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Consulting Engineers Limited

INTERTISSUE

INTERTISSUE BIOMASS BOILER

BAT ASSESSMENT

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1 Introduction

This report presents quantitative BAT assessments for acid gas abatement, nitrogen oxides abatement and combustion technologies for the Intertissue biomass-fuelled boiler (the Facility).

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 Facility includes fuel reception, storage and handling, water, natural gas and air supply systems, furnace, steam boiler, facilities for the treatment of exhaust gases, on-site facilities for storage of residues, stack, devices and systems for recording, monitoring and controlling plant operation, combustion conditions and electrical systems.

Steam generated by the Facility will be supplied to a Yankee Dryer, an important part of the paper manufacturing process. The Yankee Dryer removes excess moisture from paper pulp during its conversion into a range of paper products. There will be no power generated by the Facility.

For the purposes of this BAT assessment, the following has been assumed:

- The nominal operating capacity of the Facility will be approximately 2.25 tonnes per hour of biomass fuel, with a design calorific value of 12.8 MJ/kg.
- The Facility will have an estimated availability of above 8,200 hours per annum.
- The nominal design annual throughput is 18,450 tonnes.

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) Urea .... £145 per tonne;
(8) Bottom ash processing... £10 per tonne;
(9) Lime APCr disposal .... £125 per tonne;
(10) Sodium bicarbonate APCr disposal................................ £150 per tonne; and
(11) Landfill tax .... £80 per tonne.

2 Acid Gas Abatement

2.1 Options Considered

There are currently three technologies widely available for acid gas treatment on waste wood 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 reactions can take place.

(3) Dry, involving the injection of solid lime into the flue gases as a powder. The lime is collected on a bag filter to form a cake and most of the reaction between the acid gases and the lime takes place as the flue gases pass through the filter cake. In its basic form, the dry system consumes more lime 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, due to the production of a large volume of hazardous liquid effluent and the generation of a visible plume. The dry and semi-dry systems are considered further below.

2.2 Environmental Performance

2.2.1 Emissions to Air

The impact of emissions to air is considered in the Air Quality Assessment, which can be found in Annex 4 of the Environmental Permit application. The acid gas emissions were assessed at the daily emission concentrations of 75 mg/Nm^3 for sulphur dioxide and 15 mg/Nm^3 for hydrogen chloride, both expressed at 6% 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 a semi-dry system are expected to be the same as for a dry system so the ground level impacts are also the same.

Table 2-1 – Emissions to Air, Acid Abatement Options					
Abatement System		**Dry**		**Semi-dry**	
Pollutant	**Units**	**SO_2**	**HCl**	**SO_2**	**HCl**
Unabated emission concentration	mg/Nm^3	133	129	133	129
Unabated emission rate	tpa	11	11	11	11
Emission concentration	mg/Nm^3	75	15	75	15
Emission rate	tpa	6	1	6	1
Emissions abated	tpa	5	10	5	10
Process Contribution (PC)	ug/m^3	4.22	3.46	4.22	3.46
Background	ug/m^3	13.80	1.40	13.80	1.40
Predicted Environmental Contribution (PEC)	ug/m^3	31.82	6.26	31.82	6.26
Air Quality Objective	ug/m^3	125	750	125	750
PC as % of AQO	%	3.38	0.46	3.38	0.46
PEC as % of AQO	%	25.46	0.83	25.46	0.83

The daily average PC for sulphur dioxide and the maximum 1-hour PC for hydrogen chloride are respectively 3.38% and 0.46% of the relevant average air quality objectives.

The impact of sulphur dioxide and hydrogen chloride 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 Air Quality Assessment presented in Annex 4 of the Environmental Permit application. As can be seen from this assessment, the impact of acid deposition at all statutory designated sites is considered to be not significant.

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) of 4.8. Hence, the POCP for both the dry and semi-dry systems would be 31 tonnes ethylene equivalent.

2.2.5 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, the energy consumption is slightly different.

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.

In order to calculate the global warming potential of electricity consumption, the figure of 398 kg carbon dioxide per MWh has been used, as applied in the greenhouse gas assessment presented in Annex 6. 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.	550	530
Generation lost (water evaporation)	MWh p.a.	-	-
GWP	t CO2 eq p.a.	220	210

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**
Total site water use	tpa	3,265	4,000
Quick lime	tpa	-	300
Hydrated lime	tpa	125	-
Powdered Activated Carbon	tpa	9	9

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.

Table 2-4 – Raw Materials, Acid Abatement Options			
Parameter	**Units**	**Dry**	**Semi-Dry**
APC residues	tpa	250	240

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 9%, using the method recommended in Technical Guidance Note EPR-H1.

Table 2-5 – Costs, Acid Abatement Options			
Parameter	**Unit**	**Dry**	**Semi-Dry**
Capital Cost	£ p.a.	3,600,000	3,800,000
Annualised Capital Cost	£ p.a.	350,000	370,000
Maintenance	£ p.a.	180,000	190,000
Reagents and residues	£ p.a.	72,000	86,000
Total Annualised Cost	**£ p.a.**	**602,000**	**646,000**

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	5	5
HCl abated	tpa	10	10
POCP	t-ethylene eq	31	31
Total site water use	tpa	3,265	4,000
Global Warming Potential	tpa CO2	220	210
APC Residues, incl. fly ash	tpa	250	240
Annualised Cost	£ p.a.	602,000	646,000

The overall performance of the two technical options is similar and therefore either could be considered to represent BAT for the Facility. However, whilst the dry solution generates slightly more APC residue and has a fractionally higher Global Warming Potential, it has lower water consumption and annualised costs. A dry system is considered to represent BAT for the Facility.

3 Nitrogen Oxides Abatement

3.1 Options Considered

Three options have been considered for NOx 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.

(3) SNCR in combination with flue gas recirculation (SNCR+FGR).

3.2 Environmental Performance

3.2.1 Emissions to Air

The emission rates for nitrogen oxides and ammonia are shown in the table below.

A long term abated emission concentration of 105 mg/Nm^3 (6% 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 two SNCR systems, with and without Flue Gas Recirculation (FGR), operate to match the emission requirement of 300 mg/Nm^3.

The unabated emission with FGR is assumed to be 10% lower than the other two cases due to FGR reducing the formation of NOx.

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

Table 3-1– Air Emissions, NOx Abatement Options

Parameter	Units	SNCR	SCR	SNCR+FGR
Nitrous oxide	mg/Nm^3	22.5	22.5	22.5
Ammonia slip	mg/Nm^3	15	15	15
NO_x, unabated conc.	mg/Nm^3	475	475	428
NO_x, unabated release rate	tpa	41	41	36
NO_x, abated conc.	mg/Nm^3	300	105	300
NO_x emissions removed by abatement	tpa	15	32	11
NO_x emissions released	tpa	26	9	26

The impact of emissions to air is considered in the air quality assessment, attached as Annex 4 to the Environmental Permit application. The following table shows the predicted ground level concentrations for any of the available options.

Table 3-2 – Air Emissions, NOx Abatement Options				
Abatement System		**SNCR**	**SCR**	**SNCR+FGR**
Long Term				
Process Contribution (PC)	μg/m³	2.64	0.92	2.64
Background	μg/m³	20.30	20.30	20.30
Predicted Environmental Contribution (PEC)	μg/m³	22.94	21.22	22.94
Air Quality Objective (AQO)	μg/m³	40	40	40
PC as % of AQO	%	6.6%	2.3%	6.6%
PEC as % of AQO	%	57.4%	53.1%	57.4%
Short Term				
Process Contribution (PC)	μg/m³	9.83	3.44	9.83
Background	μg/m³	40.60	40.60	40.60
Predicted Environmental Contribution (PEC)	μg/m³	91.03	84.64	91.03
Air Quality Objective (AQO)	μg/m³	200	200	200
PC as % of AQO	%	4.9%	1.7%	4.9%
PEC as % of AQO	%	45.5%	42.3%	45.5%

There are no predicted exceedances of air quality objectives (AQO) for any of the options. Using SCR reduces the long term PEC by 4.3% of the AQO and the short term PEC by 3.2% of the AQO when compared to either SNCR or SNCR+FGR.

3.2.2 Emissions to Water

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

3.2.3 Photochemical Ozone Creation Potential

Nitrogen dioxide has a photochemical ozone creation potential (POCP) of 2.8 and nitrogen oxide has a POCP of -42.7. Assuming that 10% of NOx is released as NO2 and the rest as NO, the POCP is -1000 for the SNCR options and -300 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, thus removing ozone from the atmosphere. Hence, the abatement of NO actually has a negative impact on POCP.

3.2.4 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. 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.

In order to calculate the global warming potential of electricity consumption, the figure of 398 kg carbon dioxide per MWh has been used, as applied in the Greenhouse Gas Assessment presented in Annex 6 of the Environmental Permit application.

Table 3-3 – Global Warming Potential, NOx Abatement Options				
Parameter	**Units**	**SNCR**	**SCR**	**SNCR+FGR**
Power consumed	kWe	20	50	30
Annual power consumption	MWh p.a.	190	370	250
GWP	tpa CO2 eq	80	150	100

3.2.5 Raw Materials

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

Table 3-4 – Raw Materials, NOx Abatement Options				
Parameter	**Units**	**SNCR**	**SCR**	**SNCR+FGR**
Water	tpa	220	200	160
Urea[1]	tpa	150	140	110

3.2.6 Waste Streams

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

3.3 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 9%, using the method recommended in Technical Guidance Note EPR-H1.

Table 3-5 – Costs, NOx Abatement Options				
Parameter	**Unit**	**SNCR**	**SCR**	**SNCR+FGR**
Capital Cost	£ p.a.	150,000	2,430,000	340,000
Annualised Capital Cost	£ p.a.	15,000	237,000	33,000
Maintenance	£ p.a.	3,000	49,000	7,000
Reagents	£ p.a.	22,000	21,000	16,000
Total Annualised Cost	£ p.a.	40,000	307,000	56,000

3.4 Conclusions

The table below compares the three options.

[1] In this assessment it has been assumed that the SNCR reagent is urea, however this will be confirmed upon appointment of a technology provider who will be design and building the Facility.

Table 3-6 – Comparison Table, NOx Abatement Options				
Parameter	**Units**	**SNCR**	**SCR**	**SNCR+FGR**
NO_x emissions removed by abatement	tpa	15	32	11
POCP		- 1,000	- 300	- 1,000
Global Warming Potential	tpa CO_2 eq	80	150	100
Urea	tpa	150	140	110
Total Annualised Cost	£ p.a.	40,000	307,000	56,000

As can be seen from the table above, applying SCR to the Installation:

(1) increases the annualised costs by more than £260,000;

(2) abates an additional 17 tonnes of NOx per annum;

(3) reduces the benefit of the Facility in terms of the global warming potential by a minimum of 70 tonnes of CO_2; and

(4) reduces urea consumption by a minimum of approximately 10 tonnes per annum.

This gives an effective additional annual cost of approximately £16,000 per additional tonne of NOx abated when compared to SNCR or £12,000 per additional tonne of NOx abated when compared to SNCR + FGR. The additional costs associated with an SCR system are not considered to represent BAT for the Installation. Therefore, SNCR is considered to represent BAT for the Installation.

The two SNCR options, with and without FGR, are very similar. FGR results in a reduction of reagent consumption, but requires more power to operate, and therefore it has a higher global warming potential and slightly higher total annualised costs.

The choice of whether to include FGR is supplier dependent. A technology provider has not been appointed and will be determined through a robust procurement process. On this basis, and since the differences between the two options are small, the use of FGR for the proposed installation will be considered during the tendering process.

If the selected technology supplier has an established track record of using this technique and can demonstrate the benefits, in terms of energy efficiency and environmental performance, of applying it to his technology FGR will be included within the design.

As identified in the Supporting Information, it is proposed that a Pre-operational Improvement condition is included within the EP to allow the Operator to confirm whether the design will include FGR prior to the commencement of commissioning.

4 Reagent Selection

The selection of reagents for acid gas abatement is considered in section 2.1.3.1 of the Supporting Information document submitted as part of the Environmental Permit application. This assessment is expanded below.

4.1 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.

4.2 Environmental Performance

4.2.1 Emissions to Air

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

4.2.2 Deposition to Land

Again, there is no change between the two reagents.

4.2.3 Emissions to Water

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

4.2.4 Photochemical Ozone Creation Potential

There would be no change to POCP for either system.

4.2.5 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.

4.2.6 Raw Materials

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

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

$$NaHCO_{3(s)} + HCl_{(g)} \rightarrow NaCl_{(s)} + H_2O_{(g)} + CO_{2(g)} \quad \textbf{(Eq.1)}$$

$$Ca(OH)_{2(s)} + 2HCl_{(g)} \rightarrow CaCl_{2(s)} + 2H_2O_{(g)} \quad \textbf{(Eq.2)}$$

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 $Ca(OH)_2$ 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.

4.2.7 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 192 kg for sodium bicarbonate and 195 kg for hydrated lime.

4.3 Costs

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

The cost of $NaHCO_3$ is significantly higher than $Ca(OH)_2$, 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. Sodium based residues are more difficult to stabilise than hydrated 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 in the table 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 hydrogen chloride.

Table 4-1 – Costs, Acid Gas Reagents – abatement of 1 kmol of hydrogen chloride

Item	Unit	$NaHCO_3$	$Ca(OH)_2$
Mass of reagent required	kg	109.0	67.0
Mass of residue generated	kg	84.0	85.0
Cost of reagent	£/tonne	155	94
Cost of residue disposal	£/tonne	150	125
Overall Cost	£/kmol	29.50	16.90
Ratio of costs		1.74	-

4.4 Conclusions

There is a small environmental benefit for using sodium bicarbonate, in that the mass of residues produced is slightly smaller. However, there are a number of significant disadvantages.

(1) The residue has a higher leaching ability than lime-based residue, which will limit the disposal options.

(2) The reaction temperature doesn't match as well with the optimum adsorption temperature for carbon, which is dosed at the same point.

(3) The sodium bicarbonate system has a slightly higher global warming potential due to the reaction chemistry (by almost 50 tonnes of CO_2).

(4) The costs are almost 75% higher.

Hence, the use of hydrated lime is considered to be BAT for the Facility.

5 Combustion Techniques

5.1 Options Considered

The available techniques for fuel combustion are reviewed in section 2.4.1 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, fluidised beds and rotary kiln.

(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. Wood chips are considered to be suitable for combustion with a fluidised bed.

(3) Rotary Kilns have been proven to achieve good fuel agitation and associated burn-out rates. Rotary kilns have been demonstrated to achieved good results with clinical waste, however they have had limited application in the UK. Rotary Kilns operate at high temperature and are considered BAT for hazardous waste and lower throughput mixed feeds. The high temperatures promote NOx formation which may require additional abatement. The tumbling action of the kilns can generate high concentrations of fine particles which may require a secondary combustion chamber and additional abatement. Rotary Kilns are regarded as being an appropriate combustion technology for this type of Installation.

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 NOx 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 NOx. This is considered in section 5.2.6.

Table 5-1 – NOx emissions, Combustion Techniques

Option	NOx emissions from furnace (expressed at 6% oxygen) (mg/Nm^3)
Moving Grate	475 - 570
Fluidised Bed	375 - 450
Rotary Kiln	450 - 525

5.2.2 Deposition to Land

Deposition from atmospheric emissions would also be unchanged.

5.2.3 Emissions to Water

There would not be any emissions to water from any of the combustion systems.

5.2.4 Photochemical Ozone Creation Potential

There would be no change to POCP from any of the combustion systems.

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:

(1) 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; and

(2) the thermal efficiency of a rotary kiln is approximately 10% lower than a grate, which means that less steam would be generated and so less natural gas displaced.

In order to calculate the global warming potential (GWP) of electricity consumption, the figure of 398 kg carbon dioxide per MWh has been used, as applied in the Greenhouse Gas Assessment presented in Annex 6.

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

Table 5-2 – Global Warming Potential, Combustion Options

Parameter	Units	Grate	Fluidised Bed	Rotary kiln
Parasitic Load	MWh p.a.	2,900	3,200	2,900
Change in GWP	tpa CO_2 eq.	1,160	1,270	1,290

5.2.6 Raw Materials

The estimated consumption of raw materials for each option is shown below. The unabated NOx emissions from fluidised bed boilers are expected to be lower than grate boilers, and therefore will have a lower NOx reagent consumption within the SNCR system. Fluidised bed boilers also consume sand, which is used as bed material.

Table 5-3– Raw Materials, Combustion Options

Parameter	Units	Grate	Fluidised Bed	Rotary kiln
Urea	tpa	150	70	130
Sand	tpa	-	260	-

5.2.7 Waste Streams

The three options produce four or five solid waste streams.

(1) Residual metals within the incoming fuel will be identical for all options and so are not considered further.

(2) The bottom ash production is lower for fluidised beds. Bottom ash could be re-used as a building aggregate.

(3) 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 and it is possible that it will need to be sent to a hazardous landfill.

(4) All 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.

(5) The sand that is consumed by fluidised bed boilers leaves 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	Rotary kiln
Bottom Ash	tpa	550	440	550
Fly Ash	tpa	-	370	-
APC Residues	tpa	250	220	250

5.3 Costs

Capital costs are not readily available for the different options.

We would expect a fluidised bed unit to be up to 10-15% more expensive 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.

We have estimated the relative operating costs in the table below. We would note that this does not allow for increased maintenance costs associated with the fluidised bed option.

Table 5-5 – Operating Costs, Combustion Options

Parameter	Units	Grate	Fluidised Bed	Rotary kiln
Urea	£ p.a.	20,000	10,000	20,000
Sand	£ p.a.	-	26,000	-
Residue disposal	£ p.a.	57,000	56,000	57,000
Total Reagents and disposal annual cost	£ p.a.	77,000	92,000	77,000

5.4 Conclusions

The table below compares the three options.

Table 5-6 – Comparison, Combustion Options

Parameter	Units	Grate	Fluidised Bed	Rotary kiln
Global Warming Potential	tpa CO2 eq.	1,160	1,270	1,290
Urea	tpa	150	70	130
Total residues	tpa	800	1100	800
Total reagents and disposal annual cost	£ p.a.	77,000	92,000	77,000

The annualised costs for all options are similar. The rotary kiln has a higher global warming potential than the grate and fluidised bed and a higher urea consumption than the fluidised bed. For these reasons the rotary kiln is not considered to be BAT for the Facility.

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

Overall, the lower annualised costs associated with a grate system outweigh the additional material costs and higher ammonia consumption. On this basis a grate system is considered to represent BAT for the Facility.

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