

**Newhurst Energy Recovery Facility
Leicestershire**

**Environmental Permit (EP) Variation Application
Appendix BATOT12
Nitrogen Oxides (NOx) Abatement Review**



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1.0 INTRODUCTION

Biffa Waste Services Limited (Biffa) is applying for an environmental permit variation to the Energy Recovery Facility (ERF) at Newhurst, Leicestershire.

The plant will be designed to use established direct combustion technology to process up to 350,000 tonnes per year of residual municipal and/or commercial and industrial waste consistent with the current planning constraints. When fully operational it is anticipated that the ERF facility will during typical operation export approximately 43 MWe of electricity to the National Grid. Biffa intends to operate the plant as a Combined Heat and Power (CHP) scheme and has entered into discussions with potential users of the heat (see Heat Plan).

As part of the demonstration that Best Available Techniques (BAT) have been adopted for environmental protection, an options appraisal will be required to identify the most suitable means of controlling emissions of oxides of nitrogen (NO_x) from the installation.

The Sector Guidance Note⁽¹⁾ states that “You must provide a cost/benefit study using the methodology in Horizontal Guidance Note H1 Environmental Risk Assessment that demonstrates the relative merits of primary measures, SNCR and SCR for NO_x control at the installation. The comparison must show the cost per tonne of NO_x abated over the projected life of the plant using the asset lives and typical rates given in that document.”

This document presents the cost-benefit study that, in accordance with the EP guidance, considers the following options. Additional data on consumption rates, etc are obtained from the relevant European BREF note⁽²⁾ or suppliers technical data, as appropriate.

Options considered:-

1. Primary NO_x abatement only;
2. Selective Non-Catalytic Reduction (SNCR); and
3. Selective Catalytic Reduction (SCR).

Section 2 of this document identifies the environmental aspects considered in the assessment. Section 3 details key features of each option. Section 4 presents the environmental impacts for each option and, where relevant, associated costs. Section 5 presents annualised costs per tonne of acid abated. Conclusions and recommendations are presented in Section 6.

¹ Environment Agency, 2009. Sector Guidance Note EPR 5.01 - The Incineration of Waste.

² EC, 2006. BREF BAT Reference Document on Best Available Techniques for Waste Incineration.

2.0 ENVIRONMENTAL ASPECTS

To identify BAT for NO_x abatement, all environmental impacts of the installation need to be considered, not simply the effects of NO_x emissions. This includes air quality, energy & global gas warming potential (GWP), photo-chemical ozone creation potential (POCP) and wastes arising. The Environment Agency's H1 Assessment tool⁽³⁾ provides a systematic approach to evaluating the environmental significance of each of these aspects and has been used as the basis of this assessment.

Table 2-1 identifies relevant environmental aspects for consideration as part of the NO_x abatement review.

Table 2-1 Identification of Relevant Environmental Aspects

Impact	Comments	Relevance
Emissions to air	Significant differences between options. Techniques result in different releases that are significant for NO _x abatement options. ^{Note 1}	Y
Emissions to water	Not applicable. No emission from the process.	N
Noise and vibration	Same for all options (SCR and SNCR).	N
Odour	Same for all options (SCR and SNCR).	N
Accident management	Same for all options (SCR and SNCR).	N
Visual impact	Same for all options (SCR and SNCR).	N
Global warming potential	Potential differences due to differences in energy consumption and nitrous oxide (N ₂ O) production.	Y
Ozone creation	Potential differences due to NO _x emissions.	Y
Waste treatment and disposal	Potential differences due to different quantities of waste and methods of treatment. Air pollution control residues (APCR) will be generated and removed from the installation as hazardous waste.	Y

Note 1: Primary NO_x control measures are unable to meet the Industrial Emissions Directive (IED) limits of 200mg.m³. This option alone does not represent BAT and is not considered in isolation.

³ Environment Agency (2008) EPR H1. Environmental Risk Assessment Part 2. Assessment of point source releases and cost-benefit analysis.

3.0 NOX TREATMENT OPTIONS

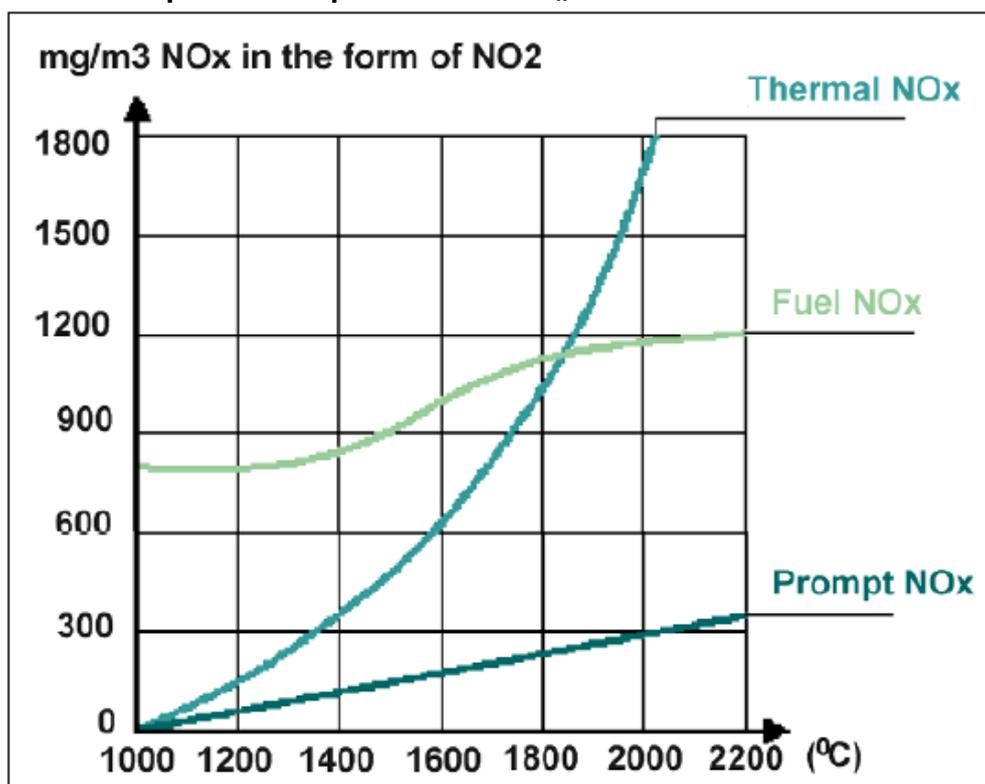
3.1 NO_x Formation

There are three ways in which NO_x may be formed during combustion⁽⁴⁾:

1. Thermal NO_x. Oxidation of nitrogen in air during combustion. Formation takes place significantly above 1300°C, with concentrations rising exponentially with temperature;
2. Fuel NO_x. Oxidation of nitrogen in feedstock fuel during combustion; and
3. Prompt NO_x. Reaction of atmospheric nitrogen with carbon and hydrogen radicals. Concentrations increase in proportion to temperature, but are low when compared with thermal and fuel NO_x.

Figure 3-1 provides a graph showing the relative importance of these three NO_x types in waste combustion plants. Primary and secondary measures to control NO_x emission concentrations are identified in the following sections.

Figure 3-1
Temperature Dependence of NO_x Formation Mechanisms



3.2 Primary Measures

A well mixed and turbulent combustion chamber minimises the potential for local hot spots and NO_x formation. In addition to primary air injection the secondary combustion chamber (SCC) is designed for optimal flow conditions with secondary air injectors that create a swirl. Secondary air is drawn from the top of the boiler house and is delivered into the combustion chamber through tangential injection into the combustion chamber. Locally adjustable

⁴ August 2006 BREF Note. Section 2.5.5.

dampers enable secondary air distribution to be preset during initial setup. Air flow rate is regulated using a frequency converter and control system to provide a constant total combustion air flow rate. The arrangement of the nozzles is derived from CFD modelling.

Flue gas recirculation (FGR) reduces NO_x in flue gas by lessening the content of fresh air (excess) in secondary air injection. Recirculation does this without raising combustion temperature or CO concentration. FGR increases boiler efficiency by approx. 2 - 3% and decreases the volume of flue gas requiring waste gas treatment by around 20% (depending on calorific value and thermal load). FGR increases maintenance requirements, parasitic energy demand and plant complexity, with more scope for downtime and repair. Effective mixing and circulation also aids secondary treatment measures such as SNCR by optimising conditions for NO_x reduction reactions to take place.

These measures improve burn out of flue gases, reduce CO & NO_x concentrations, lower corrosion and prevent the formation of substances such as dioxin. Though NO_x can be reduced by 10-20%, secondary measures are needed to comply with emission criteria.

3.3 Secondary Measures

3.3.1 SNCR

SNCR operates by injecting a reducing reagent into the furnace, which reacts with NO_x to make nitrogen gas and water vapour at temperatures between 850 and 1000 °C. The reagent is usually ammonia or urea.

Ammonia is injected into the combustion chamber as an evaporating solution (25% ammonium hydroxide) that vaporises and reacts with the flue gas. Key factors are reagent addition rate and temperature. Reducing NO_x by more than 60-80% requires more reagent, which can lead to emissions of unreacted ammonia (ammonia slip). With temperature, ammonia slip reduces and NO_x prevention increases, but ammonia begins to oxidise to NO_x.

3.3.2 SCR

Flue gases from the combustion chamber are mixed with ammonia and air and pass over a catalyst, usually a mesh. When passing through the catalyst ammonia reacts with NO_x to produce nitrogen and water vapour. The operating temperature is typically 250°C to 300°C, with more reagent required at lower temperature.

To avoid fouling and deterioration of the catalyst from dust and acid gases, it is preferential to locate the SCR at the end of the gas cleaning process. To ensure optimal operation of the catalyst and prevent PCDD/F formation, reheating of flue gases is required, either through natural gas combustion, or using heat from the boiler system. SCR gives high NO_x reduction rates (over 90 %) and nitrous oxides are not formed.

4.0 ENVIRONMENTAL CONSEQUENCES

4.1 Emissions to Air

Table 4-1 shows long term emission concentrations associated with each option, along with the source of each datum.

Table 4-2 gives the predicted NO_x environmental concentrations on the basis of the approach described in H1⁽³⁾ calculations.

Table 4-1
Long-Term Air Emission Concentrations

Option	NO _x (mg.m ⁻³)	N ₂ O (mg.m ⁻³)
Primary control measures ^{Note 1}	250	40
SNCR	150 ^{Note 2}	5 ^{Note 3}
SCR	100 ^{Note 4}	0

Note 1 – Crude flue-gas concentrations taken from August 06 BREF (Table 3.6).

Note 2 – Average emission from UK MSW incinerators. BREF (Table 4.61) indicates <180mg.m³

Note 3 – BREF 3.2.1 refers to 1-2 mg.m⁻³ average & Table 4.61 gives 10-30 mg.m⁻³ 24 hour. Value used here is conservative.

Note 4 – Taken from the BREF note, Table 4.56.

Table 4-2
NO_x Long-Term Air Quality Impacts

Option	Process Contribution (PC) (µg.m ⁻³)	% PC of headroom (EAL-background) ^{Note 1}	PEC (µg.m ⁻³)	% PEC of EAL
SNCR	1.15	12.2	31.8	79.4
SCR	0.76	8.12	31.4	78.5

Note 1 – EAL = 40 µg.m⁻³, background = 30.6 µg.m⁻³, therefore headroom = 9.4 µg.m⁻³

H1 assessment indicates that both options produce a PEC that marginally exceeds 70% of the NO_x Environmental Assessment Level and hence require detailed dispersion modelling. Detailed modelling is presented with the application and demonstrates that NO_x emissions at the IED limit of 200mg.m⁻³ through a 95m stack would present insignificant ground level concentrations. Consequently NO_x emissions at the concentrations presented in Table 4-1 are considered to cause negligible environmental impact.

4.2 Global Warming Potential

Emissions of greenhouse gases arise indirectly from electrical energy consumed and directly from the combustion process. GWP contributions are expressed as carbon dioxide equivalents (CO₂e).

The GWP potential of NO_x abatement options are considered below. Relative GWP contributions for the whole installation and comparing combustion technologies, energy use and the selected gas treatment system are provided in the GWP assessment, Appendix 6 of the BAT statement.

Options available for control of NO_x each of which results in different emissions profiles, are:

- a) selective non-catalytic reduction (SNCR); and
- b) selective catalytic reduction (SCR).

For SCR there is a significantly greater amount of energy consumed to optimise the performance of the catalyst. Consequently, although no N₂O will be generated, a much greater volume of carbon dioxide will be released.

Based on a conservative long term annual average N₂O of 5mg.m⁻³ and plant stack emission design data, this equates to an annual emission of 4.25 tonnes as N₂O from each emission stack. For the two stacks, this equates to 2,554 tonnes CO₂e GWP.

The data used to estimate energy consumption were taken from a combination of the incineration BREF guidance and from information supplied by technology advisers. This information is provided in Table 4-3.

Results from Table 4-3 indicate that SCR requires over 45% more energy than SNCR, primarily to maintain optimal functionality of the catalyst; generating 30% more CO₂ as a consequence. Taking into account the nitrous oxide emissions, the total SNCR GWP is 18,615 tonnes CO₂e, which is over 10% less than SCR at 20,905 tonnes CO₂e.

**Table 4-3
 NOx Control – CO₂ Greenhouse Gas Emissions**

Energy source	CO ₂ emission factor (tonnes. MWh ⁻¹)	SNCR		SCR	
		MWh.yr ⁻¹	CO ₂ (tpa)	MWh.yr ⁻¹	CO ₂ (tpa)
Mains electricity ^{Note 1}	0.43	429	185	429	185
Gas oil ^{Note 2}	0.25	1,282	321	1,282	321
Renewable power ^{Note 3}	0.51	25,500	13,005	30,000	15,300
Renewable heat ^{Note 4}	0.17	15,000	2,550	30,000	5,100
Total		42,211	16,061	61,711	20,906

Note 1: Technology adviser estimate of 500 MWh per year consumption mains electricity

Note 2: Consumption based on planned use during start-up and shut-down only

Note 3: CO₂ emission factor based upon non-biogenic (i.e. non-renewable) carbon released during combustion. 25,500 MWh estimated for the parasitic load. Additional load required by SCR, equivalent to 15kWh per tonne of waste throughput, accounts for the pressure drop across the catalyst, as stated in the BREF note.

Note 4: Emission factor for heat reuse is based on the assumption that thermal energy production is 3 times more energy efficient than electrical energy production (i.e. 3 units of heat are produced per unit of electricity). Consequently emissions from thermal energy production are five times lower.

Energy consumption factors were taken from the BREF note, which states that SNCR may use up to 50 kWh per tonne throughput to account for the cooling effect of in-furnace injection of reagents, and that SCR may use an additional 100 kWh per tonne of waste input to reheat flue gases for optimum performance of the catalyst.

4.3 Ozone Creation Potential

EPR H1⁽³⁾ guidance gives a NO_x Photochemical Ozone Creation Potential (POCP) value of 2.8. Total annual emissions of NO_x and the associated POCP are presented in Table 4-4. Table 4-4 indicates that SCR performs better in terms of lower annual NO_x and POCP.

**Table 4-4
 NO_x Emissions and POCP**

Option	Annual NO _x emission (tonnes)	POCP
Primary control measures	384	1075
SNCR	247	692
SCR	165	462

4.4 Materials Waste Treatment & Disposal

The main wastes from the process will be incinerator bottom ash, amounting to around 25% of the mass of waste input to the process, and boiler ash and air pollution control residues, amounting to a further 3% of mass of waste input to the process. A significant amount of metal will also be recovered from the process. The same amounts of these wastes will be produced from both SCR and SNCR abatement processes.

SNCR uses more ammonia solution than SCR but in both the ammonia is vaporised leaving little or no residual waste stream.

The main difference in wastes generated by the two options is associated with the catalyst used in the SCR process. The catalyst typically comprises a carrier material (e.g. titanium dioxide) with added active substances (e.g. vanadium). The catalyst typically requires replacement every 3-5 years. Spent catalyst is classified as hazardous waste and, due to the extent of contamination, cannot be recycled at the present time. Consequently the only currently available waste management option for this waste is landfill.

On this basis SNCR (utilizing ammonia or urea as the reagent) is the better option for waste management, as it avoids the generation of another hazardous waste stream for landfill disposal.

5.0 COSTS – ANNUALISED & NO_x ABATED

5.1 Methodology

The methodology provided in EPR H1⁽³⁾ was used to provide an annualised cost comparison. Estimated capital and operating costs were obtained from technology advisers. The approach as summarised in EPR H1 is provided in Figure 5-1.

**Figure 5-1
 Abatement Options Cost Calculations**

<p>Equivalent annual cost factor = $\frac{r}{(1+r)^n - 1} + r$, where r = discount rate, in this case 6% (minimum suggested in EPR H1); and n = lifetime of plant, in this case 25 years.</p> <p>Present value factor = $\frac{1}{\text{Equivalent_annual_cost_factor}}$</p> <p>Present value option cost (£) = CAPEX + (OPEX × Present value factor), where CAPEX = Initial capital expenditure OPEX = Annual operating expenditure.</p> <p>Equivalent annual cost (£) = Present value option cost (£) × Equivalent annual cost factor</p>

Table 5-1 summarises costs of SCR and SNCR. The upper level of capital expenditure estimates have been used to give the annualised costs. Costs are estimates based on best available information including data presented in the August 2006 BREF note. The derivation of these figures is provided in Appendix A.

Table 5-1 Summary Estimates of NO_x Abatement Costs (£)

Ref	Description	Capex ^{note 1}	Opex/yr ^{note 1}	Present Value Cost	Equivalent Annual Cost
1	SNCR	2,000,000	932,800	13,924,315	1,089,253
2	SCR	6,000,000	1,781,400	28,772,271	2,250,760

Note 1: Estimates obtained from technology advisers.

The information in Table 5-1 demonstrates that the capital expenditure required to install SCR is significantly higher than that for SNCR, reflecting the complexity of the additional abatement plant. Running costs are also substantially more as a consequence of a much greater energy requirement and need to maintain the performance of the catalyst.

Abatement costs of SCR and SNCR have been considered to fully understand the costs and benefits associated with NO_x and Photochemical Ozone Creation Potential (POCP). For the other environmental parameters, relating to Global Warming Potential and waste management, it is clear that SNCR represents BAT as it has a better environmental performance and has a lower cost.

5.2 NO_x Abatement Costs

Table 5-2 compares estimated costs per tonne of total acid abated. Costs are calculated by dividing the equivalent annual cost by the mass abated, relative reductions by primary measures only. Costs estimates are based on best available information from Table 5-1.

Table 5-2 shows that whilst SCR does reduce the mass of NO_x emitted, the overall cost per tonne of NO_x abated is substantially higher than for SNCR. To determine whether this additional cost is appropriate, it is necessary to review the emission concentrations and predicted ground-level impacts.

Table 4-1 shows that both SCR and SNCR emission limits are well within the 200 mg.m⁻³ limit required by IED, hence both techniques comply with regulatory limits. Table 4-2 indicates that although SCR would potentially provide an improved ground-level concentration, the improvement of 0.4 µg.m⁻³, from 31.4 µg.m⁻³ for SCR to 31.8 µg.m⁻³ for SNCR, is negligible.

Detailed air dispersion modelling presented with the application and in which the IED emission limit of 200 mg.m⁻³ are modelled, demonstrates ground level concentrations to be insignificant. Consequently the impact of NO_x emissions at the lower concentrations produced by secondary abatement techniques is considered insignificant.

With negligible difference in ground-level NO_x concentrations between use of SCR or SNCR and considering the significant difference in abatement cost, amounting to £2500 per tonne of NO_x, SNCR is judged to represent BAT for NO_x abatement.

Table 5-2 Comparison of Costs per Tonne Acid Abated

Ref	Description	NO _x Abated tonnes/year ^{Note 1}	Equivalent Annual Cost (£)	Equivalent annual cost per tonne of NO _x Abated (£)
1	SNCR	165	1,089,253	6,610
2	SCR	247	2,250,760	9,106

Note 1 – Primary measures only produce 448 tonnes, SNCR produces 270 tonnes, SCR produces 180 tonnes

5.3 POCP Abatement Costs

Table 5-3 presents the cost per unit of POCP abated calculated by dividing the equivalent annual cost by the number of units abated.

**Table 5-3
 POCP Abatement Costs**

Ref	Option	Units of POCP abated ^{Note 1}	Equivalent annual cost (£)	Equivalent annual cost per unit abated (£)
1	SNCR	461	1,089,253	2,361
2	SCR	692	2,250,760	3,252

Note 1 – Primary measures only produce 1075 tonnes POCP abated.

SCR provides the lower POCP, but costs over 50% more per unit. Considering the relatively low improvement of 231 POCP units per year as a consequence of SCR coupled with the high additional cost of £891 per unit, it is concluded that SNCR represents the most cost-effective POCP option.

6.0 CONCLUSIONS AND RECOMMENDATIONS

To establish BAT for the treatment of NO_x the impacts of various treatment options have been considered, along with associated implementation costs. Primary control measures would not be a suitable option on their own as emissions would not meet the mandatory emission limit values required by IED.

Consequently the review focussed on the use of selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR).

Table 6-1 provides a simple summary ranking of performance and costs. Ranks are left blank where differences between options are not distinct. Results indicate that SCR provides a marginal improvement in environmental terms but that costs are significant and overall SNCR provides the better cost-benefit.

**Table 6-1
 Summary of Ranking**

	Options and Ranking	
	SNCR	SCR
Performance Ranking		
Air NO _x	2	1
Raw Material	2	1
POCP	2	1
GWP	1	2
Waste	1	2
Visual		
Noise & Vibration		
Cost Implementation Ranking		
Raw Material Cost	2	1
Disposal Cost	1	2
Capex	1	2
Opex	1	2
Overall	13	14

Note: Performance and costs for raw material (ammonia) use are included as described in 4.4.

The following key conclusions are reached:-

1. Both SCR and SNCR meet the mandatory requirements regarding emission limits.
2. SCR provides better NO_x reduction but this has little or no significant improvement in the resulting ground-level concentrations.
3. Photochemical ozone creation potential (POCP) is lower with SCR, as a consequence of POCP being directly proportional to NO_x.
4. Global warming potential associated with SNCR is better than for SCR. This is due to the high level of additional heating required by SCR to maintain the catalyst in optimal condition; and
5. SCR generates an additional hazardous waste stream in the form of spent catalyst. This cannot be recovered, hence requires disposal in a hazardous waste landfill.

From an environmental perspective SCR appears to perform marginally better than SNCR. However, the costs associated with SCR are considerably higher in terms of the initial investment required and the ongoing costs.

The following conclusions were derived from the cost-benefit assessment:

1. SCR costs are significantly greater per tonne of NO_x abated than SNCR. Considering the negligible improvement in ground-level concentrations SNCR is considered to be the most cost-effective option; and
2. Though emissions from SCR would have a lower POCP the high abatement cost per unit of POCP is not considered to justify the additional cost.

It is concluded that SNCR (with ammonia or urea reagent) represents BAT for the Newhurst ERF and it is recommended that this is adopted preferentially over SCR.

7.0 CLOSURE

This report has been prepared by SLR Consulting Limited with all reasonable skill, care and diligence, and taking account of the manpower and resources devoted to it by agreement with the client. Information reported herein is based on the interpretation of data collected and has been accepted in good faith as being accurate and valid.

This report is for the exclusive use of Biffa; no warranties or guarantees are expressed or should be inferred by any third parties. This report may not be relied upon by other parties without written consent from SLR.

SLR disclaims any responsibility to the client and others in respect of any matters outside the agreed scope of the work.

APPENDIX A

APPENDIX A: SNCR and SCR Capital and Operating Expenditures

The following tables provide the data used to predict the capital and operating expenditure associated with SCR and SNCR for NO_x abatement. The primary source of information has been the August 2006 incineration BREF note, which provides indicative cost estimates for a number of parameters. Calculations only take into account the additional consumption by each proposed option when compared to no abatement. Hence the additional parasitic energy load for SNCR is considered negligible, whereas the parasitic energy load for SCR is significantly higher due to the additional heating requirements and associated abatement control systems.

Unit consumption

	Unit	SNCR	SCR
Parasitic electricity	MWh.t ⁻¹	0 ^{Note 1}	0.015 ^{Note 2}
Parasitic steam	MWh.t ⁻¹	0.05 ^{Note 3}	0.1 ^{Note 4}
Ammonia ^{Note 5}	Kg.t ⁻¹	4.88	2.44

Note 1 - BREF table 4.62

Note 2 - BREF table 4.57

Note 3 - BREF table 4.62

Note 4 - BREF table 4.57

Note 5 - BREF table 10.31 & 10.32

Annual consumption ^{Note 1}

	Unit	SNCR	SCR
Parasitic electricity	MWh	-	4,500
Parasitic steam	MWh	15,000	30,000
Total	MWh	15,000	34,500
Ammonia	Tonnes	1,464	732

Note 1 - Based on 300,000 tonne throughput per year

Unit costs

	Value	Unit	
Parasitic electricity	0.05	£.kWh ⁻¹	Based on sale price of 5p per kWh
Parasitic steam	0.04	£.kWh ⁻¹	Based on heat sale price (2.5p) + 33% of electricity sale price (1.5p) on the assumption that to generate 3MWth loses 1MWe for external sale
Ammonia	200	£.tonne ⁻¹	

		SNCR	SCR	
Investment costs	£ per 150,000 tonne throughput	1,000,000	3,000,000	Adapted from BREF (tables 10.31 and 10.32 and comments, and table 4.60 and comments)
Maintenance	% of investment	2	1	From BREF (tables 10.31 and 10.32)
Catalyst	£ per tonne	0	0.50	Adapted from BREF table 10.31, which states 0.3 Euros per tonne

Final Costs

	SNCR £.yr ⁻¹	SCR £.yr ⁻¹
CAPEX	2,000,000	6,000,000

APPENDIX A

OPEX		
Parasitic electricity	-	225,000
Parasitic steam	600,000	1,200,000
Ammonia	292,800	146,400
Maintenance	40,000	60,000
Catalyst	-	150,000
TOTAL	932,800	1,781,400