Final Report

Zero Waste to Landfill (ZWtL)

RMP Challenge

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Contents

1.0 Executive Summary

The primary objective of this project was to demonstrate a pathway for RMPs to achieve zero wastes to landfill. A wide range of typical Australian red meat processor wastes were considered, such as contaminated / soiled cardboard, paper, and plastics; multi-layered and difficult to recycle plastic (e.g., vacuum packaging films); cafeteria and mixed wastes; construction and demolition wastes; green wastes; other in-organic and organic wastes currently sent to landfill.

Available wastes that were suggested by red meat processors included:

- Contaminated plastic
- Contaminated cardboard
- PPE
- Animal parts with inorganics (e.g., ears with tags, oesophagus and clips)
- Paunch and DAF sludge

The primary determinants in assessing feasibility for gasification are moisture content, ash content, calorific value and carbon content, particle size (ratio of surface area to volume). Plastic, cardboard, and PPE are the driest, low-ash, and high calorific value non-recyclable wastes produced by RMPs, so should be the first choice for gasification.

Figure 1: Gasification reactor showing mulched mix of paper, cardboard, and plastic, and residual char

Testing of the waste was done to define the waste composition, syngas and hence energy generated, composition of the char/ash and to provide data for a detailed design phase. The pilot unit was hosted at a suitable R&D / testing facility to utilise existing infrastructure, safety systems, environmental systems / approvals, and skills. Comparative runs were completed using enriched air (50% O2) and pure O2 as the oxidant, with performance data summarised below.

Table 1: Summary of RMP waste gasification performance

	Enriched Air	**Pure O2**
Syngas Calorific Value (MJ/m3)	6 - 9	9.5 - 11
CO (mol%)	20 – 30	30 – 40
H2 (mol%)	20 – 30	25 – 35
CH4 (mol%)	5 – 10	5 – 10
CO2 (mol%)	15 – 25	10 – 20
N2 (mol%)	20 – 30	7 – 15
Max Reactor Temp (DegC)	190	380

There were no reported issues or collection of residual ash/slag in either run due to the low ash content of the feedstock, however, runs should be repeated many times before any definitive assessments can be made. Analyses were done on the feedstock, char, and ash/slag to inform the mass balance and suggest possible uses of by-products in a circular economy. Refer to the report body for a full reporting of major and minor elements.

Table 2: Summary of Proximate and Ultimate Analyses

	Paunch	**Plastic / Cardboard Mixed**	**Char**	**Slag**	**Unit**
Gross Moisture	84.4	14.7	6.3	0.2	% w/w
Volatile Matter	68.4	73.1	4.9	n.d.	% w/w
Fixed Carbon	21.4	13.5	55.0	n.d.	% w/w
Ash Content	7.6	10.0	38.5	n.d.	% w/w
Bulk Density	0.91	0.10	0.18	1.83	Kg/m^3
Carbon	45.63	53.3	50.86	55.21	% w/w
Hydrogen	6.27	8.59	1.54	1.35	% w/w
Nitrogen	1.4	0.27	0.74	0.78	% w/w
Sulphur	0.24	0.52	0.28	0.29	% w/w
Oxygen	38.86	27.32	4.05	7.86	% w/w
Gross Calorific Value (Dry)	19.90	18.80			MJ / kg
Gross Calorific Value (Wet)	3.11	16.09			MJ / kg
Net Calorific Value (Dry)	18.61	17.03			MJ / kg

Net Calorific Value (Wet)	0.96	14.19			MJ / kg

Detailed *ex ante* cost-benefit analyses were completed taking into account Total Capital Investment (supply & installation), operating costs and benefits. Documentation of other co-benefits such as clean energy production, emissions reduction, cost reduction, co-product composition and value, and greenhouse gas lifecycle emissions reductions were considered.

The primary determinant of revenue is the application of the produced syngas, either for use in an existing gas boiler, minimising the invested capital, or directing to a syngas engine for power generation, a higher value but higher capital cost option. For comparison, 1 m3 of syngas at 9 MJ/m3 is worth approximately $0.12 when delivering heat in a gas boiler[1] and $0.20 generating power in a syngas engine[2]. For sites running a solid fuel boiler or with more-aggressive targets for decarbonisation, cost reduction, or energy security, power generation via syngas engine is an obvious choice.

The cost benefit analysis figures operated on are summarised below. The energy cost figures are typical for large consumers on the east coast, with the main variability being due to differences in state based landfill costs. For general municipal waste, these can range from[3]:

- QLD: $88 / tonne regional, $95 / tonne metro
- NSW: $87.30 / tonne in regional area, $151.60 / tonne in metro area
- VIC: $110.79 / tonne industrial regional, $125.90 / tonne industrial metro

Table 3: Cost and energy figures for cost benefit analysis

Waste tonnages per annum	NCV skins: 340 tpa landfilled Paunch: 1,920 tpa composted Manure: 720 tpa composted General waste (plastic, clips, cardboard etc): 4,400 tpa
Average landfill disposal cost	$115 / tonne[4]
Electricity demand	15,162 MWh per year
Electricity cost	$135 / MWh
Heat demand	2,146,925 m3 of natural gas, equivalent to 84,374 GJ per annum
Natural gas cost	$70 / MWh

Feasibility analysis is summarised below

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[1] Assumed 90% heat transfer efficiency and $15/GJ gas

[2] At 40% efficiency and $0.2 / kWh for power inclusive of volume and demand charge.

[3] Consider that there are further surcharges for regulated wastes including animal effluent and residues, food processing wastes, grease trap waste, liquid food processing waste, sewage sludge and residues, tannery wastes,

[4] This is the most variable cost between sites, depends primarily on state and regional / metro area for landfill levy calculation

- Three capacity scenarios considered
- MIHG Plants
    1) 12.5 tpd; 4,166 tpa
    2) 25 tpa; 8,333 tpa
    3) 50 tpa; 16,667 tpa
- Larger plants would require sourcing additional mixed waste from local community

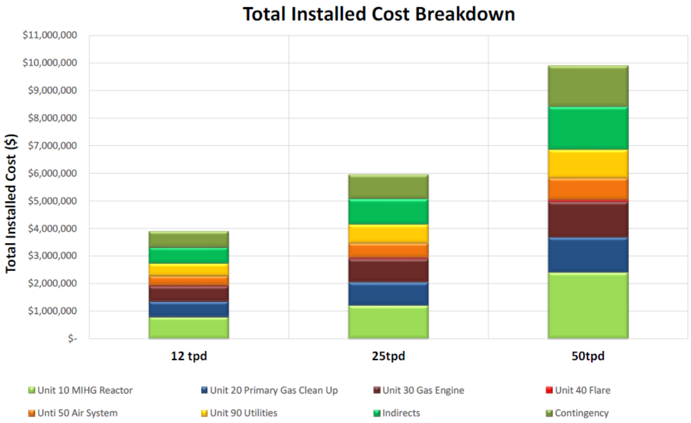

Figure 2: Scale scenarios showing contribution of major plant elements to TIC

Table 4: Summary of feasibility scenarios

Waste gate fee 117 $/t and 2%/yr CPI

Scenario	1	2	3
Capacity (tpd)	12.5	25	50
Capacity (tpa)	4,167	8,333	16,667
Total installed cost ($m)	4.4	6.8	10.6
EBITDA ($/yr, year 3)	319,776	1,243,336	2,858,096
Project IRR (%, real pretax, unlevered)	3.7	16.1	24.4
Project NPV ($)	-1,907,050	3,315,624	12,808,299
LCOE ($/MWh)	166	54	24.4

Waste gate fee 204 $/t and 2%/yr CPI

Scenario	1	2	3
Capacity (tpd)	12.5	25	50
Capacity (tpa)	4,167	8,333	16,667
Total installed cost ($m)	4.4	6.8	10.6
EBITDA ($/yr, year 3)	684,125	1,972,032	4,315,489
Project IRR (%, real pretax, unlevered)	13.5	26.6	37.6
Project NPV ($)	1,209,402	9,548,525	25,274,100
LCOE ($/MWh)	66	-46	-94

Conclusions from the above feasibility analyses are that available wastes produced by red meat processors are insufficient to match energy demand in its entirety i.e., only a portion of consumed power or thermal energy may be offset; small project economics can be very challenging without a higher waste gate fee or additional opportunity cost of landfill levies; and medium-to-large sized projects can be very economic. A key challenge of these scale of projects is the appetite of processors to accept outside organic wastes for recovering energy.

The char from the first run was combusted to preheat the reactor for run 2, whereas in operation at-scale, this would be achieved by two reactors running alternating batches for a semi-continuous process. For sites that are interested in the soil carbon sequestration applications of char, this will require preheating via gas, and must be considered against the energy content of char and the emissions offset potential. Assuming char has a similar calorific value to low quality lignite (brown) coal, the value of preheating 1 kg of char instead of natural gas at $15/GJ is around $0.2. Sites interested in soil carbon sequestration should check their eligibility and method for measurement, calculation, and credit creation with the Clean Energy Regulator[5]

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[5] http://www.cleanenergyregulator.gov.au/ERF/Choosing-a-project-type/Opportunities-for-the-land-sector/Agricultural-methods/estimating-soil-organic-carbon-sequestration-using-measurement-and-models-method

2.0 Introduction

2.1 Background

RMPs are challenged to achieve zero waste to landfill as certain contaminated / soiled materials (e.g., paper and cardboard having fat / protein / blood) and difficult to recycle plastics (e.g., laminated and multi-layer plastics such as vacuum packaging) are either not accepted for recycling, have no recycling option or are prohibitively expensive to recycle. Further, food processing, abattoir and animal wastes from food processing can be regulated wastes which attract a higher landfilling fee per tonne (in Qld, Category 2 which attracts a $105 /tonne landfill levy).

This project supported a pilot Energy from Waste (EfW) plant (e.g., pyrolysis/gasification) located at a third-party facility with detailed analysis of inputs and outputs (e.g. ash used as a soil conditioner). A key roadblock to sustainability technology adoption is the 'knowledge gap' and technical intensity of plant – high CapEx, modularity options, plant operability and environmental permitting. The proposed project documented how EfW can deliver a zero waste solution for Australian RMPs whilst filling the knowledge gap. Capital and operational costs for a commercial operation were estimated based upon the pilot results along with the benefits of reduced waste management costs, no landfill levy, landfill reduction, clean energy production, and emissions reduction. Representative samples were sourced from interested RMPs with reporting on feedstock performance, gas, and char quality. The host ran the pilot plant with an ex-post cost benefit analysis to determine the technical and economic viability of EfW for zero landfill.

The 2020 Environmental Performance Review showed the average figure for waste sent to landfill at 11.9 kg / t HSCW, a very large increase of 102% compared to the 2015 value of 5.9 kg / t HSCW. Sites in this EPR reported a wider scope of wastes sent to landfill, whereas the 2015 figure was calculated for only solid waste sent to landfill. Sites did not break down the components of their general waste, however large volumes of liquids (e.g., waste oil, non-renderable blood, un-dewatered paunch) sent to landfill are believed to have skewed these results. Due to increases in state-based landfill levies, it is not consistent with expectation that the processing sector has increased tonnages of wastes disposed to landfill. The context of the COVID period should also be considered here, where the demand for non-recyclable face masks, gloves, sanitizer, and wipes would have contributed to additional landfilled waste. There was a large variability between respondent sites in volumes of wastes produced and disposal method.

Assessments of waste produced by red meat processing have shown that the primary tonnages are organic and mostly comprised of paunch solids, manure, and yard wastes, along with sludge and pond crusts from wastewater treatment. Other organic wastes include carcasses (if not rendered), hides (if not tanned), and cardboard/paper. Organic wastes produced by red meat processing tend to be recycled where possible (i.e., not contaminated).

Inorganic wastes include rubber, ash, plastic, waste salt, scrap metal along with batteries, oil, and general waste. With the exception of uncontaminated plastic, scrap metal, and oil, these wastes tend to be landfilled.

2.2 Wildfire Energy MIHG Technology

Wildfire has developed a revolutionary batch process for gasification of biomass and other wastes which utilizes a unique horizontal configuration with a moving injection point. The MIHG process involves loading a large volume of biomass or other feedstock into a reactor and converting the feedstock through gasification by injecting an oxidant and recovering the produced syngas. Unlike all other gasification technologies, the oxidant injection point is moved during the gasification process to sweep the active gasification zone through the bed of feedstock. The MIHG process is illustrated in Figure 3.

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https://www.legislation.gov.au/Details/F2021L01696

Figure 3: MIHG process showing novel moving injection point of oxidant

An injection pipe is inserted near the bottom of the reactor and a production pipe is installed at the end of the reactor. After the reactor is filled with feedstock the top is sealed off by closing the top cover. The feedstock at the production end of the cell is then ignited and air or oxygen is supplied through the injection lance to gasify the feedstock at atmospheric pressure. The injection point is gradually retracted to sweep the hot gasification zone through the bed. Syngas is produced and flows to the production pipe for use in downstream applications.

Once the injection point has been fully swept through the bed, injection of oxidant is stopped, and the reactor is cooled and purged. The top is then opened to permit refilling with fresh feedstock. Unconverted char is simply left in the reactor to be consumed in the next run. Ash falls to the bottom which is removed using a hydraulic ram when the reactor is offline. Feedstock with high moisture content can be dried prior to gasification by injecting drying media along a manifold at the base of the bed which has been heated using waste heat from the gas engine. The process is conducted in batches and requires at least two reactors to maintain continuous gas production, where one reactor is in service while the other reactor is being filled. The reactors are designed to avoid complete consumption of feedstock at the walls leaving a layer of char which provides thermal insulation for the process and limits the temperature of the walls.

The raw syngas must be cooled and cleaned of particulates, tars, and contaminants prior to utilization. The gas clean-up process produces liquid by-products which are re-injected into the gasifier to produce hydrogen by steam-char reactions. A flow diagram showing the integration of the MIHG process into a waste to energy plant is shown in Figure 4.

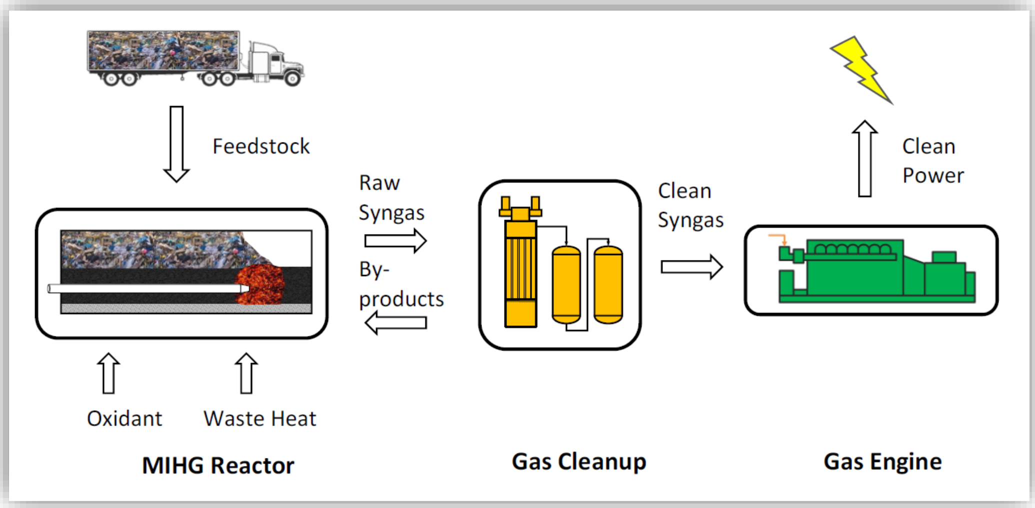

Figure 4: Waste to energy options of MIHG process

In addition to electricity, syngas produced by the MIHG process can also be used to produce other bioproducts such as alcohols, hydrocarbons and hydrogen as shown in Figure 5. These alternative products will be evaluated during the demonstration phase to determine their suitability for future phases.

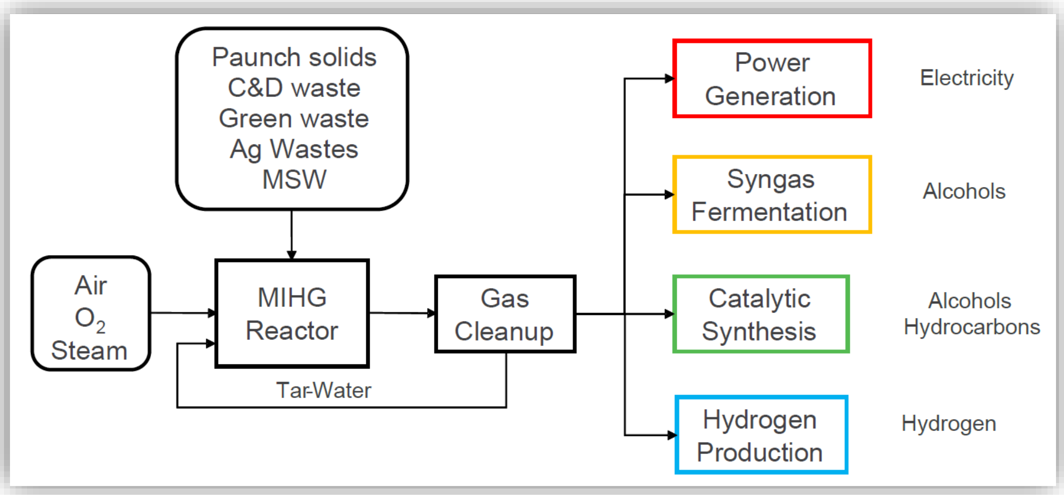

Figure 5: Energy offtake options of MIHG process

The MIHG technology provides the following key benefits compared to other gasification and pyrolysis technologies:

- Suitable for a wide range of feedstocks without pre-treatment
- Simple, robust design is less sensitive to feedstock variability and contamination
- No materials handling plant - uses existing mobile plant already available at waste management sites
- Combined storage, drying and gasification in the one unit
- Avoids bed and grate issues which are common in other gasifier designs
- Recycle and conversion of tar-water effluent, avoiding significant costs for wastewater treatment

As a true gasification technology incorporating syngas clean-up, the MIHG technology also provides the following benefits over two-stage gasification and combustion technologies as follows:

- The ability to utilise gas-fuelled power generation equipment such as gas engines, gas turbines and fuel cells providing higher thermal efficiency and lower CAPEX
- The potential to produce other products such as hydrogen, fuels, chemicals, and gases
- Reduced gas clean-up equipment sizes due to the much lower volume flow rate of gas
- Lower emissions due to cleaning of the gas prior to combustion and lower generation of dioxins/furans due to the reducing conditions in gasification

2.3 Pilot Plant

Wildfire's MIHG pilot plant is located in Brisbane and shown in Figure 6 and Figure 7. The pilot plant includes a scaled down MIHG reactor plus a gas clean-up system which is similar to the proposed commercial design.

The pilot plant MIHG reactor is constructed from steel with an insulating layer of ceramic fibre and bricks. A stainless-steel injection pipe is inserted into the reactor through a gland and is used to convey the air to the injection point. An ignition tool is inserted into the injection pipe to ignite the biomass near the end of the injection pipe. The gas produced from the reactor is sent to a gas clean-up unit including an electrostatic precipitator, indirect cooler and activated carbon bed. At the outlet of the gas clean-up unit the gas flow and composition are measured before the gas is sent to the flare.

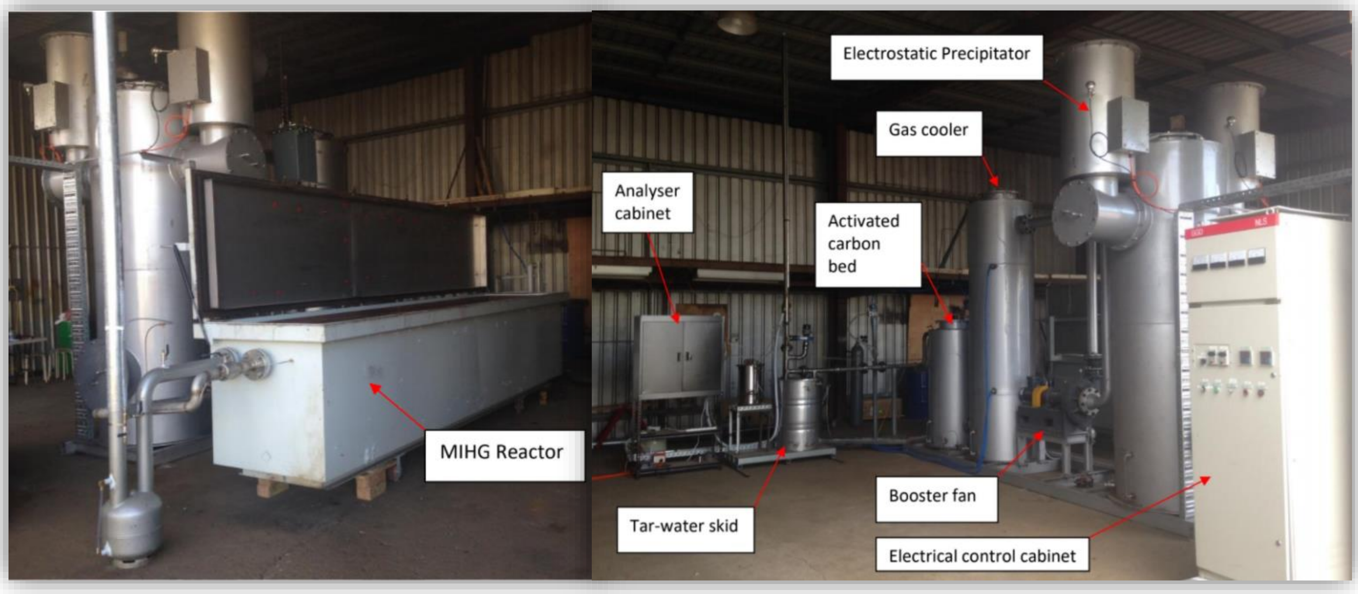

Figure 6: Wildfire Energy 1 tpd pilot plant

The pilot plant has successfully achieved its design gas quality and production rate over a series of runs and proven the moving injection concept. Example data from one of the test runs is shown in Figure 7.

Over 54 individual gasification runs have been completed in the pilot plant, with a typical duration of 4 – 6 hours. A wide range of feedstocks have successfully been gasified in the pilot plant including:

- Urban biomass and green waste from household green bins
- Green waste from a commercial waste composter
- C&I / C&D wastes from a commercial waste operator
- MSW including paper, plastic, and organics
- Biomass woodchips
- Livestock effluents & biosolids from a piggery
- Automotive shredder residues from a metal recycler
- Biosolids from wastewater treatment plants
- Wheat straw from agricultural farms

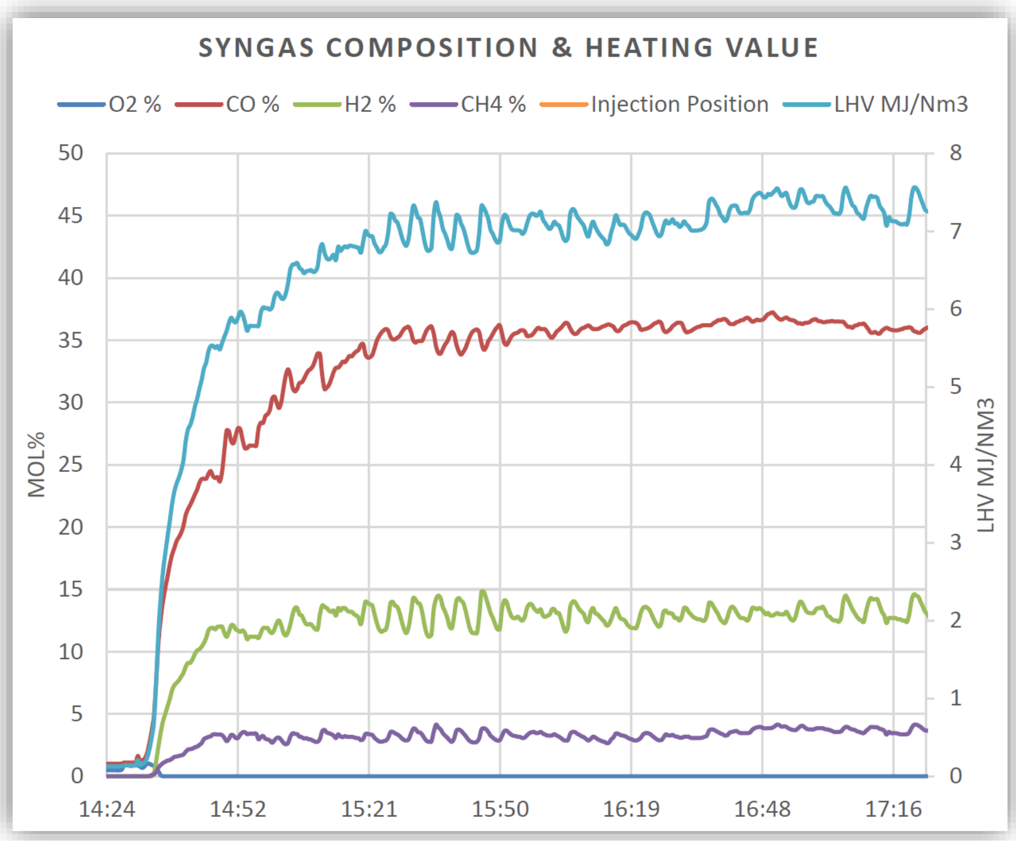

Figure 7: Syngas quality example data

An indicative plant layout is shown in Figure 8 showing the full commercial facility for a 4,000 tpa plant. The minimum plot space required is approximately 30m x 60m = 1800m2.

A single reactor design can be used to process 2,000 tpa of waste. Multiple modules can be used to process waste quantities up to around 50,000 tpa.

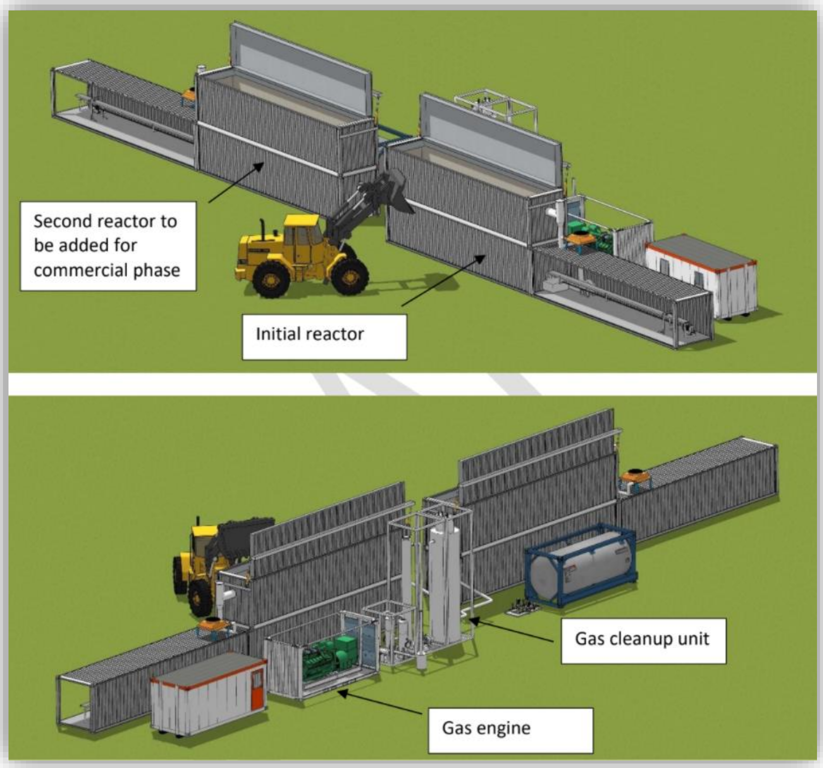

Figure 8: Wildfire Energy MIHG modular plants

For processing of wastes, the MIHG process has the following benefits:

- Simple batch loading using existing mobile equipment
- Integrated pre-drying system, that enables material to be dried prior to gasification in the same equipment (without need for separate dedicated drying equipment)
- Ability to co-process a wide range of residual wastes, such as MSW, green waste and commercial wastes
- Vitreous/sintered bottom ash
- Production of clean syngas suitable for gas engine firing

3.0 Project Objectives

The objective of the pilot plant runs were a technical assessment of the gasification performance of solid wastes from red meat processing in Wildfire Energy's MIHG pilot plant, located at Murarrie in Queensland, Australia.

Wildfire tested different feedstock blends as part of the pre-feasibility study, labelled Feedstock A, Feedstock B and Feedstock C and performed two-runs in the pilot plant with each feedstock. Feedstock blends included paper, plastic, and cardboard as the most attractive wastes, along with paunch and sludge(s) to enable extrapolation out to full scale.

The key performance indicators include syngas quality, flowrate, conversion rate, fate of contaminants and the identification of any issues handling and processing the waste.

4.0 Methodology

COVID-19 has interrupted the supply chains of international vendors of small-scale modular waste to energy systems and pushed lead times for delivery to Australia to outside the milestone due dates of this project. Hence, an off-site solution was investigated, where wastes from participating sites were trucked to an established gasification plant in SEQ for feedstock and emissions testing.

Turning the project focus to an established gasification pilot plant hosted offsite by a third party delivered the following project benefits:

- Reduce project costs. No need for significant equipment and sunken capital expense, instead a smaller operating cost in equipment hire, professional services, and transport costs.
- Streamline project delivery. Removing the need for extensive council and environmental approvals process. This was expected to be a major time-sink and in-kind cost to this project in the amount of effort required to approve energy from waste projects
- Reduced effort requirement on processors. A general trend observed in the industry during the COVID period, particularly in states with stricter lockdown(s) is scaling back of resource focus to core business with less attention given to other projects. This arrangement will allow processors to maintain focus on core business while still participating and generating project knowledge.
- Further to COVID restrictions, some sites have completely banned visitors from attending site (even from within the same company) hence RMP site access restrictions could dramatically impact the timing and completion of the pilot trials. Completing the trial at a third-party facility increases the opportunity for site visits and inspection of the facilities.
- Maximise technical success. Wildfire Energy has deep experience in gasifying a range of feedstocks and can easily overcome any operational issues that may arise including material handling, moisture, composition and mix fraction LHV, bridging, etc.
- Environmental approvals for running pilots were a potential major hurdle for the running pyrolysis / gasification systems. Completing the pilot runs at a facility that has environmental approvals in place negates the risk of obtaining approvals for a new facility.
- More in-depth analysis of char characteristics, major, and minor species of syngas.

Each feedstock consisted of a mixture of:

- Paunch or sludge solids from abattoir operations,
- Plastic packaging, bags, and films from meat packing operations,
- Cardboard and paper packaging
- Textiles, clothes, plastic from discarded PPE, and
- General waste.

The waste may be classified as either general waste, category 2 regulated waste or unregulated waste. The composition of each of the three feedstocks was assumed to be sufficiently different from site to site so that it made sense to perform separate runs. For each feedstock, a total of 3 m^3 was required for the pilot plant trials. The material was supplied in 1 m^3 bulk-bags or other containers such as IBCs that could be suitability handled onsite at the pilot plant. Putrescible wastes were pre-bagged in plastic bags to contain odours.

Paunch solids typically have a moisture content of between 45 and 80wt%. In order to improve gasification performance, the moisture content should be <30%. In the commercial MIHG system, the moisture content will be reduced using an integrated closed-loop pre-drying system using waste heat from the gas engine.

The current pilot plant has an open-loop pre-drying system which is not suitable for drying the proposed feedstocks. Moisture content was controlled via:

- Work with sites to reduce the moisture content prior to delivery (via drying in open air or mechanical dewatering)
- Mix the paunch solids with other wastes that are lower in moisture and representative of solid waste from red meat processing

Feedstock analysis was undertaken as required. The minimum analyses included the following:

- Heavy metals,
- Ultimate analysis (including C, H, O, N, Cl, S),
- Proximate analysis (including VM, FC, Ash, Moisture), and
- Bulk density.

To minimise batch variation, multiple samples were collected from the waste and blended into a single composite sample for laboratory analysis.

For each gasification run, the following outputs were recorded and summarised:

- Air (and oxygen, if used) injection rate,
- Syngas flow rate and major species composition (CO, H2, CO2, N2, CH4),
- Estimate of feedstock conversion,
- Temperature measurements,
- Photos of feed inside reactor after loading and after gasification.

The monitoring results were used to calculate an approximate mass balance for each run.

Gasification results in two solid by-products: 1) mineral matter in the form of slag and 2) char. These two by-products were sampled at the end of each gasification run to provide average, composite samples for each of the feedstocks. Each of the composite samples were analysed for the following:

- Heavy metals,
- Ultimate and proximate analysis.

It should be noted that in commercial operations, the char generated in the MIHG process is an intermediate and not normally a final product – i.e., the char generated in one batch run is consumed in a subsequent batch run of the process leaving only mineral matter as a by-product for disposal or re-use. Depending on the properties of the char, it may be possible to valorise through use as a soil amendment or carbon credit. It should be noted however that this will require a larger operating cost and reduction in decarbonisation potential as some fossil fuel will be required to preheat the reactor if char is removed.

To support potential future environmental approvals, Wildfire Energy arranged for extensive minor species measurement of the syngas during the gasification runs of one of the feedstocks.

The collection of the samples and detailed analysis was performed by an external contractor, certified by NATA, capable of performing the environmental measurements to appropriate Australian and International Standards. Wildfire Energy has used Assured Environmental in the past for the detailed minor species analysis and used them again for this work scope.

Wildfire Energy installed a syngas engine in mid-2022. Wildfire did its best to have the engine operational during the period of this work, however the extensive minor species measurements was not possible be undertaken on the exhaust from the gas engine; instead, the sampling was undertaken on the clean syngas and the exhaust emissions estimated as done previously.

The detailed minor species of interest generally include:

- Total solid particulate,
- Dioxins and furans precursors such as chlorinated compounds
- Oxides of nitrogen (as NO2),
- Carbon monoxide (CO),

- Sulphur dioxide (SO2),
- Hydrogen chloride (HCl),
- Total fluoride (as HF),
- Hydrogen sulphide (H2S),
- Volatile organic compounds (VOC),
- Heavy metals (antimony, arsenic, cadmium, lead, mercury, beryllium, chromium, cobalt, manganese, nickel, selenium, and vanadium and their compounds),
- Polycyclic aromatic hydrocarbons (PAHs), and
- Dioxins and furans (PCDD/Fs).

2 runs of approximately 6 hours each were completed per site, one with 100% O2 as the oxidant, and the other with enriched air at 50% O2 as the oxidant. The selected feedstock was a mulched mix of cardboard, paper, plastics, and animal parts, including oesophagus and clips, ears and tags, paunch, and DAF sludge.

The operating methodology was as follows:

1. Load reactor with feedstock
2. Insert injection lance
3. Close lid and purge reactor with N2
4. Start electrical ignition heater and start injecting O2 at end of reactor bed
5. Gasification and lance retraction until lance is fully retracted
6. Stop O2 injection and purge with N2
7. Once cooled, purge with air and open lid

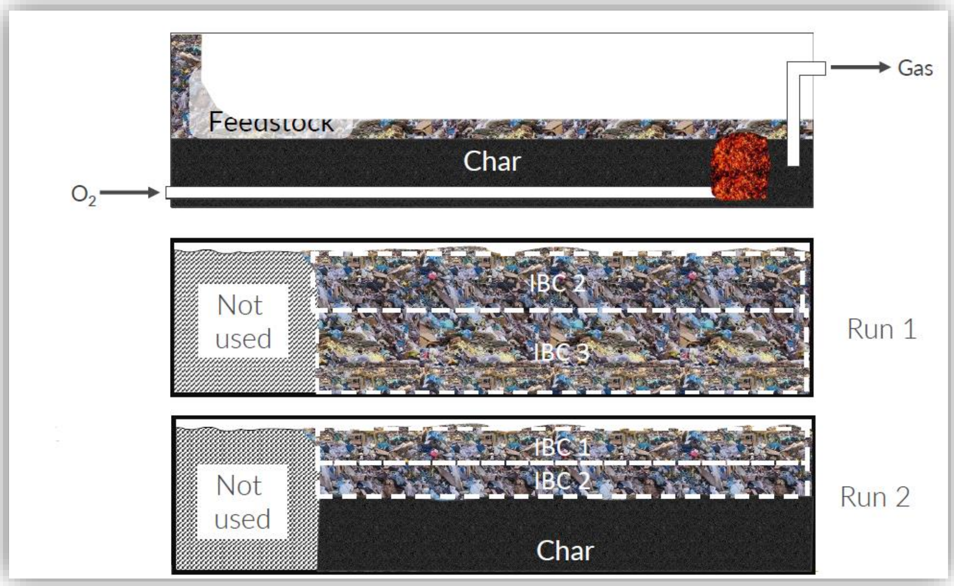

Figure 9: Schematic of reactor setup for two gasification runs. Note that the char remains after run 1, where it is subsequently used to bring the reactor to temperature for run 2

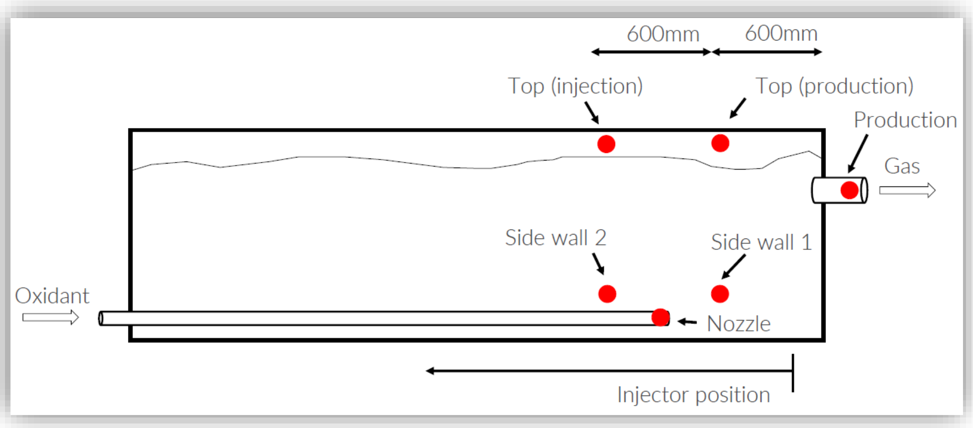

Figure 10: Temperature probe locations inside the MIHG reactor

5.0 Project Outcomes

5.1 Available Wastes

Wastes that were identified by participating sites as being suitable for this project are shown below.

Figure 11: Contaminated cardboard and plastic. Noted was the need to shred large sheets to improve packing density along with available surface area for gasification

Figure 12: Ears and tags. Tags will be an ideal gasification substrate, whereas ears may contain a prohibitively high moisture content. If possible, these should be separated, or blended with drier feedstocks.

Figure 13: Used PPE

Figure 14: Oesophagi and clips. Likewise with ears and tags, clips are expected to be a viable gasification substrate, with oesophagi likely to be better sent to rendering or other value add where a primary $/kg revenue can be generated

Figure 15: Clean plastic. This will be a strong feedstock for gasification

Figure 16: Office waste

Figure 17: Production and change room waste. Where possible, inerts such as aluminium cans should be removed as they produce no benefit in gasification and instead may present issues with materials handling and heat transfer

Figure 18: Blood lab waste

Figure 19: Paunch and DAF sludge. It was reported that these organic wastes had been put through a screw press, with some residual free water remaining. These wastes are better suited to composting, but should be investigated for gasification as this will enable extrapolation out to full scale performance

5.2 Feedstock Selection

For each participant site, one run was completed using just the available plastic, paper, and cardboard, then another was done factoring in paunch and sludge in order to give direct performance data of including the less attractive (i.e., high moisture, high ash, high inerts, and low calorific value) wastes. This was an important step in assessing the capacity of this technology to extrapolate to full commercial scale and achieve the objective of diverting wastes from landfill.

Due to the moving oxidant injection point in the Wildfire MIHG process, it was not necessary to blend wastes into a homogenous mix, instead placing shredded wastes in layers was sufficient.

A rough estimate of the composition of the wastes provided is as follows:

- 40 – 45% cardboard and paper
- 35 – 40% plastic
- 15 – 20% organic wastes

5.3 Gasification Performance

5.3.1 Plastic, Paper, Cardboard Mix

5.3.1.1 Oxidant of Enriched Air 50% O2

Figure 20: Run 1 showing compacted feedstock and remaining char/slag

The results from this run were as follows

- Gas calorific value 9.53 MJ/m3[6]
- CO 20 – 30 mol%

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[6] Approximately 25% the calorific value of natural gas

- H_2 20 – 30 mol%
- CH_4 5 – 10 mol%
- CO_2 15 – 25 mol%
- N_2 20 – 30 mol%

As mentioned earlier, the char from the first run was combusted to preheat the reactor for run 2, whereas in operation at-scale, this would be achieved by two reactors running alternating batches for a semi-continuous process. For sites that are interested in the soil carbon sequestration applications of char, this will require preheating via gas, and must be considered against the energy content of char and the emissions offset potential. Assuming char has a similar calorific value to low quality lignite (brown) coal, the value of preheating 1 kg of char instead of natural gas at $15/GJ is around $0.2. Sites interested in soil carbon sequestration should check their eligibility and method for measurement, calculation, and credit creation with the Clean Energy Regulator[7]

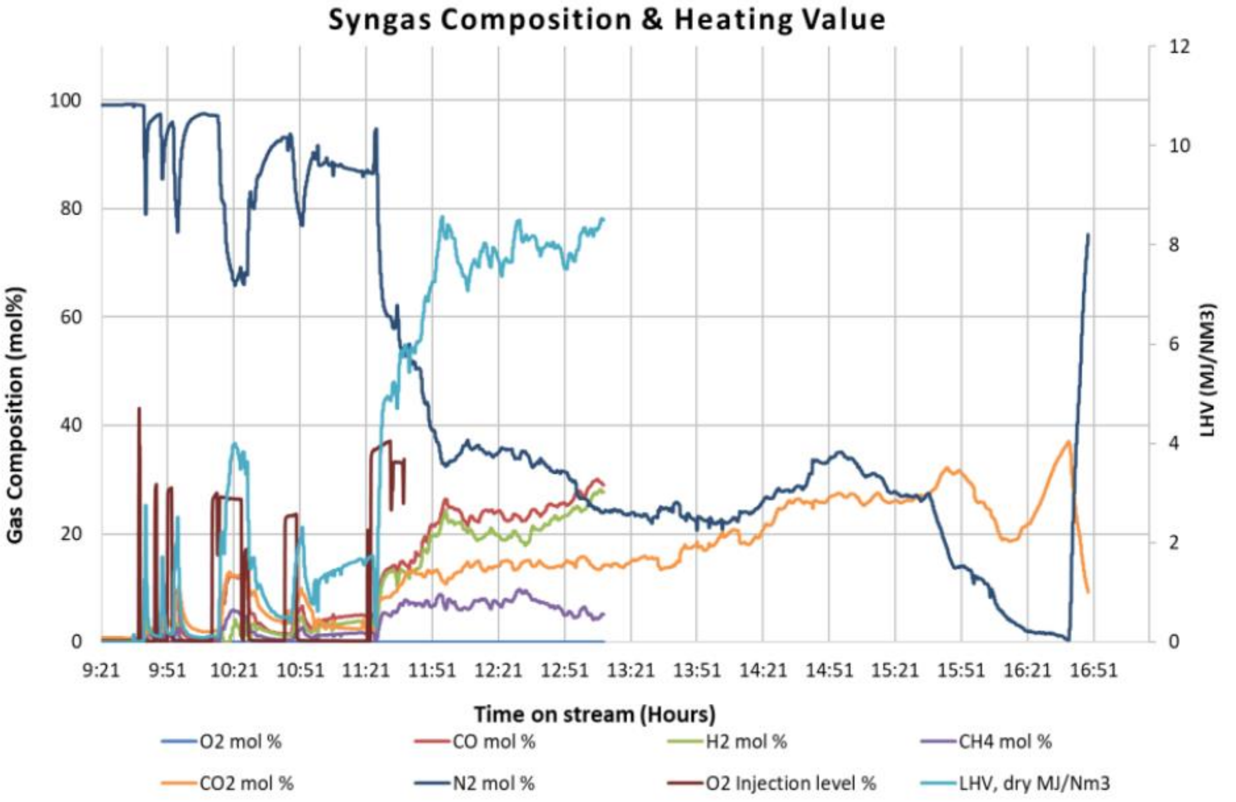

Figure 21: Run 1 syngas composition and heating value

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[7] http://www.cleanenergyregulator.gov.au/ERF/Choosing-a-project-type/Opportunities-for-the-land-sector/Agricultural-methods/estimating-soil-organic-carbon-sequestration-using-measurement-and-models-method

https://www.legislation.gov.au/Details/F2021L01696

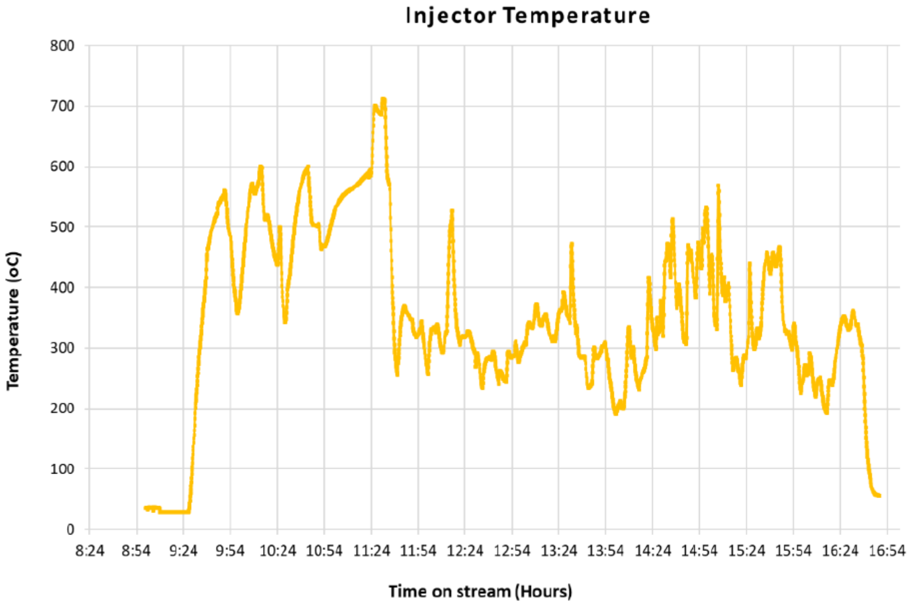

Figure 22: Injector temperature over run duration

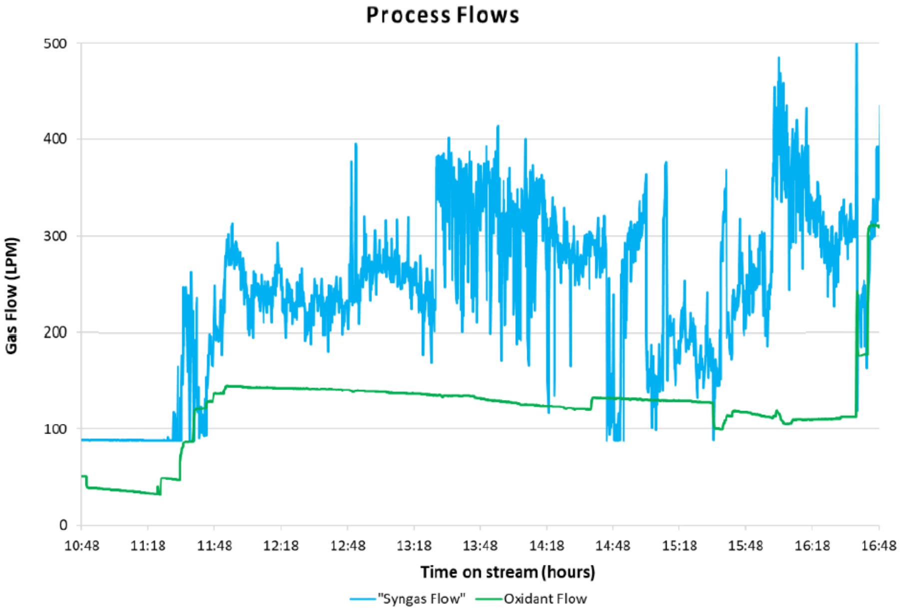

Figure 23: Flow of syngas over run duration

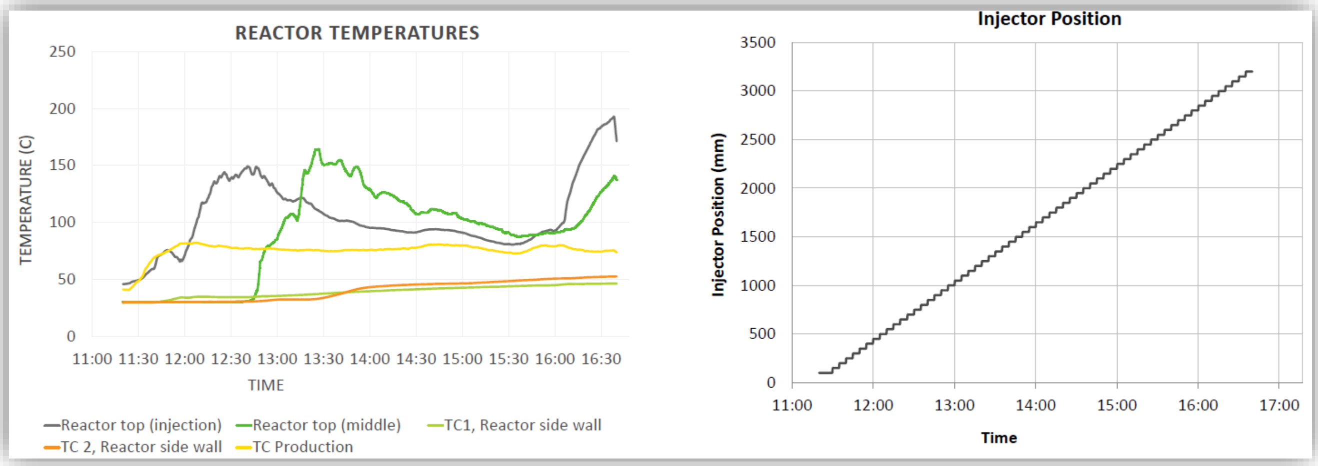

Figure 24: Run 2 reactor temperature and injector position

5.3.1.2 Oxidant of 100% O2

Figure 25: Run 2 showing compacted feedstock and remaining char/slag

The results from this run were as follows

- Gas calorific value 9.5 – 11 MJ/m3[8]
- CO 30 – 40 mol%
- H2 25 – 35 mol%
- CH4 5 – 10 mol%
- CO2 10 – 20 mol%
- N2 7 – 15 mol%

A key observation here is that using pure O2 as the oxidant significantly increases the calorific value by approximately 50% and increases the mole fraction of combustible gases and reduces CO2 and N2, improving the flame speed, flame temperature, and heat transfer capacity of the syngas. During the cost benefit analysis, it was important to factor the material cost of pure O2 as the oxidant, along with the increased safety risk of storing pure O2. This will be compared against the viability of enriched air as an oxidant, to determine if the increased cost and risk is justified.

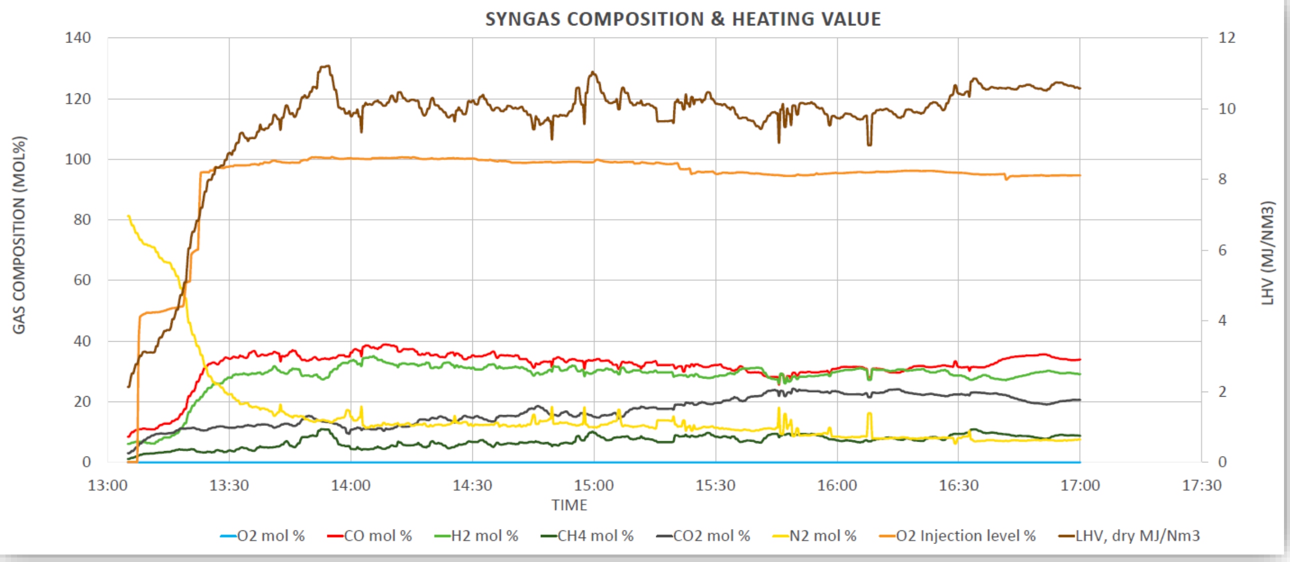

Figure 26: Run 2 syngas composition and heating value

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[8] Approximately 26 – 31% the calorific value of natural gas

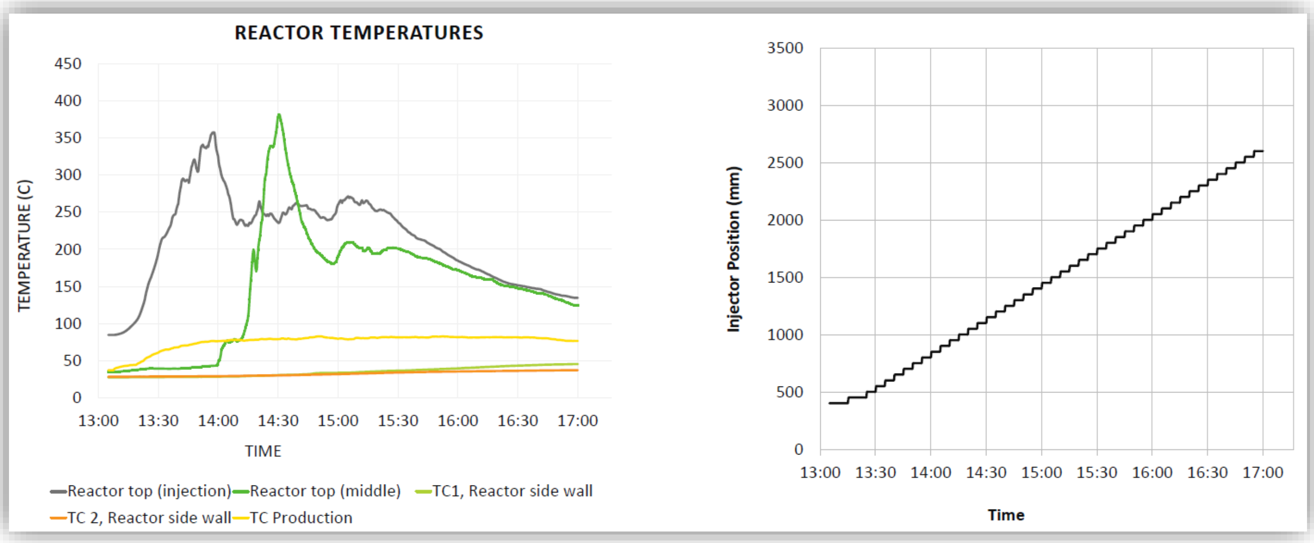


Figure 27: Run 2 reactor temperature and injector position

There were no reported issues or collection of residual ash/slag in either run due to the low ash content of the feedstock, however, runs should be repeated many times before any definitive assessments can be made.

5.3.2 Mix Including Paunch and Sludge

To enable extrapolation out to a full-scale vision of zero waste to landfill for all produced RMP wastes, runs were completed using a mixture of cardboard, paper, plastic, and paunch.

Figure 28: MIHG reactor packed with non-recyclable organics, inorganics, and paunch

Figure 29: Residual material after gasification run

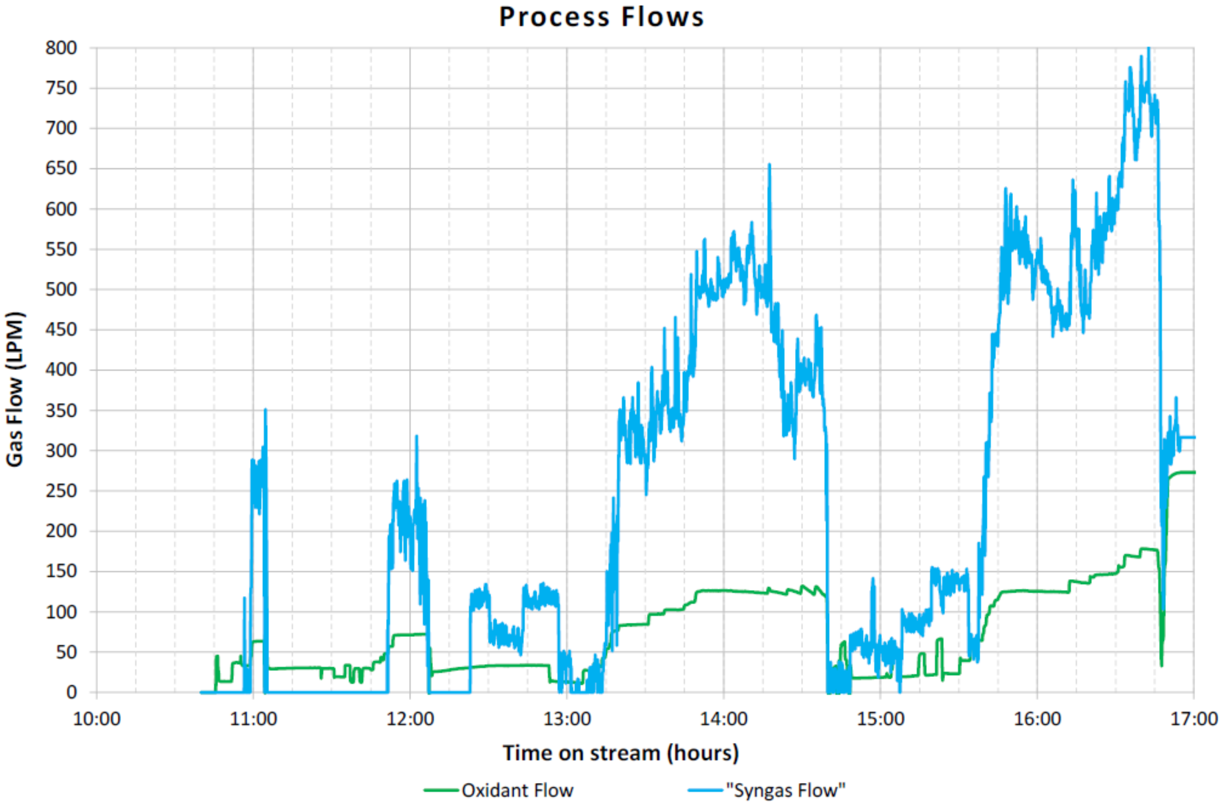


Figure 30: Syngas flow over run duration

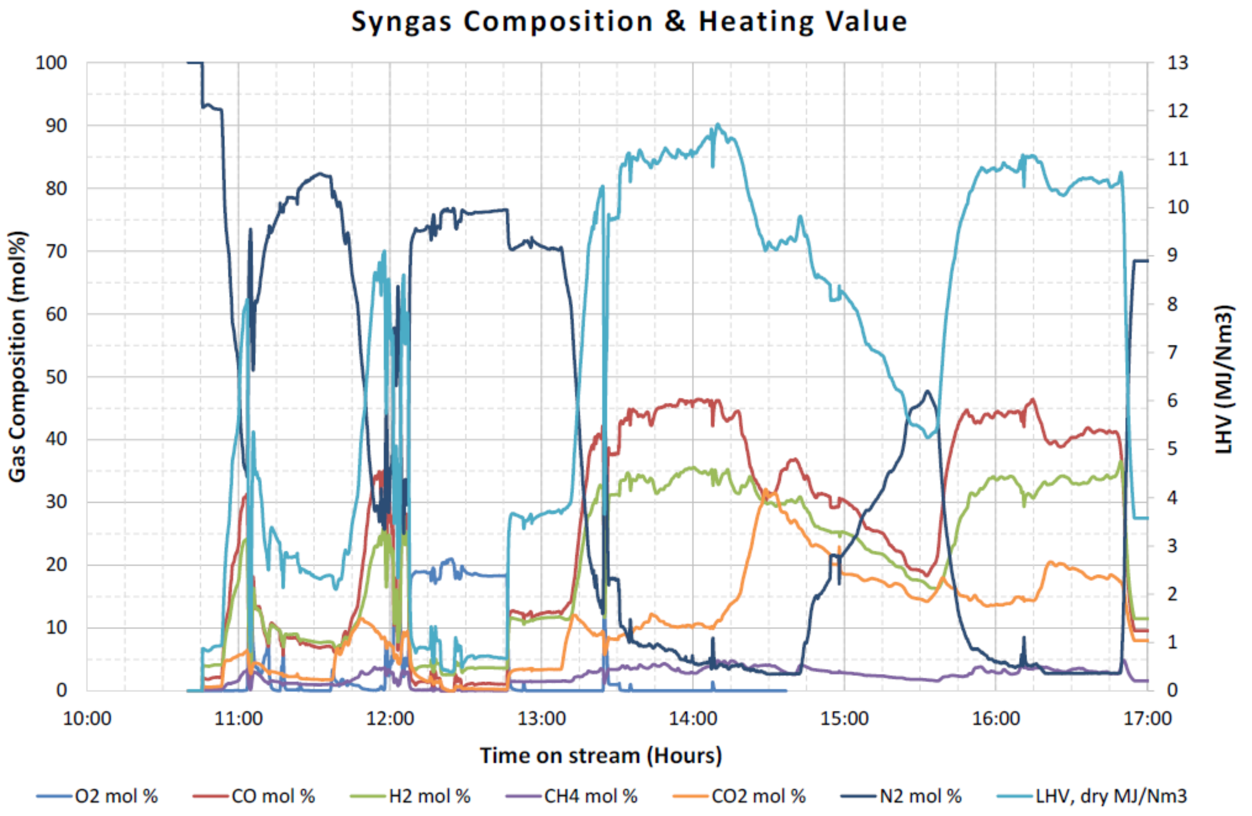


Figure 31: Syngas composition and heating value over run duration

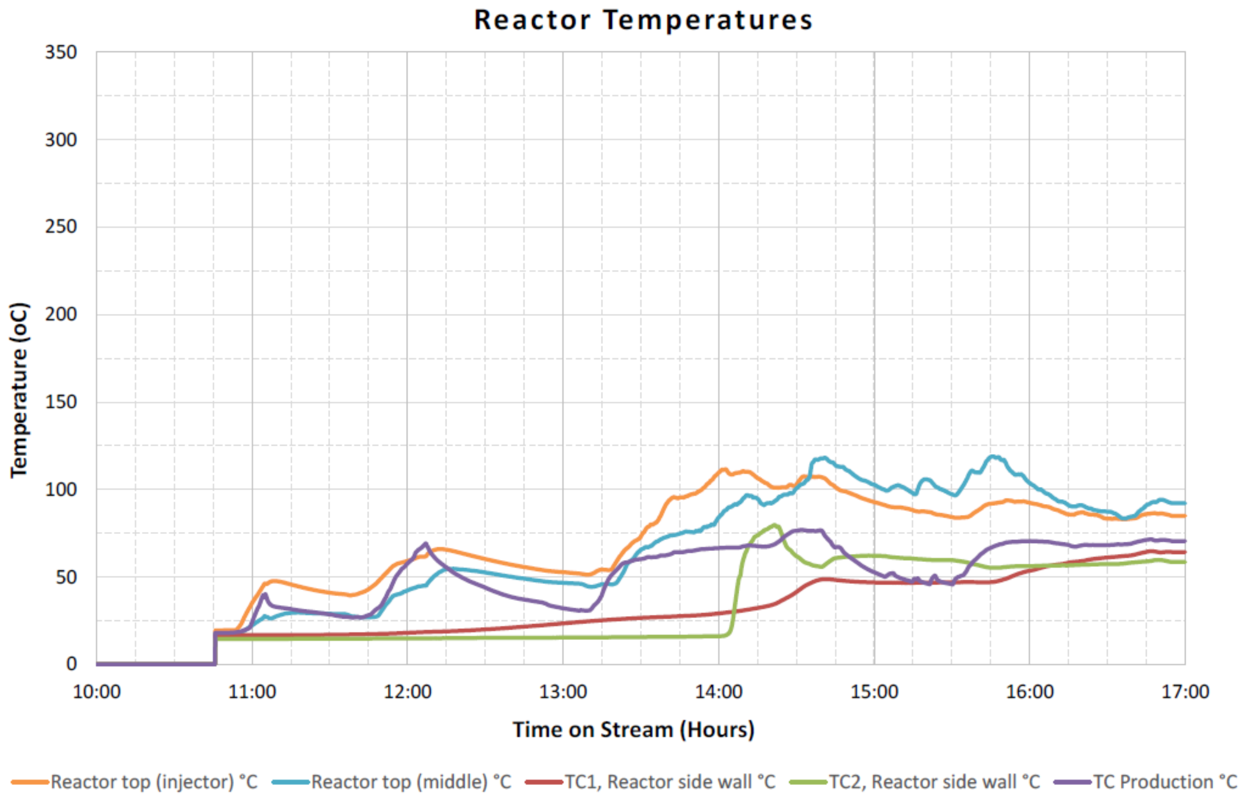


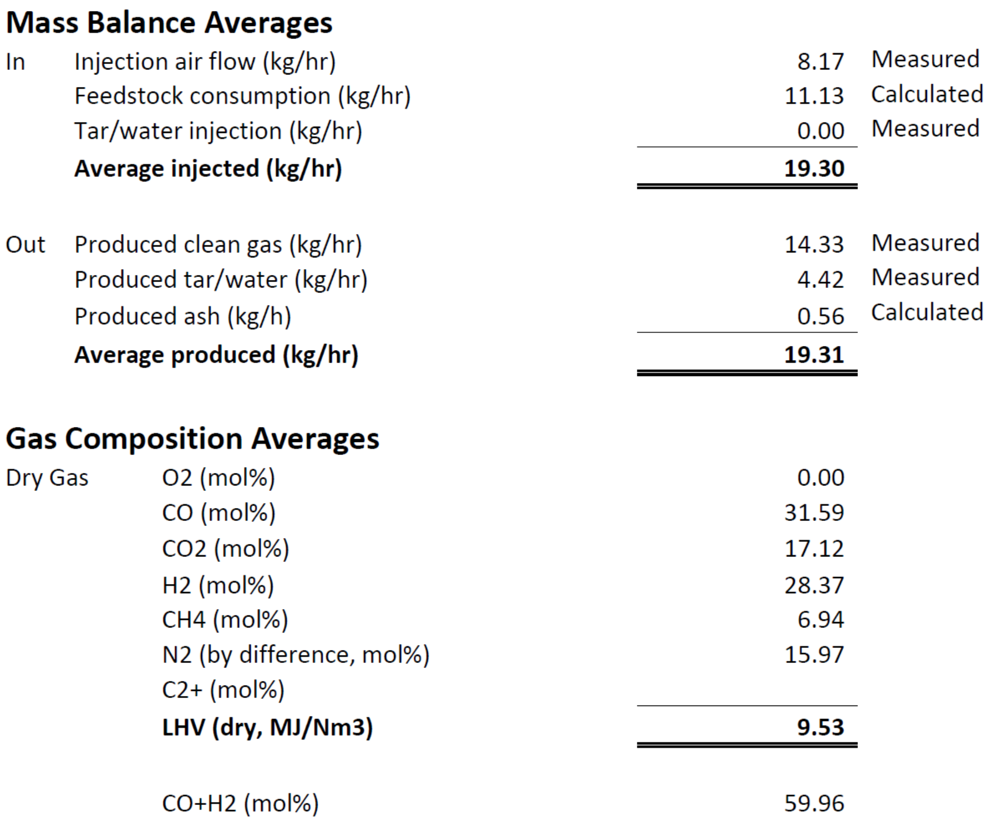
Figure 32: Reactor temperature over run duration

As expected, the higher moisture content of paunch noticeably reduces the reactor temperature over the run, leading to periodic drops in gas production and calorific value over the run duration. Thus, paunch, sludge, or other RMP organics should be mechanically dewatered to as dry as possible and then left to further air dry before application in any thermal energy recovery technology.

5.4 Heat and Mass Balances

5.4.1 Plastic, Paper, and Cardboard

Using enriched air as an oxidant, summary of mass balance data is shown below.



Mass Balance Averages

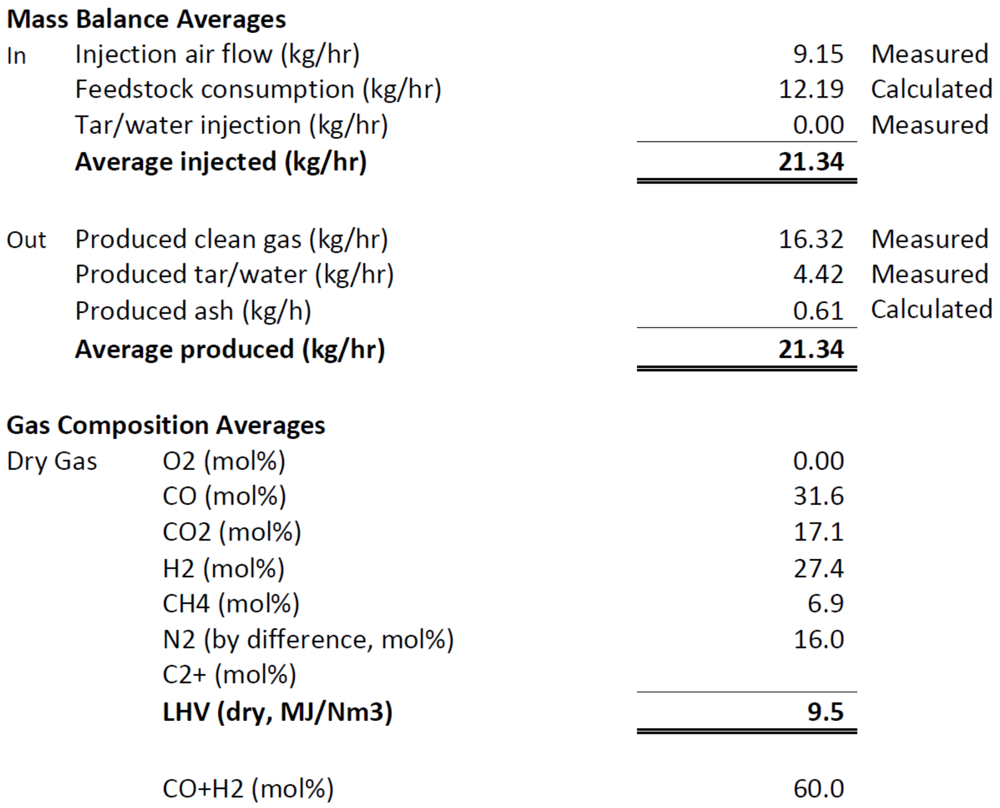
In	Injection air flow (kg/hr)	8.17	Measured
	Feedstock consumption (kg/hr)	11.13	Calculated
	Tar/water injection (kg/hr)	0.00	Measured
	Average injected (kg/hr)	**19.30**	
Out	Produced clean gas (kg/hr)	14.33	Measured
	Produced tar/water (kg/hr)	4.42	Measured
	Produced ash (kg/h)	0.56	Calculated
	Average produced (kg/hr)	**19.31**	

Gas Composition Averages

Dry Gas	O2 (mol%)	0.00
	CO (mol%)	31.59
	CO2 (mol%)	17.12
	H2 (mol%)	28.37
	CH4 (mol%)	6.94
	N2 (by difference, mol%)	15.97
	C2+ (mol%)	
	LHV (dry, MJ/Nm3)	**9.53**
	CO+H2 (mol%)	59.96

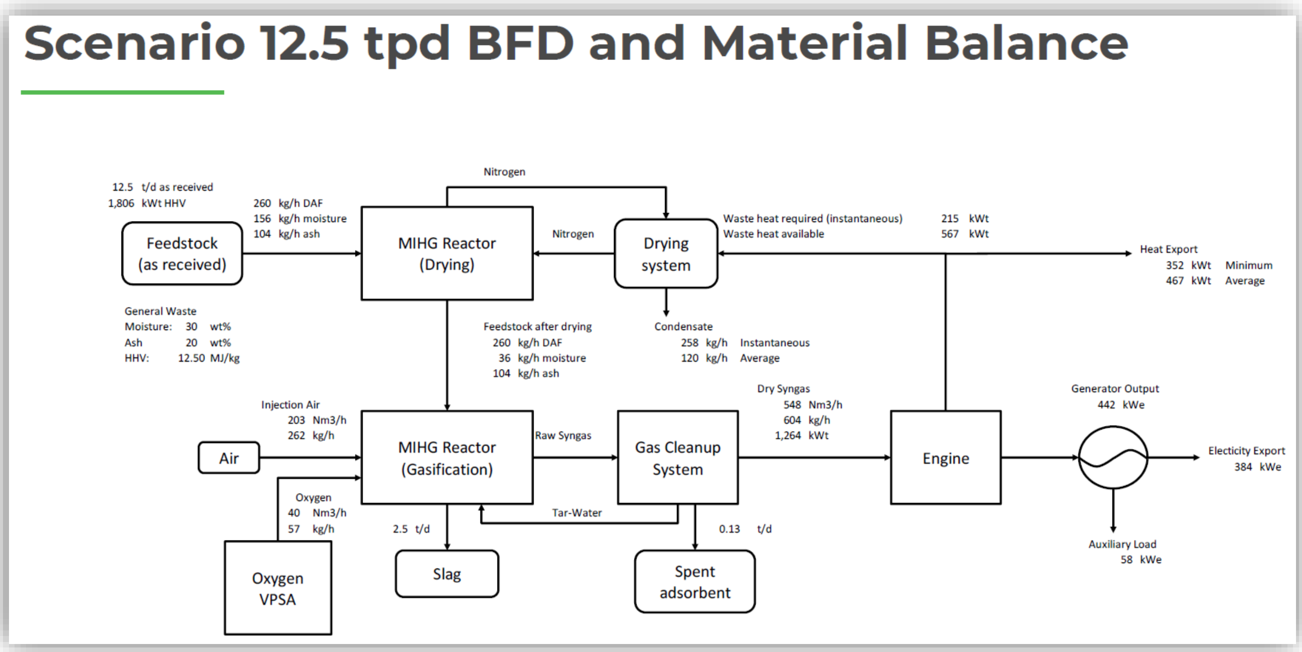
Figure 33: Run 1 mass balance averages. Syngas calorific value 9.53 MJ / m3

Using 100% O2 as the oxidant, mass balance data is calculated as



Mass Balance Averages			
In	Injection air flow (kg/hr)	9.15	Measured
	Feedstock consumption (kg/hr)	12.19	Calculated
	Tar/water injection (kg/hr)	0.00	Measured
	Average injected (kg/hr)	**21.34**	
Out	Produced clean gas (kg/hr)	16.32	Measured
	Produced tar/water (kg/hr)	4.42	Measured
	Produced ash (kg/h)	0.61	Calculated
	Average produced (kg/hr)	**21.34**	
Gas Composition Averages			
Dry Gas	O2 (mol%)	0.00	
	CO (mol%)	31.6	
	CO2 (mol%)	17.1	
	H2 (mol%)	27.4	
	CH4 (mol%)	6.9	
	N2 (by difference, mol%)	16.0	
	C2+ (mol%)		
	LHV (dry, MJ/Nm3)	**9.5**	
	CO+H2 (mol%)	60.0	

Figure 34: Run 2 mass balance averages. Syngas calorific value averaged over 10 MJ/m3



Scenario 12.5 tpd BFD and Material Balance

Figure 35: Block flow diagram and material balance for 4,000 tpa feedstock scenario

The above material balance shows that at 12.5 tpd or approximately all of the non-recyclable wastes produced by a medium-sized processor can produce up to 467 kWt of heat on average recovered as 95 DegC hot water in a water-glycerol loop and 384 kWe of electrical energy. For comparison, steady state hot water load for sterilisation and hand washing for a 950 head pd processor has been calculated previously at 636 kWt, peaking up to 2.5 MWt at the beginning and end of shifts, and refrigeration load is typically more than 1 MWe for a 24/7 load. Thus, for this scale, all of the available energy produced could be used by the plant.

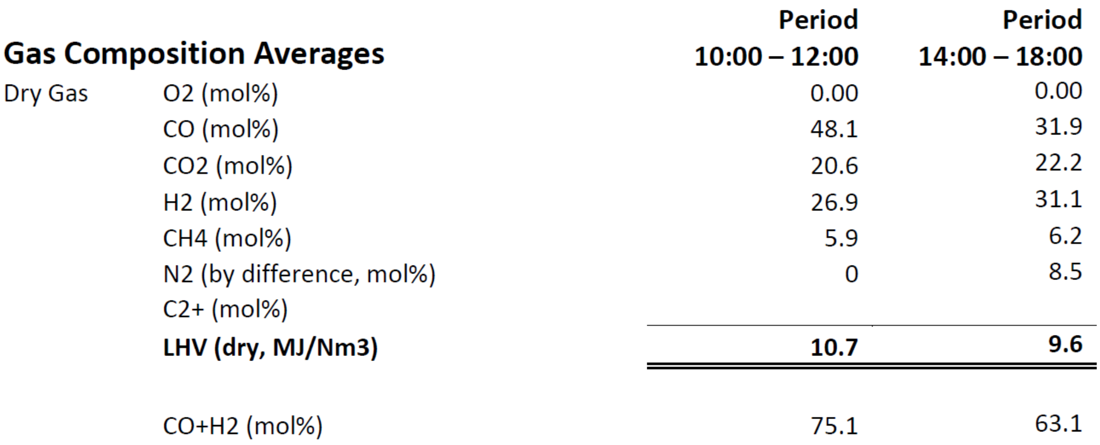
At larger scales of 25 and 50 tpd, it is likely that all of the produced electricity could be consumed by the plant (average loads generally 2-3 MWe peaking up to 5 MWe depending on specific site operations), with no requirement for grid export. At these larger scales, all of the recovered heat will not be able to be utilised as hot water for sterilisation and hand washing, so must be first used as boiler makeup water, and then boosted to steam generation at ~4-6 bar.

Solids entering the process were reduced by 79.2% w/w. Ash composition works are ongoing, however the ash composition is expected to be well suited to adding to material for composting given its composition, expected to be predominantly silica, calcium, and potassium, along with smaller amounts (0.7 to 3%) of magnesium, sodium, aluminium, iron, manganese and phosphorus[9] with lower levels of S (0.35%) and Cl (0.08%), with Br, I, F likely below detectable levels; and small amount of Sb, Cu, Sn, Ti, and Zn (expected to be in the ppm). There is a clear logical case to make around materials sourced from food processing plants and canteens are of a known source, are of food grade and would not have heavy metal contamination. Research has shown that construction and demolition wastes (floor coverings, textiles, frames) are routinely the source of contamination in ash[10] hence thermal processing of these types of materials will need to be considered from a mass balance and risk perspective.

5.5 Composition and Uses

5.5.1 Syngas and Stack Emissions

Gas compositions were measured over each run, with average values shown below



Gas Composition Averages		Period 10:00 – 12:00	Period 14:00 – 18:00
Dry Gas	O2 (mol%)	0.00	0.00
	CO (mol%)	48.1	31.9
	CO2 (mol%)	20.6	22.2
	H2 (mol%)	26.9	31.1
	CH4 (mol%)	5.9	6.2
	N2 (by difference, mol%)	0	8.5
	C2+ (mol%)		
	LHV (dry, MJ/Nm3)	**10.7**	**9.6**
	CO+H2 (mol%)	75.1	63.1

Figure 36: Syngas composition averages

The recovered syngas was measured to be between 25% - 30% of the energy content of pipeline natural gas. Use cases for syngas will be similar to biogas as produced by many RMPS, in that to minimise the payback period, reticulation to an existing gas boiler is preferred. However, to maximise net present value over the life of the project, conversion to electricity will provide a much greater return.

Projected stack emissions at standard conditions are below.

Table 5: Stack emission composition data

	Unit	Result

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[9] "Geochemistry of Ash", 2014_1_24.pdf (potopk.com.pl), accessed 27 May 2022.
[10] www.sciencedirect.com/science/article/pii/S0301479719309715, accessed 27 May 2022.

Average flue gas temperature	degC	22
Average flue gas moisture	Vol%	2.8
Dry gas molecular weight	Kg/Nm3	0.88
Oxygen	Vol%	1.4
Methane	Vol%	4.9
Carbon Dioxide	Vol%	17.1
Nitrogen	Vol%	16.0
Carbon Monoxide	Vol%	24.7
Particulate Matter	mg/Nm3	5.0
Sulphur Dioxide	mg/Nm3	<2.8
Nitrogen Oxides	mg/Nm3	216
Hydrogen Sulphide	mg/Nm3	<2
Carbonyl Sulphide	mg/Nm3	62
Hydrogen Fluoride	mg/Nm3	<0.08
Cadmium	ug/Nm3	0.4
Chromium	ug/Nm3	1.6
Lead	ug/Nm3	21.9
Manganese	ug/Nm3	0.8
Nickel	ug/Nm3	4.9
Zinc	ug/Nm3	16.2
Mercury	ug/Nm3	1.8
Total Heavy Metals	ug/Nm3	55.0
Total Polycyclic Aromatic Hydrocarbons	ug/Nm3	243
Acetone	mg/Nm3	0.10
Hexane	mg/Nm3	1.22
Benzene	mg/Nm3	8.04
Toluene	mg/Nm3	0.05
Total VOCs	mg/Nm3	6.2

The above analyses results shows that the gas cleaning unit is successfully removing contaminants and that forecast air emissions from a MIHG plant would be well below accepted standards in all Australian states.

5.5.2 Char

A photo of the residual char after the first run is shown below.

Figure 37: Residual char

Lab analyses of collected char is reported below

Table 6: Char physical parameters and proximate analysis

	Unit	Result
Gross Moisture	Wt %	6.3
Volatile Matter	Wt %	4.9
Fixed Carbon	Wt %	55.0
Ash Content	Wt %	38.5
Bulk Density	Kg/m3	0.18

Table 7: Char ultimate analysis

	Unit	Result
Carbon	Wt %	50.86

Hydrogen	Wt %	1.54
Nitrogen	Wt %	0.74
Sulphur	Wt %	0.28
Oxygen	Wt %	4.05

Table 8: Char halide analysis

	Unit	**Result**
Chlorine	Wt %	2.41
Bromine	Wt %	n.d.
Fluorine	Wt %	n.d.
Iodine	Wt %	n.d.
Total Halides	Wt %	2.41

Table 9: Char major and minor elements analysis

	Unit	**Result**
Aluminium	Wt %	1.7
Calcium	Wt %	8.5
Iron	Wt %	0.67
Potassium	Wt %	0.49
Magnesium	Wt %	0.47
Sodium	Wt %	0.56
Phosphorous	Wt %	0.98
Silicon	Wt %	0.16
Titanium	Wt %	0.06
Arsenic	mg/kg	2
Cadmium	mg/kg	2.7
Chromium	mg/kg	120
Cobalt	mg/kg	4.2
Copper	mg/kg	360
Manganese	mg/kg	270

Mercury	mg/kg	<0.05
Molybdenum	mg/kg	9
Nickel	mg/kg	150
Lead	mg/kg	9
Antimony	mg/kg	58
Selenium	mg/kg	<2
Thallium	mg/kg	<1
Vanadium	mg/kg	6.8

Emissions reduction versus creation of abatement credits (otherwise known as carbon offsets) is a huge area of debate. For example, Green Peace has called for an end to carbon offsets and for companies to cut their own emissions[11]. ZWtL offers the following opportunities for RMPs to reduce their own emissions:

[1] avoided landfill emissions (Scope 3).

[2] avoided waste haulage emissions (routinely Scope 3 for RMPs).

[3] reduced Scope 1 emissions for generating heat / steam from fossil fuels.

[4] reduced Scope 2 emissions associated with grid power.

As a general guide, pursuing an Emissions reduction Fund (ERF) project registered with the Clean Energy Regulator (CER) to generate Australian Carbon Credit Units (ACCUs) may cost towards $20,000 p.a. in set-up, auditing, project management, and internal costs. Hence, ERF projects are suited to large abatement projects. Considering [1] in detail: 4000 tpa of mixed waste is estimated to equate to 972 t CO2-e pa. Assuming annual costs of $20k, the project would be break even at $AUS 20.58 / t CO2-e. ERF ACCUs are currently valued at $AUS 29 with forward pricing in 2027 valued at $AUS 33.48[12], with European credits valued at $AUS 116.73[13]. Taking a risk minimisation approach and taking the above information into account, one option is to not generate ACCUs but rather communicate the activities of the ZWtL project towards reducing in-house emissions and hence assisting RMPs to progress towards "Zero Carbon".

Where the char created contains nutrients that adhere to the requirements of a soil management plant, that exists the opportunity for the char to be used for abatement of emissions via Soil Carbon projects. This may be well suited to vertically integrated RMI companies. In the short term, a trial could be undertaken as a future project to determine the suitability of ZWtL char for soil carbon projects.

5.5.3 Ash / Slag

Table 10: Slag physical parameters and proximate analysis

	Unit	Result
Gross Moisture	Wt %	0.2

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[11] www.cnbc.com/2021/10/07/greenpeace-calls-for-end-to-carbon-offsets.html
[12] ACCUs.com.au
[13] carboncredits.com/carbon-prices-today

Volatile Matter	Wt %	n.d.
Fixed Carbon	Wt %	n.d.
Ash Content	Wt %	n.d.
Bulk Density	Kg/m3	1.83

Table 11: Slag ultimate analysis

	Unit	**Result**
Carbon	Wt %	55.21
Hydrogen	Wt %	1.35
Nitrogen	Wt %	0.78
Sulphur	Wt %	0.29
Oxygen	Wt %	7.86

Table 12: Slag major and minor elements analysis

	Unit	**Result**
Aluminium	Wt %	5.4
Calcium	Wt %	27
Iron	Wt %	1.8
Potassium	Wt %	0.13
Magnesium	Wt %	1.5
Sodium	Wt %	0.51
Phosphorous	Wt %	2.1
Silicon	Wt %	0.27
Titanium	Wt %	0.23
Arsenic	mg/kg	2
Cadmium	mg/kg	<0.3
Chromium	mg/kg	45
Cobalt	mg/kg	11
Copper	mg/kg	430
Manganese	mg/kg	1100

Mercury	mg/kg	<0.05
Molybdenum	mg/kg	8
Nickel	mg/kg	200
Lead	mg/kg	<1
Antimony	mg/kg	11
Selenium	mg/kg	<2
Thallium	mg/kg	<1
Vanadium	mg/kg	14

5.6 Cost Benefit Analyses

5.6.1 Plastic, Paper, and Cardboard

The following were the inputs required to complete a detailed cost benefit analysis of installing an at-scale MIHG gasification plant at the first participant site in regional NSW.

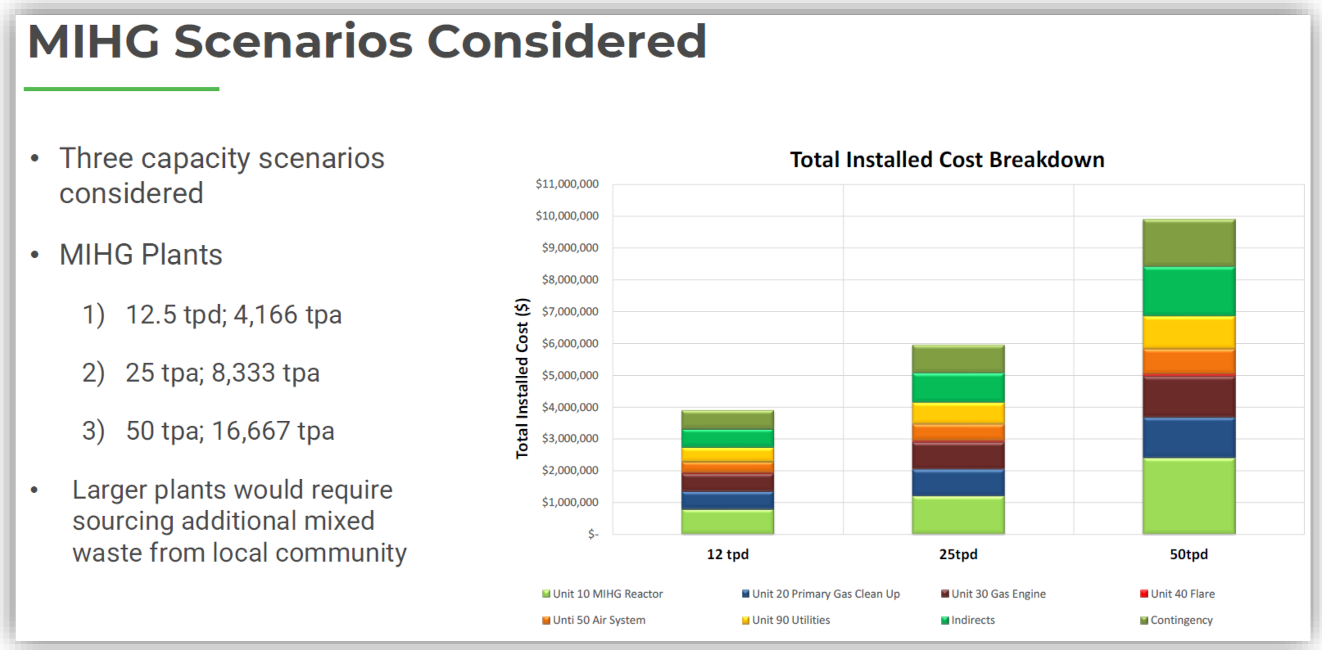
- Waste tonnages per annum; approx. composition
    - NCV skins 340 tpa landfilled
    - Paunch 1,920 tpa composted
    - Manure 720 tpa composted
    - 4,400 tpa classified as general waste landfilled. Assumed to be plastic, clips, contaminated cardboard etc
- Average disposal cost $/tonne
    - In a non-levied area from NSW EPA waste levy rate 2021-22 regional area of $84.7 / tonne. Likely to be applied at some point in the future
    - Average waste disposal cost is $115 / tonne
- Forecast on future disposal costs
    - Big change, longer horizon: may be added to regional levied area
    - Increases with CPI each year according to NSW waste regulation
    - Short term: any forecasted increases in disposal cost?
- Electricity demand: 15,162 MWh
- Electricity cost: 135 $/MWh
- Heat demand: 2,146,925 m3 of natural gas per annum, equivalent to 84,374 GJ
- Natural gas cost $70 /MWh or $19.4 GJ

The primary determinant of revenue is the application of the produced syngas, either for use in an existing gas boiler, minimising the invested capital, or directing to a syngas engine for power generation, a higher value but higher capital cost option. For comparison, 1 m3 of syngas at 9 MJ/m3 is worth approximately

$0.12 when delivering heat in a gas boiler[14] and $0.20 generating power in a syngas engine[15]. For sites running a solid fuel boiler or with more-aggressive targets for decarbonisation, cost reduction, or energy security, power generation via syngas engine is an obvious choice.

Six scenarios were modelled where the project is developed by Wildfire Energy or another third-party financier and charges the abattoir its current costs and assesses the value created by the Wildfire Energy technology. The primary advantage to this business model is the responsibility for operation and maintenance rests with Wildfire with much greater experience and intimate knowledge of the technology, giving a greater chance of project success and smoothing out potential problems with install, commissioning, and operation. After the payback period has elapsed, power and heat purchase agreements would be renegotiated at significant discount from market rate.

Three different scales of 12.5 tpd, 25 tpd, and 50 tpd with and without a waste levy of $84.7 / tonne commencing in 2024 were modelled.



MIHG Scenarios Considered

- Three capacity scenarios considered
- MIHG Plants
  1) 12.5 tpd; 4,166 tpa
  2) 25 tpa; 8,333 tpa
  3) 50 tpa; 16,667 tpa
- Larger plants would require sourcing additional mixed waste from local community

Figure 38: Cost benefit analysis scenarios

Above 12.5 tpd for a medium-large sized processor, outside wastes (e.g., MSW, construction / demolition wood, nut shells, pallets etc) will be required to be accepted to provide ample feedstock. While this will provide a gate fee and potentially boost project economics, the appetite at individual sites to accept outside wastes will have to be assessed. From a business continuity risk perspective, there is little difference between accepting outside biomasses or non-recyclable wastes than fossil fuels as the site will still be indirectly depending on third party provision of their energy.

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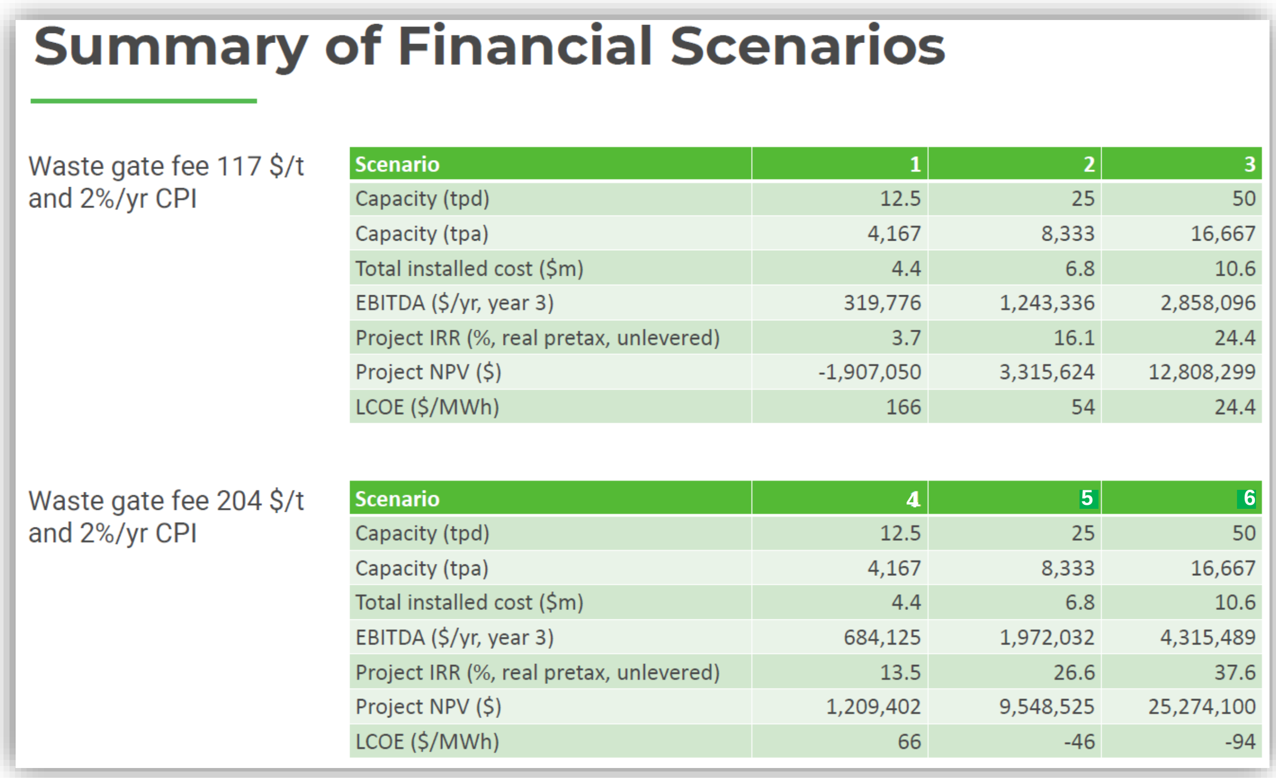
[14] Assumed 90% heat transfer efficiency and $15/GJ gas

[15] At 40% efficiency and $0.2 / kWh for power inclusive of volume and demand charge.

Table 13: Summary of financial scenarios. Negative LCoE indicates that revenue is generated for each MWh of electricity

Scenario	**1**	**2**	**3**	**4**	**5**	**6**
tpd gasified	12.5	25	50	12.5	25	50
Waste gate fee	$ 115.00	$ 115.00	$ 115.00	$ 199.70	$ 199.70	$ 199.70
Electricity supply [MWh]	3,086	6,172	12,343	3,086	6,172	12,343
Heat supply [MWh]	7,500	7,500	15,000	7,500	7,500	15,000
IRR	3.7%	16.1%	24.4%	13.5%	26.6%	37.6%
NPV [25 yr]	-$ 1,907,048	$ 3,315,624.00	$ 12,808,299.00	$ 1,209,402.00	$ 9,548,525.00	$ 25,274,100.00
Payback [yrs]	16	7	5	8	5	4
LCoE [$/MWh]	$ 166.36	$ 53.86	$ 5.73	$ 66.42	-$ 46.08	-$ 94.21



Summary of Financial Scenarios

Waste gate fee 117 $/t and 2%/yr CPI

Scenario	1	2	3
Capacity (tpd)	12.5	25	50
Capacity (tpa)	4,167	8,333	16,667
Total installed cost ($m)	4.4	6.8	10.6
EBITDA ($/yr, year 3)	319,776	1,243,336	2,858,096
Project IRR (%, real pretax, unlevered)	3.7	16.1	24.4
Project NPV ($)	-1,907,050	3,315,624	12,808,299
LCOE ($/MWh)	166	54	24.4

Waste gate fee 204 $/t and 2%/yr CPI

Scenario	4	5	6
Capacity (tpd)	12.5	25	50
Capacity (tpa)	4,167	8,333	16,667
Total installed cost ($m)	4.4	6.8	10.6
EBITDA ($/yr, year 3)	684,125	1,972,032	4,315,489
Project IRR (%, real pretax, unlevered)	13.5	26.6	37.6
Project NPV ($)	1,209,402	9,548,525	25,274,100
LCOE ($/MWh)	66	-46	-94

Figure 39: Summary of financial scenarios 1, 2, 3, 4, 5, and 6 (negative LCoE shows that revenue is created for each MWh of power generated).

General conclusions from the analysis of project economics are consistent with waste to energy projects in the Australian red meat processing industry, in that available wastes produced by the processor don’t match the energy demand, and in order to make significant reduction in site fossil energy, third party wastes must be accepted to enable a larger scale. Small scale project economics can be challenging without a high waste gate fee or opportunity cost of high landfill levies. Consequently, medium-to-large sized projects can be quite attractive, if significant barriers of waste and financing availability can be overcome.

5.6.2 Mix Including Paunch and Sludge

The following were the inputs required to complete a detailed cost benefit analysis of installing an at-scale MIHG gasification plant at the second participant site in regional VIC.

- Waste tonnages per annum; approx. composition
    - 20 tpa cardboard landfilled
    - 52 tpa plastic landfilled
    - 10,000 tpa paunch composted
    - 4,000 tpa DAF sludge composted
- Average disposal cost $/tonne
    - Rural VIC rates
        - $110.79/tonne general industrial waste
        - $262.22/tonne for Cat B wastes including from manufacturing industries
        - $125.9/tonne for Cat C wastes from manufacturing industries that pose low hazard
- Electricity demand: 20,000 MWh/yr with an average demand of 2.5 MWe
- Electricity cost: 135 $/MWh
- Heat demand: 50,000 GJ pa of natural gas
- Natural gas cost of $20/GJ

To differentiate this scenario from the first host site, a general Cat B rate of $262.22/tonne was applied to every waste. This represents an optimistic scenario for sites with little or no access to on-site waste management.

Table 14: Optimistic cost benefit scenario analysis

Scenario	A	B	C
Capacity (tpd)	12.5	25	50
Capacity (tpa)	4,167	8,333	16,667
Total installed cost ($M)	4.4	6.8	10.6
EBITDA ($/yr, year 3)	716,205	2,036,133	4,762,174
Project IRR (%, pretax, unlevered, real)	14.4	27.6	41.7
Project NPV ($)	1,524,996	10,179,713	29,259,587
LCOE ($/MWh)	+40	-95	-178

It can be seen that when a management fee is paid for all wastes, that the economics of investing in gasification become very strong. At the 8,000 and 16,000 tpa scales, LCoE becomes negative, meaning that the gate fee received for the processed wastes exceeds the averaged capital and operating cost. This represents an optimistic scenario for sites that are severely limited in their waste management options, and must pay for all produced wastes to be removed from site by a third party.

6.0 Discussion

6.1 Previous Work on Syngas Utilisation

Previous All Energy Pty Ltd works on potential uses of waste to energy gases (biogas and syngas) and their respective business case relevant to red meat processing include

[1] Injecting into the headspace of the first chamber of a solid fuel boiler (i.e., cola or woodchip) and that the advantage of using gas in a high residence boiler (e.g., solid fuel, multi-pass boiler) is to ensure complete combustion of the gas. Whilst it does not provide the highest rate of return, this option provides the shortest payback period.

[2] Fit for purpose, stand-alone packaged boiler suited to the lower CV syngas could provide a low-risk solution (i.e., low capex whilst not impacting any existing boilers). As elevated temperature of the syngas lends itself to waste heat recovery plus syngas combustion boosted boilers.

6.2 Implications of Including Paunch and Sludge in Mix

There are a number of considerations before using biomass or other lower calorific value fuels in a thermal energy system, which may require discussion with vendors and retrofits to auxiliary plant. These include:

- More fuel tonnage, more air, and more fluegas – ID fan capacity limit

A larger fuel tonnage feed rate to reach the same delivered energy rate requires a larger volume of oxidant injection. Check the available capacity of the fan for oxidant, and any FD fans for moving fluegas. The inherent variability of biomass presents a further challenge in setting the optimal air flow rate without delivering excess and sacrificing efficiency. A monitoring system, or at the minimum, regular moisture analysis on fuel can adjust air flow rate to maintain optimum gasification and heat transfer efficiency.

- Higher moisture leads to more fluegas, which can lead to possible overall efficiency drop

Related to the above point, more air required results in more fluegas and dilution of syngas, absorbing heat from the fuel – showing as low temperature in the gasification chamber. Economisers may mitigate this by recovering heat from fluegas, but the amount of gasification air should be investigated first and compared to the stoichiometric amount.

- More feedstock preparation / fuel delivery power
- Tendency for slagging in the gasification chamber and solidification of sintered deposits, especially when ash deformation / ash melting temperatures are exceeded. e.g. sudden shut down / cooling or inability to remove melted ash results in the need to jack hammer out slag during shut-downs

Higher ash contents in lower quality biomasses may result in slagging issues, and should be considered in light of maintenance schedules. Slagging results in: less available volume for gasification and drop in efficiency; damage / blockage due to lumps of slag; impacts on oxidant lance / flame front pattern; excessive soot and erosion.

- Materials handing issues

Sticky fuel (higher moisture, higher clay, smaller particles) can block chutes, hoppers and conveyors. Check the angle of hopper walls and conveyors inclines. Contaminants and inerts (rocks, steel, bricks) can block / damage hoppers, chutes and conveyors, which may be a possible issue especially if taking construction / demolition wood (less likely for sawmill and forestry residues). Sorting is often complex requiring multiple stages and hence significant capital and operating costs, thus, good selection of clean feedstocks is the best strategy to prevent contaminants and inerts in the first place.

- Low CV fuel can be more reactive in stockpiles leading to stockpile fires; strong winds aggravate stockpile fires; compacting, management and detection can reduce problem.

7.0 Conclusions / Recommendations

General conclusions from the analysis of project economics are consistent with waste to energy projects in the Australian red meat processing industry, in that available wastes produced by the processor don’t match the energy demand, and in order to make significant reduction in site fossil energy, third party wastes must be accepted to enable a larger scale. Small scale project economics can be challenging without a high waste gate fee or opportunity cost of high landfill levies. Consequently, medium-to-large sized projects can be quite attractive, if significant barriers of waste and financing availability can be overcome.

For sites that are unwilling or unable to take in third party wastes, it may be better to investigate other ways to valorise non-recyclable wastes, including combustion of plastic and cardboard for hot water generation or composting of paper, cardboard, paunch, and sludge(s) for creation of soil conditioners.