



## NORTH BECK ENERGY LTD

North Beck Energy Centre

Environmental Permit Application: EfW BAT Assessment

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## 1 INTRODUCTION

### 1.1 This report

1. This report presents an Energy-from-Waste (EfW) Best Available Techniques (BAT) assessment for an application made by North Beck Energy Limited (**NBEL, the Applicant**) to the Environment Agency (**the EA**) for an Environmental Permit. The application relates to the construction and operation of the North Beck Energy Centre (**NBEC, the Facility**).
2. This report is structured to follow the guidance offered by the EA H1 software tool and by EPR 5.01.

### 1.2 The North Beck Energy Centre

3. The site for the NBEC is located approximately 1.45 km east of the town of Immingham (at Easting: 520686; Northing 414635) and is reached from Queens Road (the A1173), which runs immediately to the north of the site (see **Annex B: Site Location Plan**).
4. The NBEC comprises a power station for the recovery of energy released from the combustion of non-hazardous wastes derived from MSW and similar non-hazardous wastes from commercial and industrial premises (**Feedstock**). The Facility will typically receive about 560,000 tonnes per annum (tpa) of Feedstock and will export 49.5MW<sub>e</sub> of electricity to the local electricity distribution network. This will be enough to supply the needs of over 127,500 homes. It will also be configured so that heat can be exported to meet the potential future demands estimated for adjacent local district heating networks that are presently under consideration by the local authorities.

## 2 FURNACE SELECTION

### 2.1 Options considered

5. There exists a range of combustion technologies that can be used for the incineration of RDF and MSW derived Feedstocks. The most common technology used in the UK and across continental Europe has been the moving grate which has been developed, improved and refined over many decades.
6. Whilst the range of technologies identified by the EA's guidance, EPR 5.01, also includes fixed stepped hearths and pulsed hearths, these are only suited to relatively low throughputs of Feedstock and are not suitable for the scale of EfW plant typical of most municipal applications. These two alternatives also offer relatively poor environmental performance in comparison with the benchmarks set by modern moving grate furnace designs. Consequently fixed stepped hearths and pulsed hearths have been discarded.
7. Further options include fluidised beds, rotary kilns and advanced thermal conversion (ATC) processes such as pyrolytic, semi-pyrolytic and gasification technologies. The ATC technologies are a relatively new development and these have so far only proven to be economically viable where a Contract for Difference (CfD) has been available to enhance the electricity revenue.
8. ATC technologies have not yet received the extensive development that has benefited moving grate systems, nor have these technologies been used so far for larger scale facilities such as NBEC where more process streams would be needed compared with moving grates. ATC technologies also offer greater uncertainty over availability and lifecycle costs for little perceivable environmental benefit when compared with the more highly developed technologies. For these reasons, ATC processes have not been developed for the NBEC.
9. Rotary kilns offer a robust solution for the incineration of wastes as these can accept feedstock in a wide variety of physical (i.e. solid and liquid) and chemical forms. Generally these have been used for hazardous waste incineration and have not been offered by suppliers for RDF or MSW applications at the scale needed for NBEC. The two UK applications that use an oscillating kiln are much smaller installations and would necessitate 5 or 6 process streams. This would result in higher investment costs, operating and maintenance (O&M) costs and lifecycle replacement costs. For these reasons the rotary kiln has not been considered further for NBEC.
10. Moving grates have dominated the EfW market in Europe owing to their extensive development, high standard of environmental performance, competitive costs and very good reliability. Fluidised beds have seen fewer applications in the EfW market but have been used for both combustion and gasification where waste has been pre-treated, such as for RDF. Although generally not quite as well developed as moving grates and offering slightly poorer availability, fluidised beds have been built in the UK, continental Europe and in Japan and at the same scale needed for NBEC.
11. There are two generic types of fluidised bed: bubbling fluidised beds (BFB) and circulating fluidised beds (CFB). The BFB design has been used for installations in the UK for conventional combustion and for gasification as an ATC technology. The BFB tends to be more restricted in capacity since the bed area is proportional to throughput and this can create fuel distribution challenges at larger capacities. A BFB solution for NBEC would require at least three process streams (e.g. Allington EfW plant), thereby adding investment cost, O&M cost and lifecycle replacement costs compared to a twin

stream moving grate or CFB solution. The BFB is better suited to MSW and is not well suited to the higher NCV of fuel that is typical of RDF and which is anticipated at NBEC. Consequently, the CFB would offer the most cost effective fluidised bed alternative to the moving grate and BFBs have not been considered further.

12. From previous comparisons carried out by Poyry, the key differences between moving grates and CFBs are:
- CFBs can be suited to higher boiler thermal capacities which can result in fewer process streams but this would not be the case for NBEC where the fuel type (i.e. MSW derived) and present status of development of CFBs for MSW applications would still necessitate two streams.
  - CFBs require greater pre-treatment of the incoming feedstock to control the maximum particle size and to remove metal and, particularly, non-ferrous metal to a very low level. Usually this requires pre-treatment equipment (i.e. magnetic and eddy current separators) at the EfW site, even if the feedstock is within a controlled size range and has had most metals previously removed by the fuel supplier.
  - CFBs produce slightly lower NO<sub>x</sub> from the furnace than moving grates due to lower combustion temperatures (c. 900°C), though CFBs would still require further abatement such as SNCR to meet IED emission limits.
  - CFBs may use slightly less excess air and therefore have slightly better thermal efficiency, though there presently exists too few reference plants to be certain and modern moving grates now require much less excess air than in the past. If there is any difference at all, then this is expected to be marginal.
  - CO emissions from CFBs are generally good but can be much more vulnerable to high 'spikes' if the fuel CV varies or if fuel feeding is inconsistent, which can happen with the screw type fuel feeders that are typical for CFBs. Generally, CFBs require a derogation to a slightly less stringent ELV for CO (NB this is allowed by the IED).
  - CFBs consume more power since the forced draught primary air fans have to overcome the resistance of the fluidised bed and bed air distribution nozzles. For a plant capacity such as that at NBEC, this would mean an increase of about 0.5 MW per stream resulting in a larger steam turbine, generator and condenser to achieve 49.5MW export power.
  - CFBs convert nearly all of the inert feedstock material into fly ash which is collected mainly in the boiler passes and pre-filter (NB usually a cyclone separator) upstream of the main flue gas treatment plant bag filter. This material can be of a hazardous classification and adds significantly to the unrecoverable residue quantities and related disposal costs.
  - Conversely, CFBs produce very little bottom ash, other than for some larger inert material, and the TOC in the bottom ash is extremely low (NB albeit also relatively low from moving grates).
  - Size reduction of the fuel is critical to the ability to remove bottom ash as this needs to discharge through slots at the base of the furnace of fixed dimensions (NB typically <100mm). Build up can create blockages necessitating shut down for removal.

- CFBs may enable higher steam temperatures and efficiencies to be achieved since part of the superheater is located in the bed sand recirculation system away from the corrosive flue gas. However, uncertainty remains for MSW applications regarding the effectiveness of these sand circuits at isolating the sand/steam heat exchangers from the flue gas and the extent of corrosion and impact on lifecycle costs that result.
  - There is little information available publicly in the EfW market sector about how investment costs compare. However, it is expected that costs would be slightly higher for the CFB owing to the additional pre-treatment plant, additional storage bunker (i.e. a reception bunker is needed before pre-treatment then fuel storage before the CFB) and slightly larger turbine, generator and ACC.
  - Although CFBs have been applied successfully for several years to a range of fuels, experience is still lacking for MSW derived fuels relative to moving grates and there is much greater uncertainty about availability, O&M costs and lifecycle replacement costs. Typically, from Poyry's experience, a lower availability would be expected for CFBs given the relatively weaker development status of the technology for RDF and MSW fuels and sensitivity to fuel quality.
  - Visual amenity is poorer with CFBs since these require a very tall furnace, typically 55 m – 65 m which is much higher than for moving grate boilers and creates additional challenges regarding planning constraints.
  - Differences in environmental performance are slight with little to choose between the two solutions. In comparison, for CFBs:
    - annual CO could be marginally higher;
    - ammonia consumption for de-NO<sub>x</sub> slightly lower since CFBs inherently produce less NO<sub>x</sub> due to a lower combustion temperature;
    - TOCs in ash lower but moving grate quantities are well within IED limits anyway;
    - Fly ash quantities higher (NB potentially hazardous material);
    - Absorbed power for primary air fans much higher;
    - Make-up supply of sand required, therefore raw materials consumption slightly higher;
    - Likely poorer availability would most likely result in more start-ups and greater start-up fossil fuel consumption;
    - Combustion efficiency marginally better by virtue of better TOC;
    - Thermal efficiency may be slightly better through higher steam temperatures but still a high level of uncertainty over corrosion and reliability of the sand/steam heat exchangers. The small efficiency gain also tends to be at least partially offset by the additional fan power needed.
13. On balance, the CFB offers a potentially viable solution at this scale but the technology would provide very marginal environmental benefit, if at all. It is considered that this would be offset by the poorer visual amenity and the much greater uncertainty over

reliability and availability for RDF and MSW applications. On this basis, it is concluded that whilst both technologies could offer BAT, the moving grate technology currently offers greater commercial certainty and has been chosen for further development for NBEC.

### 3 ABATEMENT OPTIONS AND REAGENTS USED

14. The BAT assessment has been undertaken in line with the Environmental Agency H1 Software (version 2.7.8 – January 2017). Two separate H1 models were setup; one for NO<sub>x</sub> abatement and another for acid gas abatement. Both models are enclosed with this application to allow the EA to verify the results.
15. The objective of this assessment is to compare the environmental consequences of the proposed NO<sub>x</sub> and acid gas abatement system for this project with other potentially viable options and evaluate the cost-benefit for each option.
16. Data for the assessment has mainly been obtained from technology providers, standard reference material such as the BREF note, etc. and from a thermal model setup using Thermoflow software (a proprietary modelling software). The process contribution (PC) and background emission level were obtained from the **Air Quality Assessment**, (see Table 4.1, **Annex D**) and from pro-rated base case values for the options according to the stack emission concentration.

#### 3.1 Reduction of NO<sub>x</sub>

##### 3.1.1 Options considered

17. The available options for the reduction of NO<sub>x</sub> divide into primary and secondary measures. Primary measures relating to EfW plants include:
  - Optimisation of the design of the furnace, secondary combustion air injection nozzle location and velocities and combustion control; and
  - Flue gas recirculation (FGR) whereby some flue gas from the boiler exhaust is recirculated and injected with the secondary air to enhance turbulence and mixing.
18. FGR is not offered by most suppliers of EfW boilers because they have chosen to achieve better mixing through developing the design of the furnace, secondary air injection system and combustion controls. FGR increases the size of the boiler (combustion products plus recirculated flue gas), adds a recirculation fan and adds a risk of corrosion within the FGR ducting from the untreated flue gases. Generally, the improvement gained compared to modern furnace designs without FGR is very marginal and does not merit the increased capital cost, operating cost (fan power) and maintenance (additional plant and corrosion risk).
19. Secondary measures that achieve further reductions in NO<sub>x</sub> include:
  - Selective Non-Catalytic Reduction (SNCR);
  - Selective Catalytic Reduction (SCR); and
  - Catalytic filter bags.
20. SNCR systems inject a reagent (aqueous ammonia solution or urea) into the boiler furnace where this reacts with the NO<sub>x</sub>. SNCR is generally capable of reducing NO<sub>x</sub> to below 200 mg/Nm<sup>3</sup> without significant ammonia ‘slip’ (i.e. unreacted ammonia) and has relatively low investment cost.
21. SCR systems inject the same reagent downstream of the boiler and other flue gas treatment plant. The reagent is injected upstream of a catalyst matrix which reduces the NO<sub>x</sub>. SCR systems add significant investment cost and also operational costs for extra

fan power, re-heating of the flue gas and periodic replacement of expensive catalyst matrix. The re-heating of the flue gas is usually achieved by direct firing with fossil fuel which needs to raise the flue gas temperature from around 140°C at the outlet of the FGT plant to the optimum SCR operating temperature of 250-300°C. This represents a significant addition of energy through either primary fuel or from the steam circuit via a flue gas heat exchanger. However, lower emissions of NO<sub>x</sub> can be achieved compared with SNCR systems.

22. Catalytic filter bags represent an alternative to SCR. The catalytic bags replace the 'normal' bags in the bag filter and there now exists some commercial operating plants using this system in continental Europe. These bags consist of an outer layer of 'normal' membrane (e.g. glass fibre, PTFE, P84) where particulate is arrested, the filter cake builds and the acid gas abatement reaction takes place, followed by inner layers of catalytic bags that reduce NO<sub>x</sub>.
23. Catalytic bags can be used with reagent injection (ammonia solution or urea) just upstream of the bag filter or in conjunction with an SNCR system. The latter is considered for this assessment though the choice is expected to be cost neutral. Similar performance can be attained to that from SCR processes provided that the flue gas temperature is around 200°C (NB below this temperature the abatement efficiency is understood to reduce significantly). This temperature is higher than would normally be used within the lime injection dry flue gas treatment systems (i.e. c. 140°C) that are typical of EfW plants in the UK but would align closer with the alternative use of sodium bicarbonate. Reheating the flue gas for a lime system would result in reduced efficiency for the lime / acid gas reaction which would increase emissions and residues. Consequently, it is Pöyry's view that catalytic bags would only be matched with a sodium bicarbonate solution.

### **3.1.2 Emissions to air**

24. NO<sub>x</sub> and ammonia emissions for the three NO<sub>x</sub> abatement options and baseline level are shown in Table 3-1. The baseline level (i.e. without NO<sub>x</sub> abatement) is presented for the purpose of benchmarking the costs and performance for each option.
25. The waste combustion process is estimated to generate an average NO<sub>x</sub> concentration of 350 mg/Nm<sup>3</sup>. With the SNCR option, a long term NO<sub>x</sub> emission level of 200 mg/Nm<sup>3</sup> is attainable for meeting the IED limit. The other SCR and catalytic filter bags options can achieve lower NO<sub>x</sub> emission of 70 mg/Nm<sup>3</sup> with 80% NO<sub>x</sub> removal efficiency. These assumptions are based on typical performance as per current industry standard.

**Table 3-1 Emissions to air for NOx abatement options**

Parameter	Unit	SNCR	SCR	Catalytic Filter Bags	No abatement
Option		1	2	3	Baseline
NOx removal efficiency	%	43%	80%	80%	0
Nitrous oxide (N <sub>2</sub> O)	mg/Nm <sup>3</sup>	10	10	10	0
Ammonia slip	mg/Nm <sup>3</sup>	10	10	10	0
NOx unabated concentration	mg/Nm <sup>3</sup>	350	350	350	350
NOx abated concentration	mg/Nm <sup>3</sup>	200	70	70	350
NOx release rate to atmosphere	t/y	719	252	252	1259
NOx emissions removed by abatement system	t/y	539	1007	1007	0

### 3.1.3 Deposition to land

26. Based on the H1 assessment, the results for each option with respect to long term and short term impacts are presented in Table 3-2.

**Table 3-2 Long term and short term emissions deposition to land**

Parameter	Unit	SNCR	SCR	Catalytic Filter Bags	No abatement
Option		1	2	3	Baseline
Long Term					
Process Contribution (PC) for NOx	µg/m <sup>3</sup>	2.06	0.72	0.72	3.61
PC for Ammonia (human health receptor)	µg/m <sup>3</sup>	0.15	0.15	0.15	0.00
Background*	µg/m <sup>3</sup>	31.5	31.5	31.5	31.5
Predicted Environmental Contribution (PEC)*	µg/m <sup>3</sup>	33.56	32.22	32.22	35.11
Environmental Assessment Level (EAL)	µg/m <sup>3</sup>	40	40	40	40
PC as % of EAL	%	5.2%	1.8%	1.8%	9.0%
PEC as % of EAL	%	83.9%	80.6%	80.6%	87.8%
%PC of headroom (EAL-bkgrnd)	%	24.2%	8.5%	8.5%	42.4%
Short Term					
Process Contribution (PC) for NOx	µg/m <sup>3</sup>	19.45	6.81	6.81	34.04
PC for Ammonia (human health receptor)	µg/m <sup>3</sup>	1.99	1.99	1.99	0.00
Background*	µg/m <sup>3</sup>	31.5	31.5	31.5	31.5
Predicted Environmental Contribution (PEC)*	µg/m <sup>3</sup>	50.95	38.31	38.31	65.54
EAL	µg/m <sup>3</sup>	200	200	200	200
PC as % of EAL	%	9.7%	3.4%	3.4%	17.0%
PEC as % of EAL	%	25.5%	19.2%	19.2%	32.8%
% PC of headroom (EAL-bkgrnd)	%	11.54%	4.04%	4.04%	20.20%

27. The results show that all of the options can meet the Environmental Assessment Level (EAL) based on IED limits (i.e. Predicted Environmental Contribution (PEC) < EAL). The calculated long term “PC as % of EAL” and “PEC as % of EAL” for all options exceed the Stage 1 and Stage 2 screening limits shown in Table 3-3. Short term values are within the screening limits. Since, the air emission impacts are considered “significant”, a detailed **Air Quality Assessment** was carried out for the base case (i.e. Option 1). Based on the model results, the dispersion factors for Options 2 and 3 were calculated on pro-rata basis from stack emissions. The calculated results are robust; therefore we consider separate detailed air quality assessments are not necessary for the options for the purpose of this high level optioneering study.

**Table 3-3 Air impact modelling screening Stage 1 and Stage 2 limits**

Air Impact Screening Stage 1	
Long term	PC as % of EAL $\geq$ 1%
Short term	PC as % of EAL $\geq$ 10%
Air Impact Modelling Stage 2 Screening	
Long term	PEC as % of EAL $\geq$ 70%
Short term	%PC of headroom $\geq$ 20

28. In general, both SCR and catalytic filter bags can achieve lower emission to air and deposition on land compared to SNCR because of higher NO<sub>x</sub> removal efficiency but this would be achieved after significant additional investment.

### 3.1.4 Emissions to water

29. There are no emissions to water from any of the NO<sub>x</sub> abatement systems.

### 3.1.5 Photochemical ozone creation potential

30. Photochemical Ozone Creation Potential (POCP) for each option was calculated and results are shown in Table 3-4.
31. The calculation was based on the assumption that NO<sub>x</sub> will consist of 5% Nitrogen Dioxide (NO<sub>2</sub>) and 95% Nitrogen Oxide (NO). The relative POCP values for NO<sub>2</sub> and NO are 2.8 and - 42.7 as per H1’s Annex K. A negative POCP value means Ozone is removed from the atmosphere (e.g. NO reacts with Ozone to form NO<sub>2</sub>). All of the abatement options have negative POCP values; therefore will help to reduce harmful Ozone in the atmosphere. SNCR is the favourable option in this case as it has the most negative value.

**Table 3-4 POCP for NOx abatement options**

Parameter	Unit	SNCR	SCR	Catalytic Filter Bags	No abatement
Option		1	2	3	Baseline
NOx release rate to atmosphere:					
• NO <sub>2</sub> (5%)	t/y	36	13	13	63
• NO (95%)	t/y	684	239	239	1196
Total	t/y	719	252	252	1259
Photochemical Ozone Creation Potential (POCP)	t ethylene/y	- 29,085	- 10,180	- 10,180	- 50,899

### 3.1.6 Energy recovery

The energy requirement for each option was obtained from Thermoflow’s thermal modelling software, Thermoflex. The differences in energy consumption for each option compared to the baseline (i.e. without abatement) are show in Table 3-5.

**Table 3-5 Energy consumption and recovery**

Parameter	Unit	SNCR	SCR	Catalytic Filter Bags	No abatement
Option		1	2	3	Baseline
Total Plant auxiliary power consumption	kWe	6,291	7,050	5,854	6,272
Change in auxiliary power compared to baseline	kWe	19	778	- 418	
Gross plant power output	kWe	55,788	52,251	56,303	55,789
Change in gross plant power output compared to baseline	kWe	- 1	- 3,538	514	
Net plant power export	kWe	49,497	45,201	50,449	49,517
Change in net power export compared to baseline	kWe	- 20	- 4,316	932	0
	MWH/y	- 161.6	- 34,528.8	7456.0	0
Impact of energy recovery against baseline	%	-0.04%	-8.72%	1.88%	0

32. The catalytic filter bags (Option 3) is the best energy recovery option with 1.88% gain in net power output against the baseline. This is because of the possibility for additional heat recovery from the flue gas (i.e. as opposed to the latent heat loss resulting from the water sprayed into lime systems for humidity conditioning), downstream to the filter bags and savings in power consumption for not having flue gas quench water system that requires pumping power.
33. Conversely, the SCR (Option 2) has the highest loss in energy recovery (i.e. -8.72%) due to high energy consumption for the SCR process. The SCR process requires

additional process steam for reheating the flue gas to achieve optimal temperature (i.e. around 200°C) for the chemical reaction which reduces the gross power generation and overall plant electrical efficiency. Also, additional fan power is required to overcome pressure drop in the flue gas across the SCR catalyst which reduces the plant net electrical efficiency.

34. The SNCR (Option 1) is the second best option with only a slight reduction in the overall plant energy recovery (i.e. -0.04%) compared to baseline because a small amount of auxiliary power is required for the ammonia injection system.

### 3.1.7 Global warming potential

35. Global Warming Potential (GWP) will depend on direct emissions of greenhouse gases and indirect emissions from any increase in energy consumption. Increase in energy consumption (aux. power or steam) will result in lower net power export to the grid where any shortfall in the power would need to be generated from another energy source. In this assessment, it was assumed that the other energy source would be a CCGT plant with a CO<sub>2</sub> emission rate per net MW generation of 380 kgCO<sub>2</sub>/MWh.
36. All of the options have the same level of direct emissions of greenhouse gases as they all have the same level of emissions for CO<sub>2</sub> and N<sub>2</sub>O emissions. However, the indirect emissions are different for each option as they have different auxiliary power consumptions and power generations which affect the net plant power export to the grid.
37. The results of GWP for the options were obtained from the H1 model as shown in Table 3-6.
38. Catalytic filter bags (Option 3) offer the most favourable option in this case as these have the lowest energy consumption with the highest net power export. Conversely, SCR has the highest GWP impact (i.e. 13 million tCO<sub>2</sub>/y) because of the overall low electrical plant efficiency. The SNCR (Option 1) is the middle case with a slight reduction in the net power export and with some GWP impact.

**Table 3-6 Global warming potential for options**

Parameter	Unit	SNCR	SCR	Catalytic Filter Bags	No abatement
Option		1	2	3	Baseline
Change in net power export compared to baseline	kWe	- 20	- 4,316	932	0
	MWh/y	- 161.6	- 34,528.8	7456.0	0
Global Warming Potential (GWP)	tCO <sub>2</sub> /y	61,408	13,120,944	-2,833,280	0

### 3.1.8 Raw materials

39. Estimated aqueous ammonia reagent consumption for each option is shown in Table 3-7. SCR and catalytic filter bags consume more reagent than SNCR because of the higher NO<sub>x</sub> abatement rates. However, if compared on per tonne NO<sub>x</sub> removed basis, both SCR and catalytic filter bags consume much less reagent than SNCR.

**Table 3-7 Raw materials required for NOx abatement**

Parameter	Unit	SNCR	SCR	Catalytic Filter Bags
Option		1	2	3
Aqueous Ammonia reagent (25% conc.) consumption	t/h	0.2616	0.3324	0.3324
	t/y	2,092.8	2,659.2	2,659.2
Ammonia consumption per tonne NOx removed	t/y/tNOx	3.88	2.64	2.64

### 3.1.9 Waste streams

40. There are no waste streams associated with any of the options. It was assumed that any spent catalyst will be recycled.

### 3.1.10 Environmental ranking

41. Each of the options was compared against key environmental criteria identified in the H1 tool which includes NOx emission, POCP, GWP and raw material. POCP, GWP and ammonia reagent are presented as per tonne NOx removed in
42. Table 3-8 to be able to compare the options on a like-with-like basis.

**Table 3-8 Environmental performance**

Parameter	Unit	SNCR	SCR	Catalytic Filter Bags
Option		1	2	3
NOx emissions removed by abatement	t/y	539	1007	1007
NOx release to air	t/y	719	252	252
POCP	t ethylene/y	- 29,085	- 10,180	- 10,180
POCP per tonne NOx removed	t ethylene/y/tNOx	- 54	- 10	- 10
Global Warming Potential (GWP)	t/y CO <sub>2</sub> eq	61,408	13,120,944	-2,833,280
GWP per tonne NOx removed	t/y CO <sub>2</sub> eq/tNOx	114	13,026	-2,813
Ammonia reagent consumption	t/y	2,093	2,659	2,659
Ammonia consumption per tonne NOx removed	t/y/tNOx	3.88	2.64	2.64

43. Based on the environmental assessment, the overall score for each option is shown in Table 3-9. The lowest score represents the best option. Catalytic filter bags (Option 3) scored the lowest and therefore ranked as the best options.

**Table 3-9 Environmental ranking**

Parameter	SNCR	SCR	Catalytic Filter Bags
Option	1	2	3
Release to Air	2	1	1
POCP	1	2	2
GWP	2	3	1
Raw Material	2	1	1
Total score	7	7	5
Environmental ranking	2	2	1

### 3.1.11 Costs

44. Both capital and operating costs for each option are presented in Table 3-10. The cost information was obtained from OEMs, Thermoflow PEACE (a proprietary software for estimating plant capital costs) and Poyry's in-house database. The H1 tool was used to calculate the annualised capital cost and equivalent annual cost for each option.

**Table 3-10 Capital and operations costs for NOx abatement options**

Parameter	Unit	SNCR	SCR	Catalytic Filter Bags
Option		1	2	3
Capital costs:				
Capital cost per unit	£	635,879	4,843,819	2,407,939
No. of units	No.	2	2	2
Total capital cost	£	1,271,758	9,687,637	4,815,877
Operating costs:				
Catalyst replacement cost	£/y	0	454,654	729,600
Ammonia cost	£/y	313,920	398,880	398,880
Additional operating costs associated with sodium bicarbonate system	£/y	0	0	2,191,779
Loss in revenue from export power (due to lower electrical efficiency)	£/y	11,312	2,417,016	-521,920
Total annual operating costs	£/y	325,232	3,270,550	2,798,339
Life of plant	year	30	30	30
Discount rate	%	10	10	10
Annualised capital cost	£/y	134,907	1,027,657	510,865
Annual average operating cost	£/y	325,232	3,270,550	2,798,339
Present value cost	£	4,337,692	40,518,833	31,195,580
Equivalent annual cost	£/y	460,139	4,298,207	3,309,204
Annualised cost per tonne NOx removed	£/tNOx	853	4,267	3,285
Cost ranking		1	3	2

45. Currently, OEMs only offer catalytic filter bags for acid gas abatement systems using sodium bicarbonate as reagent and not for lime. This is because both the catalytic filter bags and sodium bicarbonate operates at the same optimal temperature of around 200°C. The optimal temperature for lime reagent is 140°C which is ineffective for the catalytic filter bags reaction. Further details on the two reagents are covered in the subsequent sections which show that sodium bicarbonate involves additional operating costs compared to lime such as reagent cost and residue disposal cost. These additional costs are considered in the table above for catalytic filter bags. There are no additional costs shown for SNCR and SCR as these are based on lime.
46. The costs are compared for each option on per tonne of NO<sub>x</sub> removed to be on a 'normalised' basis. Annualised equivalent costs of SCR and catalytic filter bags are around 9 and 7 times higher than SNCR respectively. Cost per tonne NO<sub>x</sub> removed for SCR and catalytic filter bags options are around 5 and 4 times more than SNCR respectively. As a result from the above, SNCR (Option 1) ranked as the most cost effective solution with lowest cost, followed by Option 2 and 3.

### 3.1.12 BAT Conclusion for reduction of NO<sub>x</sub>

47. Both environmental and cost ranking for the options are summarised in Table 3-11.

**Table 3-11 Overall ranking for NO<sub>x</sub> abatement options**

Parameter	SNCR	SCR	Catalytic Filter Bags
Option	1	2	3
Environmental ranking	2	2	1
Cost ranking	1	3	2
Overall ranking	1	3	2

48. Following completion of the H1 assessment, it is possible to conclude the following:
- All of the options meet IED emission limits for both emissions to air and deposition on land.
  - Both SCR (Option 2) and catalytic filter bags (Option 3) offer the best environmental option in respect to air quality impact of NO<sub>x</sub> emissions.
  - SCR (Option 2) environmental benefit is offset by the high GWP (additional 13 million tCO<sub>2</sub>/y indirect CO<sub>2</sub> emission).
  - Catalytic filter bags (Option 3) offers best environmental performance and with negative GWP impact as a result of the improvement in energy recovery.
  - Both SCR and catalytic filter bags require less reagent per tonne of NO<sub>x</sub> removed than SNCR option.
  - While both SCR and catalytic filter bags offer better environmental performance in relation to NO<sub>x</sub> reduction, these options are not cost effective as they are around 5 and 4 times more than SNCR respectively.

- Catalytic filter bags (Option 3) offers the best energy recovery option in terms of exported power (i.e. by virtue of using sodium bicarbonate – see acid gas abatement below).
  - SNCR (Option 1) offers the most cost effective option while meeting the IED emission limits.
49. Therefore, on the basis of this assessment, it is concluded that SNCR represents BAT for this installation.

## 3.2 Particulate and acid gas abatement

### 3.2.1 Options considered

50. The available options for particulate and acid gas abatement for EfW plants include:
- Dry reagent injection (dry hydrated lime or sodium bicarbonate) with bag filter.
  - Semi-dry reagent injection (liquid slaked lime) with bag filter.
  - A combination of bag filter for particulate, heavy metals and dioxin/furan removal and wet scrubbing for acid gas removal using sodium hydroxide or lime.
51. Generally, all three above processes also inject activated carbon upstream of the bag filter to assist the removal of heavy metals, dioxins and furans.
52. Wet scrubbing systems for EfW plants only offer a very small improvement in the reduction of emissions compared to dry and semi-dry systems, which already achieve very low emissions that are well within the ELVs set by the IED (see **Air Quality Assessment, Annex D**). The wet scrubbing process adds significantly to the plant (e.g. bag filter plus quench tower, scrubber tower, reagent circulation, solids removal from the circuit and treatment of any liquid effluent before discharge) and also requires re-heating of the flue gas to avoid emitting a visible plume from the stack. The additional capital cost of the plant and operating costs from extra fan power and re-heating do not render this as a cost effective solution for EfW plants and this process has not been used in the UK for MSW applications. Consequently, wet scrubbing has been discarded from the BAT analysis.
53. Dry and semi-dry acid gas abatement systems with bag filters have been used extensively in the UK for EfW applications. These systems inject a reagent into a reactor tower upstream of a bag filter where the particulate, reactant and reaction products collect on the outer surface of the filter bag. Periodically, this ‘filter cake’ is pulsed free by injecting compressed air inside the bags so that the filter cake falls into the collection hoppers below. In general, dry systems have superseded the use of semi-dry systems in the UK.
54. With dry systems, the residue powder (Air Pollution Control residue, APCr) collected in the hoppers is recirculated and reinjected with the reagent into the upstream reactor tower. A proportion of the APCr is drawn off and removed to a silo for offsite disposal. With semi-dry systems the reagent is injected wet having been prepared in a lime slaker. Recirculation of APCr is not possible with the semi-dry process.
55. The dry and semi dry systems are considered by the BAT analysis below together with the alternative reagent injection options.

### **3.2.2 Emissions to air and land**

56. The acid gas emissions were assessed at the daily emission concentration of 50 mg/Nm<sup>3</sup> for Sulphur Dioxide (SO<sub>2</sub>) and 10 mg/Nm<sup>3</sup> for Hydrogen Chloride (HCl) set by the IED.
57. Table 3-12 shows the emissions to air and deposition on the ground for the dry and semi-dry acid gas abatement options. For the dry system, both lime and sodium bicarbonate reagent options were considered. All of the options are expected to result in the same air emission concentrations and therefore will have the same ground level impacts.

**Table 3-12 Emission to air for acid gas abatement options**

Description	Unit	Dry						Semi-Dry		
		1			2			3		
Option		Lime (90% Ca(OH) <sub>2</sub> )			Sodium Bicarbonate (NaHCO <sub>3</sub> )			Lime (90% Ca(OH) <sub>2</sub> )		
Reagent		Lime (90% Ca(OH) <sub>2</sub> )			Sodium Bicarbonate (NaHCO <sub>3</sub> )			Lime (90% Ca(OH) <sub>2</sub> )		
Pollutant		SO <sub>2</sub>	HCL	HF	SO <sub>2</sub>	HCL	HF	SO <sub>2</sub>	HCL	HF
Removal Efficiency	%	90.00%	99.00%	96.67%	90.00%	99.00%	96.67%	90.00%	99.00%	96.67%
Unabated emission concentration	mg/Nm <sup>3</sup>	500	1000	30	500	1000	30	500	1000	30
Unabated emission rate	t/y	1,799	3,597	108	1,799	3,597	108	1,799	3,597	108
	t/h	0.2248	0.4497	0.0135	0.2248	0.4497	0.0135	0.2248	0.4497	0.0135
Emission concentration	mg/Nm <sup>3</sup>	50	10	1	50	10	1	50	10	1
Emission abated	t/y	1619	3561	104	1619	3561	104	1619	3561	104
	kg/h	202	445	13	202	445	13	202	445	13
Emission rate	t/y	180	36	4	180	36	4	180	36	4
Long Term										
Process Contribution (PC)*	µg/m <sup>3</sup>	4.67	0.305	0.01	4.67	0.305	0.01	4.67	0.305	0.01
Background*	µg/m <sup>3</sup>	16.7	1.4	2.35	16.7	1.4	2.35	16.7	1.4	2.35
Predicted Environmental Contribution (PEC)*	µg/m <sup>3</sup>	21.37	1.71	2.36	21.37	1.71	2.36	21.37	1.71	2.36
EAL	µg/m <sup>3</sup>	20	-	-	20	-	-	20	-	-
PC as % of EAL	%	23.35%			23.35%			23.35%		
PEC as % of EAL	%	106.9%			106.9%			106.9%		
Short Term										
Process Contribution (PC)*	µg/m <sup>3</sup>	27.76	11.97	0.80	4.67	11.97	0.80		11.97	0.80
Background*	µg/m <sup>3</sup>	16.70	1.40	2.35	16.70	1.40	2.35	16.70	1.40	2.35
Predicted Environmental Contribution (PEC)*	µg/m <sup>3</sup>	44.46	13.37	3.15	21.37	13.37	3.15	16.70	13.37	3.15
EAL	µg/m <sup>3</sup>	-	750	4.91	-	750	4.91	-	750	4.91
PC as % of EAL	%		1.60%	16.29%		1.60%	16.29%		1.60%	16.29%
PEC as % of EAL	%		1.8%	64.2%		1.8%	64.2%		1.8%	64.2%

58. Long term impact of SO<sub>2</sub> exceeds both the air impact Stage 1 and Stage 2 criteria of PC > 1% and PEC > 70% and short term impact of HF exceeds both the Stage1 and Stage 2 criteria of PC > 10% and %PC of headroom >20. A more detailed assessment of impacts from the release of SO<sub>2</sub> and HF are presented within the **Air Quality Assessment**.

### 3.2.3 Emissions to water

59. Neither the dry or semi-dry systems produce any liquid effluent discharge. Therefore there are no emissions to water for any of the options evaluated.

### 3.2.4 Photochemical ozone creation potential

60. Sulphur dioxide has relative POCP value of 4.8 and the calculated POCP for both dry and semi-dry systems are 863 tonnes ethylene equivalent per annum as shown in Table 3-13.

**Table 3-13 POCP values**

Description	Unit	Dry-Lime	Dry-Sodium	Semi-Dry	No Abatement
Option		1	2	3	Baseline
SO <sub>2</sub> release rate to atmosphere	t/y	180	180	180	1799
Photochemical Ozone Creation Potential (POCP)	t ethylene/y	863	863	863	8,634

### 3.2.5 Energy efficiency

61. The energy efficiency for the dry and semi-dry options using lime as reagent are the same as shown in Table 3-14. However, for the dry system using sodium bicarbonate as reagent (Option 2), the energy efficiency is improved by 1.49% compared to a lime system. This is because sodium bicarbonate has a higher optimum reaction temperature than lime which means that flue gas quenching upstream of the process is not required and the energy in the clean flue gas downstream of the process can be recovered. This energy is recovered from the flue gas using boiler condensate feed water and returned to the deaerator which improves the plant energy efficiency. Whereas the lime system operates at lower flue gas temperature that requires flue gas quenching using water, therefore the energy is lost as latent heat in the flue gas and it is not viable to recover this energy.

**Table 3-14 Energy recovery from the plant for acid gas abatement options**

Description	Unit	Dry-Lime	Dry-Sodium Bicarbonate	Semi-Dry	No Abatement
Option		1	2	3	Baseline
Total Plant auxiliary power consumption	kWe	6,291	5,854	6,291	4,575
Change in auxiliary power compared to baseline	kWe	1,716	1,279	1,716	
Gross plant power output	kWe	55,788	56,303	55,788	55,786
Change in gross plant power output compared to baseline	kWe	2	517	2	
Net plant power export	kWe	49,497	50,449	49,497	51,211
Impact of energy recovery against baseline	%	-3.35%	-1.49%	-3.35%	0%
Change in net power export compared to baseline	kWe	- 1,714	- 762	- 1,714	
	MWh/y	- 13,712.0	-6,096.0	-13,712.0	

### 3.2.6 Global warming potential

62. The direct emissions of greenhouse gases are the same for Options 1 and 3 since the CO<sub>2</sub> and N<sub>2</sub>O emission concentrations are unchanged. Option 2 emits slightly more CO<sub>2</sub> (i.e. 5,918 t/y) than the other options due to reaction chemistry of sodium bicarbonate with HCl and SO<sub>2</sub>.
63. Indirect emissions for the two reagent options vary because of a difference in net power export. The GWP for each option was calculated based on the CO<sub>2</sub> emission rate of 380 tCO<sub>2</sub>/MWh and the results are shown in Table 3-15. The sodium bicarbonate option emits less than half of CO<sub>2</sub> compared to the lime options. As discussed before, this is due to the additional energy recovery from available heat in the flue gas downstream of the abatement system for the sodium bicarbonate option.

**Table 3-15 Global warming potential for acid gas abatement options**

Description	Unit	Dry-Lime	Dry - Sodium Bicarbonate	Semi-Dry	No Abatement
Option		1	2	3	Baseline
Direct CO <sub>2</sub> emission:					
Combustion process		No change	No change	No change	No change
Chemical reaction with reagent	tCO <sub>2</sub> /y	0	5,918	0	0
Indirect CO <sub>2</sub> emission:					
Change in net power export compared to baseline	kWe	- 1,714	- 762	- 1,714	0
	MWH/y	- 13,712	- 6,096	- 13,712	0
Global Warming Potential (GWP) compared to baseline	tCO <sub>2</sub> /y	5,210,560	2,322,398	5,210,560	0

### 3.2.7 Raw materials

64. The estimated raw material consumption for each option is shown in Table 3-16. Both dry and semi-dry systems using lime as reagent (i.e. Options 1 & 3) will require process water for flue gas quenching in order for the lime reaction process to be effective. Option 2 using sodium bicarbonate as reagent can operate at high flue gas temperature and therefore flue gas quenching is not necessary, giving savings on process water consumption.

**Table 3-16 Raw material consumption for acid gas abatement options**

Description	Unit	Dry - Hydrated Lime	Dry - Sodium Bicarbonate	Semi - Dry Lime Slurry	No Abatement
Option		1	2	3	Baseline
Process water consumption for flue gas quenching and lime slurry	t/h	10.08	0	10.08	0
	t/y	80,624	0	80,624	0
Lime	t/y	9,884		8,895	
Sodium Bicarbonate	t/y		16,186.6		
Residue	t/y	13,253.8	13,032.9	12,265.4	

### 3.2.8 Waste streams

65. The only waste stream associated with the acid gas abatement process is APCr. The amount of APCr generated from each option is shown in
66. Table 3-17. The semi-dry system generates slightly less residue than dry system because of lower reagent consumption rate due to the improved stoichiometric ratio.

**Table 3-17 Residue generation from acid gas abatement systems**

Description	Unit	Dry - Hydrated Lime	Dry - Sodium Bicarbonate	Semi - Dry Lime Slurry	No Abatement
Option		1	2	3	Baseline
Residue	t/y	13,253.8	13,032.9	12,265.4	

### 3.2.9 Costs

67. Capital and operating costs for each option are presented in Table 3-18.

The capital costs presented below are estimated from PEACE / Thermoflow software and adjusted according to recent project costs in the UK. The capital cost is the total installed cost taking into account the cost of the equipment, civils and erection costs. It also includes the cost impact on the boiler design and associated auxiliary components due to the change in flue gas condition.

68. Options 1 and 2 are assumed cost neutral as both involve a similar process and equipment level. Option 3 has the highest capital cost because of the additional equipment required for the lime slurry preparation and larger lime injection chamber.

**Table 3-18 Costs for acid gas abatement options**

Description	Unit	Dry-Lime	Dry-Sodium Bicarbonate	Semi-Dry Lime Slurry
Option		1	2	3
Capital cost per unit	£	15,408,434	15,408,434	16,949,277
No. of units	No.	2	2	2
Capital Cost (Installed)	£	30,816,868	30,816,868	33,898,555
Annualised Capital Cost	£/y			
O&M costs:				
a) Maintenance	£/y	1,540,843	1,540,843	1,694,928
b) Reagents	£/y	1,037,784	3,172,583	934,006
c) Water	£/y	80,624	-	80,624
d) Residue disposal	£/y	1,325,381	1,563,952	1,226,544
e) Loss in revenue from export power (due to lower energy efficiency)	£/y	959,840	426,720	959,840
Total annual O&M costs	£/y	4,944,472	6,704,098	4,895,941
Life of plant	year	30	30	30
Discount rate	%	10	10	10
Annualised capital cost	£/y	3,269,030	3,269,030	3,595,933
Annual Average Operating Cost	£/y	4,944,527	6,704,085	4,895,907
Present value cost	£	77,428,501	94,015,699	80,051,850
Equivalent annual cost	£/y	8,213,557	9,973,115	8,491,840

69. Operating costs for each of the options were calculated based on the material costs assumption shown in Table 3-19. These assumptions together with the capital costs were input into the H1 model which then calculated the equivalent annual cost for each

option. The result shows that Option 1 has the lowest equivalent cost followed by Option 3 and Option 2 being the most expensive solution.

**Table 3-19 Material cost assumptions**

Description	Unit	Price
Lime	£/t	£105
Sodium Bicarbonate (NaHCO <sub>3</sub> )	£/t	£196
Lime APCr disposal	£/t	£100
NaHCO <sub>3</sub> APCr disposal	£/t	£120
Water	£/t	£1
Electricity revenue	£/MWh	£70

### 3.2.10 BAT Conclusion for particulate and acid gas abatement

70. The parameters for the environmental performance and costs are summarised in Table 3-20 for each option. All of the options have the same environmental performance in terms of SO<sub>2</sub> and HCl removal rates; therefore the figures presented in the table below are directly comparable between options.

**Table 3-20 Summary and ranking of the options**

Description	Unit	Dry-Lime	Dry-Sodium	Semi-Dry
Option		1	2	3
SO <sub>2</sub> abated	t/y	1,619	1,619	1,619
HCl abated	t/y	3,561	3,561	3,561
Photochemical Ozone Creation Potential (POCP)	t ethylene/y	863	863	863
Global Warming Potential	t CO <sub>2</sub> /y	5,210,560	6,131,680	5,210,560
Reagent Consumption	t/y	9,884	16,187	8,895
APC Residues	t/y	13,254	13,033	12,265
<b>Environmental Ranking:</b>				
Release to Air		1	1	1
POCP		1	1	1
GWP		2	1	2
Raw Material		2	3	1
Disposal of APCr		2	3	1
Total score		8	9	6
Environmental ranking:		2	3	1
<b>Cost Ranking:</b>				
Annualised Cost	£/y	8,213,557	9,973,115	8,491,840
Cost per unit acid gas removed	£/t	5,074	6,161	5,246
Cost Ranking:		1	3	2
Overall ranking		1	2	1

71. As per the results, Option 3 achieved the best score on environmental performance and Option 1 achieved best cost ranking. The dry scrubbing system with sodium bicarbonate

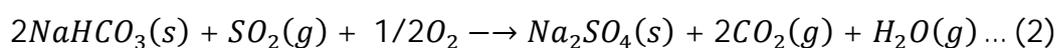
ranked the lowest in terms of environmental performance and costs. Overall, both Option 1 and Option 3 have the same ranking and both options are considered BAT. At this stage, the choice between these two options is still open and has been left to the potential EPC Contractors to propose the more commercially attractive option for the project. The final preferred technology will be selected when finalising the EPC Contract with the preferred EPC contractor.

### 3.3 Reagent selection

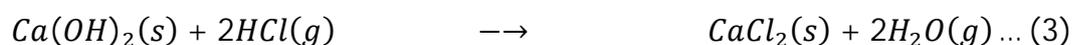
#### 3.3.1 Options considered

72. The dry acid gas abatement process can be used with hydrated lime or sodium bicarbonate reagents. The lime based process operates most effectively at a temperature of around 140°C and the sodium bicarbonate process at around 180 - 200°C. Most EfW applications in the UK have used lime on the basis that the environmental performance is very similar and lime systems have tended to be marginally more cost effective. These two options are evaluated in detail below.
73. The reactions for both options are shown below:

Sodium bicarbonate reactions with HCl and SO<sub>2</sub>:



Lime reactions with HCl and SO<sub>2</sub>:



74. Theoretically, removing 1 mole of HCl requires 1 mole of sodium bicarbonate or 0.5 mole of lime and removing 1 mole of SO<sub>2</sub> requires 2 moles of sodium bicarbonate or 1 mole of lime. Therefore, theoretically, sodium bicarbonate requires twice as much as lime for a theoretical stoichiometric ratio of 1. The ratio between the quantity of reagent supplied and the theoretical quantity required to promote the reaction is called “stoichiometric ratio”. The actual stoichiometric ratio depends on physical handling properties of the reagent. Typically, sodium bicarbonate requires a stoichiometric ratio of 1.3 and lime requires a ratio of 1.8. Therefore, the excess reagent not used in the reaction will become part of the residue stream together with the reaction product.

#### 3.3.2 Emissions to air

75. There will be no difference in terms of emissions to air for both reagent options. Both reagents can achieve the same level of acid gas removal efficiency and therefore they will have same emissions.

#### 3.3.3 Emissions to water

76. Neither reagent option generates any effluent discharge and therefore no emissions to water is associated with either options.

### 3.3.4 Deposition to land

77. Both reagents options will have same stack concentration but the sodium bicarbonate option will have a higher stack temperature around 200°C assuming the excess heat in the flue gas is not recovered. See section 3.3.6 below for further discussion on energy recovery. The higher stack temperature will help to disperse the stack plume dispersion into atmosphere and will have lower ground level concentration. Therefore, the sodium bicarbonate option with the higher stack temperature will have lower deposition to land than lime reagent option. In any case, both options will meet the IED limits.

### 3.3.5 Photochemical ozone creation potential

78. There is no difference in the POCP as both options have the same level of SO<sub>2</sub> release rate to atmosphere.

### 3.3.6 Energy efficiency

79. Sodium bicarbonate has a higher optimum reaction temperature than lime which means the flue gas temperature has to be around 200°C. The excess heat in the flue gas can be recovered downstream of the process by including a flue gas cooler for boiler feedwater heating. This improves energy recovery and overall plant efficiency (see comparison between these two options in Table 3-1).

### 3.3.7 Global warming potential

80. Since the sodium bicarbonate option has slightly lower energy recovery than lime, it is therefore has higher indirect CO<sub>2</sub> emission than lime. It is estimated that the sodium bicarbonate option would emit around 1 million tonnes of CO<sub>2</sub> more than lime options (see Table 3-20).
81. Also, the reaction between sodium bicarbonate and HCl and SO<sub>2</sub> generates CO<sub>2</sub> which contributed to global warming.

### 3.3.8 Raw materials

82. Based on the reaction formula in Section 3.3.1, the following reagent consumption per kg of HCl and SO<sub>2</sub> removed for each of the reagents is given for comparison purposes. The comparison in Table 3-21 shows that the quantity of sodium bicarbonate reagent required is around 60% more than lime reagent. Therefore, the sodium bicarbonate option requires much more raw material than the lime option.

**Table 3-21 Comparison on reagent consumption for each kg of HCl and SO<sub>2</sub> removed between lime and sodium bicarbonate reagents**

Description	Reagent consumption			
	Sodium Bicarbonate	Unit	Hydrated Lime	Unit
Stoichiometric Ratio	1.3		1.8	
HCl	3.00	kgNaHCO <sub>3</sub> /kgHCl	1.83	kgCa(OH) <sub>2</sub> /kgHCl
SO <sub>2</sub>	3.41	kgNaHCO <sub>3</sub> /kgSO <sub>2</sub>	2.08	kgCa(OH) <sub>2</sub> /kgSO <sub>2</sub>
Total	6.40		3.91	

### 3.3.9 Waste streams

83. Both reagents produce solid residues from the reactions and also from the unreacted excess reagent that will require offsite disposal.
84. A chemical balance was carried out to determine the amount of residue generated per kg of HCl and SO<sub>2</sub> removed for each option and the results are shown in Table 3-22. It shows that the amounts of residue generated for both options are very similar even with the much lower stoichiometric ratio required for sodium bicarbonate than lime. This is because the molar rate for sodium bicarbonate reaction is twice the molar rate for lime as shown in the formula in Section 3.3.1 above; therefore more residues will be generated. Overall they both have similar amount of waste discharge.

**Table 3-22 Comparison of residue generation for each kg of HCl and SO<sub>2</sub> removed between lime and sodium bicarbonate reagents**

Description	Residue generated			
	Sodium Bicarbonate	Unit	Hydrated Lime	Unit
Stoichiometric Ratio	1.3		1.8	
HCL	2.29	kgNaCl/kgHCl	2.33	kgCaCl <sub>2</sub> /kgHCl
SO <sub>2</sub>	4.31	kgNa <sub>2</sub> SO <sub>4</sub> /kgSO <sub>2</sub>	4.38	kgCaSO <sub>4</sub> /kgSO <sub>2</sub>
Total	6.60		6.71	

### 3.3.10 Costs

85. The capital costs for the acid gas removal equipment for the two reagent options will be similar as the main components are also similar. A capital cost comparison for these two options are shown in Table 3-18.
86. The operating costs mainly consist of the reagent purchase cost and residue disposal cost. Both of these costs are compared on a 'normalised' SO<sub>2</sub> and HCl abated basis (i.e. per kg) and the results are summarised in Table 3-23. Sodium bicarbonate reagent costs almost twice the cost of lime and also requires 60% more reagent to remove same amount of acid gas as lime. Also the disposal cost for the APCr from the sodium reaction is 20% more than for the lime reaction. Sodium based residues are more difficult to stabilise than lime residues, hence the higher disposal cost. In conclusion, the total reagent and residue disposal cost for sodium bicarbonate option is 90% more than lime option, which makes sodium bicarbonate an uneconomical option in comparison to lime.

**Table 3-23 Reagent and residue comparison costs for reagent options**

Description	Unit	Sodium Bicarbonate	Hydrated Lime
Reagent cost	£/t	£196	£105
Reagent consumption	kg/kgSO <sub>2</sub> + kgHCl	6.40	3.91
Cost per kg SO <sub>2</sub> and HCl removed	£/kgSO <sub>2</sub> + kgHCl	£1.26	£0.41
Residue disposal cost	£/t	£120	£100
APCr generation	kg/kgSO <sub>2</sub> + kgHCl	6.60	6.71
Cost per kg SO <sub>2</sub> and HCl removed	£/kgSO <sub>2</sub> + kgHCl	£0.79	£0.67
Total cost kg SO <sub>2</sub> and HCl removed	£/kgSO <sub>2</sub> + kgHCl	£2.05	£1.08

### 3.3.11 BAT Conclusion for reagent selection

87. There is a small environmental benefit in using sodium bicarbonate in terms of mass of residue generated which is 1.5% less than lime. However, there are several significant disadvantages:
- The residue has a higher leaching ability than lime-based residue which will limit the disposal options;
  - The reaction temperature does not match as well with the optimum adsorption temperature for carbon which is dosed at the same time; and
  - The cost of per kg HCl and SO<sub>2</sub> abated is 90% higher.

Therefore, lime reagent is considered the BAT for NBEC project.

## 3.4 Dust control techniques

88. Potential options for dust control in the flue gas are bag filter and Electrostatic Precipitator (ESP).
89. Bag filters are proven technology which are widely used in EfW plants and have high filtration efficiencies across a wide range of particle sizes. The bag filter system comprises of filter chambers in which fabric filters are suspended. Flue gas is drawn through the filter bags and dust is collected on outer surface of the bags, allowing clean flue gas to pass through. Trapped dust cake on the bag surface is removed using compressed air jet pulsing. The pulse of compressed air causes the collected dust cake on the outer surface of the bag to break loose and fall into filter hoppers below the bags. The solid material known as APCr collected in the filter hoppers is transferred to storage silos using pneumatic or mechanical conveying systems. A proportion of the APCr is recirculated and re-injected into the flue gas as medium mixed with reagent for acid gas removal. Fabric materials such as polyimide and fibreglass have normal operating temperature of around 200°C and maximum temperature up to 260°C.
90. The ESP is a possible alternative to fabric filters but has lower dust removal efficiency than bag filters. ESP works on the principal of charging the dust particles using high voltage electrical field across the flue gas stream and attract the charged particle on collection plate with the opposite polarity and forming dust cake on the plate surface. The collecting plates are cleaned at set interval automatically using rapping system (motor driven hammers) to dislodge the collected layer of dust cake from the plate surface into hoppers below the plates. This technique relies on the electrical resistivity of the dust which varies with waste composition (lower ash resistivity improves dust

removal efficiency). ESP typically achieves dust emission level of 30 mg/Nm<sup>3</sup> which is above the required IED emission level of 10 mg/Nm<sup>3</sup>. The removal efficiency can be improved by enlarging the size of the ESP and an injection chemical to reduce the resistivity of the ash but they are not very cost effective compared to bag filters.

91. Therefore, bag filters are selected as BAT for this project because it is the most proven technology for EfW and can meet the IED emission limit for dust.

### **3.5 Mercury, dioxin and furan control**

92. Mercury is highly volatile, vaporises completely at 357°C and remains gaseous in the flue gas stream. Mercury can be removed from the flue gas by either using wet scrubber using oxidants or by direct injection of activated carbon into a flue gas.
93. The wet scrubber generates liquid waste effluent that needs to be fed into waste water treatment plant to convert the mercury to a more stable form (e.g. HgS) before final disposal. The cold flue gas coming out from the wet scrubber would require reheating before can be discharged to atmosphere to avoid visible plume and help with dispersion. Therefore, the wet scrubber process is energy intensive and generates an additional effluent stream which needs to be treated.
94. The alternative activated carbon option is a simple and very effective process and widely used in most EfW plants. Activated carbon is injected directly into the flue gas conditioning tower in powdered form to react with mercury which then accumulates on bag filters downstream where it forms a filter cake and allowing more reaction time with mercury passing through. The mercury together with dust and other heavy metals in the flue gas are captured in a dry powdered form called APCr which then stored in silos prior to offsite disposal. No further treatment to the APCr residue or additional energy for flue gas reheating is required for this option.
95. Similarly, both wet scrubber and activated carbon techniques can be used to control dioxins and furans emissions in the flue gas. However, activated carbon has shown a high absorption efficiency compared with wet scrubber.
96. In summary, the activated carbon technique offers better removal efficiency, does not generate liquid effluent and is more energy efficient than a wet scrubber and also it is commonly used in almost all EfW plants in the UK. Therefore, the activated carbon option is proposed as the BAT for this project.

## 4 CONDENSER COOLING METHOD

### 4.1 Options considered

97. The potential options for power plant condenser cooling include:
- water cooling and
  - air cooling.
98. There are two basic methods of water cooling whereby the steam that exhausts from the turbine is condensed in a water cooled heat exchanger (condenser). The condenser is of the 'shell and tube' type with steam condensing on the outside of the tubes and cooling water flowing through the insides. Water cooling of the condenser offers consistent thermal performance as there is no discernible impact from high ambient air temperatures.
99. The first method (direct cooling) would source cooling water from a river or from the sea and use this supply directly within the condenser, rejecting the warmer water back to its source. The second method (indirect cooling) would use water that would be circulated through a cooling tower which would be air cooled. This method requires a make-up supply of water to compensate for losses from blowdown and evaporation.
100. The air cooled condenser (ACC) method uses air to cool the turbine exhaust steam directly in a fin/fan type heat exchanger (condenser). The steam flows through the inside of these tubes and cooling air is blown over the outside of the finned tubes by axial flow fans. The overall thermal efficiency of the power plant will vary with ambient temperature such that the efficiency will be slightly lower during the peak summer day-time temperatures.

### 4.2 BAT conclusion for condenser cooling

101. The option of direct cooling has been discarded on the basis that:
- a) Access to the River Humber would be about 1.5km distant and would need to cross the Kings/Queens Road and obtain wayleaves across land owned by others.
  - b) The Humber Estuary is a Ramsar site, a SAC and a SPA.
  - c) A detailed engineering study and CFD model would be needed to establish the length of the intake and outflow, determine the feasibility and estimate costs.
  - d) Prediction of the potential impact on the environment from the raised discharge temperature of the cooling water is challenging.
  - e) The civil engineering costs that are typical for direct cooling schemes are very high and better suited to much larger power plant where very high thermal efficiencies can be viable through economies of scale.
102. The option of indirect cooling has the disadvantage of higher absorbed power (i.e. from cooling tower fans and circulating water pumps), a need for towns water make-up to compensate for evaporative and blowdown losses from the water circuit and the need for a biocide in the circulating water. Most forced draught cooling towers also produce a visible plume which can create a visual nuisance as well as potential local icing problems in winter.

103. In terms of thermal efficiency, the indirect cooling system and ACC have the same design efficiency at the exhaust vacuum required. The ACC efficiency would reduce during very high ambient conditions but the overall impact is slight since such temperatures occur for limited periods of time (i.e. daytime and for part of the summer period). Noise emissions from the ACC would be higher than for a forced draught tower but have been shown to be of negligible impact by the noise analysis (see Supporting Information Report and **Annex M**). Consequently, it is considered that the reduced absorbed power and lack of any requirement for towns water make-up render the ACC the BAT for condenser cooling at NBEC.

## 5 OPTIONS FOR RECOVERING HEAT

104. The principle method for recovering heat from the combustion of RDF and MSW is to use a heat recovery boiler. These boilers have been developed over many decades specifically for these fuels which have the characteristics of producing a corrosive flue gas with a high content of sticky ash.
105. The supplier of the boiler has not presently been selected as the EPC contractor has not been chosen. However, the boilers from the suppliers that are being considered are similar. These have a large radiant section that ensures that the temperature and residence time requirements of the IED can be reliably achieved. Generally, the radiant section consists of membrane tube walls that cool the flue gases to below 700°C before the gases enter the convection sections. The convection surface cools the gases rapidly to an exhaust temperature of around 180°C.
106. The selection of steam pressure and temperature conditions is a balance between increased efficiency, avoidance of excessive tube corrosion and reliability of operation. Other than environmental compliance, a key driver for EfW facilities is high availability and this tends to mitigate against the use of high steam temperatures that increase the risk of corrosion. At steam temperatures of 400°C and pressures of 40bar and above, the tube metal temperatures result in a significant increase in the rate of corrosion in the furnace and superheater.
107. The approach taken for the NBEC is to adopt a slightly more conservative design that will alleviate the need for sophisticated boiler materials (e.g. Inconel) and reduce the incidence of tube failures, thereby reducing investment and lifecycle costs. Further information about the chosen steam conditions is provided in the **Energy Efficiency and CHP-Ready Assessment in Annex F**.