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Portland Energy Recovery Facility



Powerfuel Portland Limited

BAT Assessment Report

Document approval

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Document revision record

| Revision no | Date | Details of revisions | Prepared by | Checked by |
|-------------|------------|--|-------------|------------|
| 00 | 29/09/2020 | For Client | NT1 | JRS |
| 01 | 18/11/2020 | Revised following client comments – track changes shown. | NT1 | JRS |
| 02 | 21/12/2020 | For issue | NT1 | JRS |

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1 Introduction

Powerfuel Portland Limited (Powerfuel) is proposing to build the Portland Energy Recovery Facility (the Facility) at a site within Portland Port on the Isle of Portland, Dorset. The Facility will incinerate refuse derived fuel (RDF) produced from domestic (municipal solid waste) and commercial & industrial (C&I) non-hazardous waste.

In accordance with the requirements of EPR5.01, this report presents quantitative BAT assessments for acid gas abatement, nitrogen oxides abatement for the Facility.

The assessment of each aspect has been undertaken in accordance with the structure of Technical Guidance Note EPR-H1 and includes comments on all of the environmental parameters required by the H1 guidance.

1.1 Assumptions

The Facility will use a moving grate as the combustion technology. The Facility will be a single stream design, with a nominal design capacity of approximately 23 tonnes of incoming waste per hour, with an average net calorific value (NCV) of 11 MJ/kg. This equates to a nominal design capacity of approximately 183,000 tonnes per annum, assuming 8,000 hours operation per annum. Assuming a higher availability (up to 8,760 hours per annum) and to allow for variations in the NCV of the waste, the Facility will be capable of processing up to 202,000 tonnes per annum. However, for the purposes of this assessment, it is assumed that the Facility has a processing capacity of 183,000 tonnes per annum. The Facility will generate up to approximately 15.2 MWe at the nominal design capacity.

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

The following unit costs have been assumed within the relevant operating costs sections of this assessment:

- Water£1 per tonne
- Lime Slurry£90 per tonne
- Lime.....£91 per tonne
- Sodium Bicarbonate.....£155 per tonne
- Activated Carbon£710 per tonne
- Ammonia.....£164 per tonne
- Sand (with defined particle size distribution)£100 per tonne
- Bottom Ash Processing£25 per tonne
- Lime APCR Disposal.....£136 per tonne
- Sodium bicarbonate APCR Disposal.....£163 per tonne
- Landfill Tax (1 April 2020)£94 per tonne
- Imported power £70 per MWh
- Electricity revenue £55 per MWh

2 Acid Gas Abatement

2.1 Options Considered

There are three recognised technologies for acid gas abatement on waste incineration plants:

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 facilities treating hazardous waste 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 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, a reduction in the power generating efficiency of the Facility 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 Process Emissions Modelling assessment, which is presented in Appendix D of the supporting information document. The impact of emissions of acid gases was assessed at the daily emission concentrations of 30 mg/m³ for sulphur dioxide (SO₂) and 6 mg/m³ for hydrogen chloride (HCl).

The table below presents 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 hourly mean is shown. The emission concentrations for a semi-dry system are expected to be the same as for a dry system, so the predicted ground level impacts are the same.

Table 2-1: Emissions to Air

| Abatement System | Units | Dry | | Semi-dry | |
|---|-------------------|-----------------|-------|-----------------|-------|
| | | SO ₂ | HCl | SO ₂ | HCl |
| Unabated emission concentration | mg/m ³ | 450 | 900 | 450 | 900 |
| Unabated emission rate | tpa | 510 | 1,010 | 510 | 1,010 |
| Abated emission concentration | mg/m ³ | 30 | 6 | 30 | 6 |
| Abated emission rate | tpa | 30 | 10 | 30 | 10 |
| Total emissions abated | tpa | 480 | 1,000 | 480 | 1,000 |
| Process Contribution (PC) | ug/m ³ | 2.38 | 1.75 | 2.38 | 1.75 |
| Background ⁽¹⁾ | ug/m ³ | 6.64 | 1.42 | 6.64 | 1.42 |
| Predicted Environmental Contribution (PEC) | ug/m ³ | 9.02 | 3.17 | 9.02 | 3.17 |
| Air Quality Objective (AQO) | ug/m ³ | 125 | 750 | 125 | 750 |
| PC as % of AQO | % | 1.90 | 0.23 | 1.90 | 0.23 |
| PEC as % of AQO | % | 7.22 | 0.42 | 7.22 | 0.42 |
| <i>Note:</i> | | | | | |
| <i>(1) The short-term background is assumed to be twice the long-term background in accordance with Environment Agency Air Emissions Guidance</i> | | | | | |

The short-term impact of the plant is 1.90% of the daily average air quality objective for sulphur dioxide and 0.23% of the hourly air quality objective for hydrogen chloride. The impact of hydrogen chloride is considered to be 'insignificant' when applying the criteria stated in Environment Agency guidance note H1. Whilst the impact of sulphur dioxide cannot be described as insignificant, it is considered to be a 'not significant' impact in accordance with the criteria stated in Environment Agency guidance note H1.

A more detailed assessment of impacts from the release of sulphur dioxide and hydrogen chloride is presented within the Process Emissions Modelling assessment, refer to Appendix D of the Application.

2.2.2 Deposition to Land

The impact of acid deposition on sensitive habitats has been assessed in the Process Emissions Modelling assessment, refer to Appendix D of the Application. As can be seen from this assessment, the impact of acid deposition on sensitive receptors is considered to be 'insignificant' at all habitat features, with the exception of acid deposition impacts at calcareous grasslands at the Isle of Portland to Studland Cliffs (SAC and SSSI) and acid grassland at Chesil and The Fleet (SAC and SSSI). However, within the planning application for the Facility, a shadow appropriate assessment has been completed. Within the shadow appropriate assessment, it is demonstrated that at the ecological features where the impact cannot be screened as insignificant, the predicted environmental concentrations will be below the 70% threshold where a significant effect will occur. The assessment concludes that there will be a negligible magnitude of change on sites of high (or

international) importance. Therefore, it is concluded that the operation of the Facility will not be any significant impacts upon sensitive ecological features.

2.2.3 Emissions to Water

There are no emissions to water for either the dry or the semi-dry systems, therefore the impact of these systems is the same.

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 290 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, which would change the power exported from the plant. 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 349 kg CO₂ per MWh has been used, as applied in the greenhouse gas assessment, refer to Appendix D of the Supporting Information.

This is shown in Table 2-2.

Table 2-2: Global Warming

| | Units | Dry | Semi-Dry |
|-------------------------------------|----------------------|------------|-----------------|
| Power consumed | kWh/t | 30 | 28.5 |
| | MWh pa | 5,480 | 5,210 |
| Generation lost (water evaporation) | MWh pa | | 5,300 |
| Power not exported | MWh pa | 5,480 | 10,510 |
| GWP | t CO ₂ pa | 1,900 | 3,700 |

2.2.6 Raw Materials

The estimated consumption of raw materials for both options is shown in Table 2-3.

Table 2-3: Raw Materials

| | Units | Dry | Semi-Dry |
|---|--------------|------------|-----------------|
| Additional water consumption compared to a dry system | tpa | | 16,825 |
| Lime Slurry | tpa | | 2,867 |

| | Units | Dry | Semi-Dry |
|---------------------------------|-------|-------|----------|
| Lime | tpa | 3,700 | |
| Powdered Activated Carbon (PAC) | tpa | 91 | 91 |

2.2.7 Waste Streams

The only waste stream associated with the acid gas abatement treatment technologies is the Air Pollution Control Residues. These would be a hazardous waste. The production rate for a dry system would be approximately 6,000 tonnes per annum, and for a semi-dry system would be approximately 5,400 tonnes per annum.

2.3 Costs

The estimated costs associated with each option are presented in Table 2-4. 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 2-4: Costs

| | Dry | Semi-Dry |
|------------------------------|-------------------|-------------------|
| Capital Cost | £11,100,000 | £11,600,000 |
| Annualised Capital Cost | £1,080,000 | £1,130,000 |
| Maintenance | £555,000 | £580,000 |
| Reagents and residues | £1,678,000 | £1,490,000 |
| Loss of exported power | £269,000 | £515,000 |
| Total Annualised Cost | £3,582,000 | £3,715,000 |

2.4 Conclusions

Table 2-5 compares the options.

Table 2-5: Comparison Table

| | Units | Dry | Semi-Dry |
|---|-------------------------|-----------|-----------|
| SO ₂ abated | tpa | 480 | 480 |
| Photochemical Ozone Creation Potential (POCP) | t ethylene-eq pa | 140 | 140 |
| Global Warming Potential | t CO ₂ eq pa | 1,900 | 3,700 |
| Additional water consumption compared to a dry system | tpa | | 16,825 |
| APC Residues | tpa | 5,550 | 5,000 |
| Annualised Cost | £ pa | 3,582,000 | 3,715,000 |

As can be seen, the performance of the options is very similar, with the same quantities of sulphur dioxide abated by both systems.

The dry system only requires a small quantity of water for conditioning of the lime so that it is suitable for injection into the reaction chamber, whereas the semi-dry system requires the lime to be held in solution (quick lime). This requires significantly more water than a dry system.

The dry system has a reduced global warming potential and a reduced annualised cost. In addition, within a semi-dry system recycling of reagent within the process is not proven, but it is proven in a dry system. However, the semi-dry option benefits from medium reaction rates which mean that a shorter residence time is required in comparison with a dry system.

Due to the low water consumption and proven capability for recycling of reagents, the dry system is considered to represent BAT for the Facility.

3 Nitrogen Oxides (NO_x) Abatement

3.1 Options Considered

Three options have been considered for NO_x abatement and are listed below:

1. Selective Catalytic Reduction (SCR), which 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), which involves the injection of ammonia solution or urea into the combustion chamber.
3. SNCR in combination with flue gas recirculation (SNCR+FGR).

As stated previously, for the purposes of this assessment, it is assumed that ammonia solution will be the reagent used in the NO_x abatement system.

Whilst the technology provider has proposed an SNCR system to abate emissions of NO_x from the furnace, to ensure compliance with the proposed emission limit for NO_x and the reduced limit for ammonia the technology provider has indicated that it may be necessary for a layer of catalyst to be installed in the flue from the bag filters and prior to release from the stack to act as a 'polisher'.

For the purposes of this BAT assessment it has been assumed that the proposed system is classified as an SNCR system with an SCR polisher, rather than an SCR system.

3.2 Environmental Performance

3.2.1 Emissions to Air

The emission rates for nitrogen oxides, nitrous oxide and ammonia are shown in Table 3-1 together with the tonnages of nitrogen oxides abated.

Table 3-1: Air Emissions

| | Units | SNCR | SCR | FGR + SNCR |
|--|-------------------|------|-----|------------|
| Nitrous oxide | mg/m ³ | 10 | 10 | 10 |
| Ammonia | mg/m ³ | 8 | 8 | 8 |
| NO _x , unabated concentration | mg/m ³ | 380 | 380 | 340 |
| NO _x , unabated rate | tpa | 430 | 430 | 380 |
| NO _x , abated concentration | mg/m ³ | 120 | 80 | 120 |
| NO _x released after abatement | tpa | 140 | 90 | 140 |
| NO _x removed | tpa | 290 | 340 | 240 |

For the purposes of this assessment, a long term abated emission concentration of 80 mg/Nm³ (11% reference oxygen content) has been assumed for the SCR system. This is the level that the technology has been demonstrated to achieve on a long-term basis. The two SNCR systems, with and without Flue Gas Recirculation (FGR), would be required to achieve a maximum emission concentration of 120 mg/Nm³.

The unabated emission with FGR is assumed to be approximately 10% lower than the other two cases.

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

The impact of emissions to air is considered in detail within the Process Emission Modelling, refer to Appendix D. Table 3-2 shows the predicted ground level concentrations for the three abatement options.

Table 3-2: Air Emissions

| Abatement System: | | SNCR | SCR | SNCR + FGR |
|---|-------------------|-------|-------|------------|
| Long Term | | | | |
| Process Contribution (PC) | µg/m ³ | 0.77 | 0.51 | 0.77 |
| Background | µg/m ³ | 22.02 | 22.02 | 22.02 |
| Predicted Environmental Contribution (PEC) | µg/m ³ | 22.79 | 22.53 | 22.79 |
| Air Quality Objective | µg/m ³ | 40 | 40 | 40 |
| PC as % of AQO | % | 1.93 | 1.28 | 1.93 |
| PEC as % of AQO | % | 56.98 | 56.33 | 56.98 |
| Short Term | | | | |
| Process Contribution (PC) | µg/m ³ | 8.38 | 5.59 | 8.38 |
| Background ⁽¹⁾ | µg/m ³ | 44.04 | 44.04 | 44.04 |
| Predicted Environmental Contribution (PEC) | µg/m ³ | 52.42 | 49.63 | 52.42 |
| Air Quality Objective | µg/m ³ | 200 | 200 | 200 |
| PC as % of AQO | % | 4.19 | 2.79 | 4.19 |
| PEC as % of AQO | % | 26.21 | 24.81 | 26.21 |
| <i>Note:</i> | | | | |
| <i>(1) The short-term background is assumed to be twice the long-term background in accordance with Environment Agency Air Emissions Guidance</i> | | | | |

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 0.65% of the air quality objective and the short-term PEC by 1.40% of the air quality objective when compared to either SNCR or SNCR + FGR.

3.2.2 Deposition to Land

The impact of nitrogen deposition on sensitive habitats has been assessed in the Air Quality Assessment, refer to Appendix D of the Application. As can be seen from this assessment, the impact of nitrogen deposition on sensitive receptors is considered to be 'insignificant' at all habitat features, with the exception of nitrogen deposition impacts at calcareous grasslands and broadleaved deciduous woodland at the Isle of Portland to Studland Cliffs (SAC and SSSI).

However, within the planning application for the Facility, a shadow appropriate assessment has been completed. Within the shadow appropriate assessment, it is demonstrated that at the ecological features where the impact cannot be screened as insignificant, the predicted environmental concentrations will be below the 70% threshold where a significant effect will occur.

The assessment concludes that there will be a negligible magnitude of change on sites of high (or international) importance. Therefore, it is concluded that the operation of the Facility will not be any significant impacts upon sensitive ecological features.

3.2.3 Emissions to Water

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

3.2.4 Photochemical Ozone Creation Potential

Nitrogen dioxide (NO₂) has a photochemical ozone creation potential (POCP) of 2.8 and nitrogen oxide has a POCP of -42.7. Assuming that 10% of NO_x is released as NO₂ and the rest as NO, the POCP is -8,400 for the SNCR options and -5,000 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.

3.2.5 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 different in each option, which would change the power exported from the Facility 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 349 kg CO₂ equivalent per MWh has been used, as applied in the greenhouse gas assessment, refer to Appendix D.

Table 3-3: Global Warming Potential

| | Units | SNCR | SCR | SNCR + FGR |
|--------------------------|-------------------------|-------|-------|------------|
| Power consumed | kWe | 200 | 420 | 270 |
| Power not generated | kWe | - | 250 | - |
| Change in exported power | MWh pa | 1,600 | 5,400 | 2,200 |
| GWP | t CO ₂ eq pa | 600 | 1,900 | 800 |

3.2.6 Raw Materials

The estimated consumption of raw materials for each option is shown in Table 3-4.

Table 3-4: Raw Materials

| | Units | SNCR | SCR | SNCR + FGR |
|---------|-------|-------|-----|------------|
| Water | tpa | 2,000 | 520 | 1,600 |
| Ammonia | tpa | 770 | 200 | 640 |

3.2.7 Waste Streams

There will be no additional residues generated from any of the NO_x abatement 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

| | SNCR | SCR | SNCR + FGR |
|------------------------------|-----------------|-------------------|-----------------|
| Capital Cost | £500,000 | £7,500,000 | £1,000,000 |
| Annualised Capital Cost | £49,000 | £730,000 | £97,000 |
| Maintenance | £10,000 | £150,000 | £20,000 |
| Water and reagents | £128,000 | £33,000 | £107,000 |
| Loss of exported power | £78,000 | £265,000 | £108,000 |
| Total Annualised Cost | £265,000 | £1,178,000 | £332,000 |

3.4 Conclusions

The table below provides a summary comparison of the three options.

Table 3-6: Comparison Table

| | Units | SNCR | SCR | SNCR + FGR |
|---|-------------------------|----------|------------|------------|
| NO _x released after abatement | tpa | 140 | 90 | 140 |
| NO _x removed | tpa | 290 | 340 | 240 |
| Photochemical Ozone Creation Potential (POCP) | t ethylene-eq pa | -5,300 | -3,400 | -5,300 |
| Global Warming Potential | t CO ₂ eq pa | 600 | 1,900 | 800 |
| Ammonia Used | tpa | 770 | 200 | 640 |
| Total Annualised Cost | £ pa | £265,000 | £1,178,000 | £332,000 |
| Average cost per tonne NO _x abated | £ p.t NO _x . | £910 | £3,460 | £1,380 |

As can be seen from the table above, applying SCR compared to SNCR to the Facility:

1. increases the annualised costs by approximately £1 million;
2. abates an additional 50 tonnes of NO_x per annum;
3. reduces the benefit of the Facility in terms of the global warming potential by approximately 1,300 tonnes of CO₂ per annum;
4. reduces reagent consumption by approximately 570 tonnes per annum; and

5. costs approximately an additional 300% per tonne of NO_x abated.

The additional costs associated with SCR are not considered to represent BAT for the Facility. On this basis, the proposed SNCR system combined with the polishing will ensure compliance with the proposed emission limits for NO_x and ammonia and is considered to represent BAT for the Facility.

Including FGR to the SNCR system to abate NO_x increases the cost per tonne of NO_x abated by nearly 50% compared to SNCR only. It has no effect on the direct environmental impact of the plant, but it increases the impact on climate change by approximately 200 tonnes of CO₂ per annum while reducing ammonia consumption by approximately 130 tonnes per annum. Allowing for the increase in the costs of NO_x abatement for a SCR system compared to the climate change and reagent consumption associated with FGR, an SNCR system with or without FGR is considered to represent BAT.

It is proposed that a pre-operational condition is included within the EP which requires confirmation of the final design of the NO_x abatement system to be confirmed to the EA, following completion of detailed design.

4 Reagent Selection – Acid Gas Abatement

4.1 Options Considered

Within this assessment, reagents for wet scrubbing have not been considered as wet scrubbing systems have been discounted as representing BAT for the abatement of acid gases in Section 2.1 of this assessment. Therefore, only the two alternative reagents for a dry system have been considered – 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

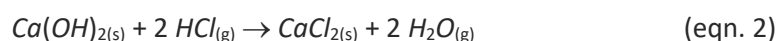
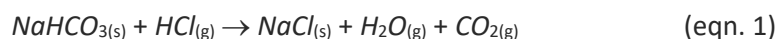
Sodium bicarbonate has a higher optimum reaction temperature than lime, which means that less heat can be recovered in the boiler. However, this can be resolved by recovering additional heat after the acid gas abatement system. Therefore, it has been assumed that there is no impact on global warming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

The reaction of hydrogen chloride and sulphur dioxide with sodium bicarbonate results in an emission of CO₂ whereas the reaction with lime does not.

4.2.6 Raw Materials

Sodium bicarbonate (NaHCO₃) has better solid handling properties and a significantly lower stoichiometric ratio than hydrated lime (Ca(OH)₂).

Sodium bicarbonate and lime 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 sodium bicarbonate, the overall consumption of sodium bicarbonate is actually 64% higher than lime on a mass basis.

The reagent required to abate one kmol of hydrogen chloride was calculated as approximately 109 kg of sodium bicarbonate and approximately 67 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 lime system produces a similar amount of residue to the sodium bicarbonate option.

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

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

4.3 Costs

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

The purchase cost of sodium bicarbonate is significantly higher than lime, with bicarbonate costing almost 65% more than 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 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 £163/tn.

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 hydrogen chloride:

Table 4-1: Costs per unit HCl abated

| Item | Unit | NaHCO ₃ | Ca(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 | 91 |
| Cost of residue disposal ¹ | £/tonne | 163 | 136 |

¹The figure shown does not include landfill tax.

| Item | Unit | NaHCO ₃ | Ca(OH) ₂ |
|----------------|---------------|--------------------|---------------------|
| Overall Cost | £/op. hr/kmol | 30.6 | 17.7 |
| Ratio of costs | | 1.73 | |

4.4 Conclusions

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

- The residue has a higher leaching ability, which will limit the disposal options;
- The reaction temperature doesn't match as well with the optimum adsorption temperature for carbon, which is dosed at the same time;
- The use of sodium bicarbonate has a slightly higher global warming potential due to the reaction chemistry; and
- The costs per kmol HCl abated are almost 73 % higher.

Considering the above, the use of lime as a reagent within the acid gas abatement system is considered to represent BAT for the Facility.

5 Combustion Techniques

5.1 Options Considered

The available technologies for the combustion of waste have been reviewed in Section 2.6.1 of the supporting information. This assessment has been expanded to provide a quantitative cost-benefit analysis of moving grates, fluidised beds and rotary kilns.

1. Moving grates are an established technology in the UK and Europe for the combustion of a range of non-hazardous wastes, such as that proposed for the Facility. The grate turns and mixes the waste along its surface to ensure that all waste is exposed to the combustion process.
2. Fluidised beds are designed for the combustion of relatively homogeneous waste. A fluidised bed requires the waste to be pre-processed to satisfy the fuel requirements for a fluidised bed combustion system.
3. Rotary kilns function best with a consistent fuel feedstock and they have been used widely within the healthcare sector in treating clinical waste. Rotary kilns can operate at higher temperatures than other systems due to the absence of exposed metal surfaces, and can therefore be used to incinerate hazardous, clinical and industrial wastes.

5.2 Environmental Performance

5.2.1 Emissions to Air

The emissions to atmosphere would not be affected by the choice of the combustion technology. Although NO_x concentrations from the furnaces would be different, both options would require further abatement to achieve the proposed 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

| Option | NO _x emissions from furnace (mg/Nm ³) |
|---------------|--|
| Grate | 320-380 ⁽¹⁾ |
| Fluidised Bed | 250-300 ⁽¹⁾ |
| Rotary Kiln | 300-350 ⁽¹⁾ |

(1) Presented at 11% oxygen with standard reference conditions

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 any of the options mentioned.

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 carbon dioxide are the same for each option. However fluidised beds, whilst having lower emissions of nitrogen dioxide, can have elevated emissions of nitrous oxide. Nitrous oxide is a greenhouse gas with a global warming potential (GWP) nearly 300 times that of carbon dioxide. Fluidised beds can be designed to minimise the formation of nitrous oxide. For the purposes of this assessment we have assumed that the fluidised bed has been well-designed and the emissions of nitrous oxide are slightly elevated and are released at a concentration of 10mg/Nm³. Rotary kilns will generate low concentrations of nitrous oxides compared to a grate and fluidised bed.

A fluidised bed will have the higher parasitic load than a moving grate system or rotary kiln due to the sand system and boiler ash separation system. The additional parasitic load in the case of the fluidised bed option has been estimated at 10%. A rotary kiln will be less efficient at recovering energy from waste than a grate and a fluidised bed.

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 349 kg CO₂ equivalent per MWh has been used, as applied in the greenhouse gas assessment presented in Appendix D.

The results are presented in the table below. In each case the overall GWP is less than zero, as there is a net reduction due to displacement of primarily fossil fuel power generation. Thus, the more negative figure produced by the grate is better.

Table 5-2: Global Warming Potential

| | | Grate | Fluidised Bed | Rotary Kiln |
|-----------------|-------------------------|---------|---------------|-------------|
| Power generated | MWh pa | 145,000 | 145,000 | 112,000 |
| Parasitic Load | MWh pa | 23,000 | 26,000 | 23,000 |
| GWP | t CO ₂ eq pa | -42,600 | -41,500 | -31,000 |

5.2.6 Raw Materials

The estimated consumption of raw materials for each option is shown in Table 5-3.

Table 5-3: Raw Materials

| | Units | Grate | Fluidised Bed | Rotary Kiln |
|---------|-------|-------|---------------|-------------|
| Ammonia | tpa | 800 | 500 | 1,000 |
| Sand | tpa | - | 2,300 | - |

5.2.7 Waste Streams

The three options produce several solid waste streams.

- It is assumed that most metals within the waste will have been removed either through source-segregation or recovery during pre-processing of the waste prior to delivery to the Facility. It is therefore assumed that the presence of metals within the residues generated by the Facility will be identical for the three options and has not been considered further.

- The fluidised bed will produce more non-hazardous ash than a grate or rotary kiln due to the addition of sand within the boiler which is used as a fluidising medium. The non-hazardous ash will include bottom ash and boiler ash. In a fluidised bed, it is assumed that the boiler ash is removed via an abatement system before the acid gas abatement reagent is added. The non-hazardous ash could be usable for building aggregate, but this is not certain. For the purposes of this assessment it has been assumed that the non-hazardous ash cannot be used as a building aggregate and will require disposal in a non-hazardous landfill.
- All three options produce APC residues. For the purposes of this assessment it is assumed that all three options will generate the same quantity of APC residue.

Estimated figures are shown in Table 5-4.

Table 5-4: Waste Streams

| | Units | Grate | Fluidised Bed | Rotary Kiln |
|------------|-------|--------|---------------|-------------|
| Bottom Ash | tpa | 34,000 | 13,600 | 34,000 |
| Boiler Ash | tpa | | 22,700 | |
| APCr | tpa | 6,000 | 5,200 | 6,000 |

The fluidised bed will produce a slightly higher quantity of waste compared to the grate and the rotary kiln due to the losses of sand which are used within the furnace for the fluidised bed.

5.3 Costs

The estimated costs associated with each option are presented in Table 5-5.

Fluidised bed technology is typically up to around 6% more expensive, due to the additional waste screening equipment, sand dosing and recycling equipment, and boiler ash separation. At the time of writing this assessment, capital costs are not readily available for the different options. Therefore, it has not been possible to consider the capital costs for the three technologies within this assessment.

Similarly, although fluidised beds typically have significantly higher maintenance costs than grate systems, maintenance costs are not readily available for the different options, so these were not considered for the proposed facility in this assessment.

Table 5-5: Annual Material Costs and Revenues

| | Grate | Fluidised Bed | Rotary Kiln |
|--|------------|---------------|-------------|
| Reagents | £130,000 | £310,000 | £160,000 |
| Residue Disposal | £2,230,000 | £2,290,000 | £2,230,000 |
| Annual Reagent and Residue Costs (Materials) | £2,360,000 | £2,620,000 | £2,390,000 |
| Annual Power Revenue | £5,978,000 | £5,831,000 | £4,361,000 |

As can be seen from Table 5-5, the fluidised bed option has significantly higher costs associated with the purchase of reagents, and slightly higher costs with the disposal of residues, assuming that the costs for treatment and re-use of boiler ash are similar to those for bottom ash.

The parasitic load associated with fuel preparation is excluded from the assessment, as it is assumed to be comparable across all three combustion technologies.

For a fluidised bed there may be costs associated with screening the fuel to ensure that there are no contaminants which could affect the operation of the fluidised bed. These costs have not been accounted for within Table 5-5.

5.4 Conclusions

Table 5-6 compares the three options.

Table 5-6: Option Comparison Summary

| | | Grate | Fluidised Bed | Rotary Kiln |
|------------------------------|-------------------------|--------------|----------------------|--------------------|
| Global Warming Potential | t CO ₂ eq pa | -42,600 | -41,500 | -31,000 |
| Ammonia Consumption | tpa | 800 | 500 | 1,000 |
| Residues (Total ash) | tpa | 38,842 | 38,842 | 38,842 |
| Annual Total Materials Costs | | £2,360,000 | £2,620,000 | £2,390,000 |
| Annual Power Revenue | | £5,978,000 | £5,831,000 | £4,361,000 |

All combustion technologies will produce similar quantities of residue, although the fluidised bed produces more residue due to the losses of sand from the furnace.

Out of the three options, the grate option has the lowest global warming potential. A grate option would consume approximately 60% more ammonia than a fluidised bed system, and approximately 20% less ammonia than a rotary kiln system.

The material costs are approximately 10% higher for the fluidised bed than the grate, whereas the grate system will have a slightly higher power revenue. However, it is acknowledged that it is marginal. However, it should be noted if the incoming waste requires any additional pre-processing treatment to be suitable for combustion within a fluidised bed, then this will significantly increase the material costs associated with the fluidised bed.

The rotary kiln is less efficient, which has a significant impact on the global warming potential and the associated operating costs. In addition, the capital cost associated with a rotary kiln is likely to be significantly higher as additional streams will be required to achieve the proposed processing capacity.

As stated within the qualitative BAT assessment (refer to Section 2.6.1 of the Supporting Information), grate combustion systems are designed for large quantities of heterogenous waste, whereas fluidised bed systems are more sensitive to inconsistencies. Due to the robustness of grate combustion systems, they are considered to represent BAT for the Facility.

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