European Commission

Support for the Development and Adoption of Monitoring and Reporting Guidelines and Harmonised Benchmarks for N_2O Activities for Unilateral Inclusion in the EU ETS for 2008-12

Final Report

February 2008

Entec UK Limited

Report for

Marco Loprieno
European Commission
DG Environment
B-1049 Brussels

Main Contributors

Tassos Shialis
Brendan Marsh
Lucia Lavric
Alistair Ritchie
Tim Scarbrough
Paul Pountney

Issued by

………………………………………………………
Tassos Shialis

Approved by

………………………………………………………
Alistair Ritchie

Entec UK Limited

17 Angel Gate
City Road
London EC1V 2SH
England
Tel: +44 (0) 207 843 1400
Fax: +44 (0) 207 843 1410

20805

h:\projects\em-260\20000 projects\20805 eu n2o scheme\project\c001 client\final report\20805_final report_february 2008.doc

European Commission

Support for the Development and Adoption of Monitoring and Reporting Guidelines and Harmonised Benchmarks for N2O Activities for Unilateral Inclusion in the EU ETS for 2008-12

Final Report

February 2008

Entec UK Limited

Certificate No. FS 13881

Certificate No. EMS 69090

In accordance with an environmentally responsible approach,
this document is printed on recycled paper produced from 100%
post-consumer waste, or on ECF (elemental chlorine free) paper

Third Party Disclaimer

Any disclosure of this report to a third party is subject to this disclaimer. The report was prepared by Entec at the instruction of, and for use by, our client named on the front of the report. It does not in any way constitute advice to any third party who is able to access it by any means. Entec excludes to the fullest extent lawfully permitted all liability whatsoever for any loss or damage howsoever arising from reliance on the contents of this report. We do not however exclude our liability (if any) for personal injury or death resulting from our negligence, for fraud or any other matter in relation to which we cannot legally exclude liability.

Executive Summary

Introduction

This is the report of the project to support the European Commission in the development and adoption of monitoring and reporting guidelines and harmonised benchmarks for N_2O activities for unilateral inclusion in the EU ETS for 2008-12.

This report focuses on the task to develop options for harmonised benchmarks for N_2O emissions. Separate documents have been submitted for the development of Draft Monitoring and Reporting Guidelines for N_2O Emissions.

Information is presented to support benchmark development for the different N_2O emitting chemical processes, including nitric acid, adipic acid, caprolactam, glyoxal and glyoxylic acid. In this study the prioritisation of information collection and analysis has been in relation to nitric acid, as agreed with the Commission. This is because, at the time of writing, this was the only N_2O emitting sector known to be the subject of an opt-in proposal in Phase II. A similar level of analysis for the other processes would not have been possible within the available budget.

It should be noted that in relation to the benchmark aspects of this study:

- This study is to provide supporting information in relation to potential benchmarks. It is outside the remit of this study to recommend a specific benchmark emission value.
- The benchmarks are only applicable to those Member States that voluntarily opt-in specified N_2O emitting activities into Phase II of the EU ETS (2008-2012).
- The benchmarks discussed in this study refer to existing and not new installations.
- The analysis in this study is only relevant to potential benchmarks for Phase II, and not later phases of ETS.
- This study does not consider the potential need for any adjustment factors, which might be applied for various reasons eg growth projections.

Evaluation criteria

A number of potential benchmark formulae and parameter values could be chosen, with the choice being dependent on the criteria which the benchmark options are to be evaluated against and the relative weighting of the criteria. As such, the evaluation criteria are a fundamental aspect of developing a recommended benchmark value.

No specific criteria for identifying the benchmark have been specified for the contract of this work. However, for the purposes of this study, some general criteria have been identified as follows:

- Feasibility - how resource intensive is the method (to develop, implement)? can the input data to the benchmark formula be verified? can factors be replicated by a third party? are benchmark values based on readily available data? is the allowance allocation simple?

- Environmental effectiveness – does the allocation maintain scarcity of allowances in the EU ETS market? will the proposed benchmark incentivise additional emissions reductions beyond the BAT requirements?
- Economic impacts – what level of benchmark would achieve a balance between costs and benefits for the sector as a whole across the EU? It should be noted that distributional impacts within the sector are not considered as a criterion for the evaluation, and an analysis of such impacts is outside the scope of this study.

Potential benchmark options

A potential benchmark formula for the nitric acid industry for Phase II of EU ETS (2008-2012) is:

Benchmark based allocation	=	*Activity level*	*x*	*Benchmark value*	*x*	*Global Warming Potential*	*x*	*1t / 1000 kg*
t CO_2 eq. per year		*production, tonnes 100% HNO_3 (averaged over specified reference period)*		*kg N_2O /tonne 100% HNO_3*		*310 tCO_2 equiv*		

Activity level: the average nitric acid production level for each installation (eg over 5 most recent years) could be considered as an option.

The main focus of the study, however, was the benchmark value. For the production base, methodological clearness must be provided and whichever production base is used, the general criteria (avoiding undue excess of allocation to individual installations and competitive distortions in general, etc) need to be respected.

Benchmark value: potential options for benchmark values that have been considered in this report include 1.85, 1.7, 1.5, 1.3 and 1.0 kgN_2O/t 100%HNO_3[1]. These span the range from the upper BREF BAT-AEL for most existing installations down to a figure close to the average estimated technically achievable level across the EU (see Section 2.4.6).

Key assumptions for analysis of potential benchmark options

Applicability and abatement efficiency of abatement measures

The following assumptions of applicability and abatement efficiency have been considered for the selected additional abatement techniques, where not already fitted. Further details are given in Section 2.4 of the main section of the report.

---

[1] Presentation of units simplified to kgN_2O/t HNO_3 in rest of report

Table 1 **Selected Abatement Technologies: Applicability and abatement efficiency assumptions**

Abatement Technology	Technical Applicability	Abatement Efficiency (%)
Secondary catalysts	Low, Medium & High pressure plants (Note 1)	80% (Note 2)
Tertiary catalysts (Variant 1 and 2)	Tail gas temperature > 300 °C	95% (Note 3)

Notes

1. Only one low pressure plant from the Entec survey indicated that they could not install secondary catalysts (and also cannot install tertiary catalysts), with their best possible technique being alternative oxidation catalysts.
2. This is the abatement efficiency for an average campaign, as indicated during consultation with nitric acid manufacturers and abatement technique suppliers.
3. An abatement efficiency of 95% is a conservative value compared to what has been demonstrated in practice. 98-99% abatement efficiency is possible, although plant specific conditions can reduce efficiency below those levels.

Abatement technology costs

The aggregated cost assumptions used in this study for abatement techniques, expressed per tonne of nitric acid production, are presented in Table 2.

Table 2 **Aggregate Cost Assumptions for Secondary and Tertiary Abatement Techniques**

Technology	Cost Type	Cost (€/t HNO_3 produced)[1]	Cost elements
Secondary catalysts	Capital / initial[4]	0.25	Total initial project cost including catalyst and possible technical modifications
	Operating	1.00	Catalyst replacement; recycling of spent catalyst; replacement of spare catalyst; loss of production due to abnormalities in operation of the catalyst[3]
	Total	1.25 [2]	
Tertiary catalysts	Capital / initial[4]	0.50	Total initial project cost including catalyst; plant / equipment; loss of production during installation of equipment
	Operating	0.50	Catalyst replacement; loss of production during replacement of catalyst
	Total	1.00 [2]	Excluding ammonia related costs that would relate specifically to the de-NOx element of the tertiary catalyst technology.

Notes

1. Figures rounded to nearest €0.05/t HNO_3; data based on a 1000 tonnes per day plant

2. In comparison, the BREF document reports costs for a range of N_2O reduction strategies of €0.98 to 1.20/tHNO_3 produced
3. It is possible that through more operating experience, production losses due to abnormalities in operation of the catalyst may be reduced
4. Capital costs (one-off investment costs) are annualised assuming an economic lifetime of 15 years (not the catalyst life) and a 4% discount rate.

Other key assumptions

- Allowance price: € 20/tCO_2e
- Value of lost production: € 75/tHNO_3, (based on Gaz Integral study)[2]
- Global Warming Potential of N_2O: 310

Evaluation of potential benchmark options

Feasibility

- The proposed benchmark formula is simple and transparent. The only input parameter to be entered is the historic production, eg for the period 2002-2006. Historic production levels at an installation level should be feasible and easy to verify using internal and external documents that each company holds. For installations lacking historic data, an approach based on capacity and utilisation rate could be developed.

Environmental effectiveness

- The benchmark value options considered in this study have aimed at ensuring scarcity of allowances in the EU ETS carbon market or at least minimise the possibility of excess allowances compared to business as usual (BAU) emissions. During the WG3 meeting (held on 24th October 2007) the different Member State representatives agreed that scarcity of allowances should be ensured for Phase II of EU ETS. As such, the benchmark would need to be set at a level more stringent than baseline emissions levels achieved under ‘business as usual’ policy commitments. For the nitric acid sector, baseline emissions are assumed to equate to those achieved through application of BAT under the IPPC Directive.
- Whilst BAT is assessed at an installation specific level (and therefore has not been possible to determine in detail in this study), BAT-based permit conditions need to have regard for the BREF document and the BAT-AELs (associated emission levels) therein. As such, the BAT-AELs provide an indication of the emissions expectation from this sector under IPPC[3], which for the majority of existing plants is up to 1.85 kgN_2O/t HNO_3. Therefore, in line with the abovementioned point, it would appear that the benchmark value should be below this level.
- Once a Member State has opted-in its nitric acid plants, there will be an incentive for each plant to reduce N_2O emissions until the marginal costs of abatement equal the allowance price, regardless of the benchmark level. Depending on the level of the benchmark value, as

---

[2] The actual value is likely to vary from operator to operator.

[3] Recent studies for the Commission as part of the Review of IPPC have highlighted inconsistencies in permit setting, although the Commission is seeking to address this through a revision to the Directive

excess allowances reach the market, they would allow other EU ETS sectors to reduce less emissions.

- Incorporation of nitric acid plants into the EU ETS should create a further driver for emissions reductions beyond current expectations eg due to further optimisation of secondary catalysts; investigations into wider application of tertiary catalysts; investigations into alternative abatement techniques; and management of portfolios of installations by increasing utilisation of lower emission installations (where technically possible) and decreasing utilisation of higher emission installations (including bringing forward closures).

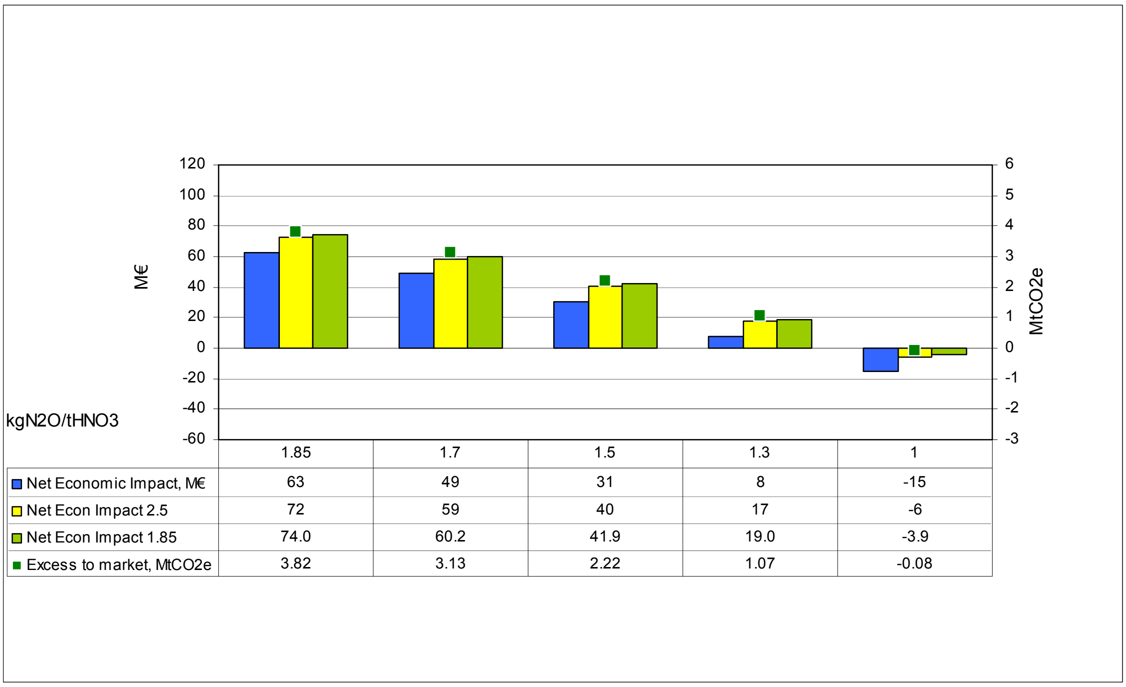
Economic impacts

- The impacts on competitiveness from opting into the EU ETS will depend largely on the benchmark value and allowance prices. At lower benchmark values, a larger number of plants would be incurring a net additional cost.
- The general criteria in relation to economic impacts is expressed as 'what level of benchmark would achieve a balance between costs and benefits for the sector as a whole across the EU?'
- Modelling of abatement techniques, emissions and costs was undertaken for each of the respondents to Entec's survey of nitric acid plants (61 production lines, about 80% of EU production). In comparison with current emissions and abatement technologies, it was assumed that each operator would consider options to invest in additional abatement technologies and also the option to continue business as usual with no (additional) investment in N_2O abatement. The analysis assumes that each operator will select the best financial option among feasible investments in abatement technology and no investment.
- The costs associated with participation in the EU ETS are calculated on basis of three baseline scenarios:
    1. current emissions / abatement technologies;
    2. emissions / abatement technologies corresponding to IPPC permit ELVs of no higher than 2.5 $kgN_2O/t\ HNO_3$ (or actual emission factor if lower);
    3. emissions / abatement technologies corresponding to IPPC permit ELVs of no higher than 1.85 $kgN_2O/t\ HNO_3$ (or actual emission factor if lower).
- The value of 1.85 $kgN_2O/t\ HNO_3$ (the upper end of the BAT range) represents the DG Environment's view on the expected (least stringent) level of emissions corresponding to "IPPC compliance" and the value of 2.5 $kgN_2O/t\ HNO_3$ is consistent with a number of actual permit conditions. These compare with current average emissions of approximately 4.4 $kgN_2O/t\ HNO_3$ taking account of current abatement techniques, and best technically achievable average emissions of 1.0 $kgN_2O/t\ HNO_3$.
- Under various modelling scenarios (including sensitivity analysis), a neutral economic impact is estimated to be achieved by the following benchmark values:

Incremental cost compared to:	Benchmark value (kgN_2O/t HNO_3)						
	Base scenario	Sensitivity on Allowance Price (€30/TCO_2e)	Sensitivity on Allowance Price (€10/TCO_2e)	Sensitivity on Abatement Costs (- 50%)	Sensitivity on Abatement Costs (+ 100%)	Pessimistic: High Cost (+100%), Low Cprice (€10/tCO2e)	Optimistic: Low Cost (-50%), High Cprice (€30/tCO2e)
Current emissions (2006) & abatement techniques	1.2	1.1	1.3	1.1	1.3	1.6	1.1
Permit ELV of 2.5 kgN_2O/tHNO_3	1.1	1.1	1.1	1.0	1.1	1.2	1.0
Permit ELV of 1.85 kgN_2O/tHNO_3	1.0	1.0	1.1	1.0	1.1	1.1	1.0

- The chart for the base scenario is shown below. Refer to Section 2.5.3 for the charts for other scenarios.

Figure 1 Summary of Economic Impacts – Base Scenario



kgN2O/tHNO3	1.85	1.7	1.5	1.3	1
🟦 Net Economic Impact, M€	63	49	31	8	-15
🟨 Net Econ Impact 2.5	72	59	40	17	-6
🟩 Net Econ Impact 1.85	74.0	60.2	41.9	19.0	-3.9
▪ Excess to market, MtCO2e	3.82	3.13	2.22	1.07	-0.08

- The base scenario indicates that, based on the modelling assumptions, a benchmark value of approximately 1.2 $kgN_2O/t\ HNO_3$ would have a neutral economic impact when assigning any further abatement costs (compared to current abatement) to the ETS. This would reduce to 1.1 and 1.0 when assigning some costs of further abatement to IPPC implementation (with permit ELVs no higher than 2.5 and 1.85 respectively). There would be positive impacts above these benchmark values and negative impacts below these values.
- Considering uncertainties in abatement costs, allowance prices and permit conditions, the range of benchmark values having a neutral economic impact is between 1.0 and 1.6 $kgN_2O/t\ HNO_3$.
- Further key uncertainties include the applicability of tertiary catalysts (greater applicability than our assumption of just over a third of the nitric acid plants from the Entec survey– see Section 2.4.4 for details - would tend to reduce the above benchmark values and vice versa) and the abatement efficiency of secondary catalysts, both of which would require site specific investigations to reduce uncertainty.
- Our analysis models any additional abatement as being installed from commencement of participation in the ETS, with no time lag. In practice, any delay in fitting additional abatement would lead to additional costs in comparison to those assumed in our modelling.
- It is noted that consideration of the distributional impacts within the sector has been outside the scope of this study. A simple analysis of the base scenario (current emissions baseline), suggests that the proportion of installations that would incur a net cost as a result of being opted into the EU ETS is disproportional to the overall economic impact due to the high gains that can be obtained by the installations with the ability to install tertiary abatement.
- Individual plants considered in this study are owned by a small number of companies with a range of plant types with different abatement capabilities (the respondents to the Entec survey operate on average approximately 6 plants), and therefore the impacts for each company are likely to be much smaller than the impacts at an individual plant level.
- Clearly the position at a company (or MS) level would follow the position at an EU level if the company's (or MS's) portfolio of plants was representative of the EU average. For companies (or MSs) with a proportionately greater share of plants that fit (or could fit) tertiary catalysts, the threshold benchmark values at which there would be a positive net economic impact would be lower than the above values and vice versa.
- It must be remembered that opting into Phase II of EU ETS is voluntary and hence Member States may decide not to opt-in rather than incur a negative net economic impact for the plants in their Member State.

Overall comments

- Decision making on proposed benchmarks is a matter for the Commission, and would depend on the relative importance (weightings) assigned to the different criteria, especially the relation to other legislative instruments, namely the application of the IPPC Directive, and Articles 87 and 88 of the Treaty. Furthermore, the decision is likely to be sensitive to the type of economic criteria that are considered and the level at which the criteria are applied (ie installation, company, Member State, EU sector level).

- Determining the applicability, effectiveness and costs of N_2O abatement technologies is complex and is significantly driven by site specific considerations. As such, more detailed and site specific investigations would be needed to reduce the uncertainty of this analysis. Given the current uncertainties, it is not possible to be precise about what specific benchmark levels would achieve specific economic outcomes.

- The incentive to reduce emissions to the level where marginal costs equal the allowance price should apply to opted-in plants regardless of the benchmark level.

- The clear focus of this study has been on Phase II of the EU ETS, and given the relatively new application of secondary and tertiary abatement, it would not be recommended to apply the findings of this study to benchmarking in Phase III. Further research would be required, taking into account latest available information and experience at the time of decision making for Phase III.

- The benchmark values discussed here refer to existing installations. As new installations would install the best available abatement in any case (presumably combined N_2O and NO_x treatment, i.e. tertiary catalyst), the business as usual (BAU) under IPPC alone would lead to very low emissions. Consequently, the benchmark would be on the lower end of the interval given as BAT-AEL by the BREF (0.12 – 0.6 kg N_2O/t HNO_3). Since no data about such cases is available, this study excluded such cases.

Contents

1. Introduction

1.1 This Report

This is the report for the project to support the Commission in the development and adoption of monitoring and reporting guidelines and harmonised benchmarks for N_2O activities for unilateral inclusion in the EU ETS for 2008-12.

The work for this study was separated into two key elements:

- Task 1: Development of Draft Monitoring and Reporting Guidelines for N_2O Emissions. This is presented in a separate document.
- Task 2: Development of options for harmonised benchmarks for N_2O emissions. This is presented in this document.

This report presents information to support benchmark development for the different N_2O emitting chemical processes: nitric acid, adipic acid, caprolactam, glyoxal and glyoxylic acid.

In this study the prioritisation of information collection and analysis has been in relation to nitric acid, as agreed with the Commission. This is because, at the time of writing, this was the only N_2O emitting sector known to be the subject of an opt-in proposal in Phase II. A similar level of analysis for the other processes would not have been possible within the available budget.

1.2 Objectives of this project

In Phase I the EU Emission Trading Scheme (EU ETS, 2003/87/EC) captures only emissions of carbon dioxide (CO_2), but under Article 24 there are procedures set out that describe the potential for unilateral inclusion of additional activities and gases in Phase II. At the time of writing, at least one Member State is proposing to opt N_2O from chemical production processes (specifically nitric acid) into Phase II of the EU ETS.

The key objectives of this study are twofold:

- to develop monitoring and reporting guidelines for the inclusion of N_2O emissions in the EU ETS (Task 1)
- to develop options for harmonised benchmarks for N_2O emissions to be applied at an EU wide level (Task 2).

This report addresses Task 2, as the deliverables for Task 1 have been presented separately.

It should be noted that in relation to the benchmark aspects of this study:

- This study is to provide supporting information in relation to potential benchmarks. It is outside the remit of this study to recommend a specific benchmark emission value.

- The benchmarks are only applicable to those Member States that voluntarily opt-in specified N_2O emitting activities into Phase II of the EU ETS (2008-2012).
- The benchmarks discussed in this study refer to existing and not new installations.
- The analysis in this study is only relevant to potential benchmarks for Phase II, and not later phases of ETS.
- This study does not consider the potential need for any adjustment factors, which might be applied for various reasons eg growth projections.

1.3 Policy Factors

There are a number of policy-related factors that can influence the design of the benchmark methodologies, as presented below:

- **'Bottom-up' or 'top-down' benchmarks**. In the context of the EU ETS, there are two main ways that technical benchmarks can be used to allocate allowances. The 'bottom-up' method is directly used to calculate the absolute installation-level allocation. The allocation for each installation is based on the sector's benchmark. These can then be totalled up to give the overall sector cap, unless the overall cap is determined in a 'top-down' manner, in which case there would need to be a check to ensure that the sum of allocations was within the sector cap. A variety of adjustment factors could be applied to the sum of allocations, depending on the policy objective (eg to equal the sector cap). In contrast, the 'top-down' method is used to distribute an agreed sector cap. This process starts with an agreed cap and the sector's benchmark is used to calculate each installation's share of that sector's overall allocation. Whether benchmarks are used in a 'bottom-up' or 'top-down' way can affect how they should be designed.

  Status: It was agreed with the Commission that benchmarks in this study will be 'bottom-up'.

- **Proportion of allowances that are benchmarked and auctioned**. The respective shares of allowances issued by free allocation and auctioning for a given sector and how this may change in the future may affect the level of importance attached to benchmarked allocations.

  Status: It is assumed that for Phase II, opted-in N_2O sectors will be allocated allowances on the basis of benchmarking rather than auctioning.

- **State Aid considerations**. These may constrain certain design decisions in order to ensure that any free allowances are balanced by an environmental benefit. Possible impacts include: the acceptability of the 'top-down' approach; the interpretation of BAT levels of performance; potential reductions in allowances where actual future activity rates are lower than estimated using a benchmarking method; etc.

  Status: All options have generally to comply with state aid rules. However, such an assessment would go beyond the scope of this study.

- **Scope of installation coverage**. It may be that technical benchmarks are easiest for one portion of an installation (e.g. up to production of a commodity product) rather than the whole installation. However, rules for benchmarking would need to consider whether this was allowable or whether benchmarking would need to be applied to an entire installation.

> Status: The benchmark options considered for the nitric acid industry apply to the whole nitric acid process.

- **Coverage of CO_2 (or other GHG) emissions from N_2O activities**. N_2O activities may also be associated with other GHG emissions which are not already covered by EU ETS (e.g. as a combustion activity).

> Status: The benchmark developed for the nitric acid industry considers only N_2O emissions, which does not exclude the necessity to include other greenhouse gases in the ETS permit (i.e. the obligation to monitor these emissions and to surrender corresponding allowances). It is known that installations which operate an NSCR unit emit considerable amounts of hydrocarbons (methane) and CO_2. However, this abatement technology is not considered BAT and, according to the Commission, should therefore be phased out during the coming years.

- **Adjustment factors**. Adjustment factors may be required for a number of reasons including: complying with a sector cap; set asides for new entrants; bonuses for certain technologies; sector level growth projections etc. These are typically policy-based factors.

> Status: This study has not considered the potential need for any adjustment factors.

- **EU-wide or MS benchmarks**.

> Status: This study is to provide background information for the decision on an EU wide benchmark for N_2O emissions from nitric acid manufacture.

- **Incumbents or New Entrants**.

> Status: The proposed benchmark applies to incumbent (existing) nitric acid plants. No consideration for new entrants has been given in this study.

1.4 Evaluation Criteria

Notwithstanding certain policy influences and constraints on benchmark methodologies, there are a number of potential benchmark formulae and parameter values due to a range of discretionary factors. The choice of preferred option is dependent on the criteria against which the benchmark variants are to be evaluated and the relative weighting of the criteria. As such, the evaluation criteria are a fundamental aspect of developing the preferred benchmark value.

The Commission has not identified and defined the specific criteria that will be used in identifying the benchmark formula and parameter values for N_2O. However, for the purposes of this study, some potential general criteria have been indicated.

There are 3 key steps in relation to evaluation criteria:

Establishing the criteria – Based on discussion with the Commission, the following general evaluation criteria have been considered:

- Feasibility - how resource intensive is the method (to develop, implement)? can the input data to the benchmark formula be verified? can factors be replicated by a third party? are benchmark values based on readily available data? is the allowance allocation simple?
- Environmental effectiveness – does the allocation maintain scarcity of allowances in the EU ETS market? will the proposed benchmark incentivise additional emissions reductions beyond the BAT requirements?
- Economic impacts – what level of benchmark would achieve a balance between costs and benefits for the sector as a whole across the EU? It should be noted that distributional impacts within the sector are not considered a criterion for the evaluation, and an analysis of such impacts is outside the scope of this study.

Operationalising the criteria – This involves ensuring that the evaluation criteria provide a clear and practical basis for decision-making, by being as specific and well defined as possible. It has been outside the scope of this study to further define the above general criteria.

Weighting the criteria – It is assumed that this step will be considered by the Commission when deciding on the proposed benchmarks, in particular weighting the environmental and economic criteria.

1.5 Structure of this Report

The structure of this report is as follows:

- Section 2: presents information gathered and benchmark option analysis for the nitric acid industry
- Section 3: presents information gathered for the adipic acid industry
- Section 4: presents information gathered for the caprolactam industry
- Section 5: presents information gathered for the glyoxal and glyoxylic acid industry.

2. Nitric Acid Industry

This section starts by describing some background information regarding production levels and processes, N_2O emissions and abatement techniques for existing nitric acid plants. It then presents details of the modelling of potential benchmark options.

2.1 Use and Production Process

Nitric acid is used as a raw material mainly in the manufacture of nitrogen and compound fertilizers. Nitric acid may also be used in the production of adipic acid and explosives (e.g., dynamite), for metal etching and in the processing of ferrous metals.

Nitric acid production involves three distinct chemical reactions that can be summarised as follows:

Box 2.1 Equation for HNO_3 formation

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$$

$$2NO + O_2 \rightarrow 2NO_2$$

$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$$

Source: IPCC guidelines for National GHG inventories 2006, Chapter 3: Chemical Industry Emissions

There are three intermediate reactions during the oxidation of ammonia that might result in the formation of N_2O (IPCC guidelines, 2006):

Box 2.2 Equation for N_2O formation

$$NH_3 + O_2 \rightarrow 0.5N_2O + 1.5H_2O$$

$$NH_3 + 4NO \rightarrow 2.5N_2O + 1.5H_2O$$

$$NH_3 + NO + 0.75O_2 \rightarrow N_2O + 1.5H_2O$$

Source: IPCC guidelines for National GHG inventories 2006, Chapter 3: Chemical Industry Emissions

It is not possible to define a precise relationship between NH_3 input and N_2O formation because in general, ‘the amount of N_2O formed depends on combustion conditions, catalyst composition and state (age), and burner design’ (IPCC guidelines 2006).

2.2 Production Levels and N_2O Emissions

Overall data

Within EU27 and Norway there are nearly 100 nitric acid plants[4] and in this context a nitric acid plant is assumed to refer to one production line. Table 2.1 presents national data for year 2005 for EU27 for production levels, nitrous oxide emissions levels and emission factors and total emissions for year 2005. These data are submitted in the National Inventory submissions to the UNFCCC where greenhouse emissions, industry activity levels and emission factors are reported. The information for year 2005 is presented in the 2007 National Inventory submissions[5] and the European Community GHG inventory 1990-2005 and inventory report 2007 (EEA, 2007).

Table 2.1 Nitric acid production and N_2O emissions in EU27 for year 2005

Country	Total Production (tonnes HNO_3)	% of 2005 total production	Emission factor used (kg N_2O/tonne HNO_3)	Total N_2O Emissions (tonnes)	% of 2005 N_2O emissions
Austria	557,870	3	1.6	884	1
Belgium	733,260	4	13.5	9,891	6
Bulgaria (Note 1)	-	-	-	3,200	2
Czech Republic	532,210	3	6.3 - 6.9	3,255	2
Finland	581,530	3	7.6 - 9.5	5,060	3
France	2,815,980	14	5.0	13,991	9
Germany	6,487,602	33	5.5	35,682	23
Greece (Note 2)	252,320	1	4.5	1,140	1
Hungary	486,416	2	13.1 - 14.5	6,261	4
Italy	571,978	3	9.5	5,444	4
Lithuania	-	-	-	7,054	5
Netherlands	-	-	-	18,254	12
Poland	2,219,374	11	6.5	14,360	9
Portugal	-	-	7.5	1,974	1
Romania	1,118,548	6	9.2	10,237	7
Slovakia	497,677	3	8.1	4,046	3

---

[4] http://ec.europa.eu/environment/climat/emission/pdf/etsworkinggroup/2007_03_08/3d.pdf (Last accessed on 21st November 2007)

[5] http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/3929.php (Last accessed on 21st November 2007)

Table 2.1 (continued) **Nitric acid production and N_2O emissions in EU27 for year 2005**

Country	Total Production (tonnes HNO_3)	% of 2005 total production	Emission factor used (kg N_2O /tonne HNO_3)	Total N_2O Emissions (tonnes)	% of 2005 N_2O emissions
Slovenia	1.94	0	5.5	0.0100	0
Spain	720,111	4	7	5,041	3
Sweden	264,262	1	5.4	1,418	1
UK	1,712,515	9	3.8	6,515	4
Total EU27	**19,551,655**			**153,708**	

Note 1: Bulgaria, Lithuania, Netherlands and Portugal did not provide any data on production levels and emission factors due to confidential reasons. The total value of 2005 production includes only production data submitted in the national emission inventories

Note 2: Greece did not provide a GHG emission inventory for year 2005, hence data for year 2004 are presented here.

Installation level data gathering

Entec undertook a survey across the EU nitric acid industry, by contacting the various nitric acid operators to gather specific data to support this study. The operators were provided with a questionnaire to complete, collecting information on production levels, N_2O emissions and abatement techniques at a production line level (see Appendix B for the questionnaire). All the major nitric acid manufacturers were contacted but due to resource and timescale limitations it was not possible to contact every single operator within the EU27. The survey collected data at a production line level for 61 production lines across EU27[6], covering over 80% of total nitric acid production i.e. the 61 lines represented in total about 13.8 million tonnes per annum of HNO_3 production for the last 5 years compared to an average of 16.9 million tonnes per annum for the period 2001-2005. Key data and information provided by the nitric acid operators is presented in Table 2.2, including current abatement techniques and 2006 emission levels.

---

[6] The survey collected data on 65 production lines in total, but some production lines were removed from the analysis because it was indicated that there are plans to close them down.

Table 2.2 Summary of data on nitric acid manufacturers from the survey

Reference	Current abatement techniques in use (Note 1)	Current emission levels (kgN2O/t HNO_3) (Note 2)
1	None	12.75
2	None	9.32
3	None	9.16
4	None	8.41
5	None	8.41
6	None	8.02
7	None	8.00
8	None	7.90
9	None	7.89
10	None	7.59
11	None	7.02
12	None	6.68
13	None	6.60
14	None	6.59
15	None	6.52
16	None	6.43
17	None	6.05
18	None	6.00
19	None	4.89
20	None	4.89
21	None	4.60
22	None	4.56
23	None	4.52
24	None	4.41
25	None	4.10
26	None	4.07
27	None	3.80
28	None	3.70
29	Improved oxidation catalysts	9.70
30	Improved oxidation catalysts	8.20
31	Improved oxidation catalysts	7.80
32	Improved oxidation catalysts	6.70
33	Improved oxidation catalysts	6.31
34	Improved oxidation catalysts	5.80
35	Improved oxidation catalysts	5.50
36	Improved oxidation catalysts	5.00
37	Improved oxidation catalysts	5.00
38	Improved oxidation catalysts	4.97
39	Improved oxidation catalysts	4.80
40	Improved oxidation catalysts	4.76
41	Improved oxidation catalysts	4.17
42	Improved oxidation catalysts	3.56
43	Secondary catalysts	2.49
44	Secondary catalysts	2.01

Table 2.2 (continued)   Summary of data on nitric acid manufacturers from the survey

Reference	Current abatement techniques in use (Note 1)	Current emission levels (kg N_2O /t HNO_3) (Note 2)
45	Secondary catalysts	1.61
46	Secondary catalysts	1.50
47	Secondary catalysts	1.50
48	Secondary catalysts	1.50
49	Secondary catalysts	1.50
50	Secondary catalysts	0.94
51	Improved oxidation catalysts & secondary catalysts	1.87
52	Improved oxidation catalysts & secondary catalysts	1.84
53	Improved oxidation catalysts & secondary catalysts	1.50
54	Improved oxidation catalysts & secondary catalysts	1.50
55	Tertiary abatement technique (Note 3)	0.24
56	Tertiary abatement technique	0.11
57	Tertiary abatement technique	0.09
58	Tertiary abatement technique	0.09
59	Tertiary abatement technique	0.09
60	Tertiary abatement technique	0.02
61	Tertiary abatement technique	0.01
	Current weighted average (for 61 production lines)	**4.4**

Notes

1. These are the techniques that the operators have indicated that they have installed when the Entec survey was undertaken i.e. during October / November 2007.
2. For the majority of production lines the data presented reflects the total 2006 N_2O emissions divided by 2006 nitric acid production. For a small proportion (approx 10%) of production lines, 2006 emissions do not take into account the abatement that is currently in place (in Autumn 2007), hence we have applied the average assumed abatement efficiency to these plants combined with the average assumed unabated emission factor, unless the actual emission factor is higher.
3. Included within the ‘tertiary abatement technique’ category is any production line with combined NOx and N_2O abatement including tertiary (Uhde) catalysts or NSCR
4. This table excludes those plants known to be closing by 2010 or sooner

To supplement this, our consideration of abatement techniques has also been informed by discussions with key abatement equipment manufacturers, as reported in the following sections.

Furthermore, site visits were also made to two nitric acid production plants, one in the UK (with attendance at the meeting from a second manufacturer) and one in the Netherlands. At these visits, more detailed understanding was obtained about the operational and physical constraints of the plants and processes and more detailed discussions took place about the opportunities for changes to improve nitrous oxide abatement.

The understanding gathered from discussions with abatement equipment manufacturers and operators has been used to help evaluate and balance information gathered in the questionnaires and through other data sources.

Table 2.3 Nitric acid production for EU27 for years 2001-2005

Year	Nitric acid production (tonnes) for EU27
2001	16,140,699
2002	15,266,452
2003	16,289,204
2004	17,242,949
2005	19,551,655
Average	**16,898,192**

Source: UN National Submission Inventories – Last accessed on 21st November 2007 (http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/3929.php)

2.3 Existing Policies Applying to N_2O Emissions

The most significant existing EU policy affecting N_2O emissions from the nitric acid sector is the IPPC Directive. This represents a ‘business as usual’ (BAU) policy commitment, against which any incremental impacts of the EU ETS should be compared. Some brief details regarding this directive and its implications on N_2O emissions are outlined below.

2.3.1 IPPC Directive

The IPPC Directive[7] was adopted in September 1996 with all Member States being required to bring it into effect nationally by 30th October 1999. The system of Integrated Pollution Prevention and Control (IPPC) applies an integrated environmental approach to the regulation of certain industrial activities, which means that emissions to air, water and land plus a range of other environmental effects must be considered. It also requires that regulatory authorities in Member States must develop and set permit conditions for operation of installations falling within the regime so as to achieve a high level of protection of the environment as a whole. These conditions should be based on the application of Best Available Techniques (BAT), which can take into account site-specific geographic, environmental and technical considerations. Reference documents on BAT (BREF Documents), adopted and published by the Commission, are the outcome of an information exchange process between stakeholders and are defining what has to be considered BAT at the EU wide level.

The compliance date for the full implementation of the requirements of the IPPC Directive in Member States was 30th October 2007, at which point Member States should have completed the issue of integrated permits in compliance with the Directive's requirements for all existing installations.

At the end of 2005 the Commission launched a review process of the IPPC Directive and related legislation on industrial emissions. One of the conclusions of this review was that BAT is not currently being implemented in a consistent way across Member States, and permit conditions

---

[7] Council Directive 96/61/EC concerning integrated pollution prevention and control – OJ L257, 10.10.1996, pp. 26-40

may have much less stringent emission limits than emissions achievable by BAT (as set out in the BREF documents – see below) without clear justification[8].

In December 2007 the Commission adopted a proposal for revising the IPPC Directive, which seeks to strengthen the application of BAT across the EU, particularly by restricting divergence from BAT to specific cases and placing greater emphasis on justifying the conditions laid down in the permits. However, the revised Directive is not due to come into effect for several years, so the existing IPPC Directive will apply during Phase II of EU ETS.

2.3.2 Permit conditions

BREF Document

The BREF Document covering nitric acid plants (European Commission, 2007) presents a range of N_2O emission levels which are considered to be associated with the application of BAT in new and existing plants. For new plants there was full consensus on the emission levels presented i.e. the highest BAT associated emission level (BAT – AEL) is 0.6 kgN_2O/t HNO_3. For existing plants however, there was a split view on the upper end of the BAT range, with the industry and one Member State stating that 2.5 kgN_2O/t HNO_3 should be included.

Table 2.4 BAT Associated Emission Levels (AELs) for N_2O for new and existing plants (BREF, 2006)

Type of nitric acid plants		N_2O emission level (Note 1)	
		kgN_2O/t HNO_3	ppmv
M/M, M/H and H/H	New plants	0.12 – 0.6	20 – 100
	Existing plants	0.12 – 1.85	20 - 300
	L/M	No conclusion drawn	

Note 1: These levels relate to the average emission levels achieved in a campaign of the oxidation catalyst

Actual permit conditions

In accordance with current practice in implementation of the IPPC Directive, combined with differences in nitric acid plants and the applicability of N_2O abatement techniques, permit conditions for N_2O are expected to vary across the EU. Obtaining details of actual permit conditions at an installation level has been outside the scope of this study although some information has been identified.

For example, one major nitric acid manufacturer indicates that some local / national authorities appear to be setting permit limits in the region of 2.5 kgN_2O/t HNO_3, which takes into consideration potential upsets in the operation of the abatement technology. In contrast, the BREF BAT associated emission levels (AELs) correspond to the emissions that occur when

---

[8] This was investigated in detail by the 2007 study by Entec, 'Assessment of the implementation by the Member States of the IPPC Directive'.

applying BAT under "normal" operating conditions. In practice, some permit emission limit values will be lower and some higher than the upper end of the BAT range (especially for some atmospheric plants and those due to close soon).

According to the Commission, taking into account the BAT range (0.12 - 1.85 kgN_2O/t HNO_3) on the one hand and the IPPCD flexibility on the other hand (local conditions leading to less stringent ELVs only if it can be justified on the basis of local conditions assessed on a case by case basis but not as a kind of general rule applying to the whole industry), it would not be appropriate to assume 'IPPC compliant' emission levels to be higher than 1.85 kgN_2O/t HNO_3 (for those plants to which this BAT AEL value applies).

For the purpose of the calculations and the assumptions of this study, the value of 1.85 kgN_2O/t HNO_3 (the upper end of the BAT range) has been used to represent the Commission's view on the expected (least stringent) level of emissions corresponding to "IPPC compliance".

To understand the sensitivity of different assumptions, the impact of a level of 2.5 kgN_2O/t HNO_3 has also been investigated.

It should be noted that both these levels are significantly lower than estimated current emissions of approximately 4.4 kgN_2O/t HNO_3 for existing EU plants, as shown in Table 2.2 (excluding those known to be closing in next few years, but with 28/61 plants having unabated emissions and 14/61 others only "improved catalyst").

2.4 Abatement Technologies

The following abatement options were considered for the development of a benchmark of nitric acid. These abatement techniques are also described in the BREF Document (2006) "*Large Volume Inorganic Chemicals – Ammonia, Acids and Fertiliers*", and the relevant sections of these techniques in the BREF are quoted below. Any reference of the "BREF document" in the report refers to the abovementioned document, unless otherwise stated.

The abatement options considered with regards to nitric acid plants (these abatement measures are also presented in the BREF document and are referenced accordingly) are presented in the following sections.

2.4.1 Alternative oxidation catalysts (section 3.4.3 of the BREF document)

This abatement technique was considered briefly, but was not included in the economic analysis because:

- details in the BREF document showed that achieved N_2O emission levels were not lower than 500 ppm (about 3 kg N_2O/t HNO_3) - this technique is not considered BAT in the conclusions of the BREF and would therefore not be sufficient, on its own, for compliance with IPPC; and,
- a lower NO yield could be experienced after installing this technology, hence decreasing HNO_3 production levels.

2.4.2 N_2O decomposition by extension of the reactor chamber (section 3.4.5 of the BREF document)

This abatement technique relates to the space between the platinum gauze oxidation catalyst and the boiler tube banks – where this is extended – and conversion of N_2O to NO takes place. This abatement technique was considered briefly, but was not included in the economic analysis because:

- details in the BREF document showed that achieved N_2O emission levels for an example plant were between 2-3 kgN_2O/t HNO_3 - this is higher than the BAT-AEL of 1.85 kgN_2O/t HNO_3 and would therefore need to be combined with other techniques;
- this technique is applicable to new plants with low additional investment costs but for existing plants the costs are considered excessive (BREF document, p122) – in practice this may require the construction of a new reactor and other plant modifications; and,
- some existing plants may have extended reactors and will benefit from a lower 'normal' level of N_2O, but would still require additional abatement measures to achieve a coefficient of 1.85.

2.4.3 Catalytic N_2O decomposition in the oxidation reactor – Secondary catalysts (section 3.4.6 of the BREF document)

This abatement technique involves the instalment of a selective De-N_2O catalyst (secondary catalyst) in the oxidation chamber, immediately below the platinum gauze pack catalyst[9]. This secondary catalyst would normally be laid on top of and partly replace the 'raschig ring' or other gas distribution bed, held in a support structure (basket) above the boiler tube bank.

The BREF document presents details for 3 catalyst manufacturers. Entec has been in consultation with all 3 manufacturers in order to understand better these technologies, their applicability for the different types of nitric acid plant and their performance. The findings of consultation from the 3 catalyst manufacturers and nitric acid producers are summarised below.

Applicability

- the secondary catalyst is technically applicable to all type of plants (low, medium or high pressure plants);
- the BREF document and consultation with the manufacturers indicated that for atmospheric (low) pressure plants this technology is not favourable as the extra pressure drop in the oxidation reactor reduces the plant capacity, hence creating losses in production. The manufacturer mentioned that high pressure plants may also experience problems with this technology; and
- the physical space available underneath the gauze and above the boiler tube bank will vary between reactors as will the current arrangements for supporting the existing packing. Sufficient strength in the reactor to withstand the extra direct weight of the catalyst and the additional load from the pressure drop across the new catalyst bed is required. The applicability and costs of this technique is therefore installation specific.

---

[9] The Platinum gauze pack initiates the oxidation of ammonia (NH_3) into nitric oxide (NO)

Achieved N_2O emission levels

The following factors determine the achieved N_2O emission levels:

- Depth of catalyst basket – the higher the catalyst filling height, the larger the N_2O emission reductions. The maximum basket height is constrained by the physical configuration of the oxidation chamber and can vary from 2 – 17 cm. Most of nitric acid plants have a basket height of 10-12cm[10]. Modifications can be undertaken to the configuration to increase the depth (e.g. modify basket, ledge, burner head etc) but in practice this may end up being so expensive it might require installation of a new reactor;
- Load factor – The gas load (space velocity) through the catalyst combined with the depth of catalyst determines the amount of contact time (residence time) between the gas and catalyst and hence the extent to which the reaction to decompose N_2O can take place. Hence a low load factor should result in better N_2O abatement;
- Operating temperature – This can depend on the pressure of the plant, higher temperatures resulting in better catalyst performance;
- Inlet N_2O concentrations – This depends on the combustion pressure, and can range from 1000ppm to 2500ppm;
- Extent to which there are any problems with catalyst filling eg bypassing and channeling

Comments on overall performance:

- Overall performance data in the BREF document indicates that an average abatement efficiency of over 80% can be achieved over a normal campaign[11] in most HNO_3 plants. This average abatement efficiency was also confirmed during consultation with secondary catalyst manufacturers. It is important to note that the secondary catalyst maybe performing better at the beginning of the campaign e.g. 90%, but by the end has degraded and performs less well e.g. 70%.
- The plant in the BREF with secondary catalysts that has the lowest N_2O emissions (0.8kg N_2O / t HNO_3, Table 3.12) has all above key factors in its favour, ie a deep catalyst basket; a low load factor; and low inlet N_2O concentrations of 1000ppm. This site can achieve an average emission over a campaign of about 1.0 kg N_2O /t HNO_3, or 0.8 at the start of the campaign. If the catalyst basket was 100% filled (vs 75% filled as in the BREF figure), then the average emission over a campaign is expected to be approximately 0.8 kg/t HNO_3, or 0.65 at the start. This would equate to a best average abatement efficiency of 87% for this plant. As all the factors at this site favour low outlet concentrations, a more typical site is likely to have an abatement efficiency of less than 87%.
- According to one technology supplier, due to variations in the above factors, the achievable emissions vary quite considerably, with the sites falling into 3 broad categories: <1kg N_2O /t HNO_3 (20% sites); 1.6 to 1.8 kg N_2O /t HNO_3 (50% sites); 2.0 to 2.5 kg N_2O /t HNO_3 (30% sites, eg one site has very deep basket (18cm) but has a high inlet concentration; another has a lower inlet concentration but has a basket which is only 10cm max).

---

[10] Based on personal experience of catalyst manufacturer

[11] A campaign is considered to be the period between oxidation gauze changes

- According to one technology supplier, emission levels of 1.85 kg N_2O/t HNO_3 in M/H plants are realistic based on their experience of operation of one existing plant over the period of one campaign (approximately 8 months).

Reliability

- Consultation with secondary catalyst manufacturers and literature research has shown that extensive research has been undertaken over the last decade with promising results.
- According to one manufacturer, the catalyst proved to be very stable and efficient (Lenoir *et al*, 2006) while another manufacturer indicated that the original results are promising but the performance and lifetime of the catalyst have to still be confirmed (Kuhn *et* al, 2001).
- A lifetime of 2-3 years has been reported from consultation with secondary catalysts manufacturers and literature search (Lenoir *et al*, 2006; Kuhn *et* al, 2001). For the purposes of this report a lifetime of 3 years is applicable.
- The secondary catalyst can develop voids and potential gas bypass could take place, which could lead to unplanned shutdowns due to catalyst failure. Some physical degradation can also occur.
- One supplier reported no instances of unplanned shutdowns due to catalyst operation/failure. Catalyst renewal is undertaken during scheduled shutdown for gauze replacement.
- One supplier reported two instances of plant shutdown due to catalyst failure. In such cases downtime ranges from 2-3 days rising to 1 week for the more complex work. Reasons for unscheduled downtime can include: valve failure leading to reverse gas flow which degrades the catalyst; dirty feed gases which poison the catalyst; etc.

2.4.4 Combined NOx and N_2O abatement in the tail gases – Tertiary abatement technology (section 3.4.7 of the BREF document)

This abatement technique involves the instalment of a combined N_2O and NOx abatement reactor between the final tail gas heater and the tail gas turbine. There are two versions of the EnviNox® that is manufactured by Uhde[12]:

- Variant 1 – this is described in section 3.4.7 of the BREF document; and,
- Variant 2 – this is described in section 3.6.1 of the BREF document as an emerging technology.

---

[12] www.uhde.biz

Key issues are discussed below:

Applicability

There are considered to be three main types of considerations that will determine the applicability of tertiary catalysts:

- Tail gas temperature: Variant 1 technology can be applied to plants > 425°C[13] according the manufacturer. In general low pressure plants have lower temperatures than 425°C and would not be able to fit this technology. Variant 2 technology[14] is suitable to a much wider temperature range between 300-520°C. Entec's survey[15] showed about 36% of existing EU nitric acid plants have a maximum tail gas temperature >300°C (ie above the applicability threshold for Variant 1 or 2) at the tail gas treatment process. In practice, it may be possible for some of these plants to have higher temperatures at different parts of the tail gas system, although this would require site specific investigation, together with consideration of whether there would be sufficient space at such locations. A recent confidential survey by one technology supplier indicates a much higher applicability than estimated in our survey, based on information on tail gas temperatures at the expander inlet part of the tail gas system. However, this focussed only on post-1980 plants which is likely to bias the sample towards plants with higher tail gas temperatures, and the applicability of the sample to the EU is not clear. Furthermore, neither survey has considered potential physical, productivity or supply considerations (see below) that could restrict applicability and availability for Phase II of EU ETS.
- Physical considerations: A tertiary abatement unit would replace any existing de-NOx unit, although it will probably be physically larger than such a unit so access and room for installation, ducting changes, etc., would need to be evaluated on a site by site basis.
- Productivity considerations: The fitting of a tertiary catalyst abatement system has the potential to affect the performance of the expander, which provides the power to the compressor to create pressure for the whole process. Any such impact could have cost implications.

In practice, in addition to applicability considerations, another constraint to fitting tertiary abatement systems is time. In particular, any project to implement a new tertiary abatement system could take, say, two years from start to finish, not taking into account any limitations in supply of technology or experienced engineers. Such limitations are likely to occur with a large number of orders, which would delay the time by which this technology could be installed.

The modelling in this study assumes that approximately 36% (see above) of existing EU nitric acid plants can fit this technology, based on temperature. This could overestimate the applicability if there were additional constraints related to space, productivity impacts or supply limitations. Conversely this could underestimate the applicability if there were parts of the tail gas system at higher temperatures and where there were no space limitations to fitting the

---

[13] the BREF document presents temperatures between 420-480°C

[14] Uhde mentioned that they have recently installed it for a number of CDM projects e.g. Abu Qir nitric acid plant in Egypt, Hu Chems nitric acid plants in Korea[14], Chile etc.

[15] The Entec survey gathered data from over 60 production lines within EU and Norway

technology. Overall, given the range of factors and site specific considerations, assessing the applicability of tertiary abatement in more detail would require site specific investigations.

Achieved N_2O emission levels

- both variant 1 and 2 technologies can achieve emission levels as low as 0.12 kgN_2O/t HNO_3. Communication with AMI Agrolinz (Nitric acid producer), which has variant 1 technology installed, indicated that this technology achieved 0.12 kgN_2O/t HNO_3 (98% abatement) but as it was reducing production levels due to increased tail gas temperatures, the plant decided to control tail gas temperatures and operate at 0.36 kgN_2O/t HNO_3 (60 ppm N_2O) (94% abatement).

Reliability

- both Uhde and AMI Agrolinz stated that the variant 1 technology is very reliable. The technology has been operating for the last 4 years and abatement efficiency has been maintained, hence no catalyst replacement costs have occurred. Uhde mentioned that experiments in their plants show that the catalyst in the Uhde technology can last for 7 years, probably even more.

Other

- As noted above, variant 2 uses hydrocarbon fuels e.g. natural gas, propane, that account for additional CO_2 emissions – for the Abu Qir nitric acid plant in Egypt the monitoring report from April 1st to June 30th 2007 measured 453 tCO_2 emissions associated with the technology (the baseline emissions were 383,256 tCO_2, hence accounted for 0.12% of the total emissions). The additional hydrocarbon supply would tend to increase capital and operating costs.

2.4.5 Non-selective catalytic reduction of NOx and N_2O in tail gases (section 3.4.8 of the BREF document)

This abatement technique has not been considered further for analysis as an additional abatement measure for the following reasons:

- the BREF document (p 131) states that "…application in existing plants will demand major adjustments, making the installation of an NSCR less feasible".
- the BREF does not consider it BAT (Best Available Technique) due to cross-media effects, namely the additional consumption of natural gas / methane as 'fuel' which will give rise to more CO_2 emissions and methane slip.
- However, it is noted that some nitric acid plants are fitted with this technology and are achieving very low emissions of N_2O. It is not clear whether nitric acid plants that have already invested in NSCR would be required to change or decommission this technique.

2.4.6 Abatement potential at an EU level

The Entec survey has gathered information at a production line level for 61 lines (these lines cover about 80% of EU27 average 2001-2005 nitric acid production), including production levels, N_2O emissions and abatement techniques. The data provided have been used to calculate a technically achievable N_2O emission level at an EU wide level, applying the assumptions for the two abatement techniques presented in Table 2.6.

The production lines were categorised into 2 main groups:

- **Group A**: Production lines that have tail gas temperatures > 300 °C – it was assumed that these can technically install tertiary tail gas treatment[16].
- **Group B**: Production lines that have tail gas temperatures < 300 °C – it was assumed that they can technically install secondary catalysts, unless already fitted with abatement (including NSCR). Only one low pressure plant (with 2 production lines) in the survey indicated that it cannot install secondary catalysts and only alternative oxidation catalysts are technically possible.

For each production line an achieved N_2O emission level was estimated, depending on the abatement techniques they can install and the assumptions related to them (see Table 2.6). The following steps describe the method applied to calculate individual plant emission levels:

For Group A, > 300 °C tail gas temperatures (tertiary catalysts installed)

- For production lines that have the Uhde technology already installed, the 2006 N_2O emissions level was taken, as these abatement techniques are achieving very low emissions i.e. < 0.3 $kgN_2O/t\ HNO_3$.
- For production lines reporting that have secondary catalysts installed already (but not Uhde or NSCR), it was assumed that they will replace this abatement technique with tertiary catalysts in order to achieve maximum emission reductions. An unabated emissions factor of 7.5 $kgN_2O/t\ HNO_3$[17] was assumed and an abatement efficiency of 95% applied - this gives an abated emission level of 0.375 $kgN_2O/t\ HNO_3$.
- For production lines reporting that they have installed improved (low N_2O) oxidation catalysts or that no abatement technique is currently installed, the 2006 emission factor was taken and a 95% abatement efficiency was applied.
- A related category is where NSCR is already installed (which achieves very low N_2O emissions). It is assumed that this technology is kept in place due to its excellent abatement of N_2O, despite not being identified BAT in the BREF document.

For Group B, < 300 °C tail gas temperatures (secondary catalysts installed)

- Manufacturers that reported that they have already installed secondary catalysts as their current abatement technology, the N_2O emission factors reported for year 2006 were taken. For a small proportion (approx 10%) of production lines, 2006 emissions do not take into account the abatement that is currently in place (in Autumn 2007), hence we have applied the average assumed abatement efficiency (80%) to these plants combined with the average assumed unabated emission factor (7.5 $kgN_2O/t\ HNO_3$), unless the actual emission factor is higher, in which case that was used.

---

[16] Although if already fitted with NSCR which achieves at least as good abatement as a tertiary catalyst, the modelling assumes that NSCR is retained as the abatement measure.

[17] This is based on an average EU emission level of 7-8 kgN_2O/t 100% HNO_3 from nitric acid industry – confirmed from nitric acid industry and BREF (2006) on nitric acid

- For manufacturers that have not installed secondary catalysts yet and they have no other abatement technique installed e.g. alternative oxidation catalysts, it was assumed that they will install secondary catalysts (all manufacturers except one reported that they can install secondary catalysts). An 80% abatement efficiency (over an average campaign) was applied to the 2006 emission levels reported from each production line to estimate the best achieved N_2O emission levels.
- For manufacturers that have not installed secondary catalysts but they have indicated that improved (or alternative) oxidation catalysts are installed, the 2006 emission levels were taken) and an 80% abatement efficiency (over an average campaign) was applied.
- For the one low pressure nitric acid manufacturer (this includes two production lines) that indicated that only (less efficient) alternative oxidation catalysts are technically possible, the best achieved N_2O emission level reported from the manufacturer was taken.

Table 2.5 presents the best abatement techniques and estimated best achievable N_2O emission levels following the abovementioned assumptions. It should be noted that the reference numbering in this table does not correspond to the referencing numbering in Table 2.2 to safeguard any company's confidential information.

Table 2.5 Abatement techniques and estimated best achievable emission levels (Note 1)

Reference	Best abatement technique installed (Note 3)	Best achieved N_2O emission levels (kg N_2O/t HNO_3)
1	Improved oxidation catalysts	4.71
2	Improved oxidation catalysts	4.71
3	Secondary catalysts	2.55
4	Secondary catalysts	2.49
5	Secondary catalysts	2.01
6	Secondary catalysts	1.94
7	Secondary catalysts	1.83
8	Secondary catalysts	1.61
9	Secondary catalysts	1.60
10	Secondary catalysts	1.60
11	Secondary catalysts	1.58
12	Secondary catalysts	1.58
13	Secondary catalysts	1.50
14	Secondary catalysts	1.50
15	Secondary catalysts	1.50
16	Secondary catalysts	1.34
17	Secondary catalysts	1.34
18	Secondary catalysts	1.32
19	Secondary catalysts	1.32
20	Secondary catalysts	1.29
21	Secondary catalysts	1.21
22	Secondary catalysts	1.20
23	Secondary catalysts	1.16
24	Secondary catalysts	1.10

Table 2.5 (continued) **Abatement techniques and estimated best achievable emission levels (Note 1)**

Reference	Best abatement technique installed (Note 3)	Best achieved N_2O emission levels (kg N_2O/t HNO_3)
25	Secondary catalysts	1.00
26	Secondary catalysts	1.00
27	Secondary catalysts	0.98
28	Secondary catalysts	0.98
29	Secondary catalysts	0.95
30	Secondary catalysts	0.94
31	Secondary catalysts	0.92
32	Secondary catalysts	0.91
33	Secondary catalysts	0.90
34	Secondary catalysts	0.88
35	Secondary catalysts	0.83
36	Secondary catalysts	0.82
37	Secondary catalysts	0.81
38	Secondary catalysts	0.76
39	Secondary catalysts	0.74
40	Secondary catalysts	0.71
41	Tertiary abatement technique	0.47
42	Tertiary abatement technique	0.41
43	Tertiary abatement technique	0.39
44	Tertiary abatement technique	0.38
45	Tertiary abatement technique	0.38
46	Tertiary abatement technique	0.38
47	Tertiary abatement technique	0.38
48	Tertiary abatement technique	0.38
49	Tertiary abatement technique	0.35
50	Tertiary abatement technique	0.33
51	Tertiary abatement technique	0.33
52	Tertiary abatement technique	0.32
53	Tertiary abatement technique	0.25
54	Tertiary abatement technique	0.24
55	Tertiary abatement technique	0.24
56	Tertiary abatement technique	0.11
57	Tertiary abatement technique	0.09
58	Tertiary abatement technique	0.09
59	Tertiary abatement technique	0.09
60	Tertiary abatement technique	0.02
61	Tertiary abatement technique	0.01
	Weighted average (for 61 production lines)	**1.0**

Notes

1. The reference numbering in this table does not correspond to the reference numbering in Table 2.2 in order to prevent disclosing any confidential information of the nitric acid producers.
2. In some cases an operator may already have installed best abatement technique possible
3. Included within the 'tertiary' category is any production line with NSCR

A weighted average N_2O emission level at an EU wide level was estimated using the individual production line emission levels calculated as described above and the 2006 nitric acid production reported for each line[18].

Based on this weighted approach and the industry data gathered from the Entec survey, an EU wide best technically achievable emission level of 1.0 $kgN_2O/t\ HNO_3$ was estimated.

It should be noted, however, that this is based on fitting the most effective abatement techniques to each installation which would clearly take some time to implement in practice for those installations that do not already have these techniques fitted.

2.5 Modelling of Potential Benchmark Options

2.5.1 Potential benchmark options

A proposed benchmark formula for the nitric acid industry for Phase II of EU ETS (2008-2012) is:

Benchmark based allocation	=	*Activity level*	*x*	*Benchmark value*	*x*	*Global Warming Potential*	*x*	*1t / 1000 kg*
t CO_2 eq. per year		*production, tonnes 100% HNO_3 (averaged over specified reference period)*		*kg N_2O /tonne 100% HNO_3*		*310 tCO_2 equiv*		

Activity level: the average nitric acid production level for each installation (eg over 5 most recent years) could be considered as an option.

The main focus of the study, however, was the benchmark value. For the production base, methodological clearness must be provided and whichever production base is used, the general criteria (avoiding undue excess of allocation to individual installations and competitive distortions in general, etc) need to be respected.

Benchmark value: potential benchmark values considered in the subsequent modelling include 1.85, 1.7, 1.5, 1.3 and 1.0 $kgN_2O/t\ HNO_3$. These span the range from the upper BREF BAT-AEL for most existing installations down to a figure close to the average estimated technically achievable level across the EU.

2.5.2 Key assumptions

Applicability and abatement efficiency assumptions of abatement measures

The following assumptions of applicability and abatement efficiency have been considered for the selected additional abatement techniques. Further details are given in the previous sections, in particular Section 2.4.6.

---

[18] For production lines that are new and did not have a 2006 nitric acid production figure, the nameplate capacity multiplied by an average utilization factor was used (this was for two production lines)

Table 2.6 Selected Abatement Technologies: Applicability and abatement efficiency assumptions

Abatement Technology	Technical Applicability	Abatement Efficiency (%)
Secondary catalysts	Low, Medium & High pressure plants (Note 1)	80% (Note 2)
Tertiary catalysts (Variant 1 and 2)	Tail gas temperature > 300 °C	95% (Note 3)

Notes

1. Only one low pressure plant from the Entec survey indicated that they could not install secondary catalysts (and also cannot install tertiary catalysts), with their best possible technique being alternative oxidation catalysts.
2. This is the abatement efficiency for an average campaign, as indicated during consultation with nitric acid manufacturers and abatement technique suppliers.
3. An abatement efficiency of 95% is a conservative value compared to what has been demonstrated in practice. 98-99% abatement efficiency is possible, although plant specific conditions can reduce efficiency below those levels.

Abatement technology cost assumptions

The aggregated cost assumptions used in this study for abatement techniques, expressed per tonne of nitric acid production, are presented in Table 2.7. These are derived from the most specific data received from technology suppliers and operating companies.

Table 2.7 Aggregate Cost Assumptions for Secondary and Tertiary Abatement Techniques

Technology	Cost Type	Cost (€/t HNO_3 produced)[1]	Cost elements
Secondary catalysts	Capital / initial[4]	0.25	Total initial project cost including catalyst and possible technical modifications
	Operating	1.00	Catalyst replacement; recycling of spent catalyst; replacement of spare catalyst; loss of production due to abnormalities in operation of the catalyst[3]
	Total	1.25 [2]	
Tertiary catalysts	Capital / initial[4]	0.50	Total initial project cost including catalyst; plant / equipment; loss of production during installation of

Technology	Cost Type	Cost (€/t HNO_3 produced)[1]	Cost elements
			equipment
	Operating	0.50	Catalyst replacement; loss of production during replacement of catalyst
	Total	1.00 [2]	Excluding ammonia related costs that would relate specifically to the de-NOx element of the tertiary catalyst technology.

Notes

1. Figures rounded to nearest €0.05/t HNO_3; data based on a 1000 tonnes per day plant
2. In comparison, the BREF document reports costs for a range of N_2O reduction strategies of €0.98 to 1.20/tHNO_3 produced
3. It is possible that through more operating experience, production losses due to abnormalities in operation of the catalyst may be reduced
4. Capital costs (one-off investment costs) are annualised assuming an economic lifetime of 15 years (not the catalyst life) and a 4% discount rate.

As illustrated in the above table, the estimated initial costs of installing the tertiary abatement technology are higher than the secondary technology, however these are more than compensated for by lower estimated operating costs (catalyst and production interruption costs).

Given the site specific applicability issues with these technologies and potentially big fluctuations in catalyst (metal) prices, there is relatively high uncertainty over the cost estimates and Entec's modelling has considered uncertainty bands on cost data of -50% to +100%.

Other key assumptions

- Allowance price: € 20/tCO_2e
- Value of lost production: € 75/t HNO_3, (based on Gaz Integral study)[19]
- Global Warming Potential of N_2O: 310

2.5.3 Economic Analysis

The analysis below is based on the technology and cost assumptions described in the sections above.

Costs and abatement assumptions were applied to the circumstances of each respondent to the Entec survey[20] (we consider responses to represent the EU plant mix well as the total number of respondents exceeds 80% of EU production), excluding a small number of plants that indicated they were planning to close by 2010. In comparison with current emissions and abatement technologies (from the survey), it is assumed that each operator will consider:

---

[19] The actual value is likely to vary from operator to operator.

[20] Covering EU and Norway

- options to invest in additional abatement technologies—costs and potential revenues from the purchase of deficit or sale of excess allowances, and
- the option to continue business as usual with no (additional) investment in N_2O abatement.

The analysis assumes that each operator will select the best financial option among feasible investments in abatement technology and no investment.

The average abatement cost per tCO2e is derived by applying to each installation the most effective technical option resulting from the analysis of the literature and the Entec survey. This cost is below any of the allowance price scenarios envisaged. Hence, we assume that operators covered by the EU ETS would have the incentive to abate as much N_2O as is technically possible. The costs associated with the participation in the EU ETS are calculated on basis of three baseline scenarios:

- (1) current emissions and abatement technologies;
- (2) emissions and abatement technologies that correspond to an IPPC permit condition of no higher than 2.5kg N_2O /t HNO_3 (actual current emission factor if lower than this figure);
- (3) emissions and abatement technologies that correspond to an IPPC permit condition of no higher than 1.85kg N_2O /t HNO_3 (actual current emission factor if lower than this figure).

The three different baselines and the lowest emissions technically possible (the EU ETS scenario) result in four total emissions volumes. Average unit costs per ton abated (as defined above) are applied to these four volumes and used to determine incremental EU ETS – related costs by subtracting the costs of reducing emissions from current levels to expected emission levels[21] under the 1.85 and 2.5 thresholds for the scenarios 2 and 3. Under scenario 1 all costs are attributed to the participation in the EU ETS.

Further, the overall economic impact is calculated for each operator. Under Scenario 1, this is determined as follows:

- Applicable abatement options are considered, using abatement efficiency and cost assumptions as above for each technology type or sub-type.
- The abatement efficiencies are applied to latest current emissions to produce post-abatement emission levels. Importantly, our analysis models any abatement as being installed from commencement of participation in the ETS, with no time lag.
- For each applicable technology type, post-abatement emission levels are compared to the allocation under each potential benchmarking level (1.85, 1.7, etc.).
- Where the final emissions are higher than the allocation, it is assumed that the operator would purchase allowances at the market price (€20/tCO2e*GWP310=€6200/t N_2O) and incur a corresponding cost; where these are below allocation, excess allowances are sold at the same rate and an economic benefit is incurred[22].

---

[21] This is 2.5 or 1.85 for the installations with current emission factors above these levels, and actual current emission factors for installations with emission factors below these levels.

[22] Free allocation of allowances is assumed as this analysis only focuses on phase II.

- The maximum value is chosen among these options (highest benefit or lowest cost) to determine net economic impact per operator.

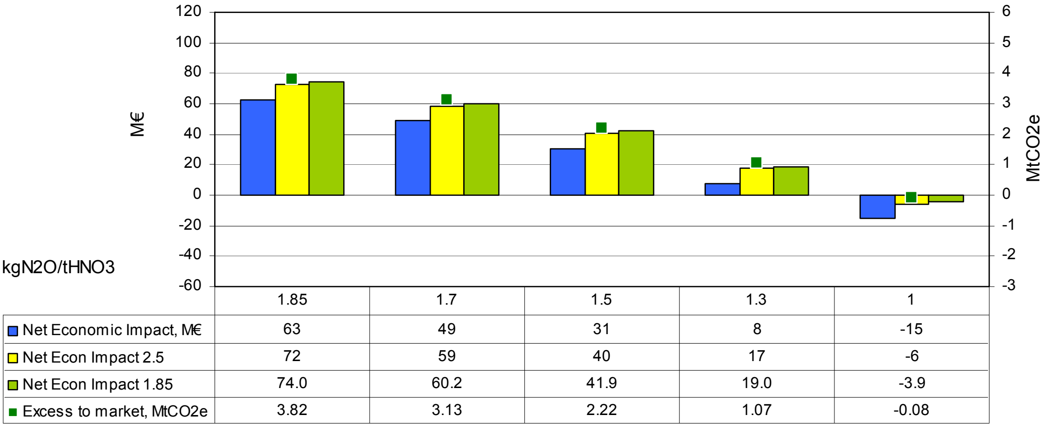
Abatement technology costs are added to the N_2O (CO_2e) trading effects to obtain an economic impact per plant for each technology. The net impacts from applying each type of relevant technology are compared among each other and with the no-investment option (this only includes the N_2O trade impacts).

Under scenario 2, the net economic impacts are calculated as for scenario 1 above. Then, the total economic impacts are calculated by adding up costs for individual installations. The total cost of reaching the 2.5 emission level is then subtracted from the baseline scenario 1 total.

The same applies for scenario 3, with the exception that higher costs of complying with the 1.85 emission level is subtracted from the baseline scenario 1 total.

The summary results of the analysis are presented in the chart below.

Figure 2.1 Summary of Economic Impacts



kgN2O/tHNO3	1.85	1.7	1.5	1.3	1
🟦 Net Economic Impact, M€	63	49	31	8	-15
🟨 Net Econ Impact 2.5	72	59	40	17	-6
🟩 Net Econ Impact 1.85	74.0	60.2	41.9	19.0	-3.9
■ Excess to market, MtCO2e	3.82	3.13	2.22	1.07	-0.08

The economic impacts in the chart are presented according to the three baseline scenarios discussed above. The units represent total economic impact for the production lines that participated in the survey (61 production lines) in millions of Euro per year.

The green dot series represents the volume of GHG traded on the market, expressed in million tons CO2e. This is positive even at benchmarking coefficients that produce negative overall economic impacts due to the fact that different proportions of the abatement costs are part of the economic impact equation.

Under this modelling scenario, an average neutral cost/benefit impact is estimated to be achieved by the following benchmark coefficients:

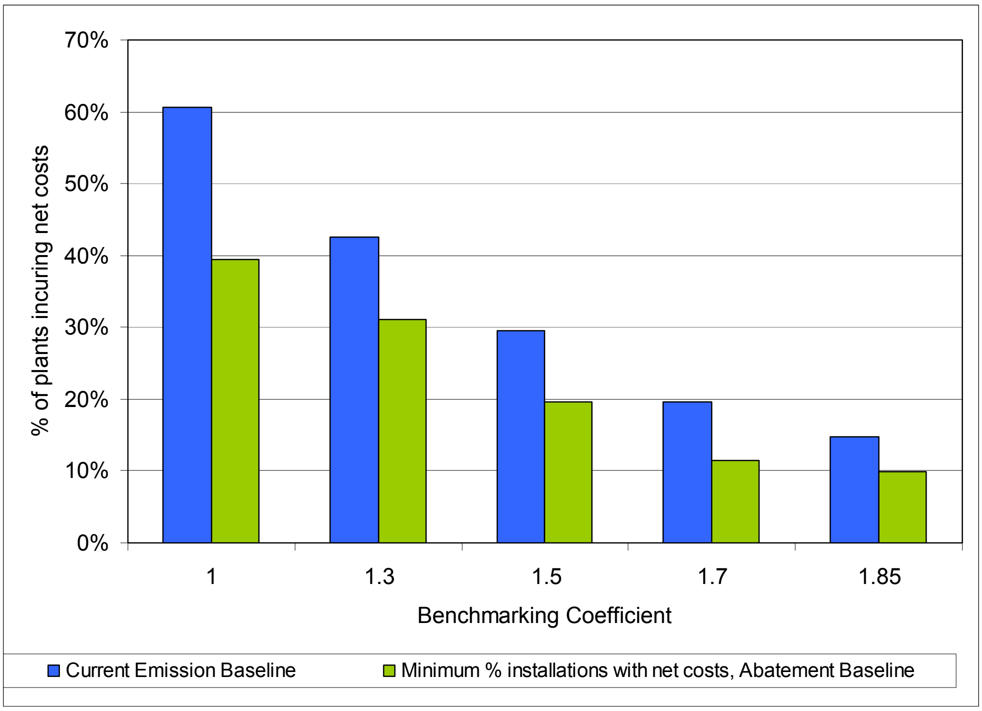
Incremental cost compared to:	Benchmark coefficient (kgN_2O/t HNO_3)
• current emissions (2006) & abatement techniques	1.2
• permit ELV of 2.5kgN_2O/tHNO_3	1.1
• permit ELV of 1.85kgN_2O/tHNO_3	1.0

Distribution of impacts

Note: This short section is for information only. Distributional impacts are not included among the evaluation criteria – see Section 1.4.

The calculations under the current emissions baseline scenario (scenario 1) suggest that the proportion of installations that would incur a net cost as a result of being opted into the EU ETS is disproportional to the overall economic impact (blue column in the figure below) due to the high gains that can be obtained by the installations with the ability to install tertiary abatement (section 2.4.6 has more detail on abatement options).

In total, a large proportion of the incremental abatement costs could potentially be attributed to IPPC implementation: approximately 70% if an IPPC permit level was no higher than 2.5 and 80% if an IPPC permit level was no higher than 1.85 (note: in addition to abatement costs, the cost/benefit of entering the EU ETS is affected by allowance trading). Given the structure of the modelling and the uncertainty regarding the distribution of abatement costs between IPPC implementation and ETS ***at an installation level***, it is impossible to determine the exact economic impact by installation under the two scenarios that take into account overall IPPC implementation costs. However, if all abatement costs are subtracted from the economic impact calculated, an estimate of the ***minimum number of plants incurring a net cost*** as a result of the EU ETS under a given benchmarking coefficient can be derived. This is presented in the figure below in green.

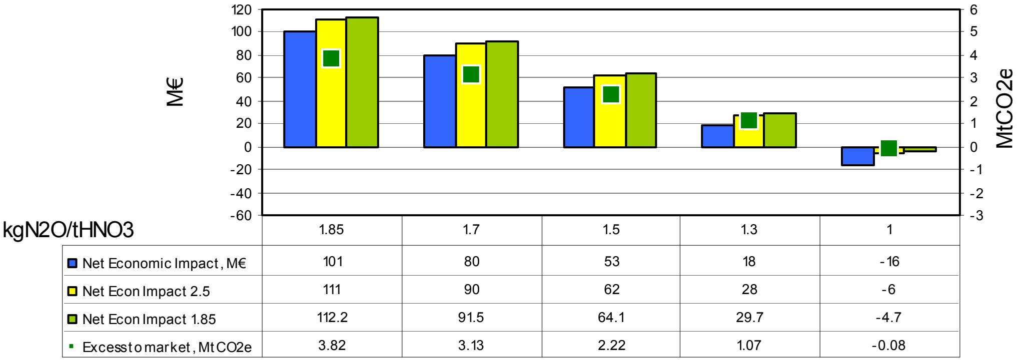


2.5.4 Uncertainties and Sensitivities

Allowance Prices

The two charts below show impacts of allowance price fluctuations to €30 and €10, the results appear to be fairly sensitive to allowance price changes.

Figure 2.2 Summary of Economic Impacts: Sensitivity on Allowance Price (€30/TCO_2e)

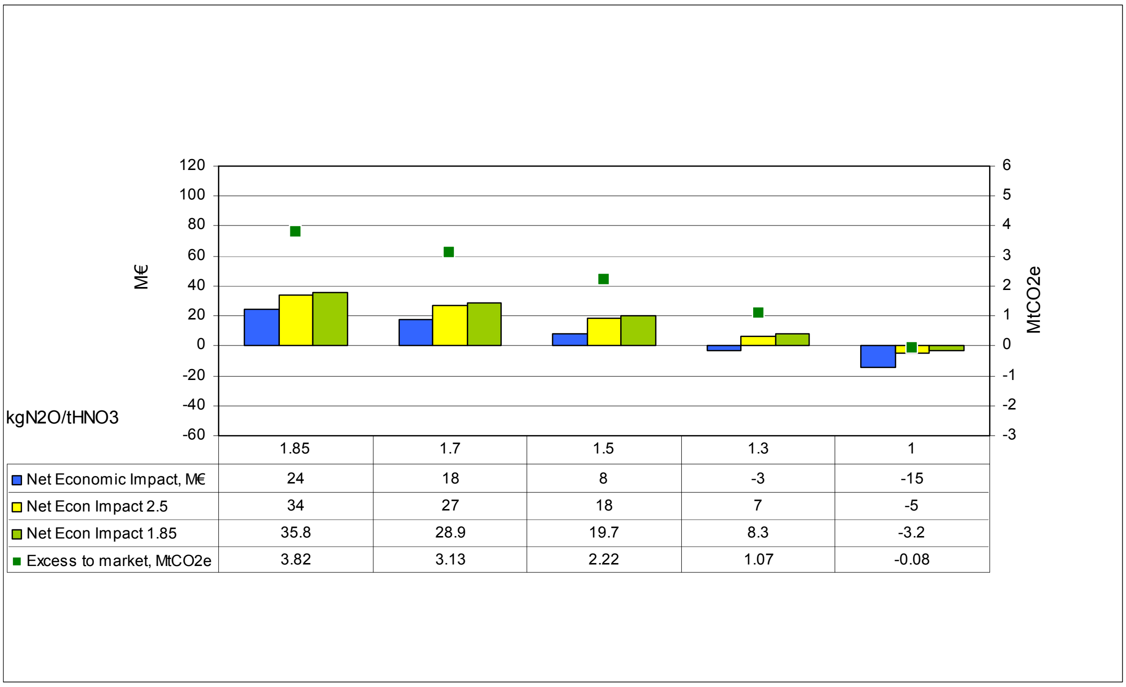


kgN2O/tHNO3	1.85	1.7	1.5	1.3	1
🟦 Net Economic Impact, M€	101	80	53	18	-16
🟨 Net Econ Impact 2.5	111	90	62	28	-6
🟩 Net Econ Impact 1.85	112.2	91.5	64.1	29.7	-4.7
▪ Excess to market, MtCO2e	3.82	3.13	2.22	1.07	-0.08

Under this modelling scenario, a neutral economic impact is estimated to be achieved by the following benchmark coefficients:

Incremental cost compared to:	Benchmark coefficient (kgN_2O/t HNO_3)
• current emissions (2006) & abatement techniques	1.1
• permit ELV of 2.5kgN_2O/tHNO_3	1.1
• permit ELV of 1.85kgN_2O/tHNO_3	1.0

Figure 2.3 Summary of Economic Impacts: Sensitivity on Allowance Price (€10/TCO$_2$e)



kgN2O/tHNO3	1.85	1.7	1.5	1.3	1
🟦 Net Economic Impact, M€	24	18	8	-3	-15
🟨 Net Econ Impact 2.5	34	27	18	7	-5
🟩 Net Econ Impact 1.85	35.8	28.9	19.7	8.3	-3.2
■ Excess to market, MtCO2e	3.82	3.13	2.22	1.07	-0.08

Under this modelling scenario, a neutral economic impact is estimated to be achieved by the following benchmark coefficients:

Incremental cost compared to:	Benchmark coefficient (kgN$_2$O/t HNO$_3$)
• current emissions (2006) & abatement techniques	1.3
• permit ELV of 2.5kgN$_2$O/tHNO$_3$	1.1
• permit ELV of 1.85kgN$_2$O/tHNO$_3$	1.1

Applicability and abatement efficiency of technologies

At an individual installation level, there are a number of parameters that give rise to uncertainty compared to the abovementioned general assumptions. These include:

- Depth of catalyst basket (for secondary catalyst);
- Load factor – the gas load (space velocity) through the catalyst combined with the depth of catalyst determines the amount of contact time (residence time) between the gas and catalyst;
- Operating temperature – This can depend on the pressure of the plant, higher temperatures resulting in better catalyst performance;
- Extent to which there are any problems with catalyst filling eg bypassing and channeling;
- Extent of catalyst poisoning etc;

- Space availability for installing abatement equipment;
- Potential productivity impacts;
- Tail gas temperatures.

Furthermore the selected abatement techniques are relatively new, especially the Variant 2 tertiary catalyst technology which has only recently been installed in some nitric acid plants, and hence there is a degree of uncertainty associated with the relatively limited operating experience.

Timescales for fitting abatement

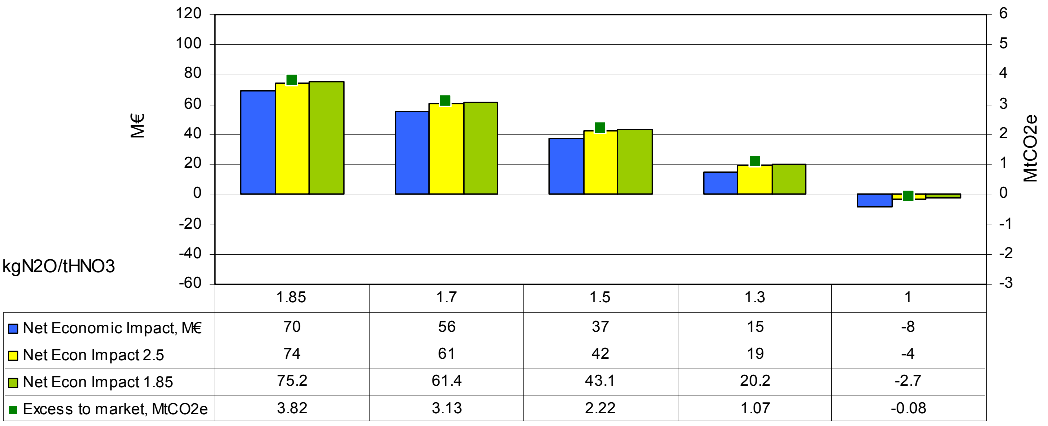
The modelling assumes that abatement is in place when plants are opted-in to the EU ETS. This could be a broadly realistic assumption for the very small number of Member States considering opting in during Phase II, based on knowledge at the time of writing. However, if a large number of Member States opted-in simultaneously and gave no notice to installations to fit abatement equipment, there could be a lag of a few years or more before all plants are abated. This would increase costs as plants may need to purchase allowances until abatement is fitted.

On the other hand, the deadline for complying with the IPPC requirements, especially the necessity to apply BAT, which is not waived by the ETS, passed before the inclusion in the ETS.

Changes in Abatement Costs

The two figures below provide information on the sensitivity to changing abatement costs by -50% and +100%:

Figure 2.4 Summary of Economic Impacts: Sensitivity on Abatement Costs (- 50%)

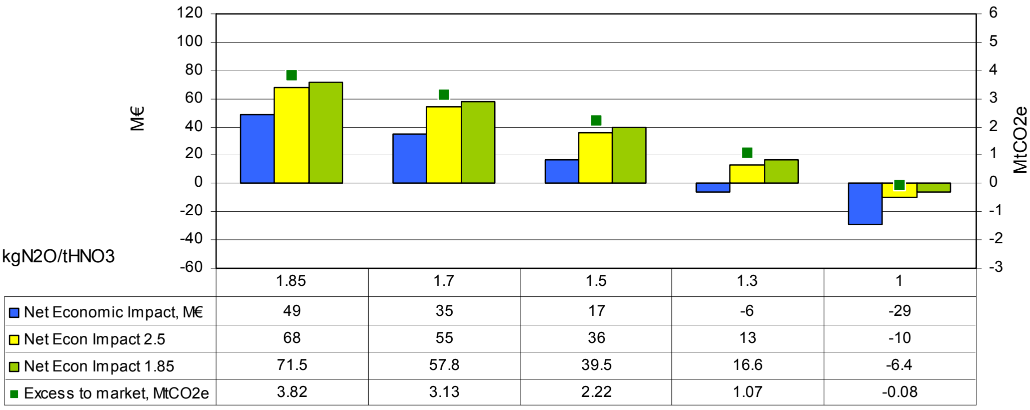


kgN2O/tHNO3	1.85	1.7	1.5	1.3	1
🟦 Net Economic Impact, M€	70	56	37	15	-8
🟨 Net Econ Impact 2.5	74	61	42	19	-4
🟩 Net Econ Impact 1.85	75.2	61.4	43.1	20.2	-2.7
■ Excess to market, MtCO2e	3.82	3.13	2.22	1.07	-0.08

Under this modelling scenario, a neutral economic impact is estimated to be achieved by the following benchmark coefficients:

Incremental cost compared to:	Benchmark coefficient ($kgN_2O/t\ HNO_3$)
- current emissions (2006) & abatement techniques	1.1
- permit ELV of 2.5$kgN_2O/tHNO_3$	1.0
- permit ELV of 1.85$kgN_2O/tHNO_3$	1.0

Figure 2.5 Summary of Economic Impacts: Sensitivity on Abatement Costs (+ 100%)



kgN2O/tHNO3	1.85	1.7	1.5	1.3	1
🟦 Net Economic Impact, M€	49	35	17	-6	-29
🟨 Net Econ Impact 2.5	68	55	36	13	-10
🟩 Net Econ Impact 1.85	71.5	57.8	39.5	16.6	-6.4
■ Excess to market, MtCO2e	3.82	3.13	2.22	1.07	-0.08

Under this modelling scenario, a neutral economic impact is estimated to be achieved by the following benchmark coefficients:

Incremental cost compared to:	Benchmark coefficient ($kgN_2O/t\ HNO_3$)
- current emissions (2006) & abatement techniques	1.3
- permit ELV of 2.5$kgN_2O/tHNO_3$	1.1
- permit ELV of 1.85$kgN_2O/tHNO_3$	1.1

Combined Scenarios

Under the following combined modelling scenarios, a neutral economic impact is estimated to be achieved by the following benchmark coefficients:

Incremental cost compared to:	Benchmark coefficient (kgN_2O/t HNO_3)	
	High Cost (+100%), Low Cprice (€10/tCO2e)	Low Cost (-50%), High Cprice (€30/tCO2e)
	Pessimistic	Optimistic
• current emissions (2006) & abatement techniques	1.6	1.1
• permit ELV of 2.5kgN_2O/tHNO_3	1.2	1.0
• permit ELV of 1.85kgN_2O/tHNO_3	1.1	1.0

Discount Rate

The discount rate used is 4%, in line with typical discount rates used in Commission studies. It is possible that the weighted average cost of capital for the industry would be higher than 4%. Analysis suggests that changing the discount rate does not lead to significant changes in results.

2.6 Evaluation of Potential Benchmark Options

2.6.1 Feasibility

- The proposed benchmark formula is simple and transparent. The only input parameter to be entered is the historic production, eg for the period 2002-2006. Historic production levels at an installation level should be feasible and easy to verify using internal and external documents that each company holds. For installations lacking historic data, an approach based on capacity and utilisation rate could be developed.

2.6.2 Environmental effectiveness

- The benchmark value options considered in this study have aimed at ensuring scarcity of allowances in the EU ETS carbon market or at least minimise the possibility of excess allowances compared to business as usual (BAU) emissions. During the WG3 meeting (held on 24th October 2007) the different Member State representatives agreed that scarcity of allowances should be ensured for Phase II of EU ETS. As such, the benchmark would need to be set at a level more stringent than baseline emissions levels achieved under 'business as usual' policy commitments. For the nitric acid sector, baseline emissions are assumed to equate to those achieved through application of BAT under the IPPC Directive.

- Whilst BAT is assessed at an installation specific level (and therefore has not been possible to determine in detail in this study), BAT-based permit conditions need to have regard for the BREF document and the BAT-AELs (associated emission levels) therein. As such, the BAT-AELs provide an indication of the emissions expectation from this sector under IPPC[23], which for the majority of existing plants is up to 1.85 kgN_2O/t HNO_3. Therefore, in

---

[23] Recent studies for the Commission as part of the Review of IPPC have highlighted inconsistencies in permit setting, although the Commission is seeking to address this through a revision to the Directive

line with the abovementioned point, it would appear that the benchmark value should be below this level.

- Once a Member State has opted-in its nitric acid plants, there will be an incentive for each plant to reduce N_2O emissions until the marginal costs of abatement equal the allowance price, regardless of the benchmark level. Depending on the level of the benchmark emissions factor, as excess allowances reach the market, they would allow other EU ETS sectors to reduce less emissions.

- Incorporation of nitric acid plants into the EU ETS should create a further driver for emissions reductions beyond current expectations eg due to further optimisation of secondary catalysts; investigations into wider application of tertiary catalysts; investigations into alternative abatement techniques; and management of portfolios of installations by increasing utilisation of lower emission installations (where technically possible) and decreasing utilisation of higher emission installations (including bringing forward closures).

2.6.3 Economic impacts

- The impacts on competitiveness from opting into the EU ETS will depend largely on the benchmark value and allowance prices. At lower benchmark values, a larger number of plants would be incurring a net additional cost.

- The general criteria in relation to economic impacts is expressed as ‘what level of benchmark would achieve a balance between costs and benefits for the sector as a whole across the EU?’

- Modelling of abatement techniques, emissions and costs was undertaken for each of the respondents to Entec’s survey of nitric acid plants (61 production lines, about 80% of EU production). In comparison with current emissions and abatement technologies, it was assumed that each operator would consider options to invest in additional abatement technologies and the option to continue business as usual with no (additional) investment in N_2O abatement. The analysis assumes that each operator will select the best financial option among feasible investments in abatement technology and no investment.

- The costs associated with participation in the EU ETS are calculated on basis of three baseline scenarios:

    1. current emissions / abatement technologies;

    2. emissions / abatement technologies corresponding to IPPC permit ELVs of no higher than 2.5 $kgN_2O/t\ HNO_3$ (or actual emission factor if lower);

    3. emissions / abatement technologies corresponding to IPPC permit ELVs of no higher than 1.85 $kgN_2O/t\ HNO_3$ (or actual emission factor if lower).

- The value of 1.85 $kgN_2O/t\ HNO_3$ (the upper end of the BAT range) represents the DG Environment’s view on the expected (least stringent) level of emissions corresponding to "IPPC compliance" and the value of 2.5 $kgN_2O/t\ HNO_3$ is consistent with a number of actual permit conditions. These compare with current average emissions of approximately 4.4 $kgN_2O/t\ HNO_3$ taking account of current abatement techniques, and best technically achievable average emissions of 1.0 $kgN_2O/t\ HNO_3$.

- Under various modelling scenarios (including sensitivity analysis), a neutral economic impact is estimated to be achieved by the following benchmark values:

Incremental cost compared to:	Benchmark value (kgN_2O/t HNO_3)						
	Main scenario	Sensitivity on Allowance Price (€30/TCO_2e)	Sensitivity on Allowance Price (€10/TCO_2e)	Sensitivity on Abatement Costs (-50%)	Sensitivity on Abatement Costs (+ 100%)	Pessimistic: High Cost (+100%), Low Cprice (€10/tCO2e)	Optimistic: Low Cost (-50%), High Cprice (€30/tCO2e)
current emissions (2006) & abatement techniques	1.2	1.1	1.3	1.1	1.3	1.6	1.1
permit ELV of 2.5kgN_2O/tHNO_3	1.1	1.1	1.1	1.0	1.1	1.2	1.0
permit ELV of 1.85kgN_2O/tHNO_3	1.0	1.0	1.1	1.0	1.1	1.1	1.0

- The main scenario indicates that, based on the modelling assumptions, a benchmark value of approximately 1.2 kgN_2O/t HNO_3 would have a neutral economic impact when assigning any further abatement to the ETS. This would reduce to 1.1 and 1.0 when assigning some costs of further abatement to IPPC implementation (with permit ELVs no higher than 2.5 and 1.8 respectively). There would be positive impacts above these values and negative impacts below these values.

- Considering uncertainties in abatement costs, allowance prices and permit conditions, the range of benchmark values having a neutral economic impact is between 1.0 and 1.6 kgN_2O/t HNO_3.

- Further key uncertainties include the applicability of tertiary catalysts (greater applicability than our assumption of just over a third – see Section 2.4.4 - would tend to reduce the above figures and vice versa) and the abatement efficiency of secondary catalysts, both of which would require site specific consideration to reduce uncertainty.

- Our analysis models any additional abatement as being installed from commencement of participation in the ETS, with no time lag. In practice, any delay in fitting additional abatement would lead to additional costs in comparison to those assumed in our modelling.

- It is noted that consideration of the distributional impacts within the sector has been outside the scope of this study. A simple analysis of the base scenario (current emissions baseline), suggests that the proportion of installations that would incur a net cost as a result of being opted into the EU ETS is disproportional to the overall economic impact due to the high gains that can be obtained by the installations with the ability to install tertiary abatement.

- The plants considered in this study are owned by a small number of companies with a range of plant types with different abatement capabilities (the respondents to the Entec survey operate on average approximately 6 plants), and therefore the impacts for each company are likely to be much smaller than the impacts at an individual plant level.

- Clearly the position at a company (or MS) level would follow the position at an EU level if the company's (or MS's) portfolio of plants was representative of the EU average. For companies (or MSs) with a proportionately greater share of plants that fit (or could fit) tertiary catalysts, the threshold benchmark levels at which there would be a positive net economic impact would be lower than the above figures and vice versa.

- It must be remembered that opting into Phase II of EU ETS is voluntary and hence Member States may decide not to opt-in rather than incur a negative net economic impact for the plants in their Member State.

2.6.4 Overall comments

- Decision making on proposed benchmarks is a matter for the Commission, and would depend on the relative importance (weightings) assigned to the different criteria, especially the relation to other legislative instruments, namely the application of the IPPC Directive, and Articles 87 and 88 of the Treaty. Furthermore, the decision is likely to be sensitive to the type of economic criteria that are considered and the level at which the criteria are applied (ie installation, company, Member State, EU sector level).

- Determining the applicability, effectiveness and costs of N_2O abatement technologies is complex and is significantly driven by site specific considerations. As such, more detailed and site specific investigations would be needed to reduce the uncertainty of this analysis. Given the current uncertainties, it is not possible to be precise about what specific benchmark levels would achieve specific economic outcomes.

- The incentive to reduce emissions to the level where marginal costs equal the allowance price should apply to opted-in plants regardless of the benchmark level.

- The clear focus of this study has been on Phase II of the EU ETS, and given the relatively new application of secondary and tertiary abatement, it would not be recommended to apply the findings of this study to benchmarking in Phase III. Further research would be required, taking into account latest available information and experience at the time of decision making for Phase III.

- The benchmark values discussed here refer to existing installations. As new installations would install the best available abatement in any case (presumably combined N_2O and NO_x treatment, i.e. tertiary catalyst), the business as usual (BAU) under IPPC alone would lead to very low emissions. Consequently, the benchmark would be on the lower end of the interval given as BAT-AEL by the BREF (0.12 – 0.6 kg N_2O/t HNO_3). Since no data about such cases is available, this study excluded such cases.

3. Adipic Acid Industry

This section describes some background information regarding production levels and processes, N_2O emissions and abatement techniques for existing adipic acid plants.

It has been agreed with the Commission Services that resource prioritisation within the benchmarking aspects of this project is focussed on the nitric acid industry. As such, the depth of analysis possible for this sector has been limited.

3.1 Use and Production Process

Adipic acid, a white crystalline solid, is used primarily as a component in the production of Nylon 6/6. Adipic acid is also used in the manufacturing of low-temperature synthetic lubricants, coatings, plastics, polyurethane resins, and plasticizers and to give some imitation foods a “tangy” flavour.

Adipic acid is a dicarboxylic acid, manufactured in a two-stage process during which N_2O is generated in the second stage. The equation below describes the 2nd stage where adipic acid is actually produced, with N_2O emissions as a by-product.

Equation for Adipic Acid production process

$$(CH_2)5CO \text{ (Cyclohexanone)} + (CH_2)5CHOH \text{ (Cyclohexanol)} + wHNO3 \rightarrow$$

$$HOOC(CH_2)4COOH \text{ (}\textbf{Adipic Acid}\text{)} + \mathbf{xN_2O} + yH_2O$$

Source: IPCC guidelines for National GHG inventories 2006, Chapter 3: Chemical Industry Emissions

Typical N_2O emissions from an adipic acid production process without any installed abatement technology are on average 270 kg N_2O/tonne of adipic acid, based on discussion with adipic acid manufacturers and literature search.

It should be noted that nitric acid is a key raw material in the oxidation process, and the source of nitrogen for N_2O. Although adipic acid plants may be integrated with nitric acid plants, for the purposes of this evaluation the two processes are considered separately and the emissions referred to here relate only to the production of adipic acid.

3.2 Production Levels and N_2O Emissions

Adipic acid production only takes place at 6 production plants in EU27 in the following Member States: France, Germany, Italy and UK (Yara International, 2007). Table 3.1 summarises adipic acid production and N_2O emissions for year 2005 as presented in the national emission inventories for 2007.

Table 3.1 Adipic acid production and N_2O emissions in EU27 for year 2005

Country	Total AA Production (tonnes)	Emission factor (kg N_2O /ton AA) – Note 2	Total N_2O Emissions (ton)	% of 2005 N_2O emissions
France (Note 1)	-	-	4,902	13%
Germany (Note 1)	-	300	10,568	28%
Italy	75,107	261	19,589	52%
UK (Note 1)	-	-	2,504	7%
Total			**37,563**	

Source: 2007 National Emission Inventories to the UNFCCC http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/3929.php

Note: AA – Adipic acid

Note 1: France, Germany and UK did not provide all data on AA production and emission factors due to confidential reasons.

Note 2: The emission factors presented as sometimes the default values presented in the IPCC guidelines (2006)

As noted above, nitrous oxide is produced in considerable quantities during the reaction to produce adipic acid and is generated as a product of a chemical reaction. (This differs from the situation with nitric acid, where N_2O is produced as a partial oxidation by-product, and the quantity of this by-product can be minimised at source). Therefore, for an EU annual capacity production of approximately 1,058,000 tonnes[24], about 285,600 tonnes of nitrous oxide would be generated from the reaction (at 270 kg/tonne). Existing abatement reduces this to 37,563 tonnes (as reported for 2005 – see Table 3.1), giving an existing overall abatement efficiency of ~ 87% and an emission level of about 36 kgN_2O/ton adipic acid produced.

Other data gathering

Entec has gathered data from 3 adipic acid manufacturers by questionnaire, similar to that developed for the nitric acid producers. However, the limited numbers of adipic acid sites in the EU and the competition within the industry has meant that data on production processes and production rates has been given in confidence and cannot be reproduced here – see also note 1 in Table 3.1 above.

Consultation with adipic acid manufacturers indicates that the total designed plant production capacity within the EU27 is approximately 1,058,000 tonnes per year, but clearly absolute adipic acid production may vary depending on the load factor of the plants.

---

[24] Based on information provided during site visits and personal communication with adipic acid producers. The BREF document on Large Volume Organic Chemicals (Commission, 2003) quotes a production capacity of 920,000 tonnes per year.

Entec has also met representatives of two adipic acid manufacturers and visited one manufacturing site, again to understand more about the technology of manufacture of adipic acid and the abatement of nitrous oxide. Confidentiality agreements require that full details of the discussions at these meetings cannot be made, but the information gathered has been used to inform the broader views expressed herein.

3.3 Abatement Technologies

Nitrous oxide is a stable gas, not readily absorbed or chemically reacted and abatement technologies are based upon its oxidation to NO / NO_2, or destruction to N_2 and O_2. Significant energy has to be imparted to create these reactions, hence the processes are generally high-temperature, but the oxidation of N_2O is also strongly exothermic and so some care has to be taken to control reaction temperatures. The heat output from the exotherm is mainly used to preheat the incoming gas, to get the reaction initiated. Post heat-exchange, the remaining lower-temperature energy has less value.

Table 3.2 lists the different abatement technologies that are used to reduce the N_2O emissions in adipic acid production plants.

Table 3.2 Abatement Technologies for Adipic Acid Production Plants

Abatement technology	N_2O abatement efficiency (uncertainty) [Note 1]	Utilisation factor (uncertainty) [Note 1]
Catalytic Destruction (End of pipe abatement technique))	92.5% (90 – 95%)	89% (80 – 98%)
Thermal Destruction (End of pipe abatement technique)	98.5% (98 – 99%)	97% (95 – 99%)
Recycle to nitric acid	98.5% (98 – 99%)	94% (90 – 98%)
Recycle to feedstock for adipic acid	94% (90 – 98%)	89% (80 – 98%)

Note 1: The uncertainty estimates for the destruction and the utilisation factors are based on expert judgement

Sources

IPCC guidelines for National GHG inventories 2006, Chapter 3: Chemical Industry Emissions

Yara International (2007), Expanding the EU ETS to other sectors and gases after 2012: N_2O from the production of nitric acid and adipic acid (http://ec.europa.eu/environment/climat/emission/pdf/etsworkinggroup/2007_03_08/3d.pdf)

European Commission (2003) BREF on Large Volume Organic Chemicals

These abatement technologies for adipic acid are also presented in the BREF document on Large Volume Organic Chemicals but the BREF does not recommend any Best Available Techniques (BAT) for N_2O emissions from adipic acid plants (it only provides some general information on the techniques, abatement efficiencies and associated costs, see Tables 3.8 and 3.9 in the BREF document).

As noted above, the N_2O content (in mixed stream with NOx) cannot be usefully recovered directly and is generally destroyed at high temperatures, including over a catalyst to promote the reaction. N_2O dissociates into N_2 and O_2 at up to 1100ºC with some possible conversion to NOx. Of the abatement technologies reviewed in more detail as part of this study, some seek to recover a fraction of any NOx content in the waste gases to convert back to nitric acid.

In general, both the 'destruction' technologies and the 'partial recovery' technologies appear to be highly efficient in removing N_2O when operating effectively, some with more than 99% abatement efficiency. However, there are some process-relating constraints which make totally effective abatement operation difficult to achieve – i.e. the availability is less than 100%:

- The abatement plants may be connected to a number of upstream producing plants and process variations can influence the performance of the abatement plant, even in normal operation.
- In some cases of abnormal operation, gases may be directly vented from the producing plants to prevent failure of the abatement plant, which may be designed to operate in largely steady-state conditions.
- The abatement plants operate very high-temperature processes, subject to more frequent and different maintenance regimes to deal with the effects of the process temperature, such as dealing with ceramic linings.

The effect of these situations is to make the abatement plants typically less than 100% available, compared to the operation of the adipic acid plants producing the N_2O. The combination of the abatement efficiency and the plant availability will affect the overall destruction of N_2O from Adipic acid plants.

One significant factor with adipic acid plants is that where the abatement plant is unavailable (e.g. breakdown, maintenance) the emissions rates of N_2O are very high (up to 10 tonnes / hour), but when the abatement plant is operating the emissions are comparatively low (typically much less than 10 tonnes / week). It can therefore be seen that impact of failure of the abatement plant is very high, which will translate into high operating costs and commercial risks under an emissions trading scheme. Capital investment (to have spares available), operational monitoring (to detect possible faults) and maintenance planning (to remedy minor faults) are therefore all key features in minimising emissions and offsetting the risks from abatement plant failure.

This 'highly geared' emissions performance contrasts with the situation in nitric acid production where a more gradual reduction in N_2O abatement efficiency is likely to be noted. Information from adipic acid producers has indicated current emission levels to be in the order of 30 kgN_2O/ton adipic acid produced or lower, depending on the performance and availability of the abatement techniques installed.

4. Caprolactam

This section describes some background information regarding production levels and processes, N_2O emissions and abatement techniques for existing caprolactam plants.

It has been agreed with the Commission Services that resource prioritisation within the benchmarking aspects of this project is focussed on the nitric acid industry. As such, the depth of analysis possible for this sector has been limited.

4.1 Use and Production Process

Similarly to adipic acid, caprolactam is primarily used in the manufacture of synthetic fibres (especially Nylon 6). Additionally caprolactam is used in brush bristles, textile stiffeners, film coatings, synthetic leather, plastics, plasticizers, paint vehicles, cross-linking for polyurethanes, and in the synthesis of lysine.

The typical caprolactam process involves production of cyclohexanone, oximation with hydroxylamine and finally the so-called “Beckmann Rearrangement” (see box below).

Equation for caprolactam production process

Oxidation of NH_3 to NO/NO_2

↓ → ***N_2O emissions from this step***

NH_3 reacted with CO_2/H_2O to yield ammonium carbonate $(NH_4)_2CO_3$

↓ → *C_2O emissions from this step*

$(NH_4)_2CO_3$ reacted with NO/NO_2 (from NH_3 oxidation) to yield ammonium nitrite (NH_4NO_2)

↓

NH_3 reacted with SO_2/H_2O to yield ammonium bisulphite (NH_4HSO_3)

↓ → *SO_2 emissions from this step*

NH_4NO_2 and NH_4HSO_3 reacted to yield hydroxylamine disulphonate ($NOH(SO_3NH_4)_2$)

↓

$NOH(SO_3NH_4)_2$ hydrolised to yield hydroxylamine sulphate ($(NH_2OH)_2.H_2SO_4$) and ammonium sulphate ($(NH_4)_2SO_4$)

↓

Cyclohexanone reaction:

$C_6H_{10}O + \frac{1}{2}(NH_2OH)_2.H_2SO_4$ (+NH_3 and H_2SO_4) → $C_6H_{10}NOH + (NH_4)_2SO_4 + H_2O$

Beckmann rearrangement:

$C_6H_{10}NOH$ (+H_2SO_4 and SO_2) → $C_6H_{11}NO.H_2SO_4$ (+4NH_3 and H_2O) → $C_6H_{11}NO$ (**caprolactam**) + $2(NH_4)_2SO_4$

Source: IPCC guidelines for National GHG inventories 2006, Chapter 3: Chemical Industry Emissions

Typical N_2O emissions from a caprolactam production process without any installed abatement technology are of the order of **9.0 kg N_2O/ton of caprolactam**[25] produced (IPCC Guidelines, 2006).

Consultation with caprolactam manufacturers showed that the particular chemical can also be produced without giving rise to N_2O emissions (this refers to a German caprolactam manufacturer) but this process has not been further investigated within the scope of this project. These alternative production routes should be further investigated in the future, as they give rise to the question of whether a benchmark could be set at zero.

4.2 Production Levels and N_2O Emissions

Table 4.1 summarises the caprolactam production and N_2O emission levels in EU27 for year 2005 (data from 2007 National Emission Inventories). The BREF document on Large Volume Organic Chemicals (LVOC) (EU Commission, 2003) quotes a European production capacity of 1,095,000 tonnes per year.

Table 4.1 Caprolactam Production and N_2O Emissions in EU27 for Year 2005

Country	Caprolactam Production (tonnes)	Emission factor (kg N_2O /ton caprolactam)	Total N_2O Emissions (tonnes)	% of 2005 N_2O emissions
Belgium - Flanders	180,202	6.02	1,108	21%
Czech Republic (Note 1)	-	-	270	5%
Germany	264,000	3.63	959	18%
Netherlands (Note 1)	-	-	2,275	42%
Poland	159,480	4.74	760	14%
Total	**-**		**5,372**	

Source: 2007 National Emission Inventories to the UNFCCC
http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/3929.php

Note 1: Czech Republic and Netherlands did not report production levels and emission factors – the total values only consider what has been submitted in the national emission inventories

Other data gathering

Entec has been in contact with various caprolactam manufacturers within EU27 in order to introduce the study and to gather information regarding their production plants with regards to

---

[25] This is a default emission factor based on high pressure plants for nitric acid production, as both caprolactam and nitric acid processes involve an initial step of NH_3 oxidation which is the source of N_2O formation and emissions.

production processes, N_2O emissions and abatement techniques. However, only one manufacturer has provided Entec with some limited information regarding their production plants. Due to confidentiality reasons, only general data can be presented here.

The caprolactam manufacturer mentioned that there are several emission points in the production plant including the ammonia combustion units and during preparation and decomposition of hydroxylamine.

4.3 Abatement Technologies

The recent European Climate Change Programme (ECCP) review meeting on Non-CO_2 gases[26] (May 2006) concluded that "…*No economic feasible reduction measures have been confirmed for N_2O emissions from caprolactam manufacturing so far, but research is ongoing*". Furthermore the BREF LVOC document (European Commission, 2003) refers to N_2O emissions from caprolactam production facilities but does not present any abatement techniques for N_2O emissions.

The Netherlands caprolactam industry is also involved in developing abatement technologies for N_2O emissions. In a recent presentation "N_2O emissions from Dutch Caprolactam industry" (Ruiter *et al*, 2006) it was also highlighted that reduction measures are not currently available; research in 2005 involving adaptation of the process and thermal decomposition had a reduction potential of 0.2 mton CO_2 equivalent but implementation is unsure and further research was recommended. Ruiter *et al* (2006) also suggested catalytic decomposition of N_2O (this measure is widely used in the nitric acid industry) as a future reduction measure for the caprolactam industry but further research/development is necessary due to the process differences (e.g. temperature, pressure) that exist between the caprolactam and nitric acid industries.

Information from the caprolactam manufacturer indicated that abatement techniques for the different emission points are still under research and development. Although a part of the production unit involves combustion of ammonia (similarly to nitric acid plants), technical issues would make it very difficult to apply similar abatement systems as in a nitric acid plant. Further research is needed before a feasible abatement technique can be applied.

---

[26] http://ec.europa.eu/environment/climat/pdf/eccp/review_gases.pdf (Last accessed on 21st November 2007)

5. Glyoxal and Glyoxylic Acid Industry

This section describes some background information regarding production levels and processes, N_2O emissions and abatement techniques for existing glyoxal and glyoxylic acid plants.

It has been agreed with the Commission Services that resource prioritisation within the benchmarking aspects of this project is focussed on the nitric acid industry. As such, the depth of analysis possible for this sector has been limited.

5.1 Use and production process

Glyoxal is used as a chemical intermediate in the production of pharmaceuticals and dyestuffs, as a cross-linking agent in the production of a range of different polymers, as a biocide, and as a disinfecting agent (IPCC guidelines, 2006). Similarly glyoxylic acid is used for the production of synthetic aromas, agrochemicals and pharmaceutical intermediates.

Glyoxal
Glyoxal is produced from acetaldehyde as shown below in continuous reactions.

Equation for glyoxal production process

$$2C_2H_4O \text{ (Acetaldehyde)} + 2HNO_3 \rightarrow 2C_2H_2O_2 \text{ (}\mathbf{Glyoxal}\text{)} + 3\ \mathbf{N_2O} + H_2O$$

Source: IPCC guidelines for National GHG inventories 2006, Chapter 3: Chemical Industry Emissions

The stoichiometric relationship indicates that complete reaction will result in 543 kg N_2O/tonne glyoxal produced. Under commercial conditions, the yield is approximately **520 kg N_2O/tonne glyoxal** produced (IPCC guidelines, 2006).

It is also understood that glyoxal can be produced from ethylene oxide, in a process that generates no N_2O emissions, but this process has not been further investigated within the scope of this project. This process is also briefly mentioned in the BREF LVOC (2003).

Glyoxylic acid
Glyoxylic acid is obtained on an industrial scale by means of the oxidation of glyoxal ($C_2H_2O_2$) with strong acids such as nitric acid (HNO_3) (IPCC guidelines, 2006) or by ozonolysis (oxidaton) of maleic acid. The second production process i.e. ozonolysis of maleic acid, replaces the use of nitric acid (and hence there are no related N_2O emissions) with ozone; the disadvantage is that it requires a high amount of electric energy for its production (BREF LVOC, 2003).

Glyoxylic acid production is a batch process where nitric acid is reduced to NO and N_2O with NO recovered as HNO_3 in the process. N_2O arises in the production process through a secondary reaction where glyoxal is converted to oxalic acid $(COOH)_2$ (IPCC guidelines, 2006).

Equation for oxalic acid production

$$2C_2H_2O_2\ (\textbf{Glyoxal}) + 2HNO_3 \rightarrow 2\ (COOH)_2 + \mathbf{N_2O} + H_2O$$

Typical N_2O emissions from a glyoxylic acid production plant without any installed abatement technology are of the order of **200 kg N_2O/ton of glyoxylic acid** produced (as 100%) – this is normally expressed as **100 kg N_2O/ton of glyoxylic acid** (IPCC Guidelines, 2006), as the material is produced and sold as a 50% solution.

5.2 Production Levels and N_2O Emissions

Table 5.1 summarises the glyoxylic acid production and N_2O emission levels in EU27 for year 2005 (data from 2007 National Emission Inventories). In Europe there is only one manufacturer of glyoxal and glyoxylic acid where the production process gives rise to N_2O emissions (Clariant, at Lamotte in France).

Table 5.1 Glyoxylic acid production and N_2O emissions for EU27 for year 2005

Country	Glyoxylic Production (tonnes)	Emission factor (kg N_2O /ton glyoxylic acid	2005 N_2O Emissions (tonnes)
France (Note 1)	-	-	1,123

Source: 2007 National Emission Inventories to the UNFCCC http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/3929.php

Note 1: France only reported N_2O emissions in the 2007 emission inventory

The current and historical production rates of Glyoxal and Glyoxylic acid are regarded as commercially confidential as are the precise details of the manufacturing and abatement processes. The following summarises the general aspects of the abatement plant.

5.3 Abatement technologies

Discussions have been held at a site meeting with Clariant, the manufacturers of Glyoxal and Glyoxylic acid in France.

As noted above in the section on Adipic acid (see section 3.3), nitrous oxide is a very stable gas which cannot be readily absorbed and requires high temperatures to decompose. The system used at Clariant is a thermal treatment, promoted by a specific catalyst, the process developed initially in 1997-2001.

The two production processes (glyoxal and glyoxylic acid) generate chemical off-gas in varying quantities – the glyoxal plant producing continuous emissions, whilst the glyoxylic acid plant emissions are from batch reactions and therefore more periodic. Typical emissions concentrations from glyoxal are >90% N_2O whilst the glyoxylic emissions to be treated are around 12% N_2O. The abatement system initially scrubs out gases which could damage the catalyst, mixes and dilutes the gas with air to a controlled concentration, then passes the heated gases, at 400ºC into a destruction plant. The catalytic reaction is exothermic and the hot waste gases are used to preheat the incoming gases. N_2O concentrations are measured before and after the abatement plant and again in the emissions stack.

Performance of the catalyst system is >95% efficient when the catalyst is fresh, but this reduces over time to around 80% abatement efficiency after 1 year. The current IPPC permit performance target is 88% reduction. Availability and reliability of the abatement plant is good, requiring few occasions when N_2O has to be vented for process reasons – only at plant start-up does this occur.

As the sole manufacturer of Glyoxal and Glyoxylic acid with emissions of N_2O in the EU, the technology used on site can be regarded as the only abatement technology which is ‘commercially available’ and the current specific emissions levels could be considered ‘BAT’. However, as plants exist which produce these substances without N_2O emissions, such alternative production routes should be further investigated in the future, as they give rise to the question of whether a benchmark could be set at zero.

Appendix A
References

1 Page

EEA (2007) “Annual European Community greenhouse gas inventory 1990–2005 and inventory report 2007. Submission to the UNFCCC Secretariat”. *Version 27 May 2007*

European Commission (2003) “Reference document on BAT in the Large Volume Organic Chemical Industry”.

European Commission (2006) “Reference document on BAT for the manufacture of Large Volume Inorganic Chemicals – Ammonia, Acids and Fertilisers”.

IEEP (2006) “CAN Europe - The potential for and implications of extending the EU emissions trading system to include industrial sources of nitrous oxide and fluorinated gases”

IPCC guidelines for National GHG inventories 2006, Chapter 3: Chemical Industry Emissions

Le Gaz Intégral. Rejets d’oxydes d’azote (NO et NO2) et de N_2O des ateliers d’acide nitrique: Synthèse d’une étude technico-économique de faisabilité concernant les possibilités de réduction des émissions sur les installations françaises. Confidential Report to UNIFA (Union of Fertiliser Industries), MEDD (Ministry for Environment and Sustainable Development, France), and ADEME (French Environment Agency).

Ruiter *et al*, (2006) “N_2O emissions from Dutch Caprolactam industry”

Yara International (2007) “N2O from the production of nitric acid and adipic acid" presentation, 1st meeting of the ECCP Working Group on the EU ETS review, Brussels (http://ec.europa.eu/environment/climat/emission/pdf/etsworkinggroup/2007_03_08/3d.pdf)

Lenoir *et al* (2006) “YARA De-N_2O Secondary abatement from Nitric Acid Production, A Proven Technology; Nitrogen 2006”, Vienna 12-15, March 2006, page18 (

Kuhn *et al* (2001) “Experiments on N_2O destruction in ammonia burners. Session 4 Control of N_2O emissions from nitric acid plants”. BASF

(http://www.infomil.nl/legsys/noxconf/uk/pdf/n2o/kuhn.pdf)

Final Report
A2

February 2008

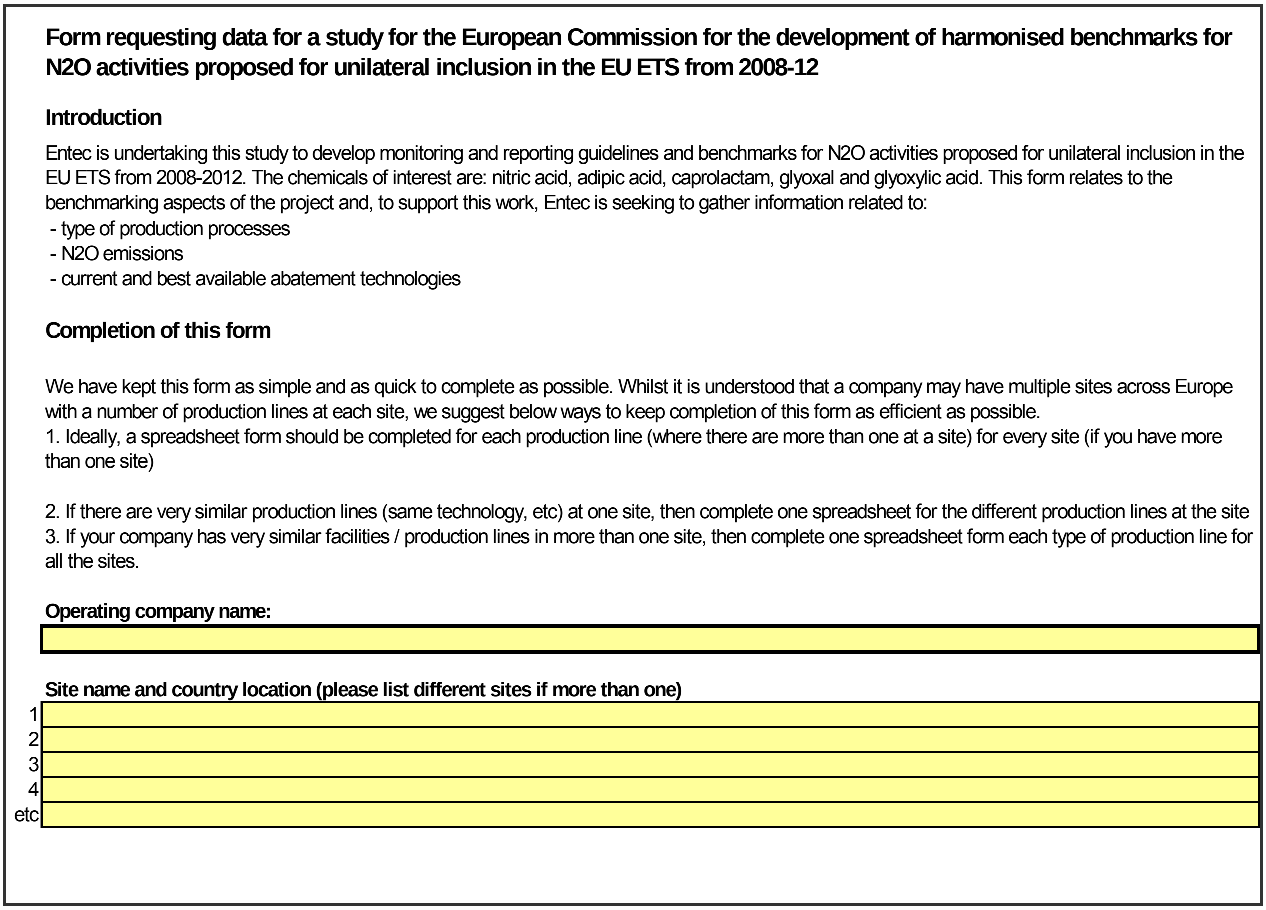
Entec

Appendix B
EU Survey Questionnaire for Nitric Acid Operators

2 Pages

February 2008

Page 1 of Questionnaire



Form requesting data for a study for the European Commission for the development of harmonised benchmarks for N2O activities proposed for unilateral inclusion in the EU ETS from 2008-12

Introduction

Entec is undertaking this study to develop monitoring and reporting guidelines and benchmarks for N2O activities proposed for unilateral inclusion in the EU ETS from 2008-2012. The chemicals of interest are: nitric acid, adipic acid, caprolactam, glyoxal and glyoxylic acid. This form relates to the benchmarking aspects of the project and, to support this work, Entec is seeking to gather information related to:

- type of production processes
- N2O emissions
- current and best available abatement technologies

Completion of this form

We have kept this form as simple and as quick to complete as possible. Whilst it is understood that a company may have multiple sites across Europe with a number of production lines at each site, we suggest below ways to keep completion of this form as efficient as possible.

1. Ideally, a spreadsheet form should be completed for each production line (where there are more than one at a site) for every site (if you have more than one site)

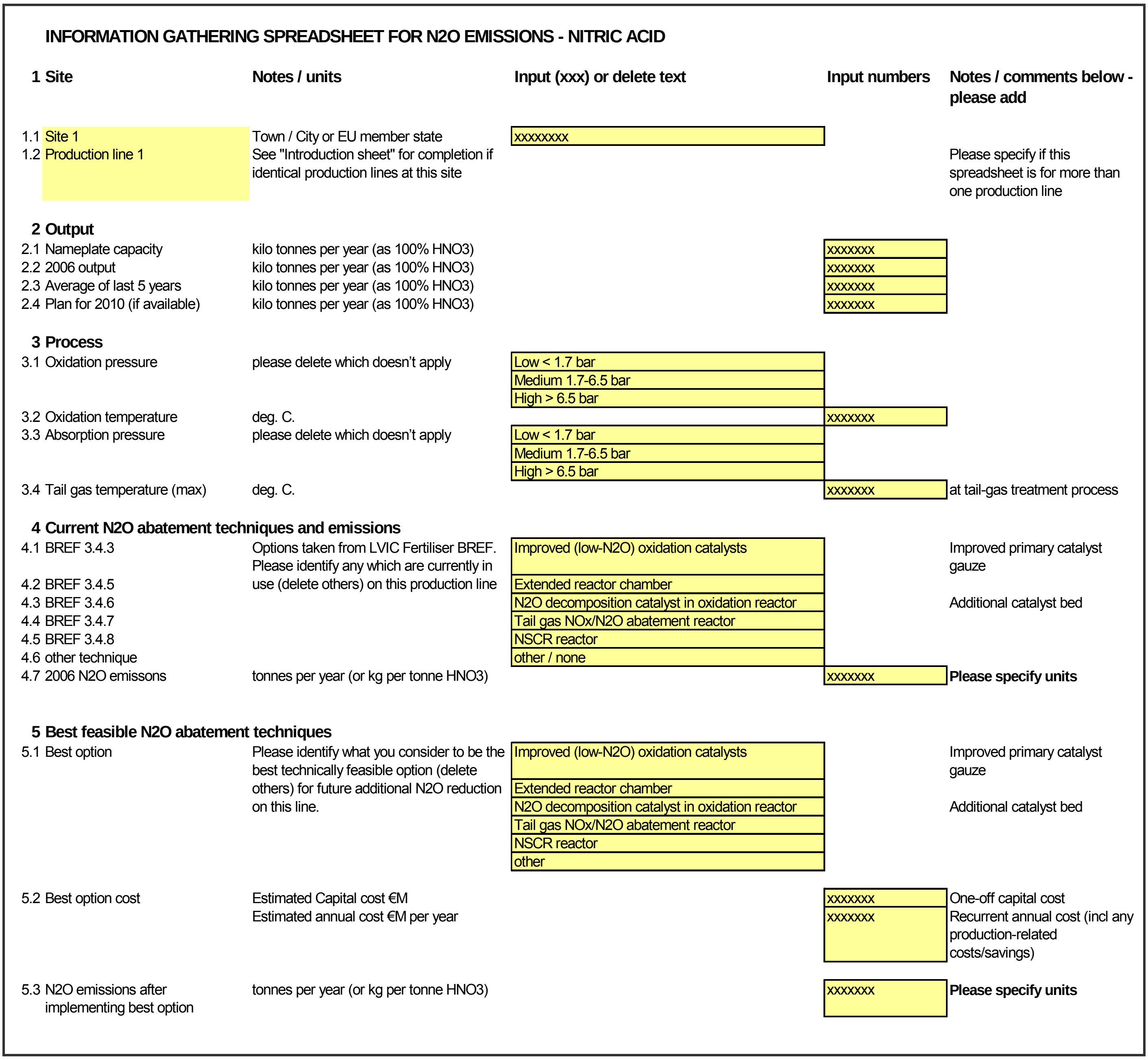
2. If there are very similar production lines (same technology, etc) at one site, then complete one spreadsheet for the different production lines at the site
3. If your company has very similar facilities / production lines in more than one site, then complete one spreadsheet form each type of production line for all the sites.

Operating company name:

Site name and country location (please list different sites if more than one)

1
2
3
4
etc

Page 2 of Questionnaire



INFORMATION GATHERING SPREADSHEET FOR N2O EMISSIONS - NITRIC ACID

1 Site	**Notes / units**	**Input (xxx) or delete text**	**Input numbers**	**Notes / comments below - please add**
1.1 Site 1	Town / City or EU member state	xxxxxxxx		
1.2 Production line 1	See "Introduction sheet" for completion if identical production lines at this site			Please specify if this spreadsheet is for more than one production line
2 Output				
2.1 Nameplate capacity	kilo tonnes per year (as 100% HNO3)		xxxxxxx	
2.2 2006 output	kilo tonnes per year (as 100% HNO3)		xxxxxxx	
2.3 Average of last 5 years	kilo tonnes per year (as 100% HNO3)		xxxxxxx	
2.4 Plan for 2010 (if available)	kilo tonnes per year (as 100% HNO3)		xxxxxxx	
3 Process				
3.1 Oxidation pressure	please delete which doesn't apply	Low < 1.7 bar		
		Medium 1.7-6.5 bar		
		High > 6.5 bar		
3.2 Oxidation temperature	deg. C.		xxxxxxx	
3.3 Absorption pressure	please delete which doesn't apply	Low < 1.7 bar		
		Medium 1.7-6.5 bar		
		High > 6.5 bar		
3.4 Tail gas temperature (max)	deg. C.		xxxxxxx	at tail-gas treatment process
4 Current N2O abatement techniques and emissions				
4.1 BREF 3.4.3	Options taken from LVIC Fertiliser BREF. Please identify any which are currently in use (delete others) on this production line	Improved (low-N2O) oxidation catalysts		Improved primary catalyst gauze
4.2 BREF 3.4.5		Extended reactor chamber		
4.3 BREF 3.4.6		N2O decomposition catalyst in oxidation reactor		Additional catalyst bed
4.4 BREF 3.4.7		Tail gas NOx/N2O abatement reactor		
4.5 BREF 3.4.8		NSCR reactor		
4.6 other technique		other / none		
4.7 2006 N2O emissons	tonnes per year (or kg per tonne HNO3)		xxxxxxx	**Please specify units**
5 Best feasible N2O abatement techniques				
5.1 Best option	Please identify what you consider to be the best technically feasible option (delete others) for future additional N2O reduction on this line.	Improved (low-N2O) oxidation catalysts		Improved primary catalyst gauze
		Extended reactor chamber		
		N2O decomposition catalyst in oxidation reactor		Additional catalyst bed
		Tail gas NOx/N2O abatement reactor		
		NSCR reactor		
		other		
5.2 Best option cost	Estimated Capital cost €M		xxxxxxx	One-off capital cost
	Estimated annual cost €M per year		xxxxxxx	Recurrent annual cost (incl any production-related costs/savings)
5.3 N2O emissions after implementing best option	tonnes per year (or kg per tonne HNO3)		xxxxxxx	**Please specify units**