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**GENT FAIRHEAD & CO LIMITED
QUANTITATIVE CHP BAT
ASSESSMENT
RIVENHALL IWMF**

Fichtner Consulting Engineers Limited
Kingsgate (Floor 3), Wellington Road North,
Stockport, Cheshire, SK4 1LW, United Kingdom

t: +44 (0)161 476 0032 f: +44 (0)161 474 0618 www.fichtner.co.uk

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1 INTRODUCTION

As required by EPR5.01 – Waste Incineration Sector Guidance, this report presents quantitative BAT assessments for acid gas abatement, nitrogen oxides abatement and combustion technologies for the CHP Plant within the Rivenhall IWMF. A quantitative BAT assessment has not been undertaken of any of the other waste treatment/technologies undertaken at the Installation as these are not required in the relevant BAT sector guidance. Qualitative BAT assessment for all installation operations is presented within section 2.6 of the Supporting Information.

Each assessment follows the structure of Technical Guidance Note EPR-H1 and includes comments on all of the environmental parameters mentioned in EPR-H1.

1.1 Assumptions

The maximum operating capacity of the CHP Plant will be 595,000 tonnes per annum. The Installation will have a designed availability of 8,150 hours per annum. A firing diagram demonstrating the range of fuels to be combusted is presented in Annex 1. As shown in the firing diagram, the CHP facility will be designed to accept RDF within a NCV design range of circa 7-13 MJ/kg.

The CHP Plant will generate up to 49MWe and will have a parasitic load of 5.5MWe¹. Furthermore, for the purposes of this assessment it has been assumed that there is no export of heat from the CHP Plant.

For the purposes of this report we have undertaken a quantitative assessment of the available technologies for the proposed capacity using data obtained by Fichtner from a range of different projects using the technologies identified within this assessment.

In the operating costs sections, the following unit costs have been assumed:

- | | |
|--|-------------------|
| (1) Water | £1 per tonne; |
| (2) Quick lime | £90 per tonne; |
| (3) Hydrated lime | £94 per tonne; |
| (4) Sand for fluidised bed | £100 per tonne; |
| (5) Sodium bicarbonate..... | £155 per tonne; |
| (6) Activated carbon | £650 per tonne; |
| (7) Ammonia solution (25%) | £135 per tonne; |
| (8) Urea solution | £145 per tonne; |
| (9) Bottom ash processing..... | £10 per tonne; |
| (10) Fly ash disposal..... | £125 per tonne; |
| (11) Lime APCr disposal | £125 per tonne; |
| (12) Sodium bicarbonate APCr disposal..... | £150 per tonne; |
| (13) Landfill tax (1 April 2017)..... | £86.10 per tonne; |
| (14) Imported power | £52 per MWh; and |
| (15) Electricity revenue | £116 per MWh. |

¹ This does not include the electricity which is consumed by the other waste management processes within the Installation.

2 ACID GAS ABATEMENT

2.1 Options Considered

There are currently three technologies widely available for acid gas treatment on waste derived fuel fired plants in the UK, as listed below.

- (1) Wet scrubbing, involving the mixing of the flue gases with an alkaline solution of sodium hydroxide or hydrated lime. This has a good abatement performance, but it consumes large quantities of water, produces large quantities of liquid effluent which require treatment, has high capital and operating costs and generates a visible plume. It is mainly used in the UK for hazardous waste incineration plants where high and varying levels of acid gases in the flue gases require the buffering capacity and additional abatement performance of a wet scrubbing system.
- (2) Semi-dry, involving the injection of lime as a slurry into the flue gases in the form of a spray of fine droplets. The acid gases are absorbed into the aqueous phase on the surface of the droplets and react with the lime. The fine droplets evaporate as the flue gases pass through the system, cooling the gas. This means that less energy can be extracted from the flue gases in the boiler, making the steam cycle less efficient. The lime and reaction products are collected on a bag filter, where further reaction can take place.
- (3) Dry, involving the injection of solid lime or sodium bicarbonate into the flue gases as a powder. The reagent is collected on a bag filter to form a cake and most of the reaction between the acid gases and the reagent takes place as the flue gases pass through the filter cake. In its basic form, the dry system consumes more reagent than the semi-dry system. However, this can be improved by recirculating the flue gas treatment residues, which contain some unreacted lime and reinjecting this into the flue gases.

Wet scrubbing is not considered to be suitable for the CHP Plant, due to the production of a large volume of hazardous liquid effluent, a reduction in the power generating efficiency of the plant and the generation of visible plume.

For the purposes of this assessment, the reagents to be used for the abatement of acid gases in the acid gas abatement system are considered in section 3.

2.2 Environmental Performance

2.2.1 Emissions to Air

The impact of emissions to air is considered in the Dispersion Modelling Report, which can be found in Annex 5 of the Environmental Permit application. The acid gas emissions were assessed at the daily emission concentrations of 50 mg/Nm³ for sulphur dioxide and 10 mg/Nm³ for hydrogen chloride, both expressed at 11% oxygen in dry gas.

The table below shows the emission concentrations at the stack and the predicted ground level concentrations for each option. For sulphur dioxide, the 99.18th percentile of the daily averages is shown. For hydrogen chloride, the maximum 1-hour average is shown.

The emission concentrations for both a dry and semi-dry system are expected to be the same as they are required to achieve the same emissions performance criteria.

| Abatement System | | Dry | | | Semi-dry | | |
|--|--------------------|-----------------------|------------|-----------|-----------------------|------------|-----------|
| Pollutant | Units | SO₂ | HCl | HF | SO₂ | HCl | HF |
| Unabated emission concentration | mg/Nm ³ | 480 | 900 | 90 | 480 | 900 | 90 |
| Unabated emission rate | tpa | 1,450 | 2,710 | 270 | 1,450 | 2,710 | 270 |
| Emission concentration | mg/Nm ³ | 50 | 10 | 2 | 50 | 10 | 2 |
| Emission rate | tpa | 150 | 30 | 10 | 150 | 30 | 10 |
| Emissions abated | tpa | 1,300 | 2,680 | 260 | 1,300 | 2,680 | 260 |
| Process Contribution (PC) | ug/m ³ | 3.70 | 9.41 | 0.10 | 3.70 | 9.41 | 0.10 |
| Background | ug/m ³ | 12.40 | 2.35 | 2.40 | 12.40 | 2.35 | 2.40 |
| Predicted Environmental Contribution (PEC) | ug/m ³ | 28.50 | 14.11 | 4.90 | 28.50 | 14.11 | 4.90 |
| Air Quality Objective | ug/m ³ | 125 | 750 | 160 | 125 | 750 | 160 |
| PC as % of AQO | % | 2.96% | 1.25% | 0.06% | 2.96% | 1.25% | 0.06% |
| PEC as % of AQO | % | 22.80% | 1.88% | 3.06% | 22.80% | 1.88% | 3.06% |

The daily average Process Contribution (PC) for sulphur dioxide; the maximum 1-hour PC for hydrogen chloride; and hydrogen fluoride are respectively 6.29%; 2.43%; and 0.06% of the relevant average air quality objectives.

The impact of sulphur dioxide; hydrogen chloride and hydrogen fluoride is considered to be insignificant, when applying the criteria stated in Environment Agency Guidance Note H1.

2.2.2 Deposition to land

The impact of acid deposition on sensitive habitats has been assessed in the Dispersion Modelling Assessment presented in Annex 5 of the EP application. As can be seen from this assessment, the impact of acid deposition on sensitive receptors is considered to be insignificant.

2.2.3 Emissions to water

There are no emissions to water for the dry and semi-dry systems.

2.2.4 Photochemical Ozone Creation Potential

Sulphur dioxide has a photochemical ozone creation potential (POCP) value relative to Ethylene of 4.8. Hence, the POCP for both the dry and semi-dry systems would be 720 tonnes Ethylene equivalent.

2.2.5 Global Warming Potential

The direct emissions of greenhouse gases are the same for the dry and semi-dry acid gas abatement options, since the carbon dioxide and nitrous oxide emission concentrations are unchanged. However, the energy consumption is slightly different, which would change the power exported from the Installation. This means that the reduction in greenhouse gas emissions due to the displacement of power generated by other power stations would be different in each case.

The semi-dry system involves the evaporation of water. Since the reaction temperature of the lime and hence the outlet temperature should be the same, this means that the flue gas temperature at the inlet to the abatement system is higher for the semi-dry system than the dry system and hence more power can be generated if a dry system is used.

In order to calculate the global warming potential of electricity consumption, the figure of 380 kg carbon dioxide per MWh has been used, as applied in the Greenhouse Gas Assessment presented in Annex 5 of the Environmental Permit application. This is shown in the table below.

| Table 2-2- Global Warming Potential, Acid Abatement Options | | | |
|--|---------------|------------|-----------------|
| Parameter | Units | Dry | Semi-Dry |
| Power consumed | kWh/te | 30 | 28.5 |
| Power consumed | MWh p.a. | 17,850 | 16,960 |
| Generation lost (water evaporation) | MWh p.a. | | 15,200 |
| Power not exported | MWh p.a. | 17,850 | 32,160 |
| GWP | t CO2 eq p.a. | 6,800 | 12,200 |

2.2.6 Raw Materials

The estimated consumption of raw materials for both options is shown below.

| Table 2-3- Raw Materials, Acid Abatement Options | | | |
|--|--------------|------------|-----------------|
| Parameter | Units | Dry | Semi-Dry |
| Additional water required in semi-dry system | tpa | | 31,000 |
| Reagent consumption ⁽¹⁾ | tpa | 8,000 | 6,900 |
| PAC | tpa | 150 | 150 |
| Note: | | | |
| (1) Sodium bicarbonate is not considered to be a suitable reagent for a semi-dry system as sodium bicarbonate cannot be made into a slurry. Therefore it has been assumed that quick lime is used as the reagent in a semi-dry system. | | | |

2.2.7 Waste Streams

The only waste stream associated with the acid gas abatement treatment technologies is the Air Pollution Control residues (APCr), including fly ash. These would be a hazardous waste, regardless of whether lime or bicarbonate is used as the acid gas reagent, or whether it is dry or semi-dry. The estimated production of hazardous waste for both options is shown below.

| Table 2-4– Raw Materials, Acid Abatement Options | | | |
|---|--------------|------------|-----------------|
| Parameter | Units | Dry | Semi-Dry |
| APC residues | tpa | 16,000 | 15,600 |

2.3 Costs

The estimated costs associated with each option are presented below. In order for direct comparisons to be made, the costs are presented as annualised costs, with the capital investment and financing costs spread over a 30 year lifetime with a rate of return of 3.5% consistent with Treasury Green Book guidance as requested by the EA.

| Table 2-5 – Costs, Acid Abatement Options | | | |
|--|--------------|-------------------|--------------------|
| Parameter | Unit | Dry | Semi-Dry |
| Capital Cost | £p.a. | £28,300,000 | £29,600,000 |
| Annualised Capital Cost | £p.a. | £1,540,000 | £1,610,000 |
| Maintenance | £p.a. | £1,415,000 | £1,480,000 |
| Reagents and residues | £p.a. | £4,754,000 | £4,807,000 |
| Loss of exported power | £p.a. | £2,062,000 | £3,715,000 |
| Total Annualised Cost | £p.a. | £9,771,000 | £11,612,000 |

2.4 Conclusions

The table below compares the options.

| Table 2-6 – Comparison Table, Acid Abatement Options | | | |
|---|---------------------|------------|-----------------|
| Parameter | Units | Dry | Semi-Dry |
| SO ₂ abated | tpa | 1,300 | 1,300 |
| HCl abated | tpa | 2,680 | 2,680 |
| HF abated | tpa | 260 | 260 |
| POCP | t-ethylene eq | 720 | 720 |
| Additional water required in semi-dry system | tpa | | 31,000 |
| Global Warming Potential | tpa CO ₂ | 6,800 | 12,200 |
| APC Residues | tpa | 16,000 | 15,600 |
| Annualised Cost | £ p.a. | £9,771,000 | £11,612,000 |

The overall performance of the technical options are similar and therefore all could be considered to represent BAT for the Installation. However, whilst the dry solution generates slightly more APC residues, it has a lower Global Warming Potential, significantly lower water consumption and lower annualised costs.

Semi-dry systems will generate a visible plume in certain climatic conditions which would be in breach of the Facility's planning permission, whereby condition 17 requires "no visible plume from the stack". Therefore, a semi-dry system is not considered to be an available technique for the abatement of acid gases.

A dry system can easily achieve the emission limits required by the IED and are less likely to generate a visible plume than semi-dry and wet systems. Dry systems are used on a number plants in Europe.

Taking the above into consideration a dry system is considered to be the only available technique for this Installation. Therefore, a dry system is regarded as representing BAT.

3 REAGENT SELECTION

The selection of reagents for acid gas abatement is considered in section 2.2.2.1 of the Supporting Information document submitted as part of the Environmental Permit application. This assessment is expanded below.

3.1 Options Considered

We have not considered reagents for wet scrubbing, since this has been eliminated as a technique in section 2. We have therefore only considered the two alternative reagents for a dry system – lime and sodium bicarbonate.

3.2 Environmental Performance

3.2.1 Emissions to Air

There is no change in emissions to atmosphere between the two reagents. Both would achieve the same level of abatement.

3.2.2 Deposition to Land

Again, there is no change between the two reagents.

3.2.3 Emissions to Water

There are no emissions to water associated with either of the two reagents.

3.2.4 Photochemical Ozone Creation Potential

There would be no change to POCP for either system.

3.2.5 Global Warming Potential

Sodium bicarbonate has a higher optimum reaction temperature than lime, which means that less heat can be recovered in the boiler. However, this can be resolved by recovering additional heat after the acid gas abatement system. Therefore, it has been assumed that there is no impact on global warming potential from this operational difference.

The reaction of hydrogen chloride and sulphur dioxide with sodium bicarbonate results in an emission of carbon dioxide whereas the reaction with lime does not.

3.2.6 Raw Materials

Sodium bicarbonate (NaHCO_3) has better solid handling properties and a significantly lower stoichiometric ratio than hydrated lime ($\text{Ca}(\text{OH})_2$).

NaHCO_3 and $\text{Ca}(\text{OH})_2$ react with the acid gases to produce alkaline salts as the following equations illustrate:



In order to promote the reactions above, excess quantities of sodium bicarbonate or lime will be required. The excess reagent is lost in the residue. The ratio between the quantity of reagent supplied and the minimum required for the reaction is called the "stoichiometric ratio".

For sodium bicarbonate, a stoichiometric ratio of 1.3 is required, whereas for lime, a stoichiometric ratio of around 1.8 is required. This initially appears to be economically advantageous for sodium bicarbonate in comparison to lime. However, due to the higher relative molecular weight, and the fewer molecules of acid gas reacting per molecule of NaHCO_3 , the overall consumption of sodium bi-carbonate is actually 64% higher than $\text{Ca}(\text{OH})_2$ on a mass basis.

The reagent required to abate one kmol of hydrogen chloride was calculated as 109 kg of sodium bicarbonate and 67 kg of lime.

Similarly, the reagent required to abate one kmol of sulphur dioxide was calculated as 218 kg of sodium bicarbonate and 133 kg of lime.

3.2.7 Waste Streams

The stoichiometric ratio indicates that the amount of residue will be higher with the lime option. However, due to the differences in relative molecular weight and the number of acid gas molecules reacting with each absorbent molecule, the hydrated lime system produces a similar amount of residue to the sodium bi-carbonate option.

The residue production rate for abatement of one kmol of hydrogen chloride was calculated as 84 kg for sodium bicarbonate and 85 kg for lime.

Similarly, the residue production rate for abatement of one kmol of sulphur dioxide was calculated as 142 kg for sodium bicarbonate and 136 kg for hydrated lime.

Furthermore, there are limited waste disposal options for sodium bicarbonate based APCr.

3.3 Costs

There is little difference in capital cost between the two reagents abatement systems.

The consumable feedstock purchase cost of NaHCO_3 is significantly higher than $\text{Ca}(\text{OH})_2$, with bicarbonate costing almost 65% more than hydrated lime per tonne. This makes sodium bicarbonate an uneconomic option in comparison to lime.

The cost of disposing of the residue must also be considered due to the differences in quantity, and the availability of outlets. Sodium based residues are more difficult to stabilise than lime residues; it has been assumed that the cost per tonne to landfill the sodium based residues is 20% higher than lime residues giving a disposal cost for sodium bicarbonate of £150 /te.

The operating costs for the two options are compared below, for a stoichiometric ratio of 1.8 for lime and 1.3 for sodium bicarbonate on the basis of the abatement of one kmol of HCl:

| Table 3-1 – Costs per Unit Hydrogen Chloride Abated | | | |
|--|---------------|------------------------------------|--|
| Item | Unit | NaHCO_3 | $\text{Ca}(\text{OH})_2$ |
| Mass of reagent required | kg/kmol | 109.0 | 67.0 |
| Mass of residue generated | kg/kmol | 84.0 | 85.0 |
| Cost of reagent | £/tonne | 155 | 94 |
| Cost of residue disposal ² | £/tonne | 150 | 125 |
| Overall Cost | £/op. hr/kmol | 29.5 | 16.9 |
| Ratio of costs | | 1.74 | 1 |

² The figure shown does not include landfill tax.

3.4 Conclusions

Whilst the use of sodium bicarbonate will lead to less residues than a lime based system, this is significantly outweighed by the advantages of using lime as a reagent, which are:

- Lime has higher removal rates of acid gases than sodium bicarbonate, which is reflected in the quantities of reagent consumed;
- Lime based APCr has a lower leaching rate than sodium bicarbonate based APCr. Therefore, there are greater waste management options available for lime based APCr. there are different options for the recovery of materials from lime based APCr, i.e. it can be recovered into substitute products displacing virgin materials. GFC are aware that currently the only 'available' option for the management of sodium bicarbonate APCr is disposal in a landfill.
- The reaction temperature for lime systems match well with the optimum adsorption temperature for carbon, which is dosed at the same time;
- The lime system has a slightly lower global warming potential due to the reaction chemistry; and
- The costs per kmol HCl abated are approximately 75% higher for a sodium bicarbonate system than a lime system.

Taking all of the above into consideration, the use of lime is considered to represent BAT for the IWMF compared to sodium bicarbonate.

4 NITROGEN OXIDES ABATEMENT

4.1 Options Considered

Two process technologies have been considered for NO_x abatement and are listed below.

- (1) Selective Catalytic Reduction (SCR) involves the injection of ammonia solution or urea into the flue gases immediately upstream of a reactor vessel containing layers of catalyst.
- (2) Selective Non Catalytic Reduction (SNCR) involves the injection of ammonia solution or urea into the combustion chamber.

All options include the use of flue gas recirculation (FGR) as an integral part of the combustion control system.

4.2 Environmental Performance

4.2.1 Emissions to Air

The emission abatement for nitrogen oxides and ammonia slip are shown in the Table 4-1.

A long term abated emission concentration of 70 mg/Nm³ (11% reference oxygen content) is used for SCR for the purposes of this BAT assessment, since this is the level that the technology can achieve on a long-term basis. The particular SNCR system chosen will operate to reflect the proposed emission limit of 150 mg/Nm³, without excessive ammonia slip. This is a significant improvement on the standard SNCR systems which are designed to meet the IED 200 mg/Nm³ limit that are a feature of a number of permitted EfW facilities in the UK. In order to achieve this emission concentration, the particular SNCR system chosen has been designed with the injection of ammonia solution at multiple points within the combustion chamber, coupled with infra-red pyrometers and integrated algorithms to allow more precise delivery of reagent.

The tonnages of nitrogen oxides removed by the abatement options are also shown.

| Parameter | Units | SNCR | SCR |
|--|--------------------|-------------|------------|
| Nitrous oxide | mg/Nm ³ | 10 | 10 |
| Ammonia slip | mg/Nm ³ | 10 | 10 |
| NO _x , unabated conc. (with FGR) | mg/Nm ³ | 315 | 315 |
| NO _x , unabated release rate | tpa | 950 | 950 |
| NO _x , abated conc. | mg/Nm ³ | 150 | 70 |
| Abated NO _x releases | tpa | 450 | 210 |
| NO _x emissions removed by abatement | tpa | 500 | 740 |

For purpose of this assessment, it has been assumed that the long term NO_x emissions concentration is equivalent to the maximum 150 mg/m³ for SNCR, this is an improvement on IED limit of 200mg/m³. The particular SNCR system chosen will be designed to operate below 150mg/m³ in order to comply with the limit. For the SCR, the long-term NO_x emissions systems have been demonstrated to 'typically' operate at 70 mg/m³.

The impact of emissions to air is considered in the Air Dispersion Assessment, attached as Annex 5 to the Environmental Permit application. The following table shows the predicted ground level concentrations for the available options.

| Table 4-2 – Air Emissions, NO_x Abatement Options with an emission limit of NO_x of 150 mg/Nm³ | | | |
|--|-------------------|-------------|------------|
| Abatement System | | SNCR | SCR |
| Long Term | | | |
| Process Contribution (PC) | µg/m ³ | 0.96 | 0.45 |
| Background | µg/m ³ | 18.60 | 18.60 |
| Predicted Environmental Contribution (PEC) | µg/m ³ | 19.56 | 19.05 |
| Air Quality Objective (AQO) | µg/m ³ | 40 | 40 |
| PC as % of AQO | % | 2.40% | 1.12% |
| PEC as % of AQO | % | 48.90% | 47.62% |
| Short Term | | | |
| Process Contribution (PC) | µg/m ³ | 17.12 | 7.99 |
| Background | µg/m ³ | 18.60 | 18.60 |
| Predicted Environmental Contribution (PEC) | µg/m ³ | 54.32 | 45.19 |
| Air Quality Objective (AQO) | µg/m ³ | 200 | 200 |
| PC as % of AQO | % | 8.56% | 3.99% |
| PEC as % of AQO | % | 27.16% | 22.59% |

It can be seen that there are no predicted exceedances of air quality objectives for any of the options. Using SCR reduces the long term PEC by 1.28% of the air quality objective and the short term PEC by 4.57% of the air quality objective when compared to SNCR.

4.2.2 Emissions to Water

There are no emissions to water from any of the NO_x abatement systems.

4.2.3 Photochemical Ozone Creation Potential

Nitrogen dioxide has a photochemical ozone creation potential (POCP) value relative to Ethylene of 2.8 and nitrogen oxide has a POCP value relative to Ethylene of -42.7. Assuming that 10% of NO_x is released as NO₂ and the rest as NO, the POCP is -17,200 for the SNCR options and -8,000 for the SCR option, meaning that SCR is less favourable. This is because nitrogen oxide converts to nitrogen dioxide in the atmosphere by reacting with ozone, this removing ozone from the atmosphere. Hence, the abatement of NO actually has a negative impact on POCP.

4.2.4 Global Warming Potential

The direct emissions of greenhouse gases are the same for each option, since the carbon dioxide and nitrous oxide emission concentrations are unchanged. However, the energy consumption is different in each option, which would change the power exported from the installation in each case. In particular, SCR imposes an additional pressure drop on the flue gases, leading to an increase in power consumption on the ID Fan. In addition, SCR requires the flue gases to be reheated which reduces the power generated by the turbine.

This means that the reduction in greenhouse gas emissions due to the displacement of power generated by other power stations would be different in each case.

In order to calculate the global warming potential of electricity consumption, the figure of 380 kg carbon dioxide per MWh has been used, as applied in the Greenhouse Gas Assessment presented in Annex 5 of the Environmental Permit application.

| Parameter | Units | SNCR | SCR |
|---------------------------|------------|-------|--------|
| Power consumed | kWe | 890 | 1,580 |
| Power not generated | kWe | | 810 |
| Reduction in power export | MWh p.a. | 7,300 | 19,500 |
| GWP | tpa CO2 eq | 2,800 | 7,400 |

4.2.5 Raw Materials

The estimated consumption of raw materials for each option is shown below.

| Parameter | Units | SNCR | SCR |
|------------------|-------|-------|-----|
| Ammonia solution | tpa | 1,500 | 460 |

4.2.6 Waste Streams

There are no waste streams associated with any of the options.

4.3 Costs

The estimated costs associated with each option are presented below. In order for direct comparisons to be made, the costs are presented as annualised costs, with the capital investment and financing costs spread over a 30 year lifetime with a rate of return of 3.5% consistent with Treasury Green Book guidance.

| Parameter | Unit | SNCR | SCR |
|-------------------------|--------|------------|-------------|
| Capital Cost | £ | £3,000,000 | £19,000,000 |
| Annualised Capital Cost | £ p.a. | £163,000 | £1,033,000 |
| Maintenance | £ p.a. | £94,000 | £380,000 |
| Reagents | £ p.a. | £297,000 | £95,000 |

| Table 4-5 – Costs, NOx Abatement Options | | | |
|---|-------------|-------------|------------|
| Parameter | Unit | SNCR | SCR |
| Loss of exported power | £ p.a. | £843,000 | £2,253,000 |
| Total Annualised Cost | £ p.a. | £1,397,000 | £3,761,000 |

4.4 Conclusions

The table below compares the two options.

| Table 4-6 – Comparison Table, NOx Abatement Options | | | |
|--|------------------------|-------------|------------|
| Parameter | Units | SNCR | SCR |
| NO _x emissions removed by abatement | tpa | 500 | 740 |
| POCP | | -17,200 | -8,000 |
| Global Warming Potential | tpa CO ₂ eq | 2,800 | 7,400 |
| Ammonia solution | tpa | 1,500 | 460 |
| Total Annualised Cost | £ p.a. | £1,397,000 | £3,761,000 |
| Cost per tonne of NOx abated | £ p. t. NOx | 2,800 | 5,100 |

As can be seen from information presented in Table 4-6, applying SCR to the Installation:

- (1) increases the annualised costs by approximately £2.4 million;
- (2) abates an additional 240 tonnes of NOx per annum;
- (3) reduces the benefit of the facility in terms of the global warming potential by a minimum of 4,600 tonnes of CO₂; and
- (4) reduces ammonia consumption by a minimum of approximately 1,040 tonnes per annum; and
- (5) has a cost per tonne of NOx abated is approximately 82% higher than an SNCR system.

In addition to the above, the additional annualised cost of the SCR system compared to the SNCR system is £2,364,000, which leads to the abatement of an additional 240 tonnes of NOx per annum. Hence the SCR system has an additional cost per tonne of NOx abated of approximately £9,850.

The additional costs associated with SCR are not considered to represent BAT for the IWMF. Taking all of the above into consideration, SNCR is considered to represent BAT for the Installation.

5 COMBUSTION TECHNIQUES

5.1 Options Considered

The available techniques for fuel combustion are reviewed in section 2.6.3.1 of the Supporting Information document submitted with the Environmental Permit application. The assessment has been expanded to provide a cost-benefit analysis of moving grates and fluidised beds.

- (1) Moving grates are the leading technology in the UK and Europe for the combustion of biomass and waste fuels. The moving grate comprises an inclined fixed and moving bars (or rollers) or a vibrating grate that will move the fuel from the feed inlet to the residue discharge. The grate movement turns and mixes the fuel along the surface of the grate to ensure that all fuel is exposed to the combustion process.
- (2) Fluidised beds are designed for the combustion of relatively homogeneous fuels, The fuel incinerated in the CHP plant will have been pre-processed, however to achieve the requirements of a fluidised bed would require additional treatment/processing. Fluidised beds require specialist sand and energy to ensure that the bed is fluidised.

5.2 Environmental Performance

5.2.1 Emissions to Air

The emissions to atmosphere would not be affected by the choice of combustion technology. Although NO_x concentrations from the furnaces would be different, both options would require further abatement to achieve the necessary emission limits. This means that the actual effect would be to change the amount of reagent required to abate the NO_x. This is considered in section 5.2.6.

| Table 5-1 – NO_x emissions, Combustion Techniques | |
|--|--|
| Option | NO_x emissions from furnace (expressed at 11% oxygen) (mg/Nm³) |
| Moving Grate | 320-380 |
| Fluidised Bed | 250-300 |

5.2.2 Deposition to Land

Deposition from atmospheric emissions would also be unchanged.

5.2.3 Emissions to Water

There are no emissions to water for either system.

5.2.4 Photochemical Ozone Creation Potential

There would be no change to POCP for either system.

5.2.5 Global Warming Potential

The direct emissions of greenhouse gases are the same for each option, since the carbon dioxide and nitrous oxide emission concentrations are unchanged. However, there are changes in parasitic load and gross power generation. In particular, a fluidised bed installation will have higher parasitic load due to the higher power consumption of the combustion air fan(s), and the presence of additional systems, e.g. the sand and the fly ash separation system.

The difference in power generation and parasitic load means that the reduction in greenhouse gas emissions due to the displacement of power generated by other power stations would be different in each case.

In order to calculate the global warming potential of electricity consumption, the figure of 380 kg carbon dioxide per MWh has been used, as applied in the Greenhouse Gas Assessment presented in Annex 5.

This is shown in the table below. Note that GWP is negative and so a higher figure is better.

| Parameter | Units | Grate | Fluidised Bed |
|------------------------|-------------------------|----------|---------------|
| Gross power generation | MWh p.a. | 399,000 | 399,000 |
| Parasitic Load | MWh p.a. | 5.5 | 6.05 |
| Net power generation | MWh p.a. | 354,000 | 350,000 |
| Change in GWP | tpa CO ₂ eq. | -135,000 | -133,000 |

5.2.6 Raw Materials

The estimated consumption of raw materials for each option is shown below. The unabated NOx emissions a fluidised bed are expected to be lower than a grate system, so ammonia consumption for SNCR will decrease. Fluidised bed boilers also consume sand, which is used as bed material.

| Parameter | Units | Grate | Fluidised Bed |
|------------------|-------|-------|---------------|
| Ammonia solution | tpa | 1,500 | 1,000 |
| Sand | tpa | | 6,210 |

5.2.7 Waste Streams

The two combustion technology options produce four solid waste streams.

- (1) Residual metals within the incoming fuel will be identical for both options and are not considered further.
- (2) Overall ash production from the waste stream for both options will be similar however:
 - a) The bottom ash production is lower for fluidised beds. It is assumed that the bottom ash would be re-used for building aggregate.

- b) Fluidised beds have much greater carry-over of fine particles and, consequently, produce an additional fly ash stream, which is removed in a cyclone before the acid gas abatement reagent is added. This separate fly ash stream could be usable for building aggregate, but this is not certain. For the purposes of this assessment it is assumed that it will need to be sent to a hazardous landfill.
- (3) Both options produce APCr. The fluidised bed option would generate less APCr because it is assumed that the fly ash will be removed from the gas stream.
- (4) The specialist sand that is consumed by fluidised bed boilers leave the bed as bottom or fly ash. Therefore, the total amount of solid residues is higher for fluidised bed boilers.

The estimated amounts of residues are shown in the table below.

| Table 5-4 – Waste Streams, Combustion Options | | | |
|--|--------------|--------------|----------------------|
| Parameter | Units | Grate | Fluidised Bed |
| Bottom Ash | tpa | 145,000 | 54,510 |
| Fly Ash | tpa | | 99,200 |
| APC Residues | tpa | 18,100 | 15,600 |
| Total solid residues | tpa | 163,100 | 169,310 |

5.3 Costs

Capital costs are not readily available for the different options.

We would the operating costs associated with a fluidised bed unit to be up to 10-15% more than a grate fired boiler due to the additional fuel preparation equipment, sand dosing and recycling equipment and fly ash separation. This would outweigh some of the savings from reduced quantities of bottom ash being generated.

The estimated costs of operating each system are presented in the table below. It should be noted that this does not allow for increased maintenance costs associated with the fluidised bed option. For the power, we have shown the lost revenue associated with reduced power export compared to the moving grate option.

| Table 5-5 – Operating Costs, Combustion Options | | | |
|--|--------------|--------------|----------------------|
| Parameter | Units | Grate | Fluidised Bed |
| Ammonia solution | £ p.a. | £170,000 | £120,000 |
| Sand | £ p.a. | | £620,000 |
| Residue disposal | £ p.a. | £5,270,000 | £12,400,000 |
| Reagents and residue disposal annual cost | £ p.a. | £5,570,000 | £17,590,000 |
| Additional loss of exported power compared to Grate | £ p.a. | | £460,000 |
| Additional costs for fluidised bed compared to a grate | £ p.a. | | £12,480,000 |

5.4 Conclusions

The table below compares the two options.

| Parameter | Units | Grate | Fluidised Bed |
|---|-------------------------|--------------|----------------------|
| Change in GWP | tpa CO ₂ eq. | -135,000 | -133,000 |
| Ammonia solution | tpa | 1,500 | 1,000 |
| Total residues | tpa | 163,100 | 169,310 |
| Reagents and residue disposal annual cost | £ p.a. | £5,570,000 | £17,590,000 |
| Additional annual costs for a fluidised bed compared to a grate | £ p.a. | | £12,480,000 |

Both the grate and fluidised bed will produce similar quantities of ash, although the fluidised bed produces more fly ash.

GFC consider that the significantly lower operating costs and better global warming potential associated with a grate system outweigh the additional ammonia consumption. Furthermore, the grate system will be able to process a variable waste composition compared to a fluidised bed system which requires a consistent and homogenous fuel.

GFC consider that grate based systems are a proven technology, with a number of operational plants in the UK. Conversely, there is only one operational fluidised bed in England, and it is well publicised that this experienced a number of issues during the commissioning phase. Taking this into consideration, GFC do not consider that a fluidised bed can be considered as a reliable technology for the combustion of RDF within the IWMF. On this basis, GFC consider that a grate system represents BAT for the Installation.

6 STACK HEIGHT ASSESSMENT

An Assessment of Stack Height as a BAT consideration has been developed and is presented in Annex 12 of the EP application.

This Stack Height Assessment has assessed the stack height in a comparable manner to other technology BAT assessments, via an approach agreed with the EA during pre-application discussions. It also compares the proposed stack height in relation to other EfW facilities which have been approved by the Environment Agency. This assessment draws the following conclusions.

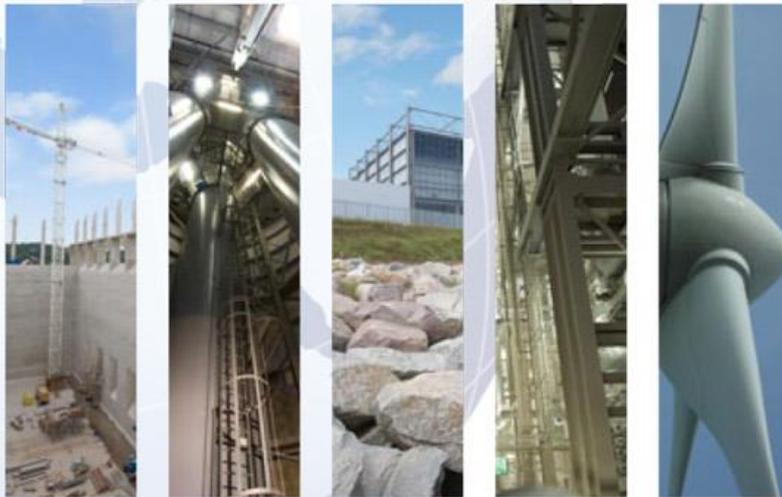
6.1 Stack Height BAT Assessment

An evaluation of stack heights from 25m above surrounding ground level (75mAOD) to 95m above surrounding ground level (145mAOD) has been made. This assessment found that the environmental benefits of increasing height above 55m are considerably less than the benefits associated with increasing from 35m to 55m, even acknowledging that the actual long term impact at all stack heights above 35m is not significant, and would be described as "negligible" under the IAQM (2017) guidance.

It is concluded that a stack of height 55m (above surrounding ground level) (105m AOD) with a long term emission limit for NO_x of 150mg/m³ represents BAT for the Rivenhall IWMF.

6.2 Stack Height comparisons

The stack heights of 34 different energy-from-waste plants have been compared to the Rivenhall IWMF 55m stack. The analysis considers a number of factors that influence the height of stacks at EfW plants. The analysis demonstrates that the proposed stack height for Rivenhall, when properly compared with the dominant factors of building height and the immediate surroundings, is not inconsistent with other similar facilities in the UK.



FICHTNER

Consulting Engineers Limited

Fichtner Consulting Engineers Limited
Kingsgate (Floor 3), Wellington Road North, Stockport, Cheshire, SK4 1LW, United Kingdom
t: +44 (0)161 476 0032 f: +44 (0)161 474 0618 www.fichtner.co.uk