricultural, forestry and soil rehabilitation purposes, as well as providing a source of renewable energy. Despite this, New Zealand disposes the majority of biosolids to landfill, at rates much higher than Australia. The reason for this is a mixture of negative perceptions, low landfill levy’s and limited national experience with the technologies and practises for biosolid treatment and reuse.

Several biosolid management processes exist which could be applied successfully in New Zealand. This paper describes one such process - biosolid gasification, and reveals the results of Australia’s first full-scale 350,000 EP demonstration (now permanent) biosolids gasification plant which was constructed in 2020 at Loganholm in Queensland by The Logan Water Infrastructure Alliance (LWIA), a partnership between Downer Group and Logan City Council.

The project sought to prove the performance of this previously unproven process again biosolid and air emission environmental standards and characterise various elements of the gasification process such as the characteristics of the resultant biochar product, biosolid volume reduction, destruction rates of persistent organic pollutants like perfluoroalkyl substance, heat balance and operating costs

The key outcomes and benefits shown from this demonstration plant which is of relevance to New Zealand wastewater treatment plant operators include >90% reduction in biosolid volume (and related transport and disposal costs), sterilisation of pathogens, destruction of persistent organic pollutants and micro-plastics and retention of the plant-available nutrients. Biochar does not generate offensive odours, is not subject to a restricted storage time before transport/application and is easier to handle than standard dewatered sludge cakes. Furthermore, Logan City Council has found that valuable markets exist for biochar as soil conditioner for the agricultural sector, fuel source and associated carbon credits, such that the biochar is a significant revenue source and contribution to a circular economy for Council.

Given the required capital investment and operating capability, this paper explores the feasibility of implementing biosolid gasification plants New Zealand. Early indications show that this process favours intensified, and landfill limited New Zealand cities such as Auckland, New Plymouth, Wellington and Otago. Additionally, these plants have the potential to be effective in regions where populations are scattered where they can act as decentralised points that receive sludge streams from several smaller surrounding townships.

KEYWORDS
Biosolid treatment and reuse, biosolid gasification, biosolid management demonstration results, circular economy

1. INTRODUCTION

Sludge is the solid fraction separated from sewage during wastewater treatment, whilst biosolids refers to sludge that has been treated to sterilise and reduce contaminated loads to meet environmental requirements for land application or landfill disposal. For this paper, we will be referring to biosolids when referring to disposed sludge from wastewater treatment plants (WWTP).

It is estimated that between 60-70% of biosolids are disposed to landfill every year (1) (2) from WWTP's in NZ. Excluding biosolid disposal from the Mangere WWTP to the Puketu quarry for soil rehabilitation (Auckland, New Zealand), less than 16% of biosolids are reused for beneficial reuse in NZ (3). This number is much lower than in countries like Australia, where over 75% of all biosolids produced (approx. 225,000 tonnes of dry solids per year) is applied to land as a fertiliser or soil conditioner and application to agricultural land is the largest end use (5). Other pathways of reuse include power generation.

Some reasons for NZ's low levels of beneficial biosolid reuse include relatively cheap landfill disposal levy's, a culture of treating biosolids as a disposal issue and limited national exposure to biosolid management technologies and practises (3). Regardless of this, biosolid management operating and environmental costs are significant to WWTP operators around the country, especially as the wastewater sector is seeing tightening of availability and consents related to landfill disposal, increases in disposal levy's as well as heightening fuel and transportation costs. As such, there is a need to explore options of feasible technologies and reuse pathways to manage biosolids in NZ.

One process that could effectively treat biosolids and produce a valuable by-product is biosolid gasification. This includes sludge dewatering, drying and thermal decomposition via pyrolysis and gasification (Fig 1). The process reduces biosolid volumes by >90% and produces a high-grade charcoal like substance called biochar (Fig 2) which retains plant-available nutrients, has high cation exchange capacity and reduced leachability of inorganics such as metals.

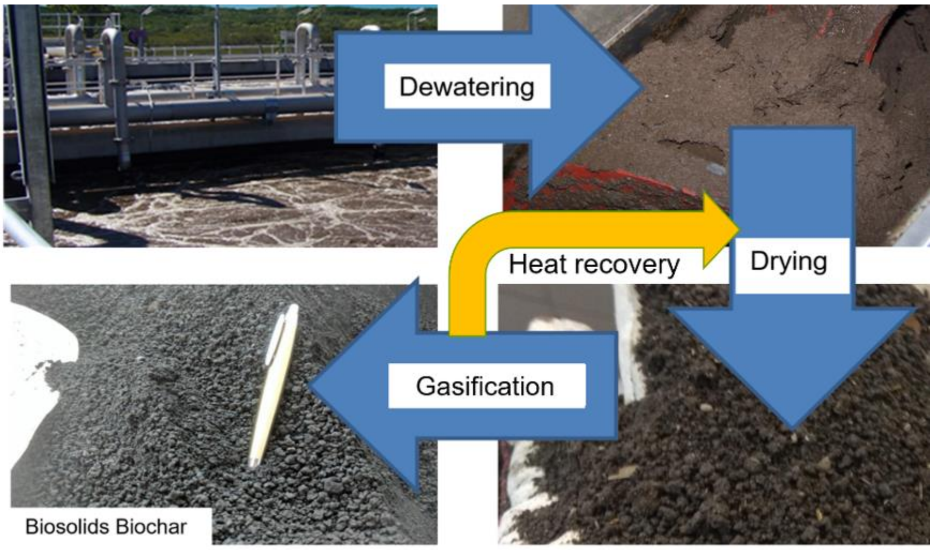

Figure 1- Simplified biosolid gasification process

Figure 2- Picture of biochar product

Each element of the above-mentioned process are proven technologies and commonly used in various industries such as forestry, food production and agriculture for waste minimisation and reuse. Furthermore, many small scale and trial pyrolysis plants have been used to research the feasibility and end use of biosolids biochar over the last few decades (6) (7). However, the combination of each technology for the purpose of developing a replicable process for domestic biosolid treatment has not been done before.

In 2020 a demonstration biosolid gasification plant was designed and developed at Loganholme wastewater treatment plant (Queensland, Australia) by The Logan Water Infrastructure Alliance (LWIA), a partnership between Downer Group and Logan City Council. This paper outlines the drivers, design development and results from the trial. Aspects such as biosolid and biochar characterisation, air emission quality, destruction of sludge contaminants, heat balance and operating costs were documented throughout this trial and are explored in this document. The permanent 350,000 EP biosolid gasification plant is now in place at Loganholme and was commissioned in March 2022. Finally, a broad assessment of the feasibility and potential areas in NZ that could benefit from biosolid gasification are considered in this paper.

2. BACKGROUND

2.1. LOGANHOLME WASTEWATER TREATMENT PLANT

Loganholme is the fastest growing city within the Logan City Council district, and its WWTP services about 350,000 people and produces 34,000 tonnes of biosolids each year, with six truckloads of biosolids transported 300 km for land application daily. The sludge was only dewatered (14%w/w dry solids) and stabilised before collection and transport.

2.2. DRIVERS FOR TRIALLING BIOSOLID GASIFICATION AT LOGANHOLME

High operating costs

> Biosolid disposal was a major operating cost for Logan Water (Logan City Council's water utility), contributing to approximately AUD 1.8 million per year or 30% of the total operating costs at the Loganholme WWTP. As such, there was a desire to explore options to effectively reduce biosolid volumes and related operating costs.

Concerns of bioaccumulated contaminants in agricultural land that has/had biosolid application

> Increasing industry and public concern of leaching or soil bioaccumulation of biosolid emerging contaminants, persistent organic pollutants (POPs) and microplastics in soils and crops where biosolids have been applied. This is particularly a concern in Australia where the largest receiver of biosolid application is the agricultural sector.

Tightening of regulations that will impose limits on Per- and polyfluoroalkyl (PFAS) substances in biosolids for reuse

> Persistent organic pollutants were a major driver for this demonstration plant, with the inclusion of PFAS into the Queensland Department of Environment and Science's (DES) End of Waste Code for Biosolids (10). In the End of Waste Code for Biosolids, target limits have been set for soil application. The measurement of other POPs, such as microplastics, are under consideration and it is anticipated they will also be incorporated in some form into the End of Waste Code for Biosolids. Thermal treatment (pyrolysis, gasification) is one of the few options available for PFAS destruction in biosolids.

Aggressive environmental policy by Council

> With aspirations to get to net carbon zero by 2025, Logan City Council wished to install processes that demonstrated reduction in carbon emissions.

2.3. PATHWAY TO BIOSOLID GASFICATION DEMONSTRATION AND PERMENANT PLANT

Since the proposed biosolid gasification plant included individually proven technologies but had not been proven in combination for the purpose of biosolid treatment, the development of the design followed years of concept designs and small-scale trials before demonstration plant was put in place. Furthermore, due to the magnitude of 'unknowns' and project scheduling, many 'final design' decisions such as criteria for selecting the appropriate dewatering and drying technologies, required solid loading composition and treatment requirements, mechanical and electrical designs had to be made early and throughout the process, without the design being fully 'locked down' (2). The research and development of this innovative technology is an interesting story on its own but is not covered in this paper. A summary of the pathway is shown below.

- First proof-of-concept trials undertaken by Downer and Pyrocal (8) - December 2016
- Concept designs and technology investigations - 2017 – 2018 by Downer
- Concept introduced to Logan Council by Downer - 2018
- Part-funding sought from Australian Renewable Energy Agency (ARENA) - 2019
- $2.5M full-scale demonstration undertaken- February – September 2020.
- Final business case approved by Logan Council - October 2020
- Final design and plant construction- 2021
- Commissioning of permanent plant -March 2022
- First biochar from permanent plant produced - April 2022

3. DEMONSTRATION BIOSOLID GASIFICATION PLANT

3.1. COMPONENTS OF THE DEMONSTRATION PLANT

For the demonstration plant, dried biosolids were sourced from two WWTP'S in Victoria (Source 1 and Source 2) as the gasification system needed 90% dry solids, and it was not considered financially feasible to install dryers in the Loganholme WWTP to serve the purpose of this trial. The variation in the external biosolid sources caused some performance issues in the demonstration trial (described later in this paper). In the permanent plant, centrifuges and thermal drying belts were installed for dewatering and drying (Fig 5).

The demonstration plant (Fig 3 and 4) consisted of 1 x Pyrocal CCT18 Train which includes the following key components.

- **1 x Dried sludge hopper** which feeds the gasifier with dried biosolids
- **1 x Gasifier hearth** heated to 600-650 degrees Celsius. The upper rings in the hearth thermally decompose biosolids via pyrolysis (high temperature in absence of oxygen) and the lower rings were injected with a small amount of oxygen which results in a gas-phase reaction that vaporises persistent organic pollutants and other gases released from the biomass to create syngas (gasification)

- **1 x Biochar dispenser and storage bins**. Remaining biosolids from the hearth are transported through several chambers before dropping out into a screw conveyor, where biochar is discharged and stored
- **1 x Thermal oxidiser** where syngas released from the hearth is combusted in this 800-degree Celsius chamber for 2 seconds
- **1 x Thermal heat exchange**. The shell of the thermal oxidiser captures excess heat which is transferred to a hot/cold water heat exchanger that is designed to return hot water to the thermal dryer for self-sufficient sludge drying
- **1 x Wet scrubber** for contaminated gas pollutant removal and emission monitoring
- **Chemical dosing** of urea in the thermal oxidiser for nitrogen oxide removal and magnesium hydroxide in wet scrubber for sulphur oxide removal
- **Control Room**

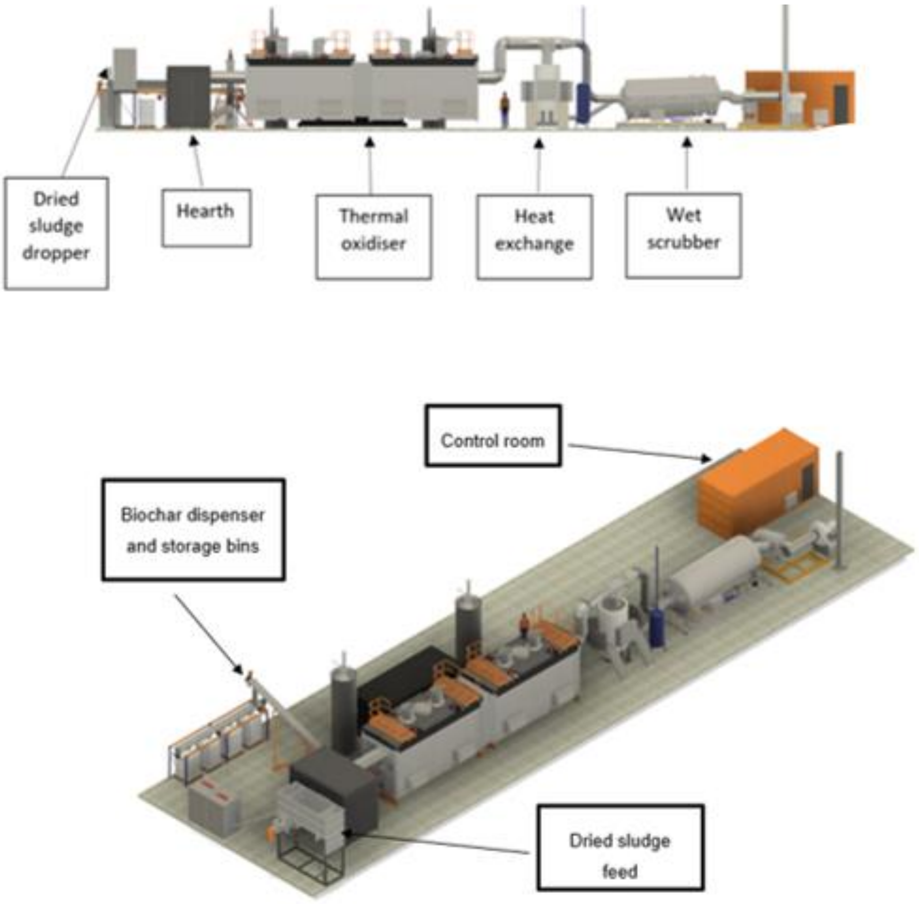

Figure 3- Cross section and isometric view showing key components of the Loganholme demonstration biosolid gasification plant

Figure 4-Picture of Loganholme's demonstration biosolid gasification plant

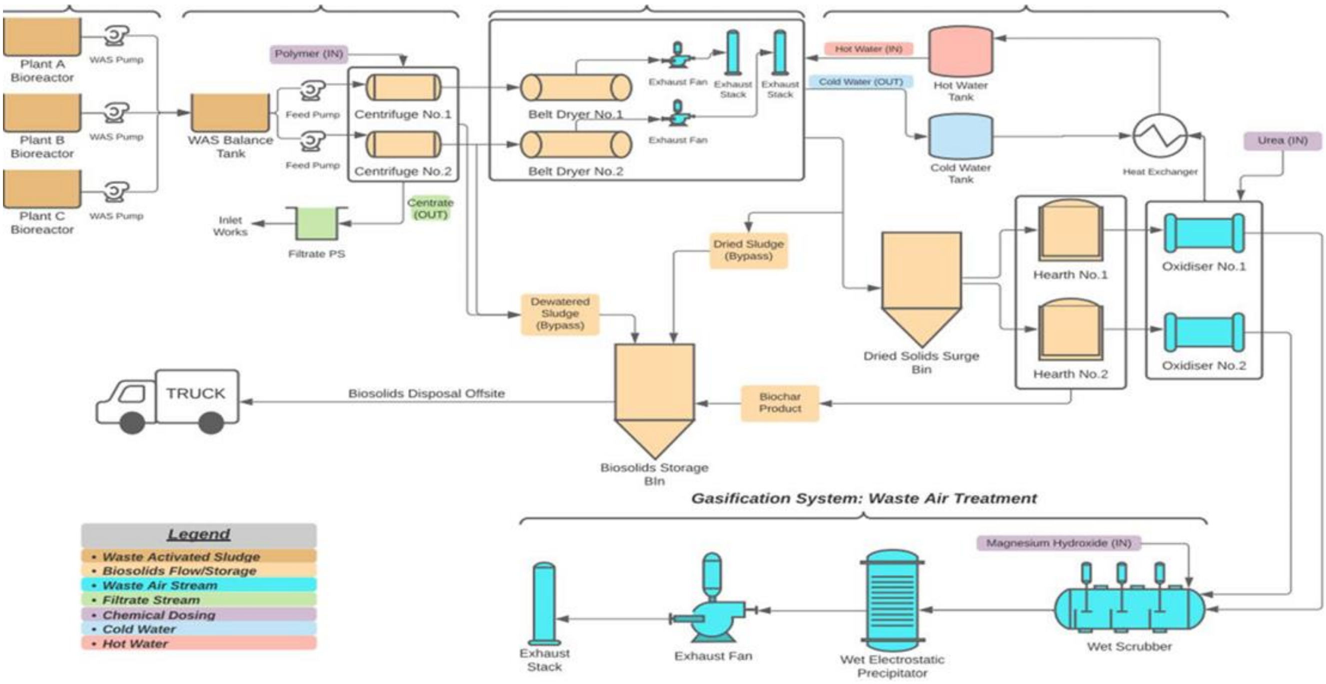

Figure 5-process diagram of Loganholme's full-scale permanent biosolids gasification plant

3.2. DEMONSTRATION PLANT TESTING METHODS

3.2.1. OBJECTIVE OF TEST

For approval to construct the full-scale permanent plant, the demonstration plant had five key objectives (9)

1. Reliability: to demonstrate reliable equipment operation
2. Air emissions: to measure the air emissions from the facility and confirm compliance with Queensland regulations
3. Persistent organic pollutant: to measure the quality of the biochar product and confirm the destruction of POPs
4. Heat balance: to confirm the heat balance for an integrated drying facility
5. Operating costs: to assess operating costs of the facility

Other aspects that were considered were carbon footprint balances and potential value and reuse options.

3.2.2. RELIABILITY

12 runs ranging from 4 to 100 hours continuous operation were completed between 22nd January and 11th of August 2020, totalling 450 hour run times. The operation and reliability of the mechanical, automatic, and monitoring components were assessed to see how reliable they are. Aspects like blockages, heat balance, efficacy of chemical dosing were tested.

3.2.3. AIR EMISSION AND HEAT BALANCE TESTING

During each run, several air emission parameters were tested, as well as heat balance. The parameters and means of testing are summarised in the table below

Table 1- Summary of test runs and parameters tested

Run	Parameters Tested	Date	Means of Testing
4–6-hour runs			
Runs 1	O, SOx, NOx, CO, heat balance	22/01/2020	Online Continuous emission monitoring unit (CEMS unit) installed on final exhaust stack
Run 2	O, SOx, NOx, CO, heat balance	4/03/2020	CEMS unit
Run 3	O, SOx, NOx, CO, heat balance	17/03/2020	CEMS unit
6-hour runs			
Run 4	O, SOx, NOx, CO, heat balance	23/03/2020	CEMS unit
Run 5	O, SOx, NOx, CO, heat balance	2/04/2020	CEMS unit
Run 6	O, SOx, NOx, CO, heat balance	11/06/2020	CEMS unit
Run 7	O, SOx, NOx, CO, heat balance	11/08/2020	CEMS unit
24-hour runs			
Run 8	O, SOx, NOx, CO, heat balance	10/08/2020	Assured Environmental

Run 9	**Full air emissions** (see table below) O, SOx, NOx, CO, heat balance	2/04/2020	Assured Environmental—full air emissions data
48-hour runs			
Run 10	O, SOx, NOx, CO, heat balance	21/07/2020	CEMS unit
100-hour runs			
Run 11	**Full air emissions** (see table below), O, SOx, NOx, CO, heat balance	22/07/2020	Assured Environmental—full air emissions data
Run 12	O, SOx, NOx, CO, heat balance	27/07/2020	CEMS Unit supplied by Assured Environmental

Table 2-All parameters in full air emission tests

Full air emission test	
Parameter	**Unit**
Average source temperature	°C
Flue gas water vapour content	vol-%
Carbon dioxide concentration	vol-%
Oxygen concentration	vol-%
Flue gas molecular weight— dry	kg/Nm3
Flue gas velocity	m/sec
Flue gas volume flow	Nm3/min
Particulate matter	mg/Nm3
Particulate matter at 11% O2	mg/Nm3
Particulate matter emission rate	g/min
Carbon monoxide	mg/Nm3
Carbon monoxide at 11% O2	mg/Nm3
Carbon monoxide emission rate	g/min
Oxides of nitrogen (as NO2)	mg/Nm3
Oxides of nitrogen (as NO2) at 11% O2	mg/Nm3
Oxides of nitrogen (as NO2) emission rate	g/min
Sulfur dioxide	mg/Nm3
Sulfur dioxide (SO2) at 11% O2	mg/Nm3
Sulfur dioxide (SO2) emission rate	g/min
Hydrogen chloride	mg/Nm3
Hydrogen chloride at 11% O2	mg/Nm3
Hydrogen chloride emission rate	g/min
Hydrogen fluoride	mg/Nm3
Hydrogen fluoride at 11% O2	mg/Nm3
Hydrogen fluoride emission rate	g/min
Total VOCs (as n-propane)	mg/Nm3
Total VOCs (as n-propane) at 11% O2	mg/Nm3
Total VOCs (as n-propane) emission rate	g/min
Cadmium	mg/Nm3
Cadmium at 11% O2	mg/Nm3
Cadmium emission rate	g/min

Mercury	mg/Nm3
Mercury at 11% O2	mg/Nm3
Mercury emission rate	g/min
Total heavy metals	mg/Nm3
Total heavy metals (medium bound) at 11% O2	mg/Nm3
Total heavy metals (medium bound) emission rate	g/min
PCDD/F — i-TEQ (medium bound)	mg/Nm3
PCDD/F — i-TEQ (medium bound) at 11% O2	mg/Nm3
PCDD/F — i-TEQ (medium bound) emission rate	g/min
PAHs—BaP (medium bound)	mg/Nm3
PAHs—BaP (medium bound) at 11% O2	mg/Nm3
PAHs—BaP (medium bound) emission rate	g/min
Total PFAS (medium bound) at 11% O2	mg/Nm3
Total PFAS (medium bound) at 11% O2	mg/Nm3
Total PFAS (medium bound) emission rate	g/min
Total TOPA (medium bound)	mg/Nm3
Total TOPA (medium bound) at 11% O2	mg/Nm3
Total TOPA (medium bound) emission rate	g/min
Average odour	ou
Average odour emission rate	ou-m3/min
Hydrogen sulfide	mg/Nm3
Hydrogen sulfide at 11% O2	mg/Nm3
Hydrogen sulfide emission rate	g/min
Sulfur trioxide	mg/Nm3
Sulfur trioxide (as H2SO4) at 11% O2	mg/Nm3
Sulfur trioxide (as H2SO4) emission rate	g/min
Hexavelant chromium	mg/Nm3
Hexavelant chromium at 11% O2	mg/Nm3
Hexavelant chromium at emission rate	g/min

3.2.4. BIOSOLID AND BIOCHAR CHARACTERISATION AND COMPARISON

The different sources of feed biosolids (Source 1 and Source 2) and resultant biochar were characterised by testing structure, calorific value, concentrations of heavy metals and POPs concentration. The imported biosolids were compared to the sludge found in the Loganholme wastewater treatment plant. The parameters tested are summarised in the table below.

To determine how the gasification process affected the biochar nutrient and contaminant concentrations, balance assessments were taken to compare the concentration or destruction rates in nutrients, heavy metals, PFAS, microplastics and carbon mass on biosolids as they go through the gasification process.

Table 3-Biosolid and biochar characterisation parameters

Biosolid and Biochar Characterisation	**Column1**
Parameter	**Unit**
Biosolid Analysis	
Volatile Residue and Calorific value	
Total residue	%
Fixed residue	%
Volatile residue	%
Calorific value	MJ/kg
Heavy Metals	
Arsenic	mg/kg
Cadmium	mg/kg
Chromium	mg/kg
Copper	mg/kg
Lead (Total)	mg/kg
Mercury (Total)	mg/kg
Nickel (Total)	mg/kg
Selenium (Total)	mg/kg
Zinc (Total)	mg/kg
Biochar Analysis	
Arsenic	mg/kg
Cadmium	mg/kg
Chromium	mg/kg
Copper	mg/kg
Lead (Total)	mg/kg
Mercury (Total)	mg/kg
Nickel (Total)	mg/kg
Selenium (Total)	mg/kg
Zinc (Total)	mg/kg
DDT/DDD/DDE (sum)	mg/kg
Alderin	mg/kg
Dieldrin	mg/kg
Chlordane (sum)	mg/kg
Heptachlor (sum)	mg/kg
HCB	mg/kg
Lindane	mg/kg
BHC (sum)	mg/kg
PCD total)	mg/kg
Perfluroalkyl substances found in Biosolid, Biochar, Oxidiser, Scrubber and Stack	
Perfluorobutanesulfonic acid	µg/kg and µg/hour
Perfluoropentane sulfonic acid (PFPeS)	µg/kg and µg/hour
Perfluorohexane sulfonate (PFHxS)	µg/kg and µg/hour
Perfluoroheptane sulfonate (PFHpS)	µg/kg and µg/hour
Perfluorooctane sulfonate (PFOS)	µg/kg and µg/hour
Perfluorodecanesulfonic acid (PFDS)	µg/kg and µg/hour

Perfluorobutanoic acid	µg/kg and µg/hour
Perfluoropentanoic acid (PFPeA)	µg/kg and µg/hour
Perfluorohexanoic acid (PFHxA)	µg/kg and µg/hour
Perfluoroheptanoic acid (PFHpA)	µg/kg and µg/hour
Perfluorooctanoic acid (PFOA)	µg/kg and µg/hour
Perfluorononanoic acid (PFNA)	µg/kg and µg/hour
Perfluorodecanoic acid	µg/kg and µg/hour
Perfluoroundecanoic acid (PFUnA)	µg/kg and µg/hour
Perfluorododecanoic acid (PFDoA)	µg/kg and µg/hour
Perfluorotridecanoic acid (PFTrDA)	µg/kg and µg/hour
Perfluorotetradecanoic acid (PFTeDA)	µg/kg and µg/hour
4:2 Flurotelomersulphonate	µg/kg and µg/hour
6:2 Fluorotelomersulphonate	µg/kg and µg/hour
8:2 Fluorotelomersulphonate	µg/kg and µg/hour
10:2 Fluorotelomersulphonate	µg/kg and µg/hour
Perfluorooctane sulphonamide	µg/kg and µg/hour
N-Methyl-heptadecafluorooctane sulphonamide	µg/kg and µg/hour
N-Ethyl-heptadecafluorooctane sulphonamide	µg/kg and µg/hour
N-Me perfluorooctanesulfonamid oethanol	µg/kg and µg/hour
Microplastics	
Fibre	particles/gram
Fragment	particles/gram
Glitter	particles/gram
Others	particles/gram
Comparative Tests	
Comparison of nutrients in biosolid vs biochar through the gasification process	
Comparison of heavy metals concentrations in biosolid vs biochar through the gasification process	
Assessment of PFAS destruction in biosolids through the gasification process	
Assessment of microplastic destruction in biosolids through the gasification process	
Carbon mass balance	

3.2.5. HEAT BALANCE

A key objective of the integration of this plant is that the overall process is heat- energy neutral where sufficient heat can be recovered from the thermal oxidiser shell and flue gas heat exchanger to operate the dryer without the need for an additional fuel source during normal operation. For the demonstration plant, the steam was re-condensed via a heating coil submerged in a water bath to allow the recovered heat to be measured.

3.2.6. CONSUMABLES OPERATING COSTS

Operating costs related to chemical dosing (urea and magnesium hydroxide), diesel for start-up and power were measured.

3.3. DEMONSTRATION PLANT RESULTS SUMMARY

An in-depth analysis of the results can be found in the public “Logan City Council Technical Report Loganholme Wastewater Treatment Plant Biosolids Gasification Demonstration Plant” (December 2020) (9). Below is a summary of the trial results.

Reliability

Although the process was considered generally reliable, several mechanical and chemical aspects had to be reconsidered or reconfigured to increase the reliability in the full-scale permanent plant. These are explained in detail in the Logan City Council Technical Report (9), and included needing to further minimise dust and particulates throughout the system and associated fouling and carbon monoxide emissions, improving feed metering, improving the heat recovery system and installing a more suitable continuous emission monitoring systems in the full-scale plant. It was also found that magnesium hydroxide was superior to lime for sulfur oxide removal.

Air Emissions

The air emission target limits for the demonstration plant were set in line with the European Commission (2007/76/EC) standards, which are generally more stringent than standards set in the NSW EPA Protection of environment policies. The limits are shown in the table below.

In general, NOx, SO2 and CO stayed below the limits once the runs were stable and biosolid feeds were controlled for dust and calorific value.

Spikes in SO2 during start-ups of the runs were observed and remained elevated until runs became stable (approx. 1h). The full-scale plant will have less of this issue as run times are longer and shut down periods will be reduced to 1-2 days per fortnight. It was also found that swapping lime for magnesium hydroxide had a better effect of keeping SO2 levels down.

The structure and calorific value of the biosolid feed source also affected levels of CO and NOx in the air emission. Biosolids that were pelletised (i.e. not crumbed) created more dust in the system and required higher temperatures and longer contact times in the thermal oxidiser for complete combustion. This resulted in more ashing and higher CO levels in the air discharge. Fresher biosolids (i.e. the source that had less storage time) resulted in higher levels of NOx in the air discharge. In both cases, this will be controlled in the full-scale plant as the biosolid feed will be from one source and will be dried using a thermal dryer which gives a more stable crumbed result. NOx levels are also kept down with urea dosing in the thermal oxidiser. To limit dust and particulates in the system, it was decided to include a wet electrostatic precipitator in the full-scale facility as a further barrier to ensure CO levels are minimised.

Table 4- Demonstration trial target air emission limits

Contaminant	NSW EPA Protection of the environment policies (POEO) Regulation (see Note 2)	European Commission (2000/76/EC) (see Note 3)	Target limits for the demonstration plant
Total solid particulate	50 mg/Nm^3 (dry)	30 mg/Nm^3 (dry)	30 mg/Nm^3 (dry) at 11% O_2
Carbon monoxide (CO)	125 mg/Nm^3 (dry)	-	125 mg/Nm^3 (dry) 11% O_2
Oxides of nitrogen as NO_2	350 mg/Nm^3 (dry)	400 mg/Nm^3 (dry)	400 mg/Nm^3 (dry) at 11% O_2
Sulphur dioxide (SO_2)	-	200 mg/Nm^3 (dry)	200 mg/Nm^3 (dry) at 11% O_2
Hydrogen chloride (HCl)	-	60 mg/Nm^3 (dry)	60 mg/Nm^3 (dry) at 11 % O_2
Total fluoride (as HF)	50 mg/Nm^3 (dry)	4 mg/Nm^3 (dry)	4 mg/Nm^3 (dry) at 11 % O_2
Total volatile organic compounds	20 mg/Nm^3 (dry)	20 mg/Nm^3 (dry)	20 mg/Nm^3 (dry) at 11% O_2
Cadmium and its compounds	0.2 mg/Nm^3 (dry)	0.05 mg/Nm^3 (dry)	0.05 mg/Nm^3 (dry) at 11% O_2
Mercury and its compounds	0.2 mg/Nm^3 (dry)	0.05 mg/Nm^3 (dry)	0.05 mg/Nm^3 (dry) at 11% O_2
Total heavy metals (see Note 1)	1 mg/Nm^3 (dry)	0.5 mg/Nm^3 (dry)	0.5 mg/Nm^3 (dry) at 11% O_2
Dioxins and furans (I-TEQ for PCDDs and PCDFs, including half LOD)	0.1 ng/Sm^3 (dry) at 11% O_2	0.1 ng/Sm^3 (dry)	0.1 ng I-TEQ/Nm3 (dry) at 11 % O_2
Polycyclic aromatic hydrocarbons (PAH)	-	-	-
PFAS extended suite containing 28 compounds (see Note 4)	-	-	-

Biosolid and Biochar Analysis

As the feed biosolids came from two different sources, there was a difference in the total solids, calorific value, heavy metal concentration and levels of organic contaminants in both sources. Source 2 had higher metal and organic contamination sources due to it coming from a more industrial catchment.

Biochar had high levels of carbon, about 4% plant available for of phosphorous and very low levels of nitrogen. The biochar also had a predictable increase in metal concentration compared to the biosolids as the solids dried out. A 50% increase was observed in metals such as chromium, lead, and zinc. However, metals that have lower boiling points and could be volatilised in the hearth such as mercury and arsenic were completely removed in the biochar. Comparing the metal concentration in biochar to the *End of Waste Code for Biosolids* (10) the biosolids here would be classified as Grade C (suitable for agricultural, forestry and soil rehabilitation purposes).

It is important to note that biochar does not have the same chemical properties as dried biosolids. Biochar has significant adsorption properties that have shown decreased leaching of heavy metals, of up to 8-10 times less leaching of copper, nickel and zinc (8). Because of this, a separate and specific biosolid guideline related to biochar is in development, which consider this unique metal-binding chemical property and increase its grading despite concentration of metals.

Persistent Organic Pollutants and Microplastic Destruction

Comparison of 25 PFAS analytes in the biosolids and the resulting biochar indicated that the gasification process destroyed between 91-100% of PFAS in the biosolid. PFAS concentrations were also measured in the oxidiser, wet scrubber and emission stack. The results showed that PFAS was completely volatilised in the hearth and no PFAS concentrations were measured in the downstream components.

Between 3-9 microplastic particles were found per gram of source biosolids. Microplastic destruction rates through the gasification process were associated with microplastic size. Destruction rates of 40-80% were seen on larger particle sizes (1mm) compared to rates of 35-56% for smaller sized particles (63 µm). Overall, the destruction rate is approximately 60% when the source has been though a pelletising thermal drying process. Higher destruction rates are anticipated in the full-scale facility as the belt dryer produces a less condensed source material.

Heat Balance

Heat balance will be negatively affected (i.e. insufficient excess heat produced) if calorific value of biosolids is too low, biosolids are not dewatered enough (more than 20% dry solid content), thermal efficiency is too low as measured by kW of heat input per tonne of water evaporated and if there is higher operating temperature for the dryer.

It was calculated that the heat balance on the Source 1 biosolids were inadequate, mostly due to the lower calorific value. The heat balance on the Source 2 biosolids were adequate. The biosolid calorific value from the Loganholme WWTP sludge is 98% to that of Source 2 and therefore balance calculations indicated that that sufficient heat would be generated in the full-scale plant to allow for auto-heating.

Consumables and Operating Costs

The operating costs were largely related to chemical dosing for emission control and electrical consumption. Maintenance and operator costs were not described in the final technical report, as the demonstration plant was more manually operated compared to the final full-scale plant. The consumables are shown below, and current market rates can be applied to gain operating costs.

Table 5-summary of demonstration trial consumables and power consumption

Power Consumption & Consumables	Consumption
Power Consumption	
Power consumption	94kWH/tonne of biosolid feed
Chemical Dosing	
Urea 0.4% concentration (for Nox mitigation)	20 L/dry tonne
Magnesium hydroxide 55% w/w slurry (for SOx mitigation)	30 L/dry tonne
Diesel for Start Up	
Diesel for 1 gasifier, requiring 2 start-ups per month	100 L/train/month
Boiler shield	
Chemical top up	50 L/month

Carbon footprint calculations

A carbon footprint comparison was made by an independent consultant that compared greenhouse gas emissions from business as usual sludge dewatering and land application operation compared to having a biosolid gasification plant using expected sludge production in 2029. The calculations demonstrated over a 40% reduction of carbon dioxide savings are expected in that year.

Furthermore, the gasification process sequesters 20-25% of the carbon in soil for hundreds to thousands of years (11) which would otherwise have been mineralised (released) in landfill or land application.

Value and reuse options

Bridle Consulting (12) prepared a report in 2020 for Logan City Council to outline the biochar characteristics and potential value and reuse options. These are summarised below.

- Use in agriculture as a fertiliser supplement
- Use as a fuel in boilers, power plants and other industrial combustors
- Use as a fuel and feedstock in cement kilns
- Use as an ingredient to produce lightweight/insulating bricks and pavers
- Use as an industrial adsorbent in place of activated carbon
- Use as a low-grade activated carbon for odour control, and
- Use as a metallurgical reductant.

The report indicated that that most financially valuable reuse pathways were the use of biochar as a soil amendment for the agricultural sector, followed by using biochar as an energy source (with an energy content of 20J/tonne). Figures reported were AUD 265/tonne for biochar soil conditioner and $40/tonne for biochar fuel.

It was also discovered that carbon credits related to the carbon sequestering effect of gasification process could be sold on national and international markets, providing a further revenue stream.

4. FULL-SCALE PERMANENT BIOSOLID GASIFICATION PLANT

The full-scale plant was commissioned in March 2022 and included

- 2 x centrifuges
- 2 x belt dryers
- 2 x hearths
- 2 x thermal oxidisers
- Heat recovery water heating unit
- 1 x wet scrubber
- 1 wet electrostatic precipitator
- Solar panels

The capital cost for construction was approximately AUD 30 million. First biochar from the WWTP was produced in April 2022.

Figure 6-Picture of the Loganholme full-scale biosolid gasification plant during construction

5. POTENTIAL NZ AREAS THAT WOULD BENEFIT FROM BIOSOLID GASIFICATION

Operational and environmental benefits from biosolid gasification such as biosolid volume reduction, reduced metal leaching, destruction of PFAS and microplastics and greenhouse emission savings has been demonstrated in the Loganholme plant as well as in hundreds of studies around the world (7).

Although biosolid gasification plants can accept wet sludges, the benefits gained from of a biosolid gasification plant is more dependent on how dry the biosolid feed is rather than the volume of the feed. As such, biosolid gasification plants are best suited following wastewater treatment plants that either already have biosolid dewatering and/drying in place producing biosolids that >20% dry solids, or have the capability to invest into the often significant capital cost of these dewatering and drying technologies. This process also includes physical, mechanical, and chemical aspects that require specific operation and maintenance and is therefore appropriate in regions that have access to skilled and capable operators.

From this point of view, this process tends to favour more intensified municipalities with a greater rate payer base and access to full time skilled operators such as Auckland, Christchurch, New Plymouth or remote/environmentally restrictive regions that have limited or increasingly expensive access to landfill disposal such as Otago and Wellington.

Downer Australia expect this plant can be effectively scaled down to populations of 20,000 EP. This gives way to for decentralised biosolid gasification plants to take multiple sludge streams from surrounding townships in areas where populations are scattered. Many potential locations fall under that criteria, including regions in the Far North, Gisborne district and the West Coast.

6. CONCLUSIONS

Biosolid gasification is an innovative technology that combines several proven processes into one that can be effectively used and replicated for biosolid management and reuse. Downer, in alliance with Logan Water have successfully demonstrated that this process works and provides significant operational and environmental benefits such as >90% biosolid volume reduction and associated disposal costs, near complete PFAS destruction and >60% microplastic destruction. Furthermore, the biochar by-product that has shown to have a multitude of valuable reuse pathways, including soil conditioning and fuel, which provides additional revenue streams for councils that employ the process.

Balancing the capital costs of this technology as well as the operational requirement, a biosolid gasification plant tends to suit to more intensified regions in NZ where there is a sufficient population base to justify capital investment and ensure access to skilled operators. Additionally, it is feasible to install decentralised biosolid gasification plants in regions with more of a scattered population and treat sludges streams from surrounding townships.

7. ACKNOWLEDGEMENT

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