Asset Intelligence & Innovation

Technical Report

For: A7S/14811 HERU for Screenings

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1 Executive Summary

Severn Trent, in partnership with HERU and the University of Huddersfield, secured OFWAT funding to trial HERU's commercial pyrolysis units at Severn Trent's sites. The preliminary results that were obtained indicated:

- HERU unit show the potential to significantly reduce the volume of wastewater screenings by approximately 92%
- The high total phosphorus content in the generated ash poses potential challenges for application at wastewater treatment sites but could be overcome with alternative outlets such as the use in an organo- mineral fertiliser or this reduced volume sent to landfill.
- Generated syngas had low value, which could make it unsuitable for energy recovery.
- The net calorific value of the char was determined to be 18,620 kJ/kg, with the material being rich in total phosphorus and nitrogen and having a substantial total carbon content. However, it had high concentrations of some heavy metals.
- Energy consumption data were not available, preventing a full assessment of the process feasibility and operational costs.

The partnership with HERU faced challenges and highlighting the need for better planning and communication with SMEs and partners. As a result of these lessons learned, key programmes have been initiated to support SMEs and start-ups, including personalised project support and structured upskilling.

2 HERU- Bid Objectives

2.1 Water Industry Context

The sector produces over 100,000 tonnes of screenings per year – nearly all are landfilled. This has a sizable carbon footprint (~20KTC02e/year) and costs the industry (and ultimately customers) ~£8.8M/year. This cost is set to increase with recent changes to landfill tax. For Severn Trent this has increased from £94.15 to £126.15 per tonne from April 2020 to April 2025, an increase in costs of over 33% over the AMP period.

The sector's current approach to screenings management sits at the foot of the waste hierarchy (landfill) and we must find ways to improve our approach to 'recovery' or 'recycling'. This will ensure the sector plays its part in meeting the Government's 2035 'no more than 10% of municipal waste to landfill[1]' target and addresses our customers' concerns around 1) the impact of plastic waste in the environment and 2) the unsustainable use of landfill. There are currently few other options for screenings disposal, which are made up of an ever-changing mix of plastic waste and organic material. Their unknown origin, mixed composition and high-water content (typically 40-60%) prevents reuse or recovery as a waste-derived fuel.

[1] See Reference 1

2.2 Mission Heru

The Home Energy Recovery Unit (HERU) is an innovative solution to a growing, intractable waste problem for the UK water industry. HERU is a small-scale waste recovery system developed to manage domestic and commercial waste. HERU uses heat pipe technology in a 125-litre reactor to deliver drying, low temperature pyrolysis and energy recovery in a batch process. The technology's scale, batch processing and drying cycle are key developments that could deliver a new paradigm for managing screenings by significantly reducing the volumes of screenings sent to landfill.

2.3 Bid Objectives

The following are the high-level objectives of the bid:

- Establish the performance of a small-scale waste recovery system using a feedstock of wastewater screenings
- Understand how much biochar, syngas and heat HERU is able to produce and the characteristics of these products to establish what reuse options are available including a potential end market for the biochar
- Permitting requirements: Deliver the Information required by the Environment Agency to establish permitting requirements for a HERU
- Create a technology development roadmap to enable the roll-out of site-based waste recovery
- Establish the operating and maintenance requirements
- Establish a lifecycle assessment
- Understand the potential uses for the biochar or its suitability as a carbon sequestration opportunity

3 Trial & Technology Overview

3.1 Trial Scaling Type

Through working with smaller starts ups Severn Trent has developed a delivery approach to help scale innovation. This trial would sit within the Proof-of-Concept pilot phase trials which is focused on understanding the technical feasibility performance and defining the sampling and performance assessment methodology.

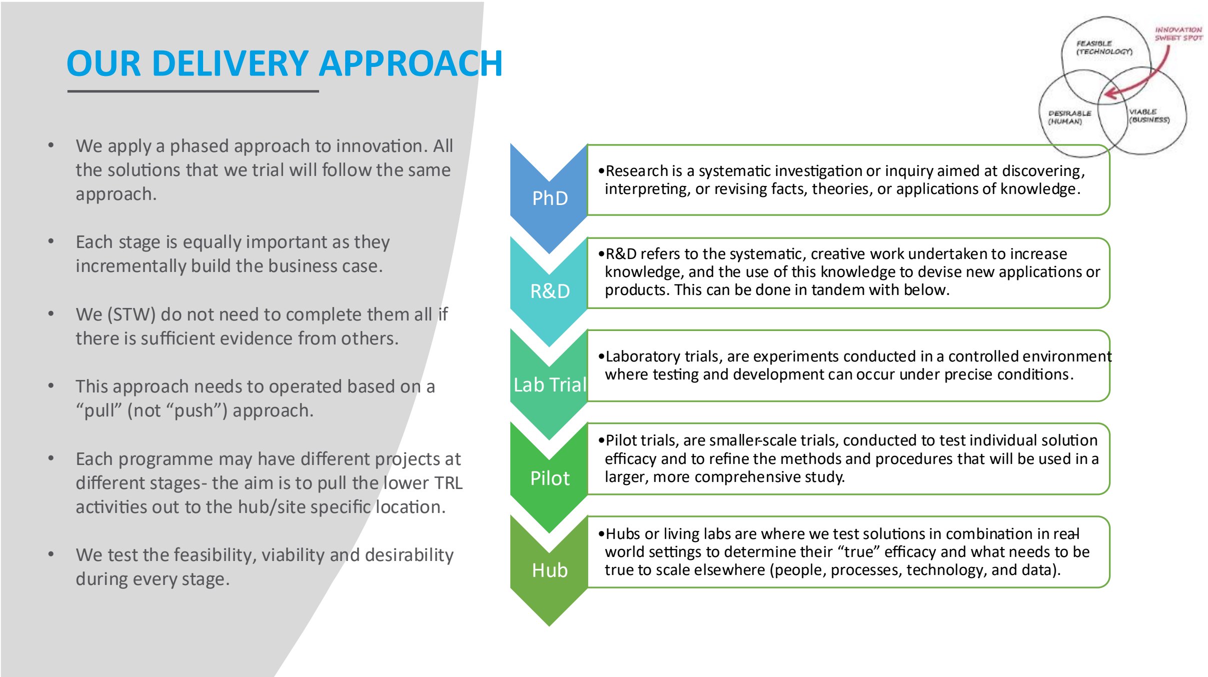

Figure 1. Severn Trent scaling innovation approach

3.2 Trial Scope

Severn Trent produces circa 15,000 wet tonnes of screenings per annum. Conventionally wastewater screenings are transported off the wastewater treatment site and taken to a landfill for disposal. The goal of the project was to introduce a low energy technology that will reduce the need for waste to landfill and potentially provide a valuable circular economy

The trial was set to take place at the Resource Recovery and Innovation Centre (R2IC) at Spernal Sewage Treatment Works. The pyrolysis unit, HERU, was to be operated in a batch manner, with each batch consisting of approximately 25 kg of sample separated from the conventional landfill route and processed for energy recovery and volume reduction.

The HERU process consists of several stages:

<u>Stage 1: Pyrolysis Only</u>

- Wastewater screenings were to be dried first, and the moisture from the process was to be exerted as steam.
- The thermal energy from this step was to be recovered by condensing steam over, heat exchangers. After drying, the temperature would be raised to begin low-temperature pyrolysis

The syngas produced from this process is stored within a cylindrical storage tank, with pressure regulated release into the combination BAXI boiler to reuse. Once pyrolysis is complete, the unit has an added functionality allowing to stop the process and cool down to allow for a char sample to be taken.

Stage 2: Combustion Only

- The next step is to combustion of the remaining char to produce energy for the unit and reduce screenings further.
- Ash and oil remaining in the chamber following the combustion is neutralised with an alkaline solution and washed off with water, then returned to the head of the works.

Energy consumption of the unit was to be monitored, and samples of char, ash, and syngas were to be taken to check for their general composition. The weight of the produced ash was monitored and compared against the mass of the batch to assess the total reduction in volume of processed screenings.

A schematic of the process is shown in Figure 1.

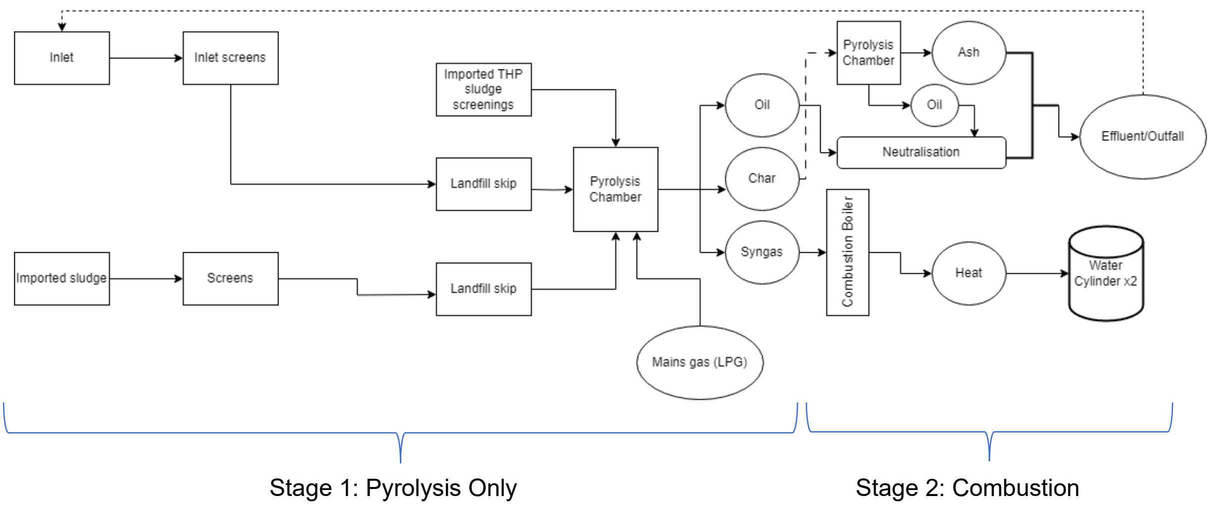

Figure 2 Schematic of a HERU process

3.3 Trial Timeline

The trial was initially planned for April 2024; however, due to delays in preparing the unit for installation and implementing all required modifications (such as relevant sampling points and the option to pause the combustion step to obtain char samples), the unit was delivered to R2IC slightly later than expected but not impactful to the programme. The commissioning stage started in August 2024.

Figure 3. Image of the HERU unit at R2IC (Spernal WWTW)

4 Key Results & Analysis

During the commissioning phase of the project Mission Heru completed an investment cycle and were able to raise a large amount of desired investment. However, without being able to raise the full amount of investment were not able to continue operations beyond the commissioning phase. However, the batches that were processed during the commissioning phase showed promising results.

Three full cycle runs were completed with screenings, each weighing approximately 25 kg. The analysis from samples of these activities is detailed in the Appendix. Although the ideal desired number of batches were not completed the Heru solution demonstrated potential to deal with the environmental and cost challenges of deposing of screenings. However, additional testing is required to prove the cost/benefits of scaling, improve confidence through a statistically significant sample size, understand the variations in sample results and optimise performance.

4.1 Volume reduction

The volume reduction happens through 2 stages in the HERU process, the screenings are converted to biochar (& other products), the biochar is then converted to ash. Below shows pictures of this conversion during the trial.

Figure 4. Images of screenings that were processed during the trial and resulting products

The total volume of the HERU loading area is 125L and can hold an average weight of screenings of 25kg. The average amount of moisture content in screenings is approx. 70%. In a mass balance approach, the amount of biochar produced was expected to be 30% of the loading weight and when the biochar is then combusted this would reduce this down further to 5-10% of the initial mass.

During the trial there were significant reduction in the weight of the screenings: 92% conversion when processing 25 kg of screenings resulting in the production of approximately 2 kg of ash. This level of reduction has significant impact on the carbon and cost penalty associated with screenings to landfill.

Based on the estimated amount of wet screenings produced by Severn Trent per annum (15,000 tonnes) and a landfilling cost of £126.15 per tonne[2], we can achieve significant savings. By reducing the weight of screenings by 92%, the savings could potentially amount to £1,740,870 annually. Additionally, with estimated emissions arising from landfilling at 520 kg CO2e per tonne[3], this could result in a potential reduction of 7.57 kTCO2e per annum.

While the theoretical reduction in emissions and costs is significant, it is important to consider that actual figures will be influenced by various factors such as operational costs, energy consumption, maintenance and repairs, efficiency of the new process, etc. The total operational costs would need to be calculated, and a complete Life Cycle Assessment conducted, provided we obtain reliable energy consumption figures and estimate the total cost to operate under business-as-usual conditions.

4.2 Char Characteristics

During the commissioning phase, char samples were obtained. Basic analysis revealed a net calorific value (CV) of 18,620 kJ/kg, for comparison anaerobic digestion of sewage sludge typically ranges from 20,000 to 24,000 kJ/kg. The biochar was also rich in total phosphorus and nitrogen while also having a substantial total carbon content.

As per the European Biochar Certification (EBC)[4], the molar H/C ratio was calculated for the biochar sample. The ratio is an indicator of the degree of carbonisation and therefore of the

[2] See Reference 2
[3] See Reference 3
[4] See Reference 4

biochar stability. The ratio is one of the most important characterising features of biochar and is indispensable for the determination of the carbon sequestration value.

- Typical high-quality biochar: H/C molar ratio < 0.3 (C/H ratio ~3.3 or higher)
- Highly carbonized biochar: H/C molar ratio < 0.1 (C/H ratio ~10 or higher)

The mass H/C ratio was calculated based on sample results as 0.1 which is comparable with higher quality biochar properties.

However, it is worth noting that the sample has elevated cadmium, selenium, and zinc concentrations. Although the EBC does not include limit values for potentially toxic elements (PTE) it does state that PTEs should not exceed the relevant countries agriculture limits. For the United Kingdom the relevant comparable PTE limits would be those as per the Biosolids Assurance Scheme[5]. The analysis shows that the biochar sample exceeded the limits for land disposal.

Despite the carbon sequestration potential, the high PTEs hinder the application potential and market use. However, the high CV value of the biochar helps the potential life cycle assessment of the HERU unit as this is combusted in stage 2 to create an ash to reduce screenings further, the excess heat from the biochar helps towards energy neutrality.

As the goal of the HERU is to reduce screenings volumes and OPEX demands, the optimum outlet for the biochar based on the characteristics is to continue into stage 2 of the HERU unit instead of finding other market uses.

4.3 Ash Characteristics

The main observation from the commissioning sample analysis was the very high total phosphorus content of the ash samples, ranging from 68,600 mg/kg to 74,800 mg/kg. This could be a concern for the wastewater treatment works, as the HERU unit design involves washing down the ash with water and returning the effluent to the head of the works. The average ash output from a single run was around 1.5-2 kg. Therefore, processing a single batch of screenings could potentially increase the total phosphorus content by up to 150,000 mg at the works inlet, posing an additional challenge at smaller works or if large quantities of screenings were processed with the pyrolysis unit. The increase in Total P is problematic due to the stringent phosphorus discharge limits set by the permits at many of Severn Trent's sites

In scaling the technology, an assessment of site-specific screenings tonnages needs to be considered, and a mass balance completed to understand how the number of batches and phosphorus content would adversely affect the wastewater treatment works.

However, if the process included sending the ash to a landfill instead of washing it out, it could solve this problem while also delivering the benefit of reduced costs and carbon footprint associated with sending screenings to landfill.

Another potential outlet for the ash could be as an input into organo- mineral fertiliser as part of meeting the TKN requirements, this would be dependent on PTE levels.

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[5] See Reference 5

4.4 Syngas

While the produced char has significant caloric value, the samples of generated syngas did show limited properties. All three samples demonstrated very low calorific value (average 0.27 MJ/m^3), making them unsuitable as a source for energy recovery.

4.5 Energy consumption

It should also be noted that, unfortunately, while HERU software engineers were still working on the machine's HMI during commissioning to complete changes to gather energy consumption data, these were never completed when Mission HERU paused trading. Consequently, it is not possible to make any assumptions about the overall feasibility of the process in terms of energy consumption and operational costs.

5 Technology Roadmap:

The next phase of the technology roadmap would be to progress from a POC pilot to an industrial scale pilot. Prior to progression into this phase the following steps need to be taken. The Industrial Pilot stage needs to include the detailed operating and maintenance requirements and life cycle assessment that was not able to be fully completed in the POC stage.

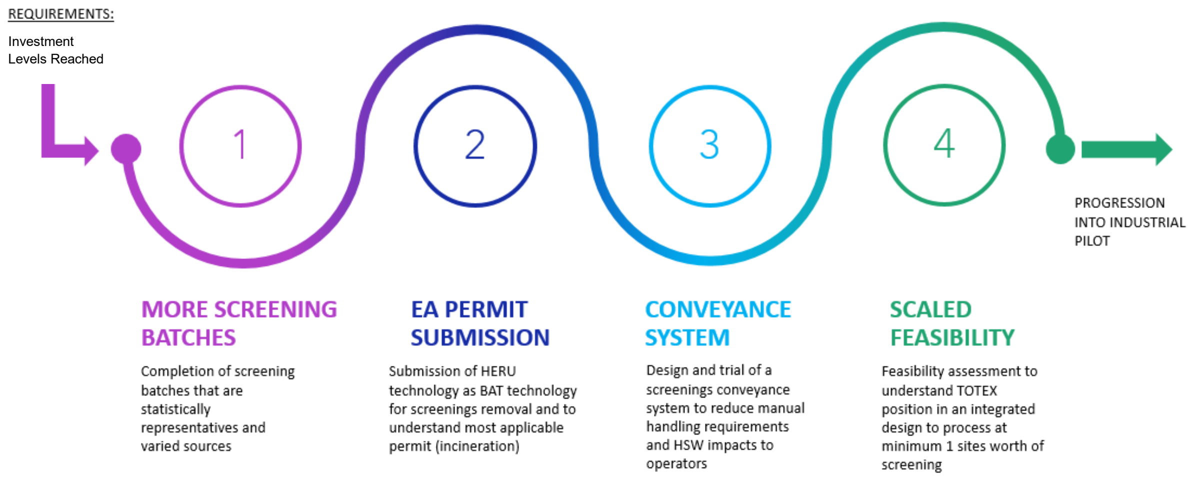

Figure 5. Key next steps on the HERU technology roadmap

6 Permitting Requirements:

Permitting with the Environment Agency will be complicated as current standards and legislations are not designed to support Advanced Thermal Conversion on Wastewater Treatment Works. Further data is required to determine the benefit over a range of scenarios and batches to evidence any variation to the Environment Agency.

The following must also be considered and evidence/narrative provided to the Environment Agency:

- Best Available Technology (BAT)- if a technology does not classify as Best Available Technology, then we must get a new permit each time to install and prove why this is better than current approved technology.
- Site by Site permitting – Understand how replicable permits are for different sites and the impact of multiple bespoke installation permits
- Long lead times- Current EA installation permits are 18- 24 months
- Local Enforcement Position[6] permitting – LEPs allow for innovation trials, generally you are only allowed to submit one LEP per technology, engagement with the EA is needed for multiple LEPS to take the technology through the scaling
- Permit definitions - most thermal treatment including the Advanced Thermal Conversion is classified as incineration when they have fundamentally different outputs from an environment perspective – the impact of this type of permitting needs to be understood.

7 Lessons Learnt- SMEs:

Throughout the project, we encountered several challenges in. These challenges underscore the importance of comprehensive planning, clear communication, and a phased approach to scaling up innovative technologies, aiming to transition lower TRL activities to site-specific locations. It is also crucial for contractors, particularly SMEs that lack experience working with water companies, to understand how the UK water industry is regulated and financed. As part of our ongoing learning through current projects, we are developing innovative strategies to enhance our partnerships with SMEs and start-up companies. We are creating a comprehensive playbook that outlines our current methodologies, lessons learned, and our future collaborative approach with these businesses. The key initiatives are:

- The implementation of a 'Hypercare' service, designed to provide personalised support throughout the entire project lifecycle. This service aims to create a mutually beneficial environment where both our company and our SME/start-up partners can thrive. Our goals include understanding the commercial maturity of potential partners, streamlining the onboarding and integration process, improving efficiency, and aligning expectations from the start and throughout the partnership.
- Launching a new initiative to support innovative startups and SMEs in the water sector. This programme will offer structured support, including water regulation upskilling, access to facilities, mentoring, and training.
- Adopting a phased approach to innovation, where each stage is crucial for building the business case, though not all stages need to be completed if there is sufficient evidence from other sources, with the goal of moving lower TRL activities to specific hub or site locations for further development

[6] Carrying out research or trials with waste at sites without an environmental permit - GOV.UK

8 Conclusions

8.1 Technical Summary

One of the primary goals of the HERU for Screenings trial was to assess potential alternative solutions to sending wastewater screenings to landfill. Although the ideal number batches were not completed, the commissioning activities demonstrated that the technology could achieve a beneficial 92% volume reduction. However, with the tested settings, there could arise a challenge of elevated phosphorus levels being returned to the head of the works. Therefore, any future screening pyrolysis trials may need to consider alternative means of ash disposal.

The trial also aimed to provide a better understanding of the value of pyrolysis products as circular economy products. Despite the limited amount of data available, it appears that focusing on biochar production could be recommended, as this may be more valuable than the produced syngas. However, the properties of by-products may vary depending on the pyrolysis settings, including temperature, pressure, and other process parameters.

The trial shows that pyrolysis of screenings could be a valuable solution and show that this type of technology can address the sector issue of screenings.

8.1 Objectives Comparison Summary

Objective	**Outcome**
Establish the performance of a small-scale waste recovery system using a feedstock of wastewater screenings	Indicative commissioning samples show a reduction of weight of 92% of screenings when processed via stage 1 and 2 of the HERU system
Understand how much biochar, syngas and heat HERU is able to produce and the characteristics of these products to establish what reuse options are available including a potential end market for the biochar	Syngas has limited value based on the CV. The biochar shows potential with a high CV and H/C ratio making it suitable for carbon sequestration, however PTE limits in the samples hinder the application to land. The ash had high phosphorus content and impact of disposal of the ash needs to be considered
Permitting requirements: Deliver the Information required by the Environment Agency to establish permitting requirements for a HERU	Further trials are required to deliver all the information needed for a EA bespoke application. Lessons learnt associated to permitting have ben identified that needs to be considered as part of the technology roadmap
Create a technology development roadmap to enable the roll-out of site -based waste recovery	A high-level plan has been developed, key activities include Misson HERU restarting trading, increased batch processing to understand variance, designing a conveyance system to remove manual handling risks

Establish the operating and maintenance requirements	Due to limited batches this was not assessed, needs to be included in the technology road map.
Establish a lifecycle assessment	Due to limited batches this was not assessed, needs to be included in the technology road map.
Understand the potential uses for the biochar or its suitability as a carbon sequestration opportunity	Characteristic testing shows high H/C content but has limited land application. The best end use of the biochar is to use this as an energy source for the HERU process to ensure energy neutral. This also reduces the inlet screenings mass further.

9 References

[1] Residual waste infrastructure capacity note - GOV.UK

[2] Severn Trent Landfill Tax

landfill Tax	From 1 April 2025	From 1 April 2024	From 1 April 2023	From 1 April 2022	From 1 April 2021	From 1 April 2020
£ per tonne (England & Northern Ireland)						
Standard rate	£ 126.15	£ 103.70	£ 102.10	£ 98.60	£ 96.70	£ 94.15
Lower rate	£ 4.05	£ 3.30	£ 3.25	£ 3.15	£ 3.10	£ 3.00
Increase per annum	£ 22.45	£ 1.60	£ 3.50	£ 1.90	£ 2.55	
% increase	17.79%	1.54%	3.42%	1.92%	2.63%	

Spend 2023 £1.681,618 per tonne excluding transport New rate 2025 - £1,981,777.84
This is with 65% Discount.

[3] Greenhouse gas reporting: conversion factors 2024; UK Government GHG Conversion Factors for Company Reporting; Department for Energy Security and Net Zero

[4] EBC (2012-2024) 'European Biochar Certificate - Guidelines for a Sustainable Production of Biochar.' Carbon Standards International (CSI), Frick, Switzerland. (http://european-biochar.org). Version 10.4 from 20th Dec 2024

[5] https://assuredbiosolids.co.uk/wp-content/uploads/2018/04/BAS-STANDARD-Issue-4-Online-version.pdf.

10 Appendix

Analysis	Units	As received	Dry
Removed Ash	%	0.0	-
Total Moisture	%	1.2	-
Ash (550°C)	%	96.7	97.9
Sulphur	%	2.43	2.46
Volatile Matter	%	8.8	8.9
Gross Calorific Value	kJ/kg	200.0	203
Nett Calorific Value	kJ/kg	162.0	194
Carbon	%	2.19	2.21
Hydrogen	%	<0.05	<0.05
Nitrogen	%	0.31	0.31
Arsenic	mg/kg	61	62
Cadmium	mg/kg	22	22
Chromium	mg/kg	168	170
Copper	mg/kg	1020	1030
Lead	mg/kg	155	157
Magnesium	mg/kg	11100	11200
Mercury	mg/kg	11	11
Nickel	mg/kg	129	130
Phosphorous	mg/kg	74800	75700
Potassium	mg/kg	9340	9450
Selenium	mg/kg	41	42
Vanadium	mg/kg	152	154
Zinc	mg/kg	1880	1900

Table 1 Ash analysis-sample 1

Analysis	Units	As received	Dry
Removed Ash	%	0.0	0.0
Total Moisture	%	1.7	1.7
Ash (550°C)	%	87.7	89.2
Sulphur	%	1.46	1.49
Volatile Matter	%	15.7	16.0
Gross Calorific Value	kJ/kg	2999	3051
Nett Calorific Value	kJ/kg	2946	3040
Carbon	%	8.01	8.15
Hydrogen	%	<0.05	<0.05
Nitrogen	%	1.09	1.10
Arsenic	mg/kg	71	72
Cadmium	mg/kg	22	22
Chromium	mg/kg	94	95
Copper	mg/kg	381	388
Lead	mg/kg	205	209
Magnesium	mg/kg	7950	8090
Mercury	mg/kg	<6	<6
Nickel	mg/kg	66	67
Phosphorous	mg/kg	70900	72100
Potassium	mg/kg	9170	9330
Selenium	mg/kg	36	37
Vanadium	mg/kg	101	102
Zinc	mg/kg	1210	1230

Table 2 Ash analysis-sample 2

Analysis	Units	As received	Dry
Removed Ash	%	0.0	0.0
Total Moisture	%	1.2	1.2
Ash (550°C)	%	90.8	91.9
Sulphur	%	1.71	1.73
Volatile Matter	%	13.8	13.9
Gross Calorific Value	kJ/kg	1905	1928
Nett Calorific Value	kJ/kg	1865	1918
Carbon	%	6.24	6.31
Hydrogen	%	<0.05	<0.05
Nitrogen	%	0.89	0.90
Arsenic	mg/kg	64	65
Cadmium	mg/kg	22	22
Chromium	mg/kg	105	106
Copper	mg/kg	648	656
Lead	mg/kg	144	145
Magnesium	mg/kg	8460	8570
Mercury	mg/kg	<6	<6
Nickel	mg/kg	83	84
Phosphorous	mg/kg	68600	69400
Potassium	mg/kg	8390	8490
Selenium	mg/kg	26	26
Vanadium	mg/kg	142	143
Zinc	mg/kg	2610	2650

Table 3 Ash analysis-sample 3

Analysis	Units	As received	Dry	Dry ash free
Removed Ash Contributors (Inerts)	%	0.0	-	-
Total Moisture	%	3.1	-	-
Total Moisture (inc Ash Contributors)	%	3.1	-	-
Ash (550°C)	%	32.8	33.8	-
Ash (550 °C inc Ash Contributors)	%	32.8	33.8	-
Sulphur	%	0.82	0.85	1.28
Volatile Matter	%	40.7	42.0	63.4
Gross Calorific Value	kJ/kg	19430	20050	30300
Nett Calorific Value	kJ/kg	18620	19290	-
Carbon	%	47.01	48.52	73.30
Hydrogen	%	3.45	3.56	5.38
Nitrogen	%	4.10	4.23	6.39
Arsenic	mg/kg	41	42	64
Cadmium	mg/kg	7	7	11
Chromium	mg/kg	57	59	89
Copper	mg/kg	144	148	224
Lead	mg/kg	152	157	237
Magnesium	mg/kg	2330	2400	3630
Mercury	mg/kg	<6	<6	<9
Nickel	mg/kg	35	36	55
Phosphorous	mg/kg	20900	21500	32600
Potassium	mg/kg	2680	2760	4170
Selenium	mg/kg	27	28	42
Vanadium	mg/kg	42	43	65
Zinc	mg/kg	438	452	682

Table 4 Char sample analysis

Component	Unit	Analysis
Oxygen (O_2)	% V/V	12.5
Carbon Monoxide (CO)	% V/V	1.5
Hydrogen (H_2)	% V/V	0.13
Methane (CH_4)	% V/V	0.14
Ethane (C_2H_6)	% V/V	0.036
Propane (C_3H_8)	% V/V	0.015
n-Butane (n-C_4H_{10})	% V/V	0.0031
n-Pentane (n-C_5H_{12})	% V/V	0.0017
n-Hexane (n-C_6H_{14})	% V/V	<0.0005
CV Gross	MJ/m³	0.31
CV Net	MJ/m³	0.30

Table 5 Syngas analysis- sample 1

Component	Unit	Analysis
Oxygen (O_2)	% V/V	14.2
Carbon Monoxide (CO)	% V/V	1.4
Hydrogen (H_2)	% V/V	0.25
Methane (CH_4)	% V/V	0.12
Ethane (C_2H_6)	% V/V	0.037
Propane (C_3H_8)	% V/V	0.011
n-Butane (n-C_4H_{10})	% V/V	0.0031
n-Pentane (n-C_5H_{12})	% V/V	0.0015
n-Hexane (n-C_6H_{14})	% V/V	<0.0005
CV Gross	MJ/m³	0.31
CV Net	MJ/m³	0.29

Table 6 Syngas analysis-sample 2

Component	Unit	Analysis
Oxygen (O_2)	% V/V	12.4
Carbon Monoxide (CO)	% V/V	1.0
Hydrogen (H_2)	% V/V	0.044
Methane (CH_4)	% V/V	0.053
Ethane (C_2H_6)	% V/V	0.013
Propane (C_3H_8)	% V/V	0.011
n-Butane (n-C_4H_{10})	% V/V	0.003
n-Pentane (n-C_5H_{12})	% V/V	0.0016
n-Hexane (n-C_6H_{14})	% V/V	<0.0005
CV Gross	MJ/m^3	0.18
CV Net	MJ/m^3	0.17

Table 7 Syngas analysis-sample 3