

Final Report

Controlling Ammonia from Non-Agricultural Sources

A report produced for DETR



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Executive Summary

1. AEA Technology were contracted by DETR to assess the abatement of non-agricultural sources of ammonia in January 2001. The study was undertaken to improve guidance available to the UK government on meeting emission ceilings for ammonia agreed under the UNECE's Gothenburg Protocol and the EU's National Emission Ceilings Directive (NECD), which currently stands at Common Position. Specifically, the study has:
 - ◆ Improved the non-agricultural emission inventory for ammonia in 2010 and beyond, identifying and estimating likely trends in emissions, and correcting projections using some updated emissions information;
 - ◆ Identified options and costs for abatement of emissions;
 - ◆ Integrated these data into a cost-curve for non-agricultural ammonia, taking specific account of uncertainty in emission and costs;
 - ◆ Assessed the completeness of ammonia inventory data for other European countries.

2. The sectors investigated here are:
 - ◆ Transport
 - ◆ Combustion (industrial and domestic)
 - ◆ Waste (landfill, incineration, sewage treatment and disposal, home composting, centralised composting facilities)
 - ◆ Chemicals (manufacture of fertilisers, explosives, petrochemicals, pharmaceuticals, chromium compounds, sodium ferrocyanide)
 - ◆ Other industry (sugar beet, cement, cokeries, steel production, mineral fibres)
 - ◆ Household products
 - ◆ Horses

3. It is assumed that there are no reasonable options for controlling ammonia emissions from the following sources (referred to subsequently as 'natural' sources, for want of a better phrase):
 - ◆ Wildlife
 - ◆ Pets
 - ◆ Biomass burning
 - ◆ Human sweat and breath
 - ◆ Cigarette smoking (on the grounds that emission ceilings are an inappropriate tool for controlling smoking behaviour, and that other tools are already widely applied)
 - ◆ Nappies (after use but before cleaning or final disposal).

Whilst these emission sources are clearly relevant to the analysis of ecological and other impacts, they are not included in the emission inventory for the purpose of comparison against the ceilings set under the Gothenburg Protocol or NECD.

4. The study has refined estimates of non-agricultural emissions of ammonia from the UK over the next 30 years. Significant improvements have been made to the inventory with respect to traffic and industrial sources. The best estimate of the non-agricultural emissions for 2010 is 51 ktonnes/year (excluding 'natural sources' reduces this to 37 kt/year). Adding together the low or high estimates for each sector provides a range of 19 to 138 ktonnes/year.

However, this approach exaggerates the limits. Although it is possible that all lower bounds or all upper bounds would apply, it is very unlikely. Further analysis, using the @RISK software package to take account of the likely probability distribution across the range for each sector, reduces the overall range considerably, to between 50 and 77 kt/year. Clarification of transport emission factors would allow significant refinement of this range.

5. It is anticipated that emissions will fall in several sectors as a result of existing actions, for example regarding the Landfill Directive, the implementation of IPPC and most especially through improvements to vehicle technologies. The development of techniques for more effective engine controls since the EURO-I standards were introduced is considered here to cause a substantial fall in traffic emissions. Regulations that are not yet in place, but which are expected (for example, limits on PAH and further controls on particulate emissions) may also yield benefits in terms of reduced ammonia emissions. However, these cannot be estimated with any certainty ahead of legislation.
6. Estimated trends in UK emissions of non-agricultural sources of ammonia from 2000 to 2030 are shown in Figure 1. Policy measures currently in the pipeline are forecast to reduce emissions by 12 kt/year over the next 10 years, largely through the development of improved vehicle technologies, and by an additional 4 kt/year over the following 20 years.
7. A more detailed breakdown of emissions of ammonia from non-agricultural sources for 2010, the year for compliance with the Gothenburg Protocol and NECD, is provided in Table 1.

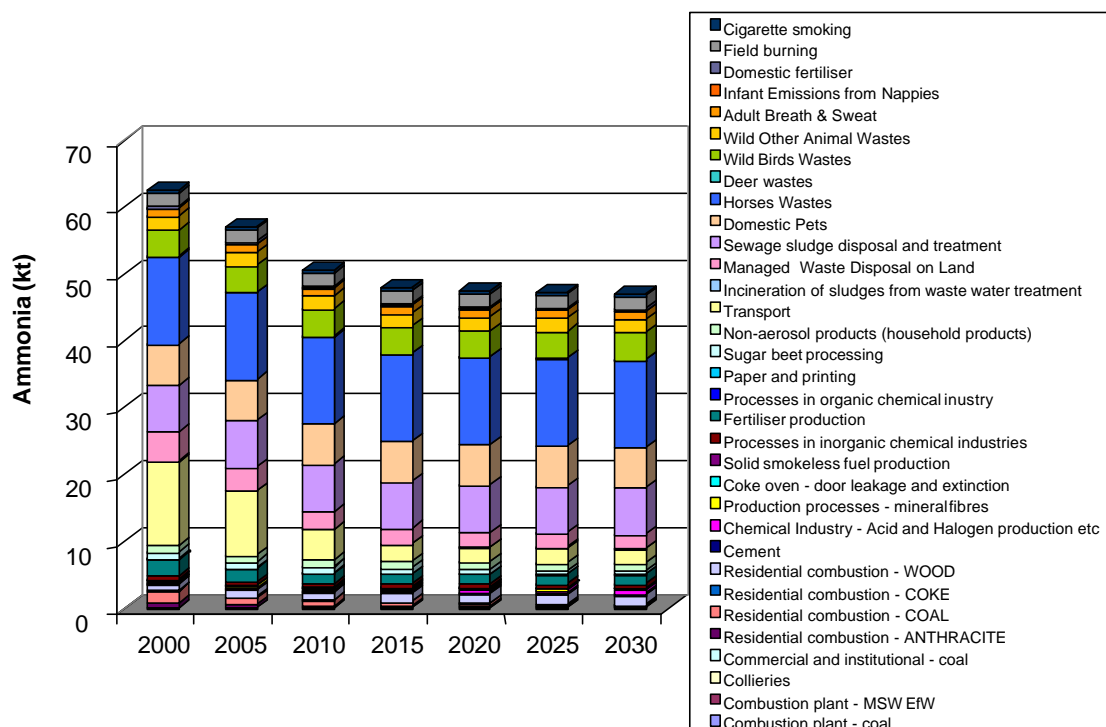


Figure 1. Trends in non-agricultural ammonia emissions in the UK, 2000 to 2030.

Table 1. Non-agricultural ammonia emissions in 2010, with ranges for each sector.

Source	lower bound, kt	best estimate, kt	upper bound, kt
Horses Wastes	6.13	13.00	23.19
Sewage sludge disposal and treatment	2.48	7.00	16.73
Transport	1.51	4.53	31.31
Managed Waste Disposal on Land	0.67	2.67	10.66
Biomass burning	0.24	1.94	8.01
Fertiliser production	0.77	1.53	2.30
Residential combustion - WOOD	0.56	1.12	2.25
Non-aerosol products (household products)	0.36	1.10	5.02
Sugar beet processing	0.78	0.90	1.46
Residential combustion - COAL	0.38	0.76	1.52
Processes in inorganic chemical industries	0.38	0.50	0.63
Residential combustion - ANTHRACITE	0.18	0.37	0.73
Production processes - mineral fibres	0.23	0.30	0.38
Domestic fertiliser	0.12	0.28	0.61
Cement	0.15	0.20	0.25
Chemical Industry - Acid and Halogen production	0.15	0.20	0.25
Coke oven - door leakage and extinction	0.08	0.10	0.13
Incineration of sludge from waste water treatment	0.03	0.07	0.26
Combustion plant – MSW incineration	0.02	0.06	0.20
Residential combustion - COKE	0.02	0.05	0.09
Solid smokeless fuel production	0.02	0.03	0.04
Processes in organic chemical industry	0.02	0.03	0.04
Paper and printing	0.00	0.01	0.01
Combustion plant - coal	0.00	0.00	0.01
Collieries	0.00	0.00	0.00
Commercial and institutional - coal	0.00	0.00	0.00
Total relevant to the Protocol/Directive (kt)		36.7	
Domestic Pets	2.61	6.10	10.00
Wild Birds Wastes	1.49	4.00	8.51
Wild Other Animal Wastes	0.28	2.00	3.10
Adult Breath & Sweat	0.22	1.20	6.00
Cigarette smoking	0.15	0.40	0.62
Deer wastes	0.01	0.05	0.09
Infant Emissions from Nappies	0.01	0.04	0.15
Total: 'Natural sources' (kt)		13.8	
Total: All non-agricultural sources (kt)		50.5	

8. A variety of abatement options have been identified for reducing emissions. In several sectors the preferred method of abatement will be the use of wet scrubbers of various types. Elsewhere, the appropriate abatement options tend to be much more specific to individual sectors, for example, the control of the carbon to nitrogen ratios in composting, or introduction of scrappage subsidies for cars with first generation catalysts.
9. The following cost curve has been produced. It demonstrates the maximum feasible reduction from non-agricultural sources as well as the costs of various levels of abatement.

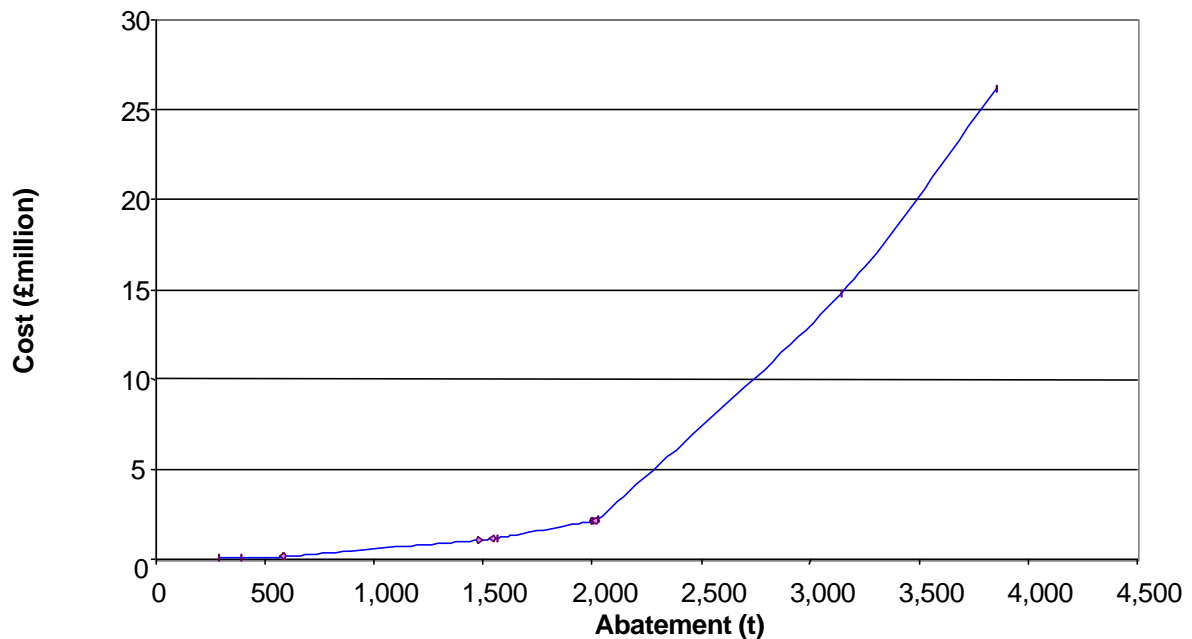


Figure 2. Cost curve for abatement of non-agricultural sources of ammonia in 2010.

10. According to Figure 1, the maximum feasible reduction (MFR) from non-agricultural sources is 3.8kt in 2010, based on what the study team consider to be the likely level of penetration of abatement techniques by 2010). The MFR is 8% of the predicted 51 kt total for that year. The most cost effective abatement measures are the use of dilute acid packed tile scrubbers to plants in the inorganic chemical and mineral fibre process industries with costs of abatement of between £118/t and £361/t.
11. Non-agricultural ammonia emissions in 2010 have been estimated for the other current Member States of the European Union. This provides a total emission of 688 kt/y (561 kt/year excluding 'natural sources') for this group of countries in 2010. This is considerably greater than IIASA's non-agricultural ammonia projection of 168kt/y. The difference is accounted for by the inventory developed here being more comprehensive, incorporating sectors such as horses and residential wood combustion for which emissions are very high.

Table 2. Comparison of total EU-15 ammonia emissions between the estimates made in this report and IIASA's estimates, and the ceilings given in the Gothenburg Protocol and the NECD.

	This report (kt/year)	IIASA inventory (kt/year)
Non-agricultural emissions (excluding 'natural' sources)	561	168
Total emissions (excluding 'natural' sources)	3,609	3,216
Total of Gothenburg Protocol ceilings for the EU-15	3,128	
Total of NECD ceilings Common Position, June 2000	3,110	

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1. Introduction

1.1 DRIVERS FOR ACTION ON NON-AGRICULTURAL SOURCES OF AMMONIA

The Gothenburg Protocol and National Emission Ceilings Directive contain emission ceilings for SO₂, NO_x, VOCs and ammonia. Past analyses for DETR carried out with respect to the ceiling for ammonia have largely concentrated on the assessment of emissions and abatement options for agricultural sources. However, emissions from non-agricultural sources constitute approximately 20% of the total, and so are clearly significant. A major driver for DETR commissioning this study was the need to understand likely trends in future emissions and possibilities for abatement from the large number of diverse non-agricultural sources of ammonia.

There appears to be some inconsistency between countries in the methods used to calculate non-agricultural emissions. Initial inspection of data used in the RAINS analysis for UNECE and the European Commission suggests that the UK has one of the most complete ammonia inventories of any European country. This study applies information from the UK emission sources and future trends, to calculation of non-agricultural emissions for the EU-15. It is intended that this study, should illustrate the possible under-estimation of ammonia in some inventories, and initiate wider discussion on methodologies for estimation of non-agricultural emissions.

1.2 OBJECTIVES OF THIS STUDY

AEA Technology Environment has undertaken this study for DETR to investigate the abatement of non-agricultural sources of ammonia in terms of the cost, uptake and efficiency of possible abatement measures. Previous work at Imperial College has characterised ammonia abatement costs for the agricultural sector (which dominates the ammonia inventory), leading to the development of the MARACCAS model. Less attention has been paid to non-agricultural sources. It is now necessary to develop a more complete view on potential abatement, in order that costs are not applied disproportionately to any one sector.

The specific objectives of this study are to:

- Identify the non-agricultural sources of ammonia, using the most up-to-date information available, considering both the location and type of sources.
- Provide an estimate of the likely changes in emissions over the next 30 years, accounting for technological advances and future trends in industries such as incineration, sewage treatment and transport.
- Assess possible methods of abatement for each source and their efficiencies in order to estimate the magnitude of abatement for each source. The cost of abatement in £/tonne is calculated where possible, with clearly stated assumptions on cost and efficiency.
- Develop a cost-curve specifically for non-agricultural ammonia abatement in the UK.
- Consider the extent to which existing ammonia inventories are adequate in describing the problem in other European countries.

1.3 INITIAL SCOPING OF THE STUDY

Non-agricultural ammonia emissions come from a diverse range of sources. This study focuses on sectors with significant emission levels, that could potentially be abated in the future. This immediately rules out emissions from some of the non-agricultural sectors listed in the inventory:

- Wild animals and ecosystems.
- Direct human emissions (from sweat and breath, and smoking).
- Pets (cats, dogs and other small animals)
- Biomass burning (heather management, etc.)

These sources are excluded from the inventory against which compliance with the Protocol and NECD will be assessed (see Article 2 of the legislation).

No sector was omitted from the outset on the grounds of having ‘insignificant’ emissions. Although such sectors will contribute little to abatement, it is possible that they may offer abatement options that are sufficiently cost-effective to be of interest.

1.4 METHODS

Data collection for this study has been based on consultation with industry, regulators, and other experts. This has provided views on the precise source of emissions, potential and preferred abatement options, and trends in the industries affected. Some disparity between the position of industry and regulators is, not surprisingly, noted.

Cost-effectiveness is described for each option using the function:

$$\text{cost}(\pounds) / \text{tonne}[NH_3]_{\text{abated}} = \frac{(\text{cost} / \text{plant}) \times \text{number of plant}}{(\text{unabated emission}) \times \text{effectiveness}}$$

The analysis of the costs of abatement follows the UK Government methodology as defined in the Treasury’s Green Book. Key issues that have been taken into account (where possible) when collecting and evaluating cost data include:

- Identification of what is included in the cost of each measure
 - capital: purchase cost depreciation, installation
 - operating: maintenance, energy, labour, insurance etc.
- Base year for costs and currency
- The potential for measures primarily aimed at other pollutants for removing ammonia
- The cost of retrofitting versus the building of a new plant
- How costs vary with location
- Whether published costs have been normalised/annualised and how

Uncertainty in emission data for present and future emissions is a major consideration throughout the analysis of potential ammonia abatement. In this study, the magnitude of the uncertainty has been included in every stage, indicating the best and worst case scenarios possible and allowing a best estimate to be given for each sector’s emissions. Uncertainties are

characterised partly from estimates of statistical error made in (e.g.) emission factors, and partly from the views of sector experts. It is clear that reported error is an insufficient basis for looking at the uncertainties present in this analysis when considering the relevance of some emissions data to current and future emissions. Take, for example, the case of the transport sector, where the emission factors used previously reflect older technologies which are being phased out, over drive cycles that are not routinely integrated in emissions modelling. The @RISK software package has been used to bring uncertainties together in a way that reflects overall uncertainty, in a suitably transparent and intelligible manner.

1.5 STRUCTURE OF THE REPORT

Chapter 2 of the report quantifies non-agricultural emissions of ammonia for the period 1990 to 1999, and projects forward to 2030, based on knowledge of drivers and emerging regulation in the sectors of interest. Chapter 2 also details the source of ammonia emissions, in the context of the likely sector trends.

Generic abatement technology and sector specific abatement methods are discussed in Chapter 3. The assessment of marginal costs of abatement then leads to the development of the cost curve, also in this chapter. There is a specific consideration of the uncertainties in the abatement costs analysis, using @RISK to identify the parameters that cause the greatest uncertainty.

Chapter 4 provides a view on likely emissions in other European countries, and considers the extent to which available inventories for these countries appear to be complete. The report ends with the conclusions in Chapter 5, references cited in Chapter 6 and a series of appendices providing underlying data and summary detail for the study.

2. Emission Trends

2.1 METHODS

2.1.1 Baseline inventory

The baseline inventory for non-agricultural ammonia is derived using the latest (1999) data from the National Atmospheric Emissions Inventory (NAEI), and the recent paper by Sutton (1999 and 2000). Further details to those presented in this chapter are given in Appendix 5.

Improvements made by both sources have greatly improved the quality of the non-agricultural ammonia inventory. The inventory adopted here covers the following sources:

- Traffic
 - Petrol engined vehicles
 - Diesel vehicles
- Combustion
 - Industrial combustion
 - Residential combustion
- Waste
 - Sewage sludge treatment and disposal
 - Sewage sludge incineration
 - MSW (Municipal solid waste) incineration
 - Landfill
- Industry
 - Sugar beet processing
 - Acid and halogen production
 - Organic and inorganic chemical industry processes
 - Fertiliser manufacture
 - Coke production
 - Mineral fibre production
 - Paper and printing
 - Cement production
- Household products
 - Non-agricultural fertiliser use
 - Solvent use
- Horses
- Other non-agricultural animal and direct human emissions

A number of other sources for which reliable emissions data are currently unavailable have been identified in the course of this work:

- Maggot farms
- Fish processing
- Ceramics industry

Discrepancies between the NAEI and Sutton inventories have been investigated and a position taken in each case as to which is most likely to provide the best estimate of emissions (see Appendix 5). Recognising the uncertainty that currently exists with respect to the inventory,

upper and lower bounds have been estimated taking into consideration the confidence limits around emission estimates, and uncertainty regarding the number of plant.

2.1.2 Trend prediction

The future of non-agricultural ammonia emissions in the UK is predicted for the next 30 years, in five yearly increments, for sectors with significant ammonia emissions. Projections are based on forecasts of activity trends, economic drivers and environmental regulation over the next 30 years. Where specific projections are not available for this period the study team has made a best estimate of the likely trend.

2.2 PAST TRENDS IN EMISSIONS

Non-agricultural ammonia emissions for the UK from 1990 to 1999 are shown in Figure 1, Figure 2 and Table 1.

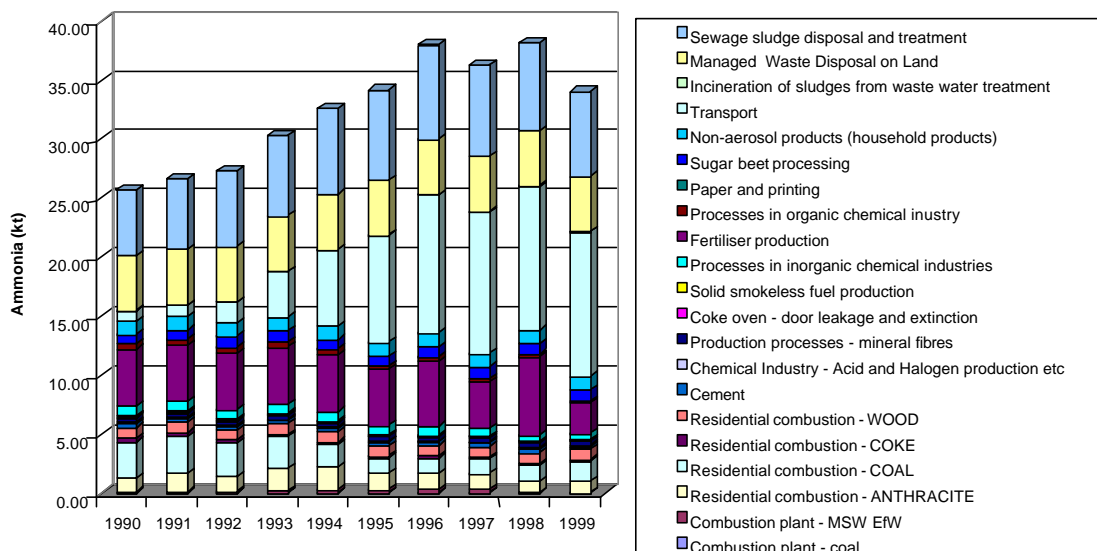


Figure 1. Industrial, domestic and transport emissions of ammonia in the UK, 1990 to 1999.

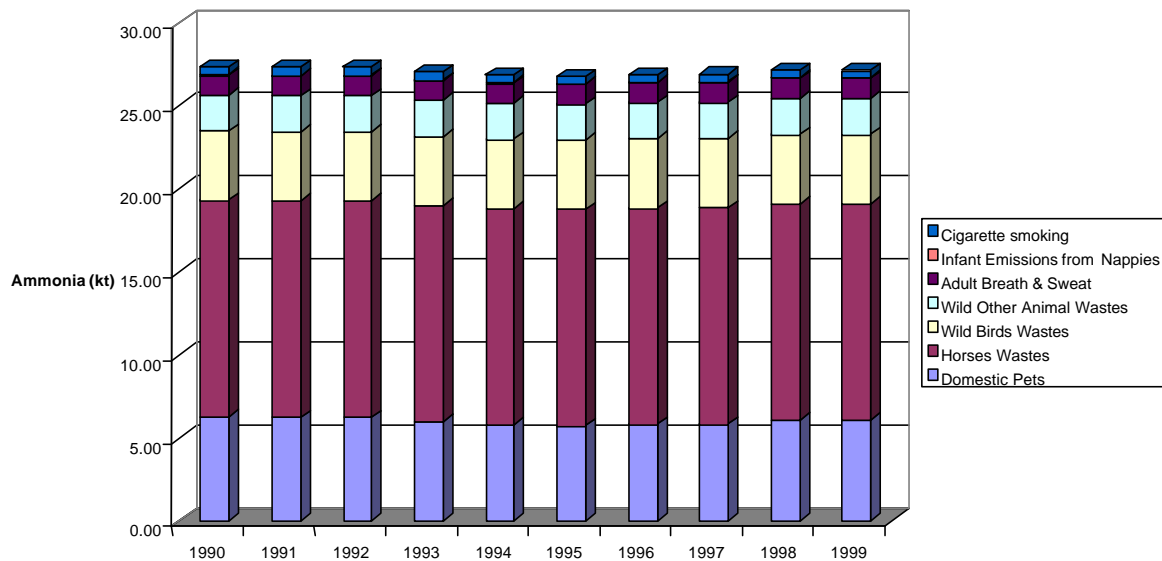


Figure 2. UK emissions of ammonia, 1990 to 1999 from cigarette smoking, human breath and sweat, nappies, and wastes from wild animals, horses and pets.

The main trends from these data are:

- Variation in non-agricultural emissions has been dominated by transport over the past 10 years, causing emissions to rise. Transport emissions increased rapidly due to the uptake of Euro I cars fitted with catalytic converters but without engine control units, which emit the vast majority of ammonia from transport (see section 2.3.1).
- The other major impact on overall emissions from 1995 – 1999 is the fluctuating ammonia emission from fertiliser production, due to temporary and permanent plant closure.
- Residential combustion emissions decrease due to fuel switching away from traditional fuels (particularly coal and anthracite).
- Sewage sludge disposal emissions show a steady increase
- Household product emissions are recorded at a constant level
- Landfill emissions are also constant, though this may be due to lack of a full time series
- There are large fluctuations (1995 – 1998) in emissions from fertiliser production, due to the small number of plants each emitting large amounts of ammonia
- The trend in direct emissions from humans and animal wastes (Table 1) has remained constant from 1990 – 1999, as there is comparatively little change in source activity and emission factor.

Data for 1999 are presented in Table 2.

Table 1. Non-agricultural emissions of ammonia in the UK, 1990 to 1999 (kt/year).

Emission in kt	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Horses Wastes	13.02	13.02	13.02	13.02	13.02	13.02	13.02	13.02	13.02	13.02
Transport	0.85	0.98	1.74	3.87	6.47	9.05	11.67	11.98	12.17	12.19
Sewage sludge disposal and treatment	5.56	5.97	6.38	6.78	7.19	7.60	8.01	7.73	7.45	7.16
Managed Waste Disposal on Land	4.69	4.69	4.69	4.69	4.69	4.69	4.69	4.69	4.69	4.69
Fertiliser production	4.79	4.79	4.79	4.79	4.79	4.79	5.53	3.93	6.63	2.61
Residential combustion - COAL	3.02	3.12	2.82	2.68	1.89	1.23	1.32	1.30	1.39	1.70
Non-aerosol products (household products)	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14
Residential combustion - ANTHRACITE	1.18	1.61	1.29	1.91	1.97	1.44	1.36	1.27	0.95	0.97
Sugar beet processing	0.79	0.77	0.93	0.90	0.80	0.80	0.88	1.00	0.89	0.95
Residential combustion - WOOD	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89
Processes in inorganic chemical industries	0.79	0.79	0.79	0.79	0.79	0.79	0.76	0.66	0.50	0.52
Production processes - mineral fibres	0.33	0.33	0.33	0.33	0.33	0.35	0.32	0.36	0.41	0.35
Cement	0.35	0.29	0.26	0.27	0.31	0.30	0.31	0.32	0.33	0.21
Processes in organic chemical industry	0.48	0.48	0.48	0.48	0.48	0.29	0.34	0.25	0.23	0.16
Chemical Industry - Acid and Halogen production etc	0.10	0.10	0.10	0.10	0.10	0.10	0.08	0.10	0.11	0.12
Residential combustion - COKE	0.38	0.31	0.26	0.22	0.18	0.17	0.18	0.08	0.11	0.11
Coke oven - door leakage and extinction	0.14	0.13	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Solid smokeless fuel production	0.09	0.09	0.08	0.08	0.07	0.06	0.06	0.05	0.04	0.04
Incineration of sludges from waste water treatment	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.04	0.04
Combustion plant - MSW incineration	0.10	0.10	0.12	0.17	0.27	0.28	0.29	0.36	0.05	0.02
Paper and printing	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total: Protocol/Directive (kt)	38.7	39.6	40.3	43.2	45.5	47.1	51.0	49.3	51.2	47.0
Domestic Pets	6.30	6.24	6.25	5.97	5.80	5.74	5.83	5.84	6.10	6.10
Wild Birds Wastes	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15
Wild Other Animal Wastes	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.19	2.19
Adult Breath & Sweat	1.19	1.19	1.20	1.20	1.21	1.21	1.21	1.22	1.22	1.22
Cigarette smoking	0.45	0.53	0.51	0.50	0.46	0.41	0.44	0.42	0.44	0.42
Infant Emissions from Nappies	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Total: 'Natural sources' (kt)	14.3	14.3	14.3	14.0	13.8	13.7	13.8	13.9	14.1	14.1
Total: All non-agricultural sources (kt)	53.0	53.9	54.6	57.3	59.4	60.9	64.8	63.1	65.3	61.1

Table 2. Best, low and high estimates of annual non-agricultural ammonia emissions for 1999. Source, NAEI; Sutton, 2000.

Sector 1999	low estimate (kt)	best estimate (kt)	high estimate (kt)
Horses Wastes	6.13	13.00	23.19
Transport	4.06	12.19	19.19
Sewage sludge disposal and treatment	2.48	7.16	16.73
Managed Waste Disposal on Land	1.17	4.69	18.75
Fertiliser production	1.30	2.61	3.91
Biomass burning	0.24	1.94	8.01
Residential combustion - COAL	0.85	1.70	3.40
Non-aerosol products (household products)	0.36	1.14	5.02
Residential combustion - ANTHRACITE	0.48	0.97	1.93
Sugar beet processing (Low limit)	0.78	0.95	1.46
Residential combustion - WOOD	0.45	0.89	1.78
Processes in inorganic chemical industries	0.39	0.52	0.65
Production processes - mineral fibres	0.26	0.35	0.43
Domestic fertiliser	0.12	0.28	0.61
Cement	0.16	0.21	0.26
Processes in organic chemical industry	0.12	0.16	0.20
Chemical Industry - Acid and Halogen production processes	0.09	0.12	0.15
Residential combustion - COKE	0.06	0.11	0.23
Coke oven - door leakage and extinction	0.08	0.11	0.13
Solid smokeless fuel production	0.03	0.04	0.05
Incineration of sludges from waste water treatment	0.01	0.04	0.10
Combustion plant - MSW incineration	0.01	0.02	0.10
Power stations - coal combustion	0.01	0.01	0.02
Paper and printing	0.00	0.01	0.01
Total: Protocol/Directive (kt)		49	
Domestic Pets	2.61	6.10	10.00
Wild Birds Wastes	1.49	4.00	8.51
Wild Other Animal Wastes	0.28	2.00	3.10
Adult Breath & Sweat	0.22	1.20	6.00
Cigarette smoking	0.15	0.42	0.62
Deer wastes	0.01	0.05	0.09
Infant Emissions from Nappies	0.01	0.04	0.14
Total: 'Natural sources' (kt)		14	
Total: All non-agricultural sources (kt)		63	

2.3 FUTURE TRENDS BY SECTOR

2.3.1 Transport

Ammonia emissions from traffic increased rapidly over the last 10 years since the introduction of vehicles equipped with Euro I standard catalysts. Future trends in both catalyst and engine technology will have a major impact on ammonia emissions over the next 30 years for diesel and petrol-engined vehicles.

2.3.1.1 Source of ammonia from petrol-engined vehicles

The use of catalytic converters with unsophisticated fuel management systems has led to a significant increase in ammonia emissions from the transport sector (COPERT III, 2000). Ammonia is generated in two stages. First, hydrogen is produced from the fuel rich phase in cycling of the air:fuel ratio through there being insufficient oxygen for complete combustion. This then reacts with NO in the catalytic converter to generate ammonia (Rototest, 1998).

For gasoline the ratio of air to fuel is equal to 14.5 by weight for stoichiometric combustion conditions: this ratio is referred to as λ , and set equal to 1. It follows that $\lambda < 1$ for a fuel rich engine and that $\lambda > 1$ for an air rich engine. The sensitivity of ammonia emissions to variation in λ , and the effect of using a catalyst, are shown in Table 3. The data shown are now quite old, but the principle remains the same.

Table 3. Effect of variation in λ on ammonia emissions from cars (UBA/AECC, 1989).

λ	NH ₃ from catalyst (ppm)	NH ₃ from direct engine output (ppm)
0.95	350-950	3-30
0.975	400-700	3-10
1	0-20	0-10
1.025	0-2	2-5
1.05	0-2	2-5

Note: Results are from 3 different catalysts, displayed as the range of values recorded

Volkswagen carried out ammonia testing for cars manufactured from 1982 to 1986, with and without catalytic converters, on vehicles sold in the USA. With the engine fully warmed the tests again demonstrated that cars with catalysts produce many times more ammonia than those without (20-300ppm with, and 2-5ppm without). Diesel cars tested did not emit ammonia as they run air rich without a catalyst (Volkswagen, 1988).

The automotive industry has made considerable efforts to improve the control of the fuel supply and combustion conditions within car engines. This has greatly reduced deviation of λ from 1 when the engine is running. Industrial sources estimate that an 80% improvement was made in moving from traditional carburation to fuel injection. The use of Engine Control Units (ECU), developed in the early 90s for the Euro II and Euro III standards made a further substantial improvement, reducing deviations around λ to just 2% of those in carburettor controlled vehicles, or 10% of those for fuel injection. The ECU tunes the engine to $\lambda = 1$ by adjusting the air to fuel ratio in an electronic feedback loop.

There are two further factors that influence ammonia generation:

- **Temperature:** The production of ammonia requires a temperature in excess of 200 to 300°C. Ammonia generating temperatures are reached at the light-off stage (the exothermic stage when the catalyst generates its own heat) and so emission will be negligible until the catalyst is fully heated.

- **Catalyst:** Ammonia production is primarily catalysed by platinum. There is scope for changing the capacity for ammonia generation by changing the catalyst or combination of catalysts used, though there are inevitably compromises to be reached given that performance has to be measured against a range of different pollutants.

2.3.1.2 Emission factors for petrol-engined vehicles

Current COPERT emission factors are based on analysis of vehicles with catalytic converters using fuel injection. These have led to very high estimates being made for total UK emissions from traffic. For this study, a Euro II/III petrol car emission factor was calculated using the weighted average of emission factors from reports by Kean *et al* (2000), Rototest (1998) and TRL (unpublished), described in Table 4 and Table 5. Then, a factor for Euro IV emissions was calculated at 20% of the Euro II and III factors. This was based on information from industrial sources, reflecting further progress with respect to engine tuning. In summary, the emission factors used here are as follows:

Euro I - 0.1g/km (COPERT III)
 Euro II - 0.03 g/km (Kean, Rototest, TRL)
 Euro III - 0.03 g/km (Kean, Rototest, TRL)
 Euro IV - 0.005g/km (Industrial Source, 2001)

Additional unpublished information gathered from industrial sources further supported the case for moving away from the COPERT III factor to much lower figures.

Some developments in vehicle technology will reduce emissions further, for example, by reducing the time taken for cars to reach $\lambda \sim 1$. Other developments may cause problems, particularly the use of Gasoline Direct Injection (GDI) that requires cars to run fuel rich, and which provides a 10% improvement in fuel economy and is necessary for cars fitted with NO_x trap technology. Consultation with industry during this study suggests that market penetration of the GDI-NO_x trap technology is very uncertain, ranging from an estimated 2% of cars in 2005 to a large proportion of the new vehicle fleet.

Paper	Emission factor (g/km)		
	petrol with catalyst	Number of vehicles tested	car type (age etc)
Hori <i>et al</i> 1990	Normal : 0.0123 Feedback cut: 0.0419 Jaoanese 10-mode: 0.0196 First phase of federal LA-4 cycle:0.0678	2 3 5 5	Pre-1990, Electronic fuel injection, 5 three way catalyst cars
Kean <i>et al</i> 2000	Average ammonia emission factor for total vehicle fleet: 0.049	Pollutant concentration measured in Caldecott tunnel	Measurements 1999 (1999 and pre-1999 Veh.)average of tunnel traffic in USA, 99% petrol cars, 95% 1984 and newer models (~all TWC)
Moeckli 1996	Average emission factor for total vehicle fleet (80-100km/h): 0.015+/- 0.004	Pollutant concentration measured in Gubrist Tunnel, Zurich	Measurements 1995 (1995 and pre-1995 vehicles) average of tunnel traffic in Switzerland
Fraser <i>et al</i> 1998	Attribute ammonia emissions to cat vehicles: 0.073 (att to all veh: 0.061)	Van Nuys Tunnel - 3 lanes traffic	1993 and pre-1993 USA vehicles. Assume 76% of fuel burned by dual bed and TWC, attribute all ammonia to these vehicles, sampling in September 1993
COPERT III 2000	0.070(urban), 0.100(rural), 0.100(highway)	7 vehicles	Vehicles 1982 - 1986 with catalysts: Predicted source: Volkswagen Report ~ 1990
Baum <i>et al</i> 2000	Only ppm figure quoted, but estimate average emission factor of 0.14 g/km based on concentrations of other pollutants measured	9 vehicles (oxidative or TWCs)	1984 - 1997
TRL, Barlow 2000	0.0047(overall), 0.0038(ECE EUDC sub-cycle), 0.0123(motorway 113 cycle), 0.0072(motorway 90 cycle) 0.0062(ECE urban sub-cycle) 0.00927(urban cycle) Assume average of 0.01 (2dp): all cycles & ambient temperatures as best estimate (Murrells)	11 cars, Laboratory	Euro II 1995 - 1999 registration: mix represents fleet
Rototest AB 1998	0.068(easy drving), 0.09(medium), 0.16(tough), 1.825(max torque 4th gear) average of 4 cars	4 vehicles, Laboratory	New passenger cars with TWCs' report' (1998 or pre-1998)

	Cars are 1996 to 2000 models - up to Euro II standards
	Cars are pre-1996 and thus not likely to meet Euro II standards. Data not considered for estimate of emission factor for this study

Table 4. Literature review of vehicle emission factors for ammonia.

Rank	Justification
European cars ranked higher than Non-European Cars	UK cars are European models (US etc have different emission levels)
Laboratory emission test ranked higher than tunnel studies	Controlled conditions and known car type gives a more accurate emission factor for petrol, catalyst cars

Estimate post-Euro I emission factor for catalyst cars based on weighting of results from 3 studies				
Study	Average emission factor		No. vehicles tested	Weighting factor for study
Kean <i>et al</i> , 2000	0.05		tunnel test	1
TRL, unpublished	0.01		11	2
Rototest, 1998	0.09		4	2
Weighted average factor for Euro II/III car	0.032			

Table 5. Calculation of the transport emission factor for ammonia for Euro II and Euro III vehicles.

The use of alternative fuels, such as CNG, may cause problems as these have poor λ control (whilst still meeting the emission regulations applied to them). It is of course possible that emission controls will be tightened on vehicles running on alternative fuels once they attain larger market share. The introduction of low sulphur fuels should have little effect on ammonia emissions. The resulting improvements in catalyst efficiency that could lead to increased emissions (Baum *et al*, 2000) will be countered by improvements in the control of the air:fuel ratio (industry sources, 2001).

2.3.1.3 Source of ammonia from diesel-engined vehicles

As noted above, ammonia emissions for diesel vehicles at present are negligible, as they run air rich without a catalyst. This situation may change given more stringent emission standards for NO_x.

Heavy duty diesel vehicles (over 3.5 tonnes) will have to fit NO_x abatement technology to reach emission standards by 2008. One option is urea injection over a catalyst, based on selective catalytic reduction (SCR). A small tank of urea would be fitted for injection into the exhaust. The urea would then be converted into ammonia which would, in turn, reduce NO_x levels. Urea is used as the feedstock reagent in preference to ammonia as the latter is deemed less safe. Industrial sources predict that the main barriers to market penetration of the urea injection system are infrastructure problems and the need to keep the 30-40% solution from freezing in sub-zero temperatures. An alternative is to use a NO_x trap. However, this technology requires fuel rich conditions to be created in the naturally oxygen rich diesel engine, and overall, the urea system is cheaper.

NOx traps are, in contrast, the more likely technology for light duty diesel vehicles as the urea injection system is complex and considered unsuitable for smaller diesel vehicles (industry sources, 2001). NOx traps may start to penetrate the market as early as 2003, causing pressure on ammonia emissions to rise given the need for fuel rich conditions.

2.3.1.4 Trends in ammonia emissions from traffic for the UK, 1999 to 2030.

Based on the information given above, trends in ammonia emissions from traffic have been generated and are shown in Figure 3. The upper bound is based on the COPERT III emission factor, the best estimate on data from Kean (2000), Rototest (1998), and unpublished material from TRL and industry. The low estimate has been generated through this study accounting for typical errors in emission factor estimation. The extreme divergence between the upper bound and best estimate demonstrates the need to account for technological developments in this sector.

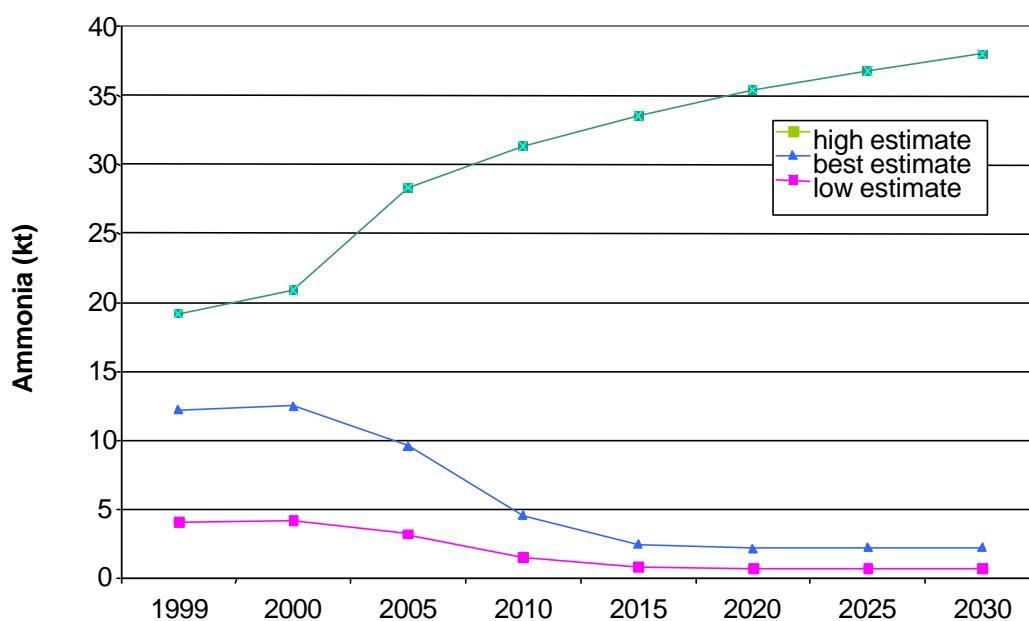


Figure 3. Trend in ammonia emissions from transport

2.3.2 Residential Combustion

The principal source of emissions from domestic combustion is inefficient burning of wood and coal. Emissions from this sector are increasingly regarded as a serious problem, though mainly in relation to PM₁₀ and PAHs rather than ammonia. Given that the use of solid fuels is a relatively high labour activity compared to the ease of using other fuels, such as oil and gas, it must be recognised that there are good reasons for people continuing to use them, and that these factors will influence the success of any control measures for the sector. They include:

- ◆ Cost of buying fuel
- ◆ Lack of access to alternative fuels
- ◆ Habit (experience of using solid fuels makes reluctance to change to other fuels)
- ◆ Desire to use a renewable source of energy e.g. wood
- ◆ Aesthetic appeal of an open fire

This sector is estimated to have generated 3.7 kt (in a range of 1.8 to 7.3 kt) of ammonia in 1999 (NAEI, 2001). The trend for the next 20 years was predicted using DTI data for sector fuel demand into the future, with extrapolation of the trend to 2030 (Figure 4). The DTI dataset does not include domestic anthracite, so it has been assumed that its trend would follow that for coal. The fall in emissions into the future is dominated by the decrease in coal combustion, continuing the pattern observed in the 1990s. There is an increase in forecast emissions from wood burning, though is not sufficient to fully counteract the decreasing influence of other solid fuels. Emissions from this sector are estimated to decrease to 2.9 kt (in a range of 1.2 – 4.6 kt) by 2010.

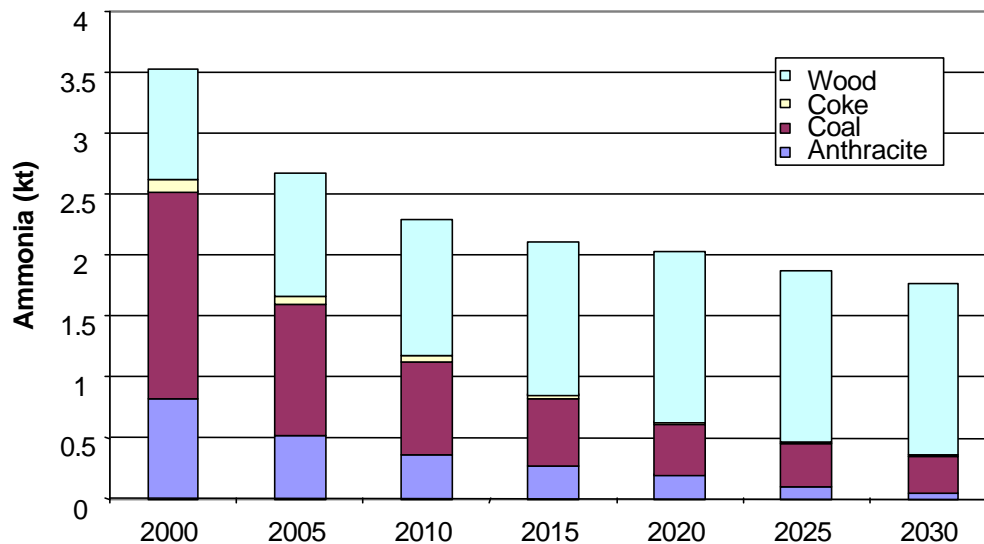


Figure 4. Emission trends for residential combustion. Source: DTI fuel use projection statistics.

2.3.3 Landfill

Ammonia can be generated by many types of landfilled waste, such as food, human and animal wastes, paper, garden refuse and so on. Bacteria break proteins down to amino acids which then further degrade, releasing ammonia (Martin, 1991). An emission factor equivalent to 0.73% of the amount of methane generated has been adopted here. The amount of biodegradable municipal waste sent to landfill will fall from 1995 levels by 25% by 2010, by 50% by 2013 and by 65% by 2020 as a result of the Landfill Directive. This will drive ammonia emissions down as it is the biodegradable waste from which ammonia is generated. This, on its own, will not lead to an immediate fall in emissions proportional with the diversion of biodegradable material because emissions from landfill occur over a period of years following disposal. However, other aspects of the Landfill Directive, notably those relating to capping of sites and the increased implementation of gas collection and flaring (see below), will help to reduce emissions relatively quickly. Overall, ammonia emissions from this source are predicted to fall from 4.7 kt (in a range of 1 to 18 kt) in 1999 to 2 kt (in a range of 0.5 to 8 kt) in 2030 (Figure 5).

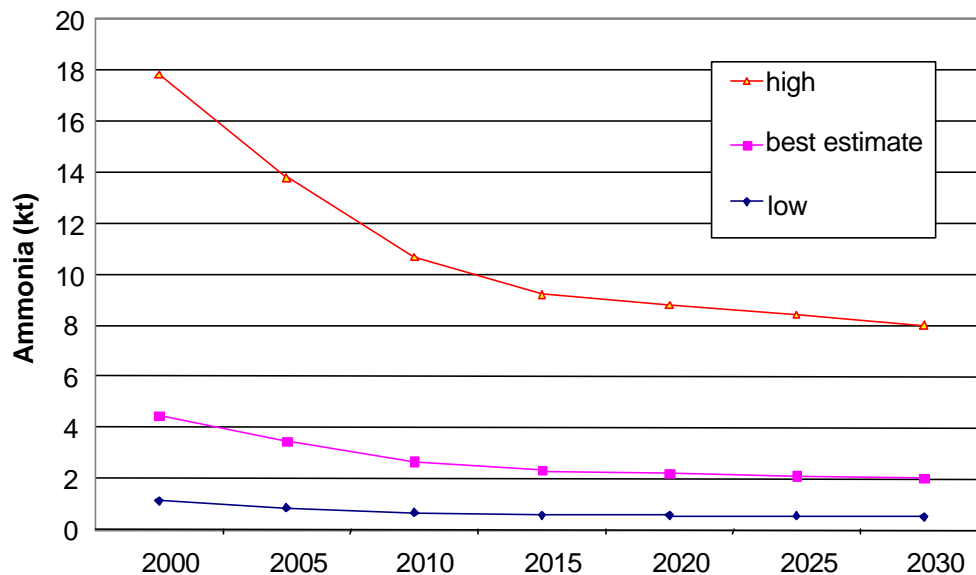


Figure 5. Trend in ammonia emissions from landfill. Sources: Burnley *et al*, 1999; NAEI, 2001.

2.3.4 MSW Incineration

Emissions of ammonia per tonne of waste incinerated are forecast to be far lower than for landfill, even though there will be a rapid increase in the number of incinerators in the UK partly in response to the Landfill Directive. The Incineration Directive has strict NO_x limits that will be difficult to meet (Ian Taylor, Environment Agency, 2001). This is likely to mean that end of pipe NO_x abatement will be essential in addition to improved combustion conditions (IPC Incineration Guidance 1996). Ammonia is used as a reducing agent to abate NO_x emissions from municipal solid waste (MSW) incinerators. There are two NO_x abatement techniques; selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR) which can both result in ammonia slippage

- 1) Selective Non- Catalytic Reduction – SNCR: Ammonia reduces NO_x in the stream of exhaust gases. Either urea or ammonia is injected into the flue gas stream; the end result is the same, as the urea is converted into ammonia - some of which can escape. Ammonia injection can also be used as a means of dioxin control.
- 2) Selective Catalytic Reduction – SCR. This technique uses a catalyst with ammonia present to reduce NO_x. It is more efficient than SNCR. However, it is only used on fluidised bed incinerators and not for the normal mass burn incinerators.

SELCHP (the South East London Combined Heat and Power MSW incinerator) is the only energy from waste plant in the UK that currently injects ammonia directly into the furnace. Other mass burn incinerators inject urea (although as already noted, this is rapidly converted to ammonia).

The Incineration Directive makes no reference to a limit on ammonia (although a limit of 10mg.m⁻³ was given in the draft Directive). Again, in the IPC incineration guidance notes, there is no limit specified for ammonia emissions, only levels occurring in practice and levels achievable. If ammonia is injected for NO_x control, residual ammonia in the flue gas can be as

high as 40 mg m^{-3} . Given increased concern over ammonia it may be considered likely that there will be future tightening of ammonia emission limits.

The ammonia trend is based on a waste growth scenario of 1% predicted by waste management modelling (Burnley *et al*, 1999). This is forecast to lead to 19 incinerators operating in the UK in 2020, burning 17.5 million tonnes of waste. On this basis the emission in 2010 is 0.06 kt (in a range of 0.02 to 0.2 kt) rising in 2020 to 0.16 kt (in a range of 0.05 to 0.5 kt). Ranges are based on Sutton *et al* (1999) (Figure 6). Opposition to incineration from the public may delay the trend: experience shows that it may take 10 years after planning permission is first gained before plant-commissioning takes place (S. Burnley, personal communication, 2001).

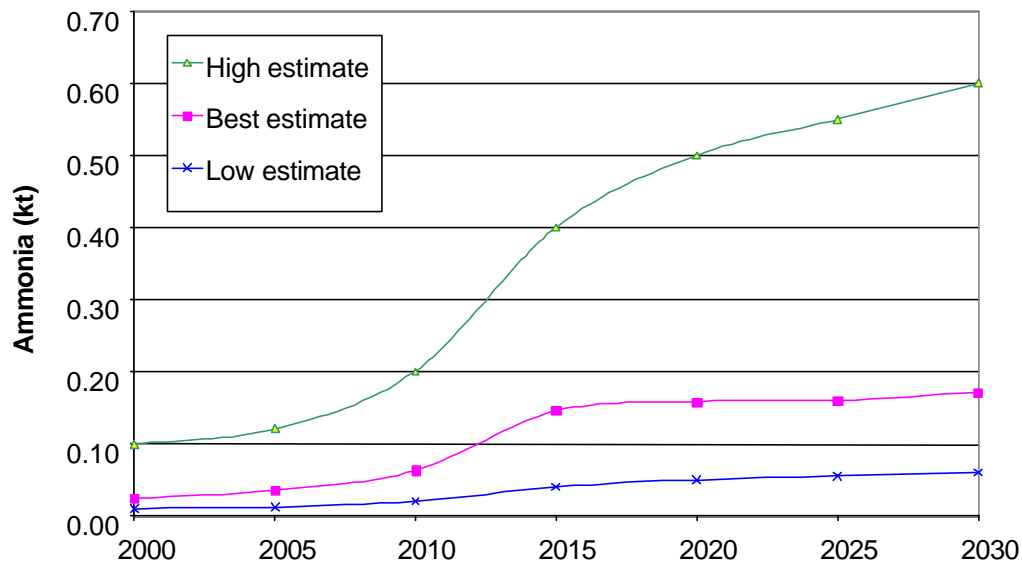


Figure 6. Trend in ammonia emissions from incineration. Sources: Burnley *et al*, 1999; Sutton *et al*, 1999.

2.3.5 Composting

Composting of biodegradable waste is a viable alternative to landfill. However, there are still ammonia emissions from the biodegradation of the waste, and ammonia is a common odour problem from composting facilities. Ammonia is formed both aerobically and anaerobically, so control strategies purely for anaerobic odours cannot be directly applied (Richard 2000).

The main controlling factor for ammonia emission from compost is the carbon/nitrogen ratio (Richard, 2000). Ammonia is emitted when nitrogen is in excess and carbon/energy is limiting instead. Not surprisingly therefore, ammonia emissions are common when composting high nitrogen materials such as fresh grass clippings or manure. The pH also affects ammonia volatilisation. Gaseous ammonia is in equilibrium with the aqueous ammonium ion at a pH of about 9, whilst a higher pH forces ammonium ions into the gas phase. Thus ammonia emissions are much lower under acid conditions, and so adding lime to compost increases emissions.

2.3.6 Sewage sludge treatment and disposal

Sewage sludge disposal practices leading to ammonia emissions are as follows:

- ◆ disposal of sewage sludge onto land
- ◆ sewage sludge treatment (lime treatment, aerobic and anaerobic digestion)
- ◆ sewage sludge incineration

This Section summarises the activities that lead to the ammonia emissions and the trends in emissions from these sources. The trends analysis accounts for policy influence such as the Sewage Sludge Matrix, abatement resulting from odour nuisance and increased sewage sludge incineration.

Disposal of sewage sludge to sea was halted two years ago by legislation. The majority of sewage sludge is now disposed of to land. Originally material was simply spread onto land, though the industry is moving rapidly towards injection (on the grounds of appearance, acceptability to farmers, the retail industry and the public, and also odour control). Emissions are reduced by 75% compared to spreading, and 60% of material is now disposed of in this way (Environment Agency, 1997). However, there is pressure from retail – particularly supermarkets – to stop this and in 1998 the Safe Sludge Matrix was drawn up between the 14 UK water and sewage operators and the British Retail Consortium. The matrix gives guidelines to stop spreading of untreated sewage on land in the interest of food safety and to assure retailers that sludge usage is safe. The other change in land disposal of sewage sludge resulting from the Safe Sludge Matrix, is the requirement for treatment of the sludge before spreading. Sludges treated by biological, chemical or heat techniques (the most common being anaerobic digestion) can only be spread on combinable and animal feed crops, grass and maize crops. Enhanced treatment of sludge to eliminate all pathogens means sludge can be spread on all crops. The Matrix is likely to have a strong influence over the water industry because all the key stakeholders were involved in the agreement between the British Retail Consortium and Water UK (1998) from MAFF, DETR, EA, National Farmers Union through to food manufacturers and food processors. The increase in treatment requirement will lead to greater ammonia emissions from the sludge treatment phase though the requirement for deep injection into the soil (to a depth of 6 inches) will reduce ammonia emissions at that stage.

Data on sewage sludge show a total of 54% being treated by anaerobic digestion (WRc, 1997, Table 6). Anaerobic digestion tanks have a lifetime approaching 50 years and are a major investment. Thus the technology is fairly old with a low market uptake for new equipment, reducing the rate at which the sector is likely to change. Anaerobic digestion is advantageous as the solid mass of the sludge is only increased by 0.1% organic chemical mass. Ammonia is likely to be emitted after treatment and before disposal (Imperial College 2001, personal communication). Table 6 shows a low rate of incineration of (3%) and lime stabilisation (2%), though these two treatment methods have rapidly increased recently and are now more significant (ADAS, Personal Communication 2001).

Lime stabilisation is used for de-watering sludge. However, the large amount of lime required increases the solid mass of the sludge significantly, and hence increases transport burdens. The neutralising reaction generates enough heat to produce ammonia as well as removing moisture. The reaction takes the form:



Treatment with lime also forms calcium salts of the many heavy metals present. These salts are notoriously insoluble and lock-in heavy metals so that they cannot leach out of the finished product. The use of lime for sewage treatment is limited to a small proportion of the water treatment industry. Northumbrian Water are using lime treatment and have installed sulphuric acid packed tile scrubbers in order to abate the ammonia produced (Northumbrian Water 2001, personal communication).

Table 6. Sewage sludge treatment. Source: WRc (1997).

Sludge treatment 1997/97	Sludge treated (tds a-1)	%
Mesophilic anaerobic digestion	347800	31
Anaerobic digestion and dewatering and storage	252500	23
Thermophilic aerobic digestion	<100	<1
TAD and dewatering and storage	300	<1
Composting	20000	2
Lime stabilisation	27800	2
Liquid storage for 3 months	21300	2
Unstabilised, dewatered and stored	118800	11
Thermal drying of treated sludge	4800	<1
Thermal drying of untreated sludge	100	<1
Other (Includes incineration)	31100	3
None	291900	26

Increased pressure from local communities and councils to reduce odour emissions from treatment plants should lead to abatement of ammonia, though the problem is mainly related to hydrogen sulphide which has a comparatively low odour threshold. This has led to the development of sophisticated odour abatement systems such as ODOURGUARD (ERG, 2001) which are fortunately also efficient at abating ammonia through the use of catalytically enhanced chemical scrubbing.

There is also pressure on landfilling sludge from landfill tax. Together these factors mean that incineration is the key growth area for sewage sludge disposal. This should lead to a reduction in the treatment of sewage sludge and hence of ammonia emissions as no pre-treatment of sludge or dewatering is required for fluidised bed combustion.

Knowledge of ammonia emissions from sewage sludge incineration appears to be patchy, with some operators unaware of emission rates. South West Water (personal communication) have reported some ammonia odour problems around one of their sites, close to a campsite. North West Water incinerated 10% of their sewage sludge in 1999. One of their incinerators - The Shell Green Sludge Incinerator - uses a 3 stage chemical scrubber (sulphuric acid, caustic bleach etc.) to control emission (North West Water, Personal Communication, 2001). They are also seeking markets for the ash produced, which is landfilled at present.

There are two types of sewage sludge incinerators – multiple hearth and fluidised bed. Multiple hearth incineration is used to convert de-watered sludge cake into an inert ash. The process is complex and requires trained operators, so multiple hearth furnaces are normally used on large plant. A wet or dry scrubber is normally required to collect particulates to comply with air

pollution standards. The only pre-treatment of the sludge required is the dewatering (Metcalf and Eddy, 1991).

Fluidised bed incinerators are used in medium to large plants, with high flow ranges (they are occasionally used for low sludge flow ranges). Combustion gases are normally scrubbed with a Venturi scrubber (see below). Untreated sewage sludge is incinerated on a fluidised sand bed. Evaporation of the water and combustion of the sludge solids takes place rapidly. (Metcalf and Eddy, 1991)

The majority of the ammonia in the sludge will be combusted in the high temperatures of incineration, to NO_x. Currently, there is no specific injection of ammonia or urea to abate NO_x. It is likely that this injection technology will be necessary to meet NO_x standards when the sewage sludge incinerators come under the waste incineration directive.

Forecast emissions from sewage sludge incineration are shown in Figure 7. The 10% increase in incineration observed from 1998 to 1999 is assumed to continue for 5 years and then level out (NAEI, 2001).

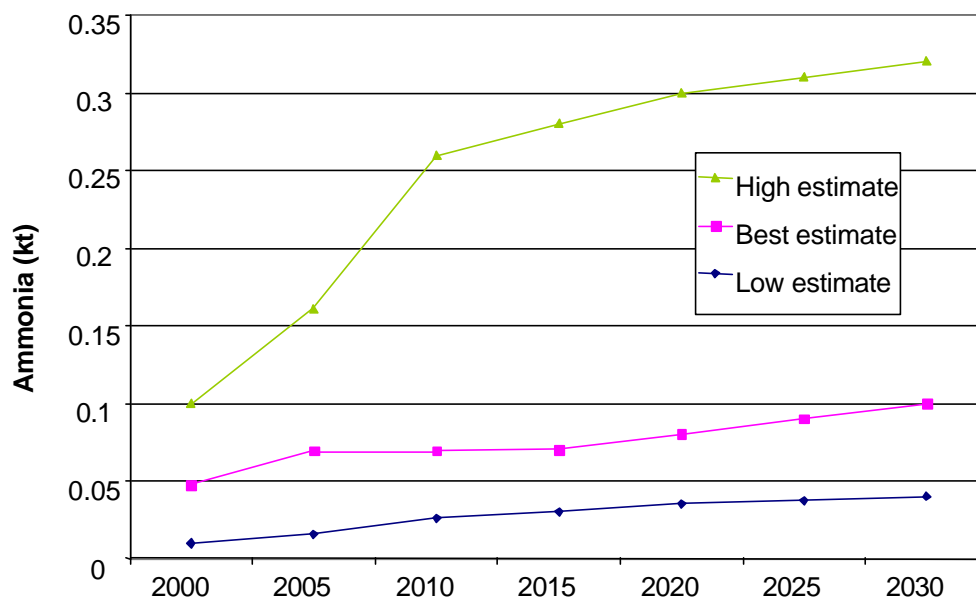


Figure 7. Trend in ammonia emissions from sewage sludge incineration. Sources: Sutton *et al*, 1999; NAEI, 2001.

The overall trend in sewage sludge treatment and disposal is assumed to be constant at 7kt per year. As has been indicated, there are many factors that will influence emissions in the future. Increased treatment due to tougher food safety requirements requiring treatment before spreading on land are likely to increase ammonia emissions from treatment and a move away from surface spreading to injection will reduce ammonia emissions from disposal. The actual trend may well be a decrease in emissions, as discussed above, though the size of change is unknown and therefore cannot be predicted reliably at this stage.

2.3.7 Overall trend for emissions from waste treatment and disposal

Overall, there is a decreasing trend in waste disposal emissions due to the trend from landfill. Projections are shown in Figure 8.

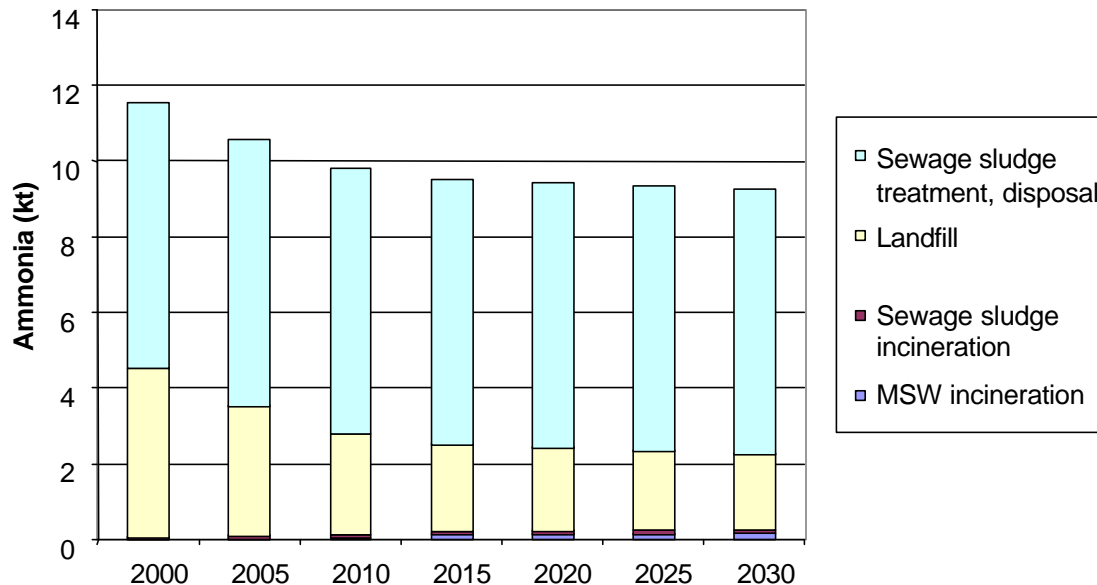


Figure 8. Trend in ammonia emissions from waste disposal. Sources: Burnley *et al*, 1999; Sutton *et al*, 1999, NAEI, 2001.

2.3.8 Production processes

2.3.8.1 Sugar beet processing

Ammonia is emitted from sugar beet processing when lime is added to increase the pH to 11.5. Detailed studies at one beet processing plant indicate that the ammonia emissions arise from a large number of vents (over 20) at various process steps.

Table 7. Emission sources at sugar beet processing plant.

Source	% of total ammonia emitted
1) Slaker 2) Vacuum filters (x7) 3) Carb (x2) 4) Heaters @135°C (x5) 5) Vacuum pans (crystalisation stage)	Source (1) to (5) = 50% total emissions
6) Cooling tower (evaporative)	Source 6 = 50% total emissions

Total ammonia emissions to air for the sector are 0.95 kt/year, though this is much lower than the emission to water of around 100 kt/year.

The production level of sugar beet processing in the UK will remain constant even though several plants are due to close. Three out of nine processing plants are closing though production will be increased at the remaining plants. Significant abatement measures are predicted to be implemented by 2015 (British Sugar – personal communication 2001). Emissions are predicted to be 0.9 kt (in a range of 0.78 to 1.5 kt) in 2010. Increased competition from the pending free trade agreement may also reduce UK production levels. The predicted trend in emissions for the next 30 years is shown in Figure 9.

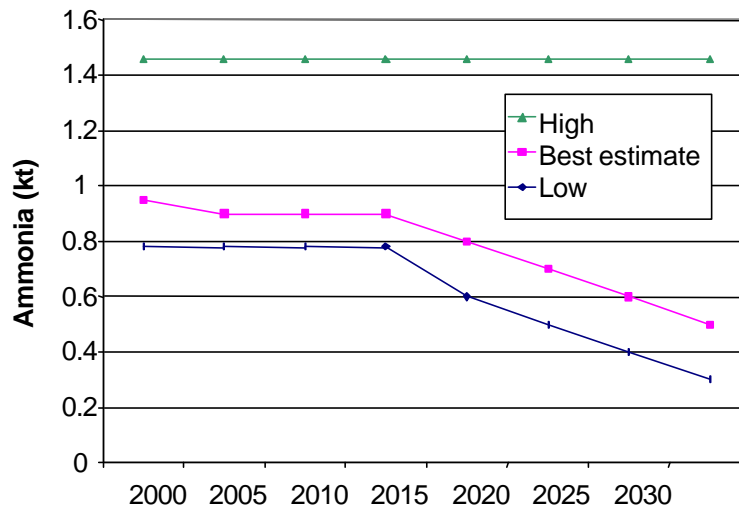


Figure 9. Future trend in ammonia emissions from sugar beet processing. Sources: NAEI, 2001; Sutton *et al*, 1999; Theobald *et al*, 2000.

Local pressure and pressure from English Nature to protect the Site of Special Scientific Interest adjacent to the plant at Cantley is likely to lead to additional ammonia abatement measures being taken in the short term future at that site and one other located near sensitive ecosystems. In the medium term future (2010) it is likely that further abatement will be installed. British Sugar predict that replacement of the cooling tower at Cantley by a non-evaporative cooling system would abate total plant emissions by about 50%. Penetration of this technology into the sector is likely to cover two of the total of six remaining plant by 2010, and this is thought by the industry to account for the effects of IPPC (British Sugar, 2001).

2.3.8.2 Fertiliser production

Fertiliser production (including nitric acid production for use in fertilisers) is the main source of ammonia emissions in the production processes sector: the 1999 emission was 2.6 kt (range of 1.3 to 3.9 kt), and is predicted to decrease to 1.5 kt (range of 0.77 to 2.3 kt) by 2010. The past trend in ammonia emissions was very variable with time, though showing an overall decrease. The future trend is based on a 5% annual decrease as a result of future emission reductions reflecting the overall decrease in emissions and better plant operation in the future. The production of fertilisers in the UK has dropped by 60% from 1990 to 1995 (IPC Guidance note S2 4.03) compared to UK fertiliser consumption which only showed a 10% decrease from 1990 to 1995 and remained approximately constant until 1997 (Office for National Statistics 1999). The difference between the change in UK production and use is made up for by net import.

Fertiliser production involves the use of ammonia, or can lead to the emission of ammonia, at the following process stages. The following describes the control of emissions at a plant run by Hydro Agri in their production of ammonium nitrate, though this will shortly close down. The abatement technology described is for both ammonium nitrate and ammonia.

1. Storage of ammonia, using ammonia as a refrigerant to keep the storage tank cool. Any build up of vapour is vented straight into a nitric acid process.
2. Conversion of ammonia to nitric acid. Minimal amounts of ammonia are emitted at this stage. It is almost completely burnt to avoid explosion.
3. Formation of ammonium nitrate. This stage involves a small ammonia loss in a steam vent, but is considered to be too small to be worth regulation.
4. Solidification of ammonium nitrate. The fume stream is filtered using thimbles or candles to reduce emissions to a concentration of 10 mg.m^{-3} . These contain a mesh of glass fibre irrigated with slightly acidic water and are effective for removing both ammonium nitrate and ammonia. For a typical plant the candles cost £200 000 to replace every 3-4 years (assuming 60 to 70 candles measuring 3m x 0.5m). This system was described to the study team by the company that owns the plant as the 'most efficient technology in Europe for ammonium nitrate abatement'.

The glass fibre candles described above are fitted in order to abate ammonium nitrate, they also abate ammonia, though would not be fitted solely for ammonia abatement as there are cheaper methods. For this reason, the technology cannot be included in the cost curve, discussed in the next chapter.

There are a further five plants in the UK that will continue to produce nitrogenous fertilisers and emit significant levels of ammonia (Pollution Inventory, 1999). One of these is run by Terra Nitrogen UK at Middlesbrough, and another by Kemira Agro at Ince.

At the Kemira plant, the main source of ammonia emissions is the release of surplus ammonia at end of the fertiliser manufacture process. Older control technologies in particular have a very limited abatement efficiency, in some cases as low as 10%.

In the case of Terra Nitrogen at Severnside, the main source of ammonia is from Non-Selective Catalytic Reduction (NSCR). The NSCR system uses hydrogen over a catalyst to reduce NO_x , the non-selective catalytic reduction process leads to a significant amount of NO_x being reduced to nitrogen and then to ammonia. It has been estimated that 750 t of emissions from the Severnside plant was due to ammonia slip (Terra Nitrogen, personal communication 2001). Introduction of a selective catalytic reduction system (SCR) resulted in a cut of about 92% in these emissions in 2000. This is a site specific case and has not been incorporated into the trend as the numbers have not yet been submitted for verification in the Pollution Inventory. However, it illustrates the site specific nature of ammonia emissions in this sector and identifies a suitable abatement method.

Fugitive emissions are also present, although by their nature they tend to be difficult to quantify. The production process itself is not the main source of these as it is typically well sealed. The IPC guidance notes state that plants will have vapour return lines for unloading tankers and that they should have leak detection and repair programmes in place. The application of IPPC to the fertiliser industry is likely to lead to a tightening of ammonia emissions in the sector.

2.3.8.3 Cement industry

Ammonia is emitted at the clinker production stage in the kiln exhaust gases. Ammonia or ammonium salts are sometimes contained in the raw material being fed into cement kilns. If chloride is also present, there is evidence that ammonium chloride is formed. It is reported that no successful abatement method has been found or applied for ammonium salt emissions (HMIP CPR2). The effect of ammonium salts is to create a dense plume as the salts form white particulates in the air.

The cement BAT Reference notes quote the NO_x abatement technologies (SCR and SNCR) as a potential source of ammonia. However, the Environment Agency report that there are no cement plant in the UK fitted with SNCR or SCR as the NO_x standard of <500 mg.m⁻³ can be met with new kiln technology (Environment Agency, Brierley, personal communication 2001).

Ammonia emissions per tonne of cement produced are low, though the size of the industry in the UK results in this sector having significant emissions to air. The trend in production is predicted to be constant, though the current and future pattern is away from smaller plants to bigger, modern plants (British Cement Association [BCA], Personal Communication 2001). The industry has no plans to abate emissions (BCA after consultation with industry)

The largest reported single source of emissions in the 1999 Pollution Inventory was the Blue Circle Caudon Cement works (Pollution Inventory 1999). This source was pursued by the Environment Agency, as it was anomalously large. The ammonia test carried out at Caudon was done when the raw meal mill was off, thus omitting the dry scrubbing normally achieved as the kiln exhaust gases pass through the mill, and the ammonia emissions were disproportionately large. The figures for 2000, accounting for mill down time over the year, are 29 tonnes ammonia to air accounting for the short periods when the mill is not functioning. From this we can derive a recommendation to minimise annual ammonia emissions by ensuring mill downtime is minimised when the kilns are firing.

2.3.8.4 Explosives industry

There are only two major explosive plants in the UK, run by Nobel Explosive and Royal Ordnance plc, both located in Scotland. Ammonia was used in the industry for manufacture of nitric acid, but is now bought in direct. SEPA, responsible for the IPC regulation of these plant, has found that they do not emit significant amounts of ammonia (R. Brown, SEPA, personal communication).

2.3.8.5 Sodium ferrocyanide manufacture

Raw cyanide material contains ammonia, which is volatilised during the production of sodium ferrocyanide. Individual plant emissions in the order of 12 tonnes of ammonia per year are given in the 1999 (Pollution Inventory, 1999).

2.3.8.6 Chromium chemicals manufacture

The largest emitter of ammonia from the inorganic chemical industry sector is from Elementis Chromium Ltd. at 290 tonne in 1999 (Pollution Inventory 1999). Ammonium sulphate is used

to make ammonium dichromate which is thermally decomposed in a rotary kiln. Ammonia is released in the flue gases.

2.3.8.7 Other parts of the chemical industry, including petrochemicals and pharmaceuticals

This grouping of sectors contains numerous relatively small sources, each with their own characteristics for ammonia release. Although this sector has been growing by 5% every year since 1995 (NAEI, 2001), the emission predicted in 2010 is only 203 t (in a range of 150 to 250 t).

2.3.8.8 Coke manufacture

Ammonia is produced from the reduction of nitrogen in coal during carbonisation in the coke making process. This ammonia may escape from coke ovens:

- when charging (loading the oven),
- during operation through leakage from the oven, particularly through oven doors,
- when the coke is removed from the oven,
- and through emergency venting.

The problem is thus mainly one of fugitive emissions, which are currently characteristic of the process. Collected gas from coke ovens is treated for ammonia, which is converted to ammonium sulphate. Stack emissions are therefore minimal (Environment Agency, personal communication, 2001). The industry does not regard ammonia emissions as a pollutant for concern due to the low emissions present (CORUS, personal communication, 2001).

The coking industry is generally old and the introduction of new plant in the near future is very unlikely. Plant closure and tighter plant control resulting from IPPC in the next 4 years, make it likely that ammonia emissions will decrease (Environment Agency, personal communication, 2001). The emissions in coke production from coke oven door leakage and extinction are thought to have totalled 106 tonnes ammonia to air in 1999.

2.3.8.9 Mineral fibre processes

Ammonia is used as a raw material to make binder solution for mineral fibres. Ammonia emissions can be significant - the Rockwool plant, for example, emitted 93 tonnes of ammonia in 1999.

2.3.8.10 Overall trends for the production process sector

The overall trend in emissions from production processes is a decrease, due mainly to tightening controls through the implementation of IPPC (Environment Agency, personal communication 2001). The trend in Figure 10 accounts for general improvements in industry and reflects the past time series for the production process sector. It is assumed that no measures specifically directed at ammonia will be implemented under IPPC as the Environment Agency and industry were both unaware of future plans to target ammonia.

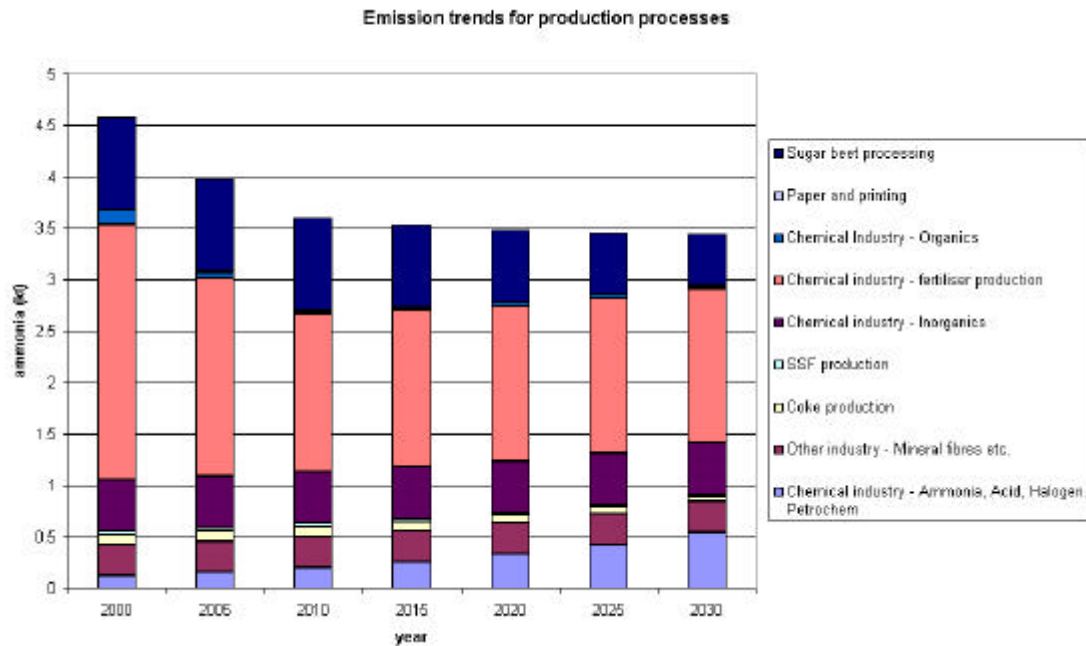


Figure 10. Trend in ammonia emissions from production processes. Sources: NAEI, 2001; Sutton *et al*, 1999; DTI fuel projections; Environment Agency, 2001, industry predictions (FMA, British Sugar etc).

2.3.9 Household products

The future trend in ammonia emitted from household products is difficult to predict as there is large uncertainty in current emission estimates and a time series for UK emissions is not available. The largest ammonia emission is from floor screeding latex solution at 1 kt in 1998 (Sutton *et al*, 1999). This forms the large proportion of emissions from this sector. The trend is assumed to be constant with time, with emissions of 1.1 kt (NAEI, 2001) for 1999 domestic solvent use and for non-aerosol products. This is similar to the forecast of 1.2 kt for appliance and household products from Sutton and Theobald *et al* (2001). The low and high estimates are 0.36 and 5.0 kt, respectively.

2.3.10 Horses

This represents a difficult sector for the present study. Four categories of horse (which is, necessarily, here used in its widest sense to include ponies and donkeys) can be distinguished for our purposes:

- Racehorses
- Other horses kept in larger stables (e.g. with more than 4 horses)
- Horses kept either individually or in groups of up to 3
- Semi-wild ponies

These distinctions are made largely to reflect the level of opportunity for control of emissions.

There seems, perhaps surprisingly considering the apparently good knowledge of the numbers of cats and dogs in the country, to be significant uncertainty in the number of horses in the UK. The BETA (British Equestrian Trade Association) survey for 1995/96 reported 500,000 horses

in UK in professional use, a figure that subsequently increased to 900,000 for the 1998/99 survey, partly due to an improvement in the survey method. Factors likely to increase numbers include the availability of rate relief for farmers entering into horse enterprises. A ban on fox hunting would probably reduce numbers.

Most ammonia from this sector is emitted from urine and solid manure. Patches of free standing urine will act as hotspots, continuously emitting ammonia to air. Solid excreta also emit ammonia. A major source will be wet bedding. For horses in the field – approximately 40% of their day – ammonia emissions from urine and manure are dependent on ground conditions, the abatement options involving straw treatment cannot apply to the horse when it is in the field. If the urine is quickly absorbed by the soil, ammonia emissions are very low. However, if the ground is water logged or hard packed then urine remains on the surface and hotspots of ammonia emissions will build up (IGER 2001).

2.4 OVERALL PROJECTIONS OF FUTURE EMISSIONS

Data on each sector given in the preceding parts of this chapter have been combined to generate an overview of likely trends in ammonia emissions to the year 2030 (Figure 11 and Table 8).

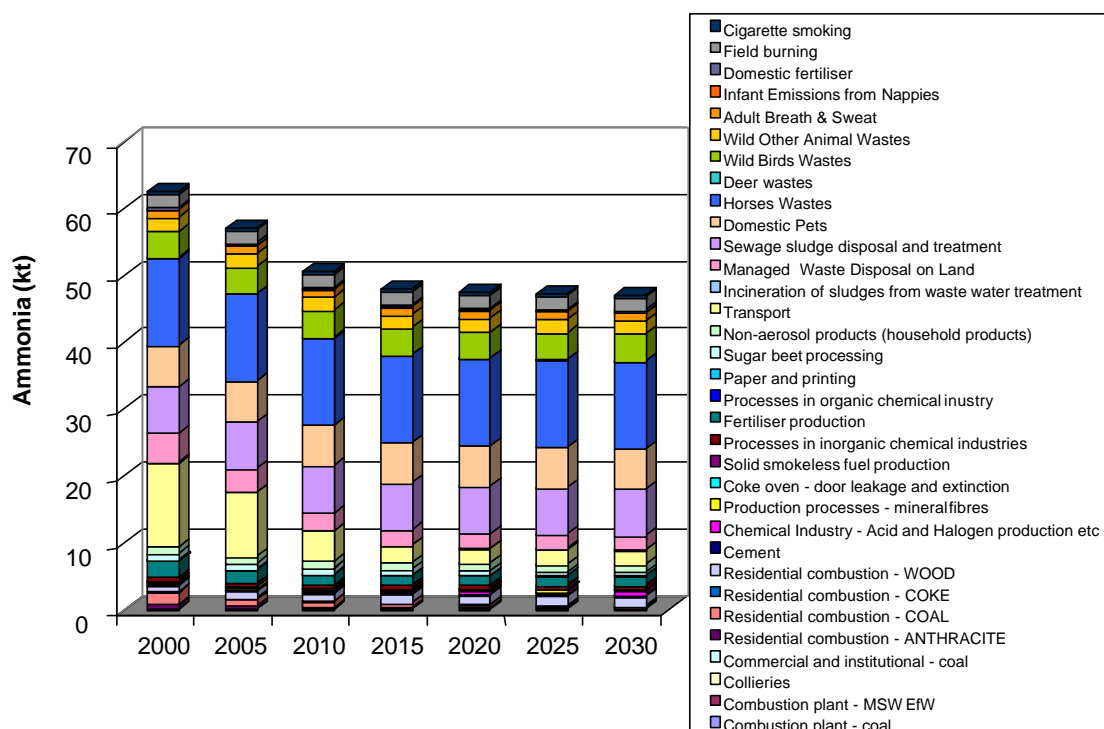


Figure 11. Non-agricultural ammonia emissions for the UK, 2000 to 2030.

The main factors affecting these projections up to 2030 are summarised as follows:

- Traffic: Fleet growth, opposed by increased penetration of advanced catalyst and engine management systems.
- Waste disposal: Effects of the waste strategy regarding increased restriction on landfill and a trend towards incineration (Burnley *et al*, 1999). Also, changes in procedures for handling

sewage sludge, partly through the increased trend towards incineration, and the trend to injection of sludge into fields rather than spreading (BRC, April 2000), compensated by a potential increase in sewage treatment and thus emissions (ADAS, personal communication 2001).

- Sewage sludge treatment: Increased pressure from local communities and councils to reduce odour emissions from treatment plants. Although these relate primarily to control of hydrogen sulphide, the necessary measures will also control ammonia. The predicted increase in treatment levels is predicted to compensate increase in abatement technology (ADAS, personal communication 2001).
- Industry: Internationalisation of markets, closure of older plant (industrial contacts, 2001), and penetration of IPPC (Environment Agency, personal communication, 2001).

Upper and lower bounds to the total emission can be calculated simply by summing all high, or all low, values for each sector (Figure 12). The resulting range is extremely broad. The range can be restricted to provide more realistic guidance using statistical sampling techniques. For this, the @RISK software package was used to provide a 90% confidence interval. To do this it is necessary to make some assumption about the probability distribution within the ranges for each sector. @RISK provides many options, though for all cases except transport a triangular probability distribution shape was assumed here. Given the low confidence in the upper bound for transport (based on what we consider to be outdated COPERT III emission factors), a lognormal distribution around the best estimate value was taken for transport, heavily weighting the analysis to the lower end of the transport range. However, this requires additional information on the standard deviation around the best estimate, reliable evidence for which was not available. Sensitivity to this assumption was investigated using the standard deviation calculated from the original data, and a standard deviation of 1.0. The overall results are shown in Figure 13 and Figure 14. The results using the standard deviation of 1.0 for transport forces the boundaries closer in Figure 14 than in Figure 13. It is not possible to say which approach is more valid on the limited evidence available. The contrast between the original uncertainty boundary and that modelled is significant (Figure 12):

Table 8. Non-agricultural ammonia emissions for the UK, 2000 to 2030 (kt/year).

Emission in kt	2000	2005	2010	2015	2020	2025	2030
Horses Wastes	13.00	13.00	13.00	13.00	13.00	13.00	13.00
Sewage sludge disposal and treatment	7.00	7.00	7.00	7.00	7.00	7.00	7.00
Transport	12.5	9.59	4.53	2.46	2.16	2.23	2.23
Managed Waste Disposal on Land	4.45	3.45	2.67	2.30	2.20	2.10	2.00
Biomass burning	1.94	1.94	1.94	1.94	1.94	1.94	1.94
Fertiliser production	2.48	1.92	1.53	1.52	1.51	1.51	1.50
Residential combustion - WOOD	0.90	1.01	1.12	1.25	1.40	1.40	1.40
Non-aerosol products (household products)	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Sugar beet processing	0.90	0.90	0.90	0.80	0.70	0.60	0.50
Residential combustion - COAL	1.70	1.08	0.76	0.55	0.41	0.35	0.30
Processes in inorganic chemical industries	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Residential combustion - ANTHRACITE	0.82	0.52	0.37	0.27	0.20	0.10	0.05
Production processes - mineral fibres	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Domestic fertiliser	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Cement	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Chemical Industry - Acid and Halogen production etc	0.12	0.16	0.20	0.26	0.33	0.42	0.54
Coke oven - door leakage and extinction	0.10	0.10	0.10	0.09	0.08	0.07	0.05
Incineration of sludges from waste water treatment	0.05	0.07	0.07	0.07	0.08	0.09	0.10
Combustion plant - MSW incineration	0.02	0.04	0.06	0.15	0.16	0.16	0.17
Residential combustion - COKE	0.10	0.06	0.05	0.03	0.02	0.02	0.02
Solid smokeless fuel production	0.03	0.03	0.03	0.03	0.02	0.02	0.02
Processes in organic chemical industry	0.14	0.06	0.03	0.03	0.03	0.03	0.03
Paper and printing	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Combustion plant - coal	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Collieries	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Commercial and institutional - coal	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total: Protocol/Directive (kt)	48.7	43.3	36.7	34.1	33.6	33.4	33.2
Domestic Pets	6.10	6.10	6.10	6.10	6.10	6.10	6.10
Wild Birds Wastes	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Wild Other Animal Wastes	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Adult Breath & Sweat	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Cigarette smoking	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Deer wastes	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Infant Emissions from Nappies	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Total: 'Natural sources' (kt)	13.8	13.8	13.8	13.8	13.8	13.8	13.8
Total: All non-agricultural sources (kt)	62.4	57.1	50.5	47.9	47.4	47.2	47.0

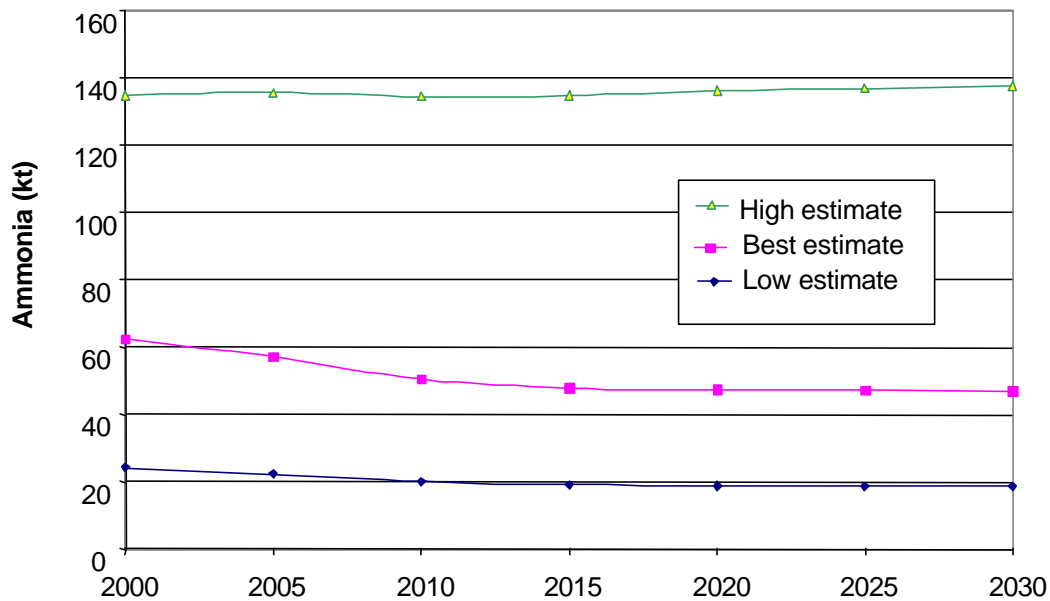


Figure 12. Trends in non-agricultural ammonia emissions 2000-2030, with upper and lower bounds calculated by simple summation of limits for each sector.

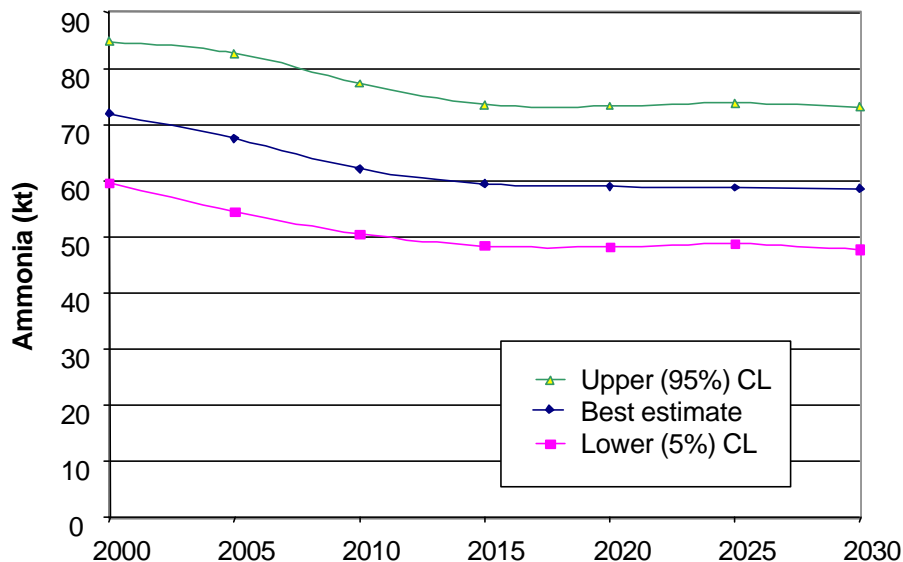


Figure 13. @RISK trend prediction for UK non-agricultural emissions using the standard deviation derived from all data points for transport.

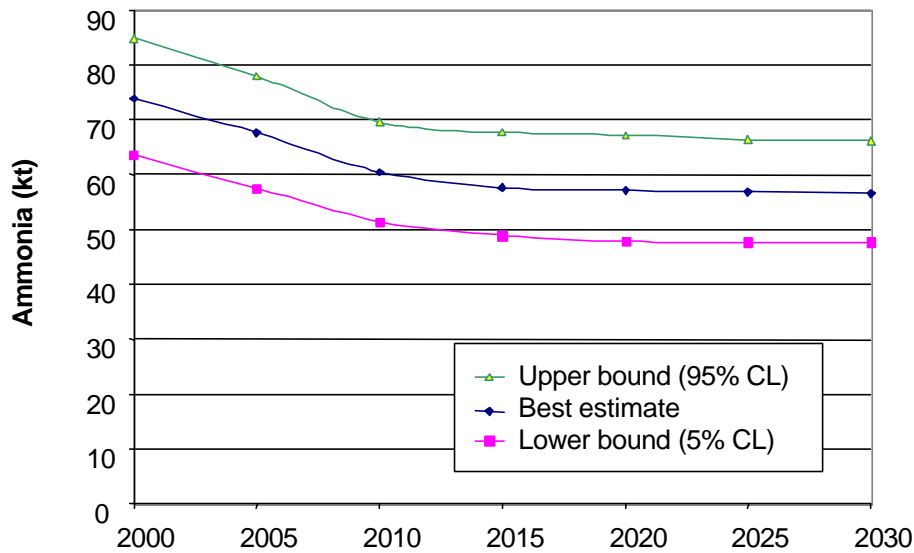


Figure 14. @RISK trend prediction for UK non-agricultural emissions using a standard deviation of 1.0 for transport emissions.

Use of the @RISK model has shown that the simple summation of uncertainties gives exaggerated upper and lower estimates (19 to 138 kt/year). The range calculated by @RISK, combining the probability distribution assumed for each sector, is therefore considered more robust. The @RISK range includes the best estimate of 51 kt/year, albeit at the lower end of the 50 to 77 kt/year range forecast. This implies that this figure is more likely to underestimate actual emissions than to overestimate them. Clarification of the emission factors for transport would greatly assist in resolving these issues.

3. Abating Non-Agricultural Ammonia Emissions: Options and Costs

3.1 METHOD

Cost-effectiveness is described for each option using the function:

$$\text{cost}(\text{£})/\text{tonne}[\text{NH}_3]\text{abated} = \frac{(\text{cost}/\text{plant}) \times \text{number of plant}}{(\text{unabated emission}) \times \text{effectiveness}}$$

The analysis of the costs of abatement follows the UK Government methodology as defined in the Treasury's Green Book. Key issues that have been taken into account (where possible) when collecting and evaluating cost data include:

- Identification of what is included in the cost of each measure
 - capital: purchase cost depreciation, installation
 - operating: maintenance, energy, labour, insurance etc.
- Base year for costs and currency
- The potential for measures primarily aimed at other pollutants for removing ammonia
- The cost of retrofitting versus the building of a new plant
- How costs vary with location
- Whether published costs have been normalised/annualised and how

The cost curve was constructed using the annualised cost of abatement technology and the efficiency of the resulting abatement. Cost data was gathered for the following technologies through telephone interview with the industries who manufacture the technology:

- ◆ Venturi Scrubber
- ◆ Dilute acid packed tile scrubber
- ◆ Regenerative thermal oxidiser
- ◆ Biofilter
- ◆ Non-evaporative cooling system
- ◆ Silage treatment of horse manure

These are discussed in the next section, which is followed by description of the application of these and other techniques to the sectors identified above.

3.2 MAIN ABATEMENT TECHNIQUES

3.2.1 Venturi Scrubber

The Venturi scrubber is suitable only for large gas flows with high tonnages of ammonia emitted each year. It has been applied to fertiliser plant with larger emissions in the cost curve. The advantages of this technology are that it can efficiently abate ammonia travelling in a high

velocity gas stream, where as technologies such as the dilute acid packed tile scrubber would not be able to cope under these conditions. The disadvantage of the technology is the expensive operating and initial costs:

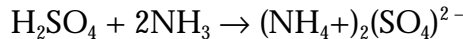
- ◆ £3 million initial investment to abate one gas stream
- ◆ The Venturi scrubber requires high velocity gases – only suitable for plant with a large pressure drop (Environment Agency)
- ◆ Recurring cost of sulphuric acid dosing (necessary for ammonia abatement): up to £400,000 per year (ABB Environmental)
- ◆ Electricity demand ~1kW, costing ~ £31,000 a year (DUKES and ABB Environmental)

The cost per tonne of ammonia abated for a Venturi scrubber is of the order of £1,600/tonne (6% discount rate), with a total annualised cost of around £800,000 per year (includes capital investment and recurring costs).

Effluent treatment costs have not been identified as these are dependent on plant licensing and other conditions. However, the costs of this effluent treatment are likely to be high, though in many cases are likely to be counteracted by on-site salt recovery.

3.2.2 Dilute acid scrubber

The dilute acid scrubber is a common choice for abating ammonia at flows of 50 – 500 tonnes a year (industry contacts, 2001). Dilute acid scrubbers consist of a tower randomly packed with tiles, through which the waste gas containing ammonia is passed. Slightly acidic water is re-circulated through the tower over the packing. Ammonia is absorbed until the solution becomes saturated, sulphuric acid being added to neutralise the ammonia:



The ammonium sulphate generated is normally of weak enough concentration to be sent to drain. Pure water scrubbers can be used for very low levels of ammonia

Investment for a flow in the order of several hundred tonnes of ammonia per year is of the order £80,000 for equipment, with additional running costs of around £10,000. The dilute acid scrubber is a versatile technology that can also abate smaller sources at a lower initial cost of £5,000. Barriers to more widespread uptake of this technology include:

- ◆ Limited suitability for higher velocity gas flows.
- ◆ Potentially high effluent treatment costs.
- ◆ Preference for the use of pure water scrubbers for dealing with very low levels of ammonia – replacement with a dilute acid system would be unjustified due to increased raw material consumption (acid) and a more pollutant rich effluent.
- ◆ Safety hazards linked to on-site storage of sulphuric acid.

3.2.3 Regenerative thermal oxidation

The regenerative thermal oxidiser is effectively an ammonia flare that maintains the combustion level required by burning a supplementary fuel. An advantage of this technology is that it destroys ammonia rather than moving it between media. It is also a relatively cost effective solution with an installation cost of around £100,000 (Anguil Environmental). The disadvantages are:

- ◆ The ammonia is converted to NO_x
- ◆ The supplementary fuel required emits CO_2 as the natural gas is combusted in the flame. Gas costs are relatively low, estimated at £1 hour for a typical burner. A 95% efficient heat exchanger minimises the use of supplementary fuel (Anguil Environmental).

3.2.4 Biofiltration

Biofiltration is only suitable for abating low velocity gas flows containing low concentrations of ammonia. The initial investment cost is of the order £15,000 for a system estimated to last 30 years, with a main recurring cost of £2,500 for the replacement of the filter bed every three years. The biofilter is the lowest cost end-of-pipe ammonia abatement method for small point sources. The drawbacks of the biofilter could be considered as follows:

- ◆ They are only suitable for abating ammonia flows in the region of 1 tonne per year (ERG, personal communication, 2001).
- ◆ Anomalously large ammonia flows could pass through with less than optimal abatement (below 90% abatement of ammonia).
- ◆ The low pressures involved may lead to requirement for gases to be blown through a system, with additional energy costs.
- ◆ Poor maintenance of the organic material bed and non-replacement of the filtration media may result in low abatement performance.

3.2.5 Non-evaporative cooling system

In the context of this report, this system is confined to the sugar beet industry. Much of the ammonia lost from sugar beet processing (about 50%) is emitted from evaporative cooling towers that are open to the air (British Sugar, personal communication, 2001). Replacement of these towers with a non-evaporative cooling system and a new effluent treatment plant would cut emission from this stage by almost 100%. This would abate an estimated 75 tonnes of ammonia per plant per year. The costs and drawbacks are as follows:

- ◆ Non-evaporative cooling systems cost about £1million to install, with new effluent treatment plant costing a further £4million.
- ◆ Ammonia from the effluent plant is unlikely to find a market because of contamination.
- ◆ Costs of £2,000 a week are estimated for powering the drying fans (annual operating costs ~ £60,000: British Sugar, personal communication 2001).
- ◆ All of the six plant that will continue to operate are owned by a single company. This, combined with the high cost of the new systems, may slow the uptake of the technology - a penetration of 50% by 2010 has been estimated.

3.2.6 Silage treatment of horse manure

Horse manure is normally disposed via a muck-heap that is unprotected and open to the air. The use of silage bags to contain and degrade the manure into a useful fertilising material is preferable. The barriers to the uptake of this technique are likely to be cost and effluent containment:

- ◆ A conservative estimate of the staff time cost is £500 a year for a stable of 8 horses.
- ◆ The costs of silage spreading and ploughing is estimated at £30 per tonne.
- ◆ Effluent escaping from silage bags needs to be contained. A major barrier for some stables would be having to install a concrete pad with effluent containment system – this would be an additional cost to those identified here.

- ◆ Sources of ammonia from this sector are small and diverse. The penetration of this treatment method by 2010 is assumed to be low at 20% (even after stables with fewer than 4 horses have been excluded) due to problems influencing the uptake of new methods in a traditional industry which has many different types of business, ranging from riding schools to race horses.

3.3 ABATEMENT OPTIONS BY SECTOR

3.3.1 Traffic

3.3.1.1 Petrol-engined vehicles

Significant abatement has been achieved for petrol cars through the use of improved engine management controls. However, the costs of these systems, including on-going improvements, are a consequence of other concerns, for example improved fuel efficiency and control of NO_x and hence are not attributable to ammonia. Full market penetration of advanced engine control units is predicted (Industry, personal communication 2001).

The main option for reducing traffic emissions is likely to be the use of scrappage subsidies to clear older, more polluting, vehicles from the streets. Other options such as promotion of public transport would reduce vehicle use, but seem unlikely to influence emissions significantly. In any event, such options are already being considered under local transport strategies and the air quality action plans that are being developed by local authorities. It may be possible to retrofit vehicles with ammonia control equipment such as a platinum catalyst clean up box, though this option has not been investigated by industry for petrol engined vehicles and may only be possible for diesel HGVs.

No other abatement options for transport specific to ammonia have been identified in the course of this study. This is not surprising given that this pollutant has been given so little attention in the past for this sector. Improved awareness of the problem by the automotive industry may assist in designing out the likelihood of ammonia generation in future vehicles.

3.3.1.2 Diesel-engined vehicles

Ammonia emissions from diesel vehicles may arise as slip from urea or ammonia use in the NO_x control systems that are currently emerging. Companies developing the urea injection system are aiming at 100% conversion of urea in the exhaust and thus 100% abatement of NO_x and ammonia slip. However, due to varying engine conditions, NO_x emissions vary rapidly and it is hard to correlate the urea:NO_x ratio exactly. Over-injection of urea is possible and thus a clean up catalyst will be needed to convert the ammonia slip from the SCR. This will take the form of a platinum catalyst box fitted after the urea injection point, the platinum will oxidise NH₃ to N₂. Ammonia slip is negligible if urea is under-injected. This of course leads to lower NO_x abatement, but eliminates the need for a catalyst. Urea injection is being tested in Germany on trial buses attaining a 50% NO_x abatement level.

Urea injection is only likely to be viable for heavy duty diesel vehicles. NO_x legislation for heavy diesel vehicles will be in place by 2005, leading to limited market penetration of SCR by 2010, the date for compliance with the NECD and Gothenburg Protocol. By 2008 SCR uptake will have increased to 80-90% market penetration for new vehicles. SCR technology is

likely to be aimed at 90% NO_x abatement to reach and go beyond HGV NO_x limits giving effectively zero ammonia slip compared to the 10-15ppm ammonia slip encountered with 100% NO_x abatement levels (industry, personal communication, 2001). The 90% urea injection level system will also include the ammonia clean-up box to control slip. A NO_x sensor will be fitted to produce a feed-back loop to regulate urea injection.

The catalyst in the NH₃-slip clean up box will cost about 0.1% of the cost of a heavy duty truck (around £100). Canning, fabrication and fitting costs would be additional, with a total cost in the region of £140. However, all costs linked to ammonia emissions from diesel-vehicle NO_x control systems are considered here to be outside the scope of the present study, as they are directly related to legislation on NO_x rather than ammonia.

3.3.2 Residential Combustion

There are a number of options for reducing emissions from domestic solid fuel burning. These range from simple measures such as promotion of good practice with respect to fuel selection, maintenance, etc., to measures involving (for example) more advanced appliances and fuel switching.

In homes that use some form of stove, rather than a simple open fireplace there will be the opportunity to optimise older systems. The majority of ammonia is emitted when combustion is inefficient and the stove is not operating at its optimum temperature. Emission optimisation measures would include heat insulation in order for the stove to quickly reach its operating temperature, improved air balance and a flame retaining plate. Here it is assumed that this would result in a reduction of ammonia emissions of about 45%, based on observations on PAH emissions (which are also products of poor combustion conditions, Holland *et al*, 2001). From experience with the Dutch national type approval program for stoves the incremental cost of stove optimisation is 10-15%. At an average production cost of £315, the additional cost of heat optimisation measures would be £40, with no increases in operating costs or energy costs. A certain degree of emission optimisation will result from European regulations on new stoves that might become more relevant in the future. In this case replacement would be considered cost neutral with respect to ammonia control.

A more advanced method of wood burning has been developed that has reduced emissions further. The optimised unit can be automatically controlled and use wood pellets as fuel, the pellets can be fed to the combustor at a precisely controllable rate. It is not clear whether the technology could see large-scale application in the future – market penetration rates would be very slow.

Open fire places could be replaced with optimised stoves in new residential buildings. This could be enforced fairly easily and the cost of £315 for the stove would be acceptable, compared to the cost of a new home or the cost of alternatives. However, there are many barriers to uptake of optimised stoves for houses already constructed with open fires including: aesthetic attraction, costs and change in habit. The range of experience that people have with using real fires in the home is now very varied, given that there is something of a trend for people to start using them once more, after relying on gas and oil central heating and electric fires for the last 40 or more years. Accordingly, many people are now likely to operate their fires inefficiently, and so there is scope for dissemination of best practice for starting, maintaining and extinguishing a fire. Advice for good practice is listed below.

Table 9. Elementary techniques for reducing emissions from domestic solid fuel use.

Optimisation	Best practice
Optimise fuel characteristics	Moisture content, hardwood vs. softwood, use of different types of coal
Lay fire to ensure it lights well and reaches high temperature quickly	Structure of fuel, kindling etc.
Optimising combustion conditions	Clearing ash to improve air flow, ensuring flues are not blocked
Keeping the fire going	Control the size of the fire, Stoking, waste material to add and that to avoid
Putting the fire out	Extinguishing the fire vs. letting it down naturally

A public information campaign would communicate these points through a leaflet mailshot, for example adding material to information supplied by local councils. The impact of a scheme such as this on emission levels is not known, though as emissions from open domestic fires are significant for ammonia, PAHs and PM₁₀, it would appear to be a step worthy of consideration.

The majority of houses in the UK have already switched from domestic fires to central heating using gas or oil as a result of convenience and the Clean Air Act. This is the most effective measure to reduce ammonia emissions from residential combustion. However, there is still predicted to be some burning of coal in 2010 for a variety of reasons, these being:

- ◆ Legal – free coal is supplied to retired miners as a condition of earlier employment.
- ◆ Political – no local legislation to enforce the use of smokeless fuels (e.g. in remote rural areas).
- ◆ Economic – the expense of installing new gas pipelines
- ◆ Geographic – physical barriers to provision of alternative fuels

The first Clean Air Act in 1956 saw the enforcement of regulation on urban domestic fires, with smokeless fuel zones declared and large improvements in urban conditions as a result. However, the trend toward burning wood for aesthetic purposes would be difficult to prohibit, especially in rural areas where air quality is not perceived to be a problem. The costs of prohibition – which are unknown – depend on the price paid by individuals for solid fuels and the price of alternative fuels.

Overall there are several difficulties with this sector. Firstly there is undoubtedly significant variation in emission factors, an issue worthy of further investigation not just in the context of ammonia but also in respect of PAHs and PM₁₀. Then there are the problems that would affect regulation of a large number of dispersed sources using equipment of varying age and condition. However, action here could provide some very cost-effective options for abatement, and would help address other serious issues.

3.3.3 Industrial combustion

As described above, the emissions of ammonia from industrial combustion are low. They are dictated by the type of fuel burnt, the level of control of combustion conditions, and the presence of abatement technologies for other pollutants. These are all typically very well controlled in modern plant, greatly reducing the opportunity for ammonia release, as confirmed

by the data held in the Environment Agency's Pollution Inventory. As a result, no additional abatement options have been identified for this sector.

3.3.4 Landfill

The amount of ammonia generated in landfill could be reduced by either pre-treating the wastes to reduce the degradable content or by reducing the amount of waste landfilled. Both options are a consequence of the Landfill Directive. Alternative disposal routes include composting and incineration as well as control of emissions at landfill sites. Trends in emissions will be driven partly by the waste strategy, though emissions from existing landfill will continue for some time.

Controls put in place to address methane emissions generally have the effect of reducing ammonia as well. These include improvement of the site engineering, collection of gases and burning, either in gas engines or through flaring. The Landfill Directive sets out clear instructions for the control of landfill gas:

'4.2. Landfill gas shall be collected from all landfills receiving biodegradable waste and the landfill gas must be treated and used. If the gas produced cannot be used to produce energy it should be flared.'

The temperature of an open landfill gas flare is between 800 and 1000°C (AEA Technology Waste Team, personal communication 2001). At these temperatures ammonia is readily combusted – it is a fairly combustible gas with ease of combustion similar to that of hydrocarbon oils. Problems will persist at older landfills that are not equipped with these technologies.

Effective capping of sites increases the residence time of ammonia and other gases and thus provides greater opportunity for microbial biodegradation (AEA Technology, Waste Team, personal communication). However, ammonia formed from the break down of nitrogenous wastes mainly goes into solution as it is highly water-soluble. The treatment of ammonia leachate is likely to be done by introducing oxygen and aerobic organisms to the solution (AEAT Waste Team, Personal Communication 2001). Bacteria such as *Nitrobacter* spp. then oxidise the ammonia to nitrate, this process is also a potentially large source of ammonia release to air – a source that has subsequently been overlooked (AEAT Waste Team, Personal Communication 2001).

A site has been built in Hong Kong to burn ammonia stripped from leachate using landfill gas as the fuel for combustion. The leachate contains 265 mg NH₃ m⁻³. This is then concentrated 92,000 mg.m⁻³ and combusted to give a burner output of 47.4 mg.m⁻³. 99.9% of the stripped ammonia is incinerated. Concentrations of ammonia and other gases in the system are shown in Table 10.

Table 10. Concentrations of various gases in the combustion system.

	Burner exhaust	Burner inlet	After ammonia stripper	Directly reduced emission by conc (%)
Methane (% v/v)	<0.002	50.1	5.9	100.0
Carbon dioxide (% v/v)	19.4	28.0	13.6	n/a
Oxygen (% v/v)	69.0	12.5	214.8	n/a
Nitrogen (% v/v)	340.5	57.4	893.1	n/a
Carbon Monoxide (% v/v)	<0.08	<0.03	<0.20	n/a
Flammable gas (% v/v)	<0.03	50.1	6.0	99.9
Vinyl Chloride (ppmv)	<0.002	0.2	<0.01	98.8
Benzene (ppmv)	<0.002	0.1	<0.01	98.3
NMOC (ppmv C)	0.2	1251.6	600.0	100.0
Nitrogen Monoxide (mg/m ³)	9.5	0.3	3.7	n/a
Nitrogen Dioxide (mg/m ³)	17.2	0.3	3.8	n/a
Nitrous Oxide (mg/m ³)	26.7	0.7	7.6	n/a
Ammonia (mg/m³)	47.4	265.0	91572.6	99.9

Source: Organics - Landfill technology company



Figure 15. Ammonia burner, using landfill gas to combust the ammonia. Source: Organics (landfill technology company) – Personal Communication

3.3.5 Municipal Solid Waste incineration

Like a number of other sectors, much of the ammonia emitted from MSW incineration is linked to ammonia slippage from NO_x abatement. Various options are identified for control.

Scrubbing NH₃ slip. The amount of ammonia required for NO_x abatement of 90% will produce slip of around 40 mg.m⁻³. Typically 90% of this slip can be abated by wet or dry scrubbing, leaving 4 mg.m⁻³ in the plume (IPC Incineration Guidance 1996).

Effective system control. There is a narrow temperature range of 870-950°C for effective injection of ammonia, outside this range NO_x abatement decreases and ammonia slip increases. Injection points should clearly be positioned to ensure the optimum temperature range under different load conditions.

Minimising NH_3 slip from SCR. End of pipe ammonia emissions from SCR are not influenced by the choice of urea or ammonia for the feedstock (industry, 2001, personal communication). Switching from ammonia to urea would therefore not reduce emissions at that stage, though clearly the fugitive emissions of ammonia would be higher when handling ammonia. Correlation of ammonia/urea injection with NO_x levels minimises slip, though is difficult given the variable quality of fuel for incinerators, creating a possible demand for more sophisticated feedback controls.

Methane addition (future technology) Excess ammonia (slip) can be converted to nitrogen and water by the addition of methane to the combustion gases. However, this method is not yet commercially proven (IPC Incineration Guidance 1996).

3.3.6 Composting

Zeolites can be used to trap excess nitrogen and are being tried on a pilot basis in a centralised composting facility in the USA. The zeolite most commonly used to trap ammonium ions in wastewater treatment is clinoptilolite. A reduction in ammonium ion concentration also reduces the NH_3 concentration proportionally as the two forms adjust to a new equilibrium. The use of lime to regenerate zeolite should be avoided, as it liberates any ammonia present (Richard, 2000).

Biofiltration at centralised facilities is effective at treating all odours associated with composting, including ammonia and amines. A biofilter (see Figure 16) fitted to a source of ammonia, such as the air flow from a contained compost facility, uses moist organic materials to absorb and biologically degrade ammonia and other odorous gases. Cooled and humidified compost process air is injected through a grid of perforated pipes into a bed of filtration media. Various materials can be used in the biofilter, such as compost, soil, peat, chipped brush and bark, sometimes blended with an inert material such as gravel to increase porosity. The depth of the biofilter is between 1 and 1.5 m.

Biofilters are recommended for flows containing up to 1 tonne of ammonia per year (ERG, personal communication, 2001). Installation costs are about £15,000, with a recurring yearly cost of around £1,000.

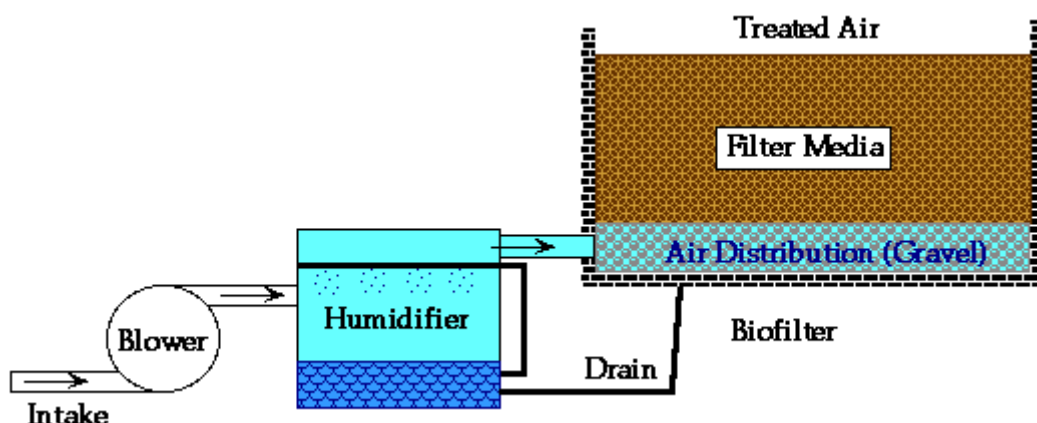


Figure 16. Biofilter (Source: Cornell Composting, 2000).

Another option for controlling emissions is through control of the carbon/nitrogen ratio, for which the ideal is 30:1 by weight. At lower ratios excess nitrogen is lost as ammonia gas and at higher ratios there is insufficient nitrogen for optimal growth of the microbial populations, so compost remains cool and degrades slowly. High nitrogen materials are green and moist whilst high carbon materials are brown and dry. Table 11 gives the C/N ratios for some household wastes.

Table 11. Carbon/nitrogen ratios for various composted materials. Source: Richard (2000).

Materials high in carbon	C:N
Autumn leaves	30-80:1
Straw	40-100:1
Wood chips or saw dust	100-500:1
Mixed paper	100-130:1
Newspaper or corrugated cardboard	150-200:1

Materials high in Nitrogen	C:N
Vegetable scraps	15-20:1
Coffee grounds	20:1
Grass clippings	15-25:1
Manure	5-25:1

An alternative to composting is the use of aerobic digestion, which produces biogas for energy recovery and digestate - solid and liquor high in nutrients that can be used as a liquid fertiliser or treated as sewage (Bates *et al*, 1999). The growth in composting and digestion plants will increase in the next 20 years due to the diversion of biodegradable municipal waste from landfill. The number of plants of the two types of treatment is modelled to increase from around 10 (1998) to between 65 (0% waste growth) and 125 (3% waste growth) in 2020 (Burnley *et al*, 1999).

3.3.7 Sewage treatment and disposal

One of the main options for control of emissions from sewage treatment works is the use of dilute acid scrubbers. The cost of a dilute acid scrubber depends on gas volume, size of equipment required and concentration of ammonia in the gases emitted. The following information has been supplied by ERG Environmental Equipment Suppliers and relates to a system that they have fitted for a major water company.

- ◆ Gas is emitted at 6000m³ per hour.
- ◆ Concentration of ammonia in the gas = 100 mg.m⁻³.
- ◆ Scrubbing package approximate costs = £80,000 (includes pumps, excess steel work, sulphuric acid storage tank).
- ◆ Operating costs: mainly power usage by pumps and costs of chemicals used.
- ◆ Power: 15kW power used, scrubbers operates 24 hours a day (constant).
- ◆ Operator costs: ~0.75 days a week to check pH probe, pump seals, maintain acid supply.

- ◆ Raw material costs: 20% sulphuric acid solution – 2 litres per hour used, £100 per tonne (£0.1 per litre) of solution delivered (£1,747 per year for 17,472 litres sulphuric acid solution).
- ◆ Maintenance costs: 10% of original cost of plant in total ~£8,000 over life of plant.
- ◆ Lifetime of plant: 20 year scrubber life.
- ◆ 99.9% abatement of ammonia achieved.

Small wet scrubbers, costing around £5,000 are also used for controlling emissions from storage tanks during refilling. The technique is technically applicable to any facility where ammonia is stored – it is not an option for the sewage treatment industry alone. There is a fairly high demand for the installation of scrubbers for storage tanks at present (AGM, Environmental Equipment Supplier, personal communication, 2001).

Another option is the use of activated carbon. The activated carbon is impregnated with citric acid and then ammonia is absorbed into the carbon until all the acid has been neutralised – the carbon is then removed for regeneration and new activated carbon is used to replace it (ERG, personal communication, 2001). The cost of using activated carbon is high - installation costs are around £30,000 and recurring yearly costs are up to £80,000 for replacing the carbon and maintenance, for capture of only about 4 tonnes of ammonia per year (ERG, 2001 Personal Communication). This option has not been included in the cost curve development below.

Peat and heather filters are used to abate ammonia emissions from smaller sources such as livestock slurry emitting low levels of ammonia. These biological filters may also contain wood bark. Pig farms often use biological filters (ERG, Personal Communication 2001). This option, significantly cheaper than activated carbon, is described in more detail under composting, above.

Venturi scrubbers can be used for gas cleaning at sewage sludge incinerators. The annualised cost of Venturi scrubbers has been estimated at £800,000 per year (industry, personal communication, 2001), this is discussed in the context of abatement from fertiliser plant. Increased pollution control for sewage sludge incinerators under IPPC is likely to curb the growth in ammonia emissions from this source, though there is no limit on NH₃ emissions in the Incineration Directive (see incineration trends section).

3.3.8 Sugar beet processing

Control of emissions from evaporative cooling towers was described above in Section 3.2. Emissions from this stage could be abated by almost 100%, with a non-evaporative cooling system costing £5million to install, including the necessary effluent treatment plant. Added to this are energy costs of around £60,000 annually (British Sugar, personal communication, 2001). A 50% technology penetration (e.g. at three out of the six plants likely to operate in the UK by 2010) would provide an emission reduction of 225t ammonia. The technology penetration would depend on the pressure applied to the industry by stakeholders and through legislation. As the drivers are external to the sector, the uptake of this solution is difficult to predict, particularly given the level of investment required. British Sugar currently predict a maximum of two plant being converted by 2010.

3.3.9 Fertiliser production

The main option for the fertiliser industry is likely to be the use of Venturi scrubbers (see Section 3.2). Details specific to the fertiliser industry are as follows. At present there is a low uptake of the Venturi scrubber in fertiliser plants (ABB Environmental, personal communication). However, IPPC requirements will mean that the scrubbers will have to be fitted to one plant that currently emits 1,600 t/yr of ammonia – it is unknown whether other plants will need to install the Venturi under IPPC.

The operational and maintenance costs relating to environmental control as a whole can be 10-20% of the total production costs. According to the European Fertiliser Manufacturers Association (EFMA), the initial cost of the pollution control equipment for ammonium nitrate production can be 10-20% of the total cost of the plant. The retrofit costs of abatement between plants vary by a factor of 2-3 (Environment Agency – Technical Guidance Manager, personal communication, 2001). This variation can be explained by differences in the equipment already present on site, plant geometry, availability of space at existing works for additional facilities, and so on.

The Venturi scrubber is not suitable for all plants as it requires a lot of energy, a high pressure drop and a high gas flow rate to make it a practical abatement technology. The packed tile scrubber (as described for ammonia abatement in the sewage industry) will be more suitable for smaller plants. In the costs analysis, the Venturi Scrubber is applied to plants emitting above 500t.y⁻¹ ammonia and the packed tile acid gas scrubber (Section 3.2.2) is applied at plants emitting below 500t.y⁻¹, this decision was based on the communications with industry discussed above. Glass fibre candles are also used in the scrubbing of ammonium nitrate from small fertiliser production plants, they also abate ammonia though would not be installed solely for this purpose.

3.3.10 Cement industry

As discussed above, the ammonia is emitted in the kiln flue gases and may form the ammonium chloride salt. Options for abatement include glass fibre candles and water scrubbers. There are a number of plants that already have this latter technology for abatement of a number of pollutants (Environment Agency, Brierley B, personal communication, 2001). Whilst water scrubbers will capture the majority of the ammonia emitted from the process, it is unknown how effective they would be at abating the ammonium salts that are a more significant emission to air.

Some ammonia slip may arise through NO_x control, for which the main abatement option is proper control of the SCR and SNCR processes. This is not likely to be a problem in the UK.

A more detailed assessment of the source of ammonia may reveal that it is emitted mainly from the ammonia captured in the raw material. Choosing a low ammonia and ammonium salt input to the process would therefore reduce emissions perhaps at little or no cost.

3.3.11 Sodium ferrocyanide manufacture

At the Degussa Huls plant, Manox House, Manchester, vapours are removed by an extraction fan and passed through a water scrubber which is approximately 90% efficient at removing

ammonia. An acidified scrubber would be more efficient at removing ammonia, but the plant is unlikely to install one as it would cause an acid handling safety hazard, and because of the costs involved (in the region of £50,000 for purchase and installation). 99% abatement could be achieved using this approach. The existing water scrubber is more economical for the plant and uses recycled grey water. This grey water would need treatment if it were to be used in an acidified scrubbing system (Degussa Huls, personal communication 2001) adding to costs.

3.3.12 Chromium chemicals manufacture

Elementis Chromium Ltd. are likely to fit a dilute acid scrubber that will abate 99% of the ammonia passing through the stack.

3.3.13 Other parts of the chemical industry, including petrochemicals and pharmaceuticals

Regenerative thermal oxidation is likely to be the main method used by other parts of the chemical industry (see Section 3.2.3). Running costs for these systems are low as 95% of the heat is recovered. Gas costs for combusting 3kg NH₃ per hour (6500 m³ per hour exhaust flow) are about £1 per hour (Anguil Environmental Europe, personal communication, 2001). More gas to fuel the process would be required if there were larger quantities of ammonia present. This technology is suitable for exhaust flows of 400 – 80000 m³ per hour.

Industries where it has been used to abate ammonia include:

- ◆ Oil and gas industry
 - ◆ Pharmaceutical industry
 - ◆ Land reclamation (burning off landfill gas)
 - ◆ Sterilising processes
 - ◆ Any industry where ammonia is a by-product
- (Source: Anguil Environmental Europe, Personal Communication 2001)

The oxidation system can be up to 99% efficient at abating ammonia, though at present, the installations normally aim for abatement for compliance with regulation.

3.3.14 Coke manufacture

IPC Guidance on Coke Production describes BAT for reducing fugitive emissions. The guidance stipulates that coke oven gas leakage must be below 1% for leakage from the oven doors and 1% from the oven lids. 'Pushing emissions', which arise when the coke is removed from the oven are described below. Recent developments in low emission technology have reduced ammonia releases to air at this stage to below 0.2mg/m³. In comparison emergency venting allows 30 mg/m³ of ammonia to air when venting storage tanks, but this is a low frequency event and thus not a major emission source. Further abatement options from existing plant are extremely limited, as the problems of cokeries are well known particularly in relation to emissions of PAHs (polycyclic aromatic hydrocarbons). Indeed, further investigation of BAT in this area may be prompted by the forthcoming Directive on PAHs, a draft of which is expected later this year. PAH emissions from cokeries lead to very high local hotspots

BAT for the sector covers the following (S2 1.06, 1995):

Oven doors:

- ❑ effective insulation of door and frame to prevent heat distortion.
- ❑ sealing surfaces should be maintained in clean condition by water jet/mechanical cleaning when a door is removed.
- ❑ doors should be regularly maintained in a repair bay.
- ❑ action should be taken to avoid leaks resulting in flames around doors (this accelerates thermal distortion and thus deterioration).
- ❑ door leakage should be below 1% (Door leakage control factor 99%).

Oven top lids:

- ❑ Charge hole rims and lids should be kept clean to prevent leakage.
- ❑ Ascension pipes were a source in the past – the use of water-sealed caps minimises this problem.
- ❑ Tops leakage should be below 1% (99% Tops leakage control factor)

Charging emissions:

- ❑ Charging of coal to coke oven is best done on the main (i.e. with the oven connected to the gas collecting main)

Pushing emissions:

- ❑ *Recent low emission technology:* connect coke oven to a steel container of the same shape and push the coke into it as an integral cake, this is then withdrawn from battery and cooled (IPC emission must be below 0.2mg.m^{-3}).

Emergency Venting:

Emergency venting should be minimised – the vent should be flared, with releases kept below 30mg.m^{-3} .

Overall, it is unlikely that the sector will be required to adopt measures specifically for ammonia abatement (Environment Agency, I. Taylor, personal communication 2001). Problems from other pollutants cause more concern, and will drive further action to reduce emissions. However, it is difficult to see what might be done beyond the current level of BAT for existing plant.

3.3.15 Mineral Fibre processes

The most cost effective option for this sector is to fit a dilute acid scrubber to the flue gas stream. It is also possible to fit a scrubber to the storage tank to abate ammonia emissions from venting, etc. Improved bunding may also be necessary.

3.4 HOUSEHOLD PRODUCTS

The average ammonia content of floor cleaning solution is assumed to be 10% (Sutton *et al*, 1999). Use of alternative products containing less ammonia could be encouraged in order to abate emissions. However, the impact is difficult to predict and the uptake hard to measure. More research into viable alternatives would be required.

3.5 HORSES

Ammonia is produced in both anaerobic and aerobic conditions. More ammonia is emitted if straw is wet, saturated with excreta or in cases where there is insufficient straw. The first step towards abatement is therefore to make sure there is enough straw to soak up urine and to cover manure. This reduces the surface area available for emission to air. The second step is to muck out the stable as regularly as possible. In good livery yards this is done once a day at present but best practice needs to be followed in all stable types from professional to domestic.

Investigation of IPPC for pigs and poultry suggests the following (Environment Agency, personal communication, 2001):

- ◆ Moisture content should be kept below 40% (over 60% dry bedding).
- ◆ Methods should be used to ensure that bedding is kept as dry as possible. Ventilation should be good, opportunity for spillage of water from drinkers onto bedding should be minimised
- ◆ Keep as high a straw content as possible

Manure from mucking out is typically dumped on a heap outdoors, exposed to rain and the air. Modifying the heap to reduce the surface area will help to reduce ammonia emission – a pyramid shape is recommended. If the manure were to be put in a covered slurry tank then emissions could be contained and passed through an ammonia abatement technology such as a simple biofiltration bed, a diagram of this is shown in Figure 16.

Another way to deal with manure is to treat it as silage and contain the emission by wrapping in silage plastic and storing it. It can then be spread on the land and (to reduce the potential for emission) ploughed in immediately. Abatement of 80 –90 % is possible if manure is thoroughly incorporated into the earth shortly after application (IGER 2001). Field injection is not possible because of the high solid content of the manure (30-35%).

The costs involved in silage treatment are:

- Purchase silage plastic – silage bags £11.30 for 10 bags 88 x 120 cm
- Or silage sheet 4 x 25m £8.95 for a large heap of manure (Mole Valley Suppliers)
- Staff time for manure containment
- Optional costs of installing a concrete pad with a simple leachate collection system
- Cost of spreading and ploughing silage into land

3.6 DEVELOPMENT OF THE COST CURVE

The costs and efficiencies of the main abatement technologies identified in Section 3.2 are summarised in Table 12.

Table 12. Ammonia abatement technology costs and application range

Technology applicable	Biofilter (AGM)	Regenerative thermal oxidiser (Anguil Environmental 2001)	Dilute acid - wet scrubber (ERG)	Venturi scrubber - large gas flows (ABB Environmental and Kemira Agro)
Ammonia emission (tonnes)	0.01 - 2	2- 50	50 - 550	Over 500
annualised cost (£/year) 6% DR	1,291	15,197	16,839	706,698
Range of costs	800 - 2,000	10,000 - 20,000	14,223 - 22,070	606,523 - 868,077
Abatement efficiency (%)	96.5	98	99	90
Range of efficiency (%)	90 - 97.5	70 - 99	94 - 99.9	85 - 92

From discussion with industry it was clear that the application range for amount of ammonia each technology could abate was in the order Venturi scrubber > Packed tile scrubber > Regenerative thermal oxidiser > biofilter (Table 12). The borders of the abatement boundaries listed in the table may cross, though the designation to different ammonia emissions is as accurate as the industrial survey permitted.

The data required to calculate the cost of abatement in £/tonne for each industrial sector and sources of information are:

- 1) The number of plant in each sector (Pollution Inventory)
- 2) The ammonia emissions of the plants, estimated for 2010 (Pollution Inventory)
- 3) The annualised cost (£/year) of abatement technology (Industrial contacts)
- 4) The efficiency of the abatement technology (% NH₃ abated) (Industrial contacts)
- 5) Technology penetration by 2010 (Industry and expert opinion)

The cost curve was constructed for 2010 in order to predict the maximum feasible reduction possible from ammonia abatement technology and the costs incurred. The equation used to calculate the average cost per tonne abated for each sector is shown above.

The potential penetration of the technology into the market was incorporated into the cost curve after the cost per tonne had been calculated.

Uncertainty in inputs for the cost curve have been quantified by first developing ranges for each of the parameters used, based on manufacturers' predictions, the reporting uncertainty in the Pollution Inventory and the literature and research on which emission levels for 2010 were based. These uncertainty ranges were wide as they incorporated:

- a) Prediction of ammonia emissions for 2010
- b) The difference in costs when applying the same technology to different plant sizes and types
- c) The uncertainty in market penetration of the technology.

The shape of the probability distribution has also been estimated. These data are brought together using the @RISK programme, which uses Monte-Carlo techniques to describe the uncertainty in the study results, typically in the form of a 95% confidence interval.

Table 13 summarises the data that were used to generate the cost curve, using the @RISK programme. The sectors are divided into broad size bands, according to ammonia emission at each plant, in order to assign the correct abatement technology. The emission for 2010 was predicted, with a suitable range to account for the uncertainty – the @RISK model then used

the three points to calculate the most probable emission in 2010. The number of plants in the UK in 2010 is also predicted, with a range, based on the plants in the Environment Agency's Pollution Inventory and the trends in growth for each sector. The annualised cost per plant was calculated using a 6% discount rate, a range to account for cost variation with plant size etc. was also recorded. The effectiveness of the abatement technology is included in the table, this is based on manufacturers quotes, as is the range. To estimate the likely technology penetration by 2010, the number of plants involved was considered, and the potential barriers that were sector specific. For example, the penetration of horse silage treatment is estimated to be low at 20 % as it will be difficult to implement in the estimated 56,000 stables in the UK of diverse nature from private use to riding schools and race horses. The broad ranges for this estimate account for the unpredictable nature of technology uptake. Finally, Table 13 gives the emission reduction likely in each sector and thus the maximum feasible reduction, this is discussed in greater detail in the results section 3.7.

There is a need to consider the extent to which a single cost-curve represents 'the truth'. In reality there is frequently a need to consider factors that are mutually exclusive. It is also desirable, for the sake of transparency, not to make the modelling work too complex. So, for example, here we have considered the technology penetration level calculated as the most probable by the @RISK package. Still to be completed are the sensitivity analysis on high and low emission scenarios, and on scenarios featuring high and low penetration rates for abatement technologies.

The method for calculating the maximum feasible reduction for the most probable technology penetration scenario is described below:

- ◆ The @RISK software package was used to calculate the most probable value for each category (e.g. for annualised cost and number of plants)
- ◆ The cost per tonne of abatement for each sector was calculated (Equation 1), and then the potential emission reduction for that sector was calculated:

$$\text{Potential emission reduction} = \text{Effectiveness of abatement technology} \\ \text{(@RISK prediction)} \times \text{Predicted market penetration} \\ \text{(@RISK prediction)} \times \text{emission of sector (@RISK} \\ \text{prediction)}$$

This enabled the maximum feasible reduction in emissions in 2010 to be found, with the total cost for each sector: these results were used to plot the cost curve.

Table 13. Input data for @RISK estimation of the cost-effectiveness of options for non-agricultural ammonia abatement. Projections of emissions and percentage technology penetration to 2010 and calculated emission reductions for 2010.

Sector title	Fertiliser	Fertiliser	Mineral fibre processes	Mineral fibre processes	Chem industry organic chemicals	Chem industry organic chemicals	Inorganic chemical processes	Inorganic chemical processes
<i>Sector</i>	large emission plant > 500t	small emission plant < 500t	50 - 100 t	10 - 50 t	2 - 50 t	0.1 - 2 t	50 - 300 t	2 - 50 t
2010 Emission by sector best estimate (t)	1,500	15	332	15	30	1	359	166
2010 Emission by sector range(t)	500 - 2,000	10 - 20	150 - 350	12 - 18	10 - 100	0.1 - 8	200 - 550	100 - 250
Number of plant in UK best estimate	2	4	4	1	17	5	2	14
Number of plant in UK range	1 - 2	4 - 5	4-8	1	1 - 28	3 - 9	2-3	12 - 16
Technology	venturi scrubber	dilute acid scrubber	dilute acid scrubber	regenerative thermal oxidation	regenerative thermal oxidation	biofilter	dilute acid scrubber	regenerative thermal oxidation
Annualised Cost / plant (£ per plant) best estimate	706,698	16,839	16,839	15,197	15,198	1,291	16,839	15,198
Annualised Cost / plant (£ per plant) Range	606,500 - 868,100	14,223 - 22,070	14,223 - 22,070	10,000 - 20,000	10000 - 20,000	800 - 2,000	14,223 - 22,070	10,000 - 20,000
Effectiveness best estimate (%)	90	99	99	98	99	97	99	99
Effectiveness range (%)	85 - 92	94 - 99.9	94 - 99.9	70 - 99	71 - 99	90 - 97.5	94 - 99.9	71 - 99
Technology penetration (% of plants)	100%	80%	70%	50%	50%	50%	100%	50%
Range of technology penetration	0 - 100%	20% - 90%	20 - 90%	10 - 70%	10 - 70%	10 - 70%	50 - 100%	10 - 70%
Emission abated (kt) Best estimate	890	9	194	6	12	0	292	65

Table 13 continued: Input data for @RISK estimation of the cost-effectiveness of options for non-agricultural ammonia abatement. Projections of emissions and percentage technology penetration to 2010 and calculated emission reductions for 2010.

Sector title	Coating processes and printing	Chemical Industry - Acid processes	Chemical Industry - Acid processes	Chemical Industry - Acid processes	Sewage treatment	Sugar beet processing	Horses	
<i>Sector</i>	all plant	50 - 200 t	2 - 50 t	0.1 - 2 t	anaerobic digestion and lime drying	all plant	horses in stables of 4 or more animals	
2010 Emission by sector best estimate (t)	27	150	15	5	1,457	900	6,500	
2010 Emission by sector range(t)	18 - 35	80 - 180	8 - 20	4 - 6	800 - 4,000	600 - 1,000	3,000 - 8,000	
Number of plant in UK best estimate	2	1	2	3	1,500	4	56,000	
Number of plant in UK range	2 - 3	1	2 - 3	2-4	1,000 - 3,000	2 - 6	10,000-70,000	
Technology	regenerative thermal oxidation	dilute acid scrubber	regenerative thermal oxidation	biofilter	dilute acid scrubber	non-evaporative cooling system + effluent treatment plant	silage treatment + spreading	
Annualised Cost / plant (£ per plant) best estimate	15,198	16,839	15,198	1,291	16,839	447,900	800	
Annualised Cost / plant (£ per plant) Range	10,000 - 20,000	14,223 - 22,070	10,000 - 20,000	800 - 2,000	14,223 - 22,070	250000 - 60,0000	400 - 2,000	
Effectiveness best estimate (%)	99	99	99	97	99	97	80	
Effectiveness range (%)	71 - 99	94 - 99.9	71 - 99	90 - 97.5	94 - 99.9	95 - 100	50 - 90	
Technology penetration (% of plants)	50%	100%	100%	50%	50%	50%	20%	
Range of technology penetration	0 - 100%	0 - 100%	0 - 100%	10 - 70%	30 - 70%	20 - 80%	10 - 40%	MFR
Emission abated (kt) Best estimate	16	98	7	2	711	438	1,112	3,852

3.7 RESULTS

Results are shown in the following tables and figures, showing estimated cost-effectiveness of abatement and identifying the parameters that cause the greatest uncertainty in estimates. The full output data from the @RISK package are summarised in Table 14.

The maximum feasible reduction (MFR) is 3.9kt in 2010, calculated with the @RISK technology penetration value (taken from best estimate for penetration in 2010). The MFR is 8% of the predicted 50.5kt total for 2010.

The most cost effective ammonia abatement measures are to fit dilute acid packed tile scrubbers to plants in the Inorganic Chemical Process Industry, the Acid Processes Chemical Process Industry and the Mineral Fibre Process industry. The plants where it would be economical to fit the dilute acid scrubber have yearly ammonia emissions between 50 and 300 tonnes and are assumed to have flue gases at a medium flow rate. The cost of abatement per tonne for these three sectors is between £118/t and £361/t. The technology penetration by 2010 in these sectors for this scenario is between 60% and 83%, giving a maximum feasible reduction at 584 tonnes.

The next most cost effective technology, would be to fit a biofilter to plants with low ammonia emissions in the acid processes sector, although this would yield a small total abatement of 2 tonnes ammonia.

Table 14. Marginal cost of options for reducing emissions of ammonia from non-agricultural sources.

Sector title	Plant category (by emission size)	1999 Emission best estimate (t)	Technology	Cost/t abated (Best Estimate) (£/t)	@RISK 5% C.I. (£/t)	@RISK 95% C.I. (£/t)	Calculated potential emission reduction (t)	Calculated cost of abatement (£)	Calculated cost of abatement 5% (£)	Calculated cost of abatement 95% (£)	Cumul. emissions abated (t)	Cumul. cost of abatement (£)
Inorganic chemical processes	50 - 300 t	359	Dilute acid scrubber	110	80	180	292	33,400	23,000	51,900	292	33,400
Chemical Industry - Acid processes	50 - 200 t	97	Dilute acid scrubber	130	100	190	98	13,000	9,900	18,300	389	46,400
Mineral fibre processes	50 - 100 t	332	Dilute acid scrubber	350	230	560	194	67,800	45,300	109,700	584	114,200
Chemical Industry - Acid processes	0.1 - 2t	4	Biofilter	860	560	1,260	2	1,800	1,100	2,600	586	116,000
Fertiliser	plant>500t/y	2,100	Venturi scrubber	1,020	660	1,840	890	908,900	583,800	1,639,400	1,476	1,024,900
Mineral fibre processes	10 - 50 t	15	Regenerative Thermal Oxidation	1,130	830	1,510	6	6,500	4,800	8,700	1,482	1,031,400
Inorganic chemical processes	2 - 50 t	165	Regenerative Thermal Oxidation	1,370	920	2,020	65	88,300	59,700	130,500	1,546	1,119,700
Coating processes and printing	all plant	27	Regenerative Thermal Oxidation	1,470	990	2,120	16	23,900	16,000	34,400	1,563	1,143,600
Sugar beet processing	all plant	900	Non-evaporative cooling + effluent treatment	2,130	1,300	3,270	438	934,500	570,300	1,433,800	2,001	2,078,100
Chemical industry - organic chemicals	0.1 - 2 t	6	Biofilter	2,610	1,030	12,520	0	1,100	400	5,300	2,001	2,079,200

Table 14 (continued).

Sector title	Plant category (by emission size)	1999 Emission best estimate (t)	Technology	Cost/t abated (Best Estimate) (£/t)	@RISK 5% C.I. (£/t)	@RISK 95% C.I. (£/t)	Calculated potential emission reduction (t)	Calculated cost of abatement (£)	Calculated cost of abatement 5% (£)	Calculated cost of abatement 95% (£)	Cumul. emissions abated (t)	Cumul. cost of abatement (£)
Chemical Industry-Acid processes	2 - 50 t	10	Regenerative Thermal Oxidation	2,740	1,780	4,300	7	18,400	12,000	28,900	2,008	2,097,600
Fertiliser	plant<500t	18	Dilute acid scrubber	5,240	4,030	7,140	9	48,600	37,300	66,300	2,017	2,146,200
Chemical industry - organic chemicals	2- 50 t	152	Regenerative Thermal Oxidation	5,520	1,840	15,740	12	64,400	21,400	183,400	2,029	2,210,500
Horses	stables of 4 or more horses		Silage treatment + spreading	11,300	4,160	23,510	1,112	12,572,400	4,624,100	26,151,700	3,141	14,783,000
Sewage treatment	anaerobic digestion and lime drying	2,323	Dilute acid scrubber	15,950	580	3,280	711	11,341,300	409,700	2,329,400	3,852	26,124,200
Total											MFR	Total cost

The Venturi Scrubber technology applied to the fertiliser plant emitting a high volume of flue gases containing high concentrations of ammonia is the 5th most cost effective abatement technique at £1021 per tonne. The technology requires a large investment with an annualised cost of over £700,000 y⁻¹ over a technology lifetime of 20 years. However, the cost per tonne is fairly low as a large tonnage of ammonia could be abated – with a maximum feasible reduction (MFR) of 1,476 tonnes. There is a high degree of uncertainty with regard to IPPC and the implementation of this technology. By 2004 it is a possibility that Venturi scrubbers will be fitted in a plant contacted, due to IPPC, though this could not be confirmed. As a result this is included in the cost curve as it is not definitely an IPPC technology.

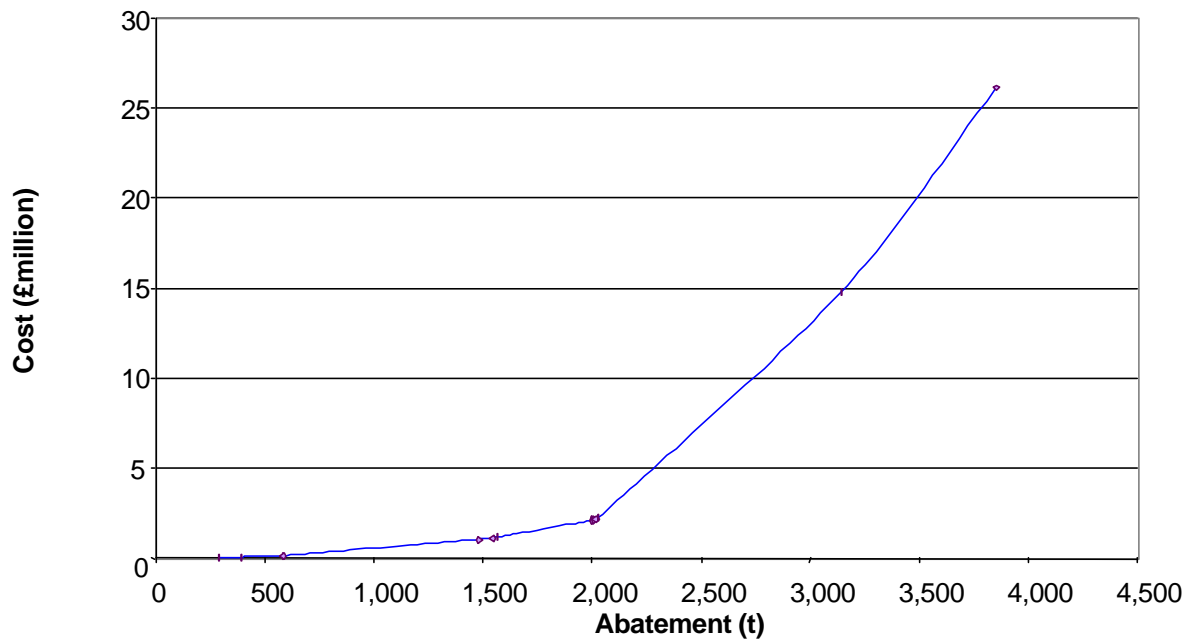


Figure 17. Cost-curve for abatement of non-agricultural sources of ammonia in 2010.

The cost curve shows the large increase in cost for abatement in the sectors with large emissions: sewage treatment and horses. The cost for horses is £11,300 t⁻¹, this is high because of the huge numbers of stables involved ~56,000 (10,000 – 70,000), and the small emission per stable (~8 tonnes ammonia). The cost for abatement in the sewage treatment industry is also high at £15,950 t⁻¹ due to the large numbers of plant (~1,500) involved. There is a significant break in the cost curve, at ~2,000t abatement level, between the points that refer to sectors with a small number of point sources and those with a large number which are horses and sewage. Significant abatement can be achieved by the end of pipe measures discussed above, for example in the fertiliser industry, though this still requires large investments.

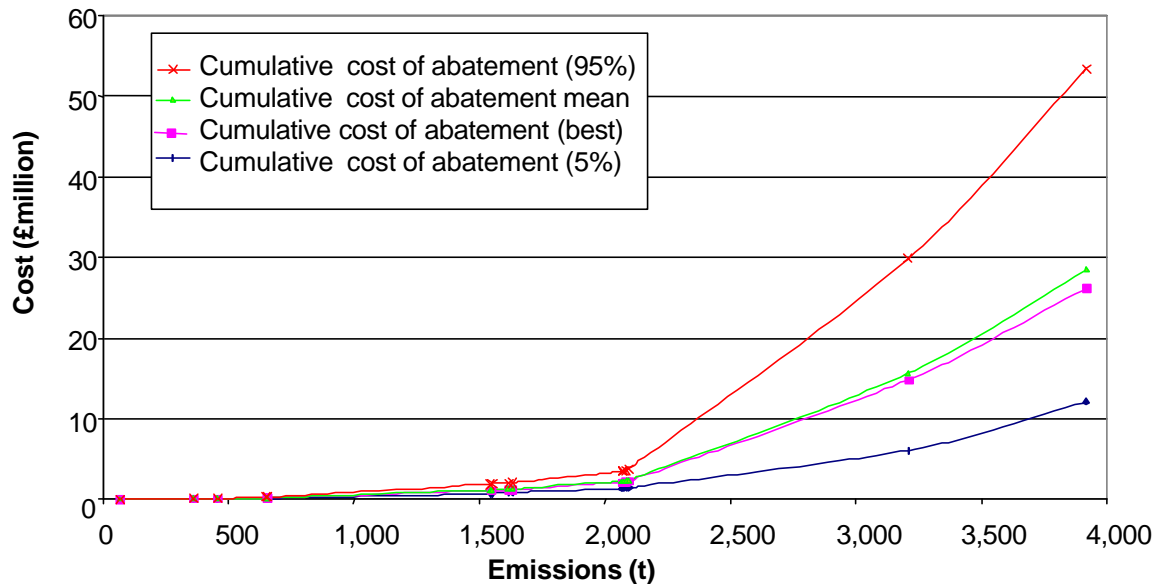


Figure 18. Uncertainty in the non-agricultural cost curve for 2010.

The @RISK package was used to perform a Monte Carlo probability analysis on the cost of abatement to produce boundaries around the cost curve representing the 5% and 95% confidence intervals – the actual cost curve has a probability of 90% of lying between the upper and the lower curves in Figure 18. The significant increase in cost of the 95% confidence interval reflects the high uncertainty in the upper range for the abatement costs, caused by variation in plant size and modification of the technology required affecting the costs in an unpredictable manner.

There is a great deal of uncertainty in the data input for the cost curve. The most sensitive value inputted for each sector division has been calculated using @RISK, shown in Table 15. Not surprisingly, the most uncertain data value is the emission from each sector, this is mainly due to the uncertainty in the emission factor used to calculate the value and the uncertainty in predicted the emission in 2010. More testing of ammonia levels and accurate emission factor calculation is urgently needed to reduce uncertainty in current and future emission estimates.

Table 16 ranks the 5 most uncertain values used as data input for the cost curve, with rank 1 as the most uncertain point. Where there are a small number of plants in the sector e.g. 2, uncertainty bands of 0-2 are highly significant. It is difficult to predict whether the small number of plants will still be operating in 2010 in the changeable climate of the UK industry at present.

There is a great uncertainty in the number of plant for sewage treatment that will exist in 2010. The last survey was conducted in 1996 – 1997 and many variables affecting the trend make changes difficult to predict for 2010.

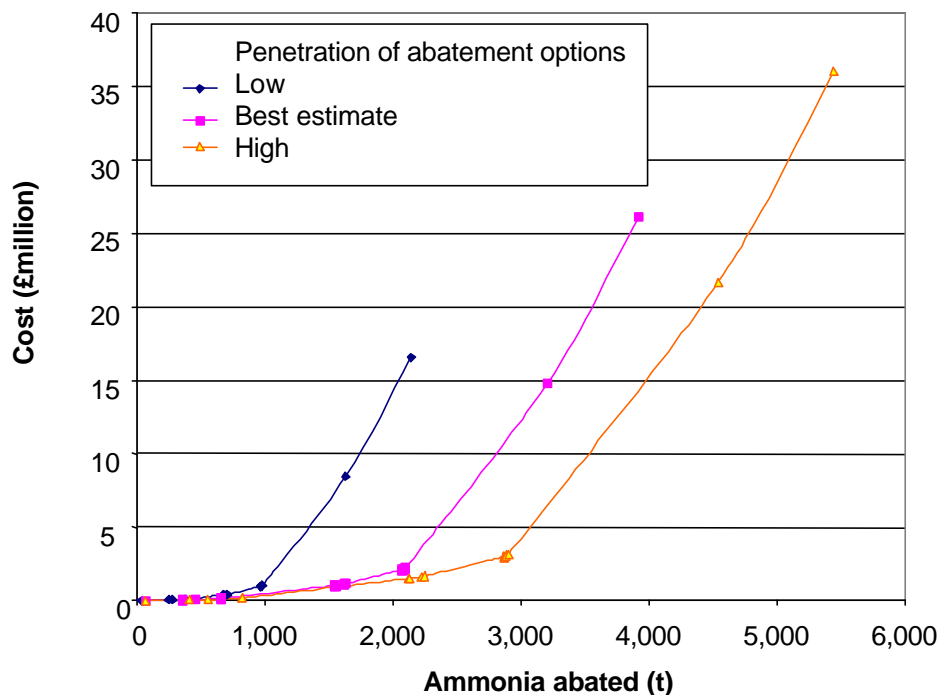
Table 15. Key sensitivities in assessment of each option.

Sector title	Technology	Key source of uncertainty
Coating processes and printing	Regenerative Thermal Oxidation	Annualised cost per plant
Fertiliser	Venturi scrubber (large flow, lg emission)	Emission by sector
Fertiliser	Dilute acid scrubber (medium flow, sml ammonia)	Emission by sector
Inorganic chemical processes	biofilter	Number of plant in UK
Inorganic chemical processes	Dilute acid scrubber (medium flow, med ammonia)	Emission by sector
Inorganic chemical processes	Regenerative Thermal Oxidation	Emission by sector
Mineral fibre processes	Dilute acid scrubber (medium flow, med ammonia)	Emission by sector
Mineral fibre processes	Regenerative Thermal Oxidation	Annualised cost per plant
Production - Chem ind - organic chemicals	Biofilter	Emission by sector
Production - Chem ind - organic chemicals	Regenerative Thermal Oxidation	Emission by sector
Production processes Chemical Industry - Acid processes	Dilute acid scrubber (medium flow, med ammonia)	Emission by sector
Production processes Chemical Industry - Acid processes	biofilter	Annualised cost per plant
Production processes Chemical Industry - Acid processes	Regenerative Thermal Oxidation	Emission by sector
Horses	Silage treatment of manure	Annualised cost per plant
Sugar beet processing	Non-evaporative cooling system	Annualised cost per plant
Sewage treatment	Dilute acid scrubber (medium flow, med ammonia)	Number of plant in UK

Table 16. Identification and ranking of the most important five sensitivities in the cost-effectiveness analysis.

Sector	Technology	Factor	Uncertainty ranking
Production processes	Dilute acid scrubber	Emission by sector	1
Chemical Industry - Acid processes	(medium flow, medium emission)		
Inorganic chemical processes	Biofilter	Number of plant	2
Fertiliser	Venturi scrubber (large flow, large emission)	Emission by sector	3
Inorganic chemical processes	Dilute acid scrubber (medium flow, medium emission)	Emission by sector	4
Sewage treatment	Dilute acid scrubber (medium flow, medium emission)	Number of plant	5

A sensitivity analysis of the cost curve was performed to assess the impact of different technology penetration scenarios, again using @RISK. Results for the UK are shown in Figure 19.

**Figure 19. Non-agricultural cost curve sensitivity to technology penetration (2010).**

The left- and right-hand curves represent the boundaries of the likely uptake such that the study team estimate there to be a 90% probability that the curve will lie between these boundaries.

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The @RISK model has shown that the potential abatement and cost incurred is highly dependant on technology uptake. For a UK investment of £5 million, over 3kt of ammonia would be abated if there was a high level of abatement technology market penetration in each sector, with the most probable uptake level for the same investment giving a 2.3kt cut. However, if there was only low technology uptake (5% confidence interval boundary) then an investment of £5 million would give abatement of only 1.3kt. The practicality of the technology and the potential barriers to its uptake are highly significant variables when considering a potential non-agricultural ammonia abatement strategy on a cost-effective basis.

The maximum feasible reduction is increased from 3.8kt to 5.4kt when the technology uptake in each sector is taken at the upper limit of the range for 2010. Ensuring that all sites in the sectors considered installed ammonia abatement technology would therefore increase the maximum emission reduction to over 5.4kt.

4. Estimates of Future European Emissions

The ammonia inventories for the EU15 countries were calculated from the ratio of each specific activity in each country to UK sector activity, and scaling against UK emissions in 2010:

$$\frac{1998 \text{ activity UK}}{1998 \text{ activity X}} = \frac{2010 \text{ activity UK}}{2010 \text{ activity X}}$$

$$2010 \text{ Emission X} = 2010 \text{ Emission UK} \times \frac{1998 \text{ activity X}}{1998 \text{ activity UK}}$$

Most activity data were taken from the OECD 1999 review for the ensuing calculations. The data generated for each country and the activity data used are displayed in Appendix 4. **It is acknowledged that this method for estimating emissions is not perfect, but does provide a basis for scoping the problem in other countries.**

The fall in transport emissions dominates the trend in non-agricultural ammonia. Transport activity was calculated using the STEEDS model produced for DG TREN to project vehicle km in 2010 for petrol driven vans and cars with a catalyst (pre-Euro I vehicles excluded). The activity ratio for each country was then used to scale the predicted UK 2010 emission to that of the other countries, as shown above. The AEA transport projection for the EU15 is compared to the new projection data from IIASA (IIASA, Personal Communication 2001) in Table 17. It is noticeable that the estimates made here are significantly lower than those generated at IIASA, resulting from a major reduction in the emission factor (see chapter 2).

Estimated emission totals for 1999 and 2010 in each country are shown in Table 18. Based on the estimated future trend for the UK, there is a small decrease in the estimated ammonia emissions for the EU15 from 727kt for 1999, to 688kt for 2010. The majority of sectors with large emissions remain constant, except for transport, which is predicted to have a Europe wide decrease in emissions by around a factor of three due to the replacement of EURO I cars with EURO II/III vehicles with advanced engine controls.

Full results of the projections for the EU15 are shown in Table 19, and compared with the full IIASA inventory, though the version used here does not include IIASA's updated transport estimates. Although inclusion of these new transport estimates would increase the sum of the total EU15 IIASA inventory by around 100kt, it would still fall 400kt short of the non-agricultural inventory proposed here. The major factor is the extent of completeness of the different inventories. Table 19 incorporates sectors such as horses that have a very significant emission of 213kt for the EU15 as a whole, the largest emission for a sector by a large margin. The second largest sector is residential wood combustion at 157kt (based on the activity statistics for fuel wood and charcoal production in the late 1990's from OECD, 1999).

Table 17. AEAT and IIASA transport projections for the EU15 (kt/year).

Country (EC15)	AEA Transport prediction best estimate 2010	New IIASA transport emission 1990	New IIASA transport emission 2010
Austria	0.51	0.5 - 1	2 - 4
Belgium	0.56	0.2 - 0.4	3 - 5
Denmark	0.50	0.4 - 0.7	1.5 - 3
Finland	0.51	0.2 - 0.4	2 - 4
France	4.07	1.5 - 3	12 - 23
Germany	7.58	2.5 - 5	23 - 46
Greece	0.31	0.05 - 0.1	3 - 6
Ireland	0.24	~ 0.1	1 - 2
Italy	3.99	0.2 - 0.4	15 - 30
Luxembourg	0.04	0.05 - 0.1	0.2 - 0.4
Netherlands	1.28	0.5 - 1	4 - 8
Portugal	0.74	~ 0.1	1.5 - 3
Spain	1.89	0.1 - 0.2	7 - 15
Sweden	0.76	1 - 2	4 - 7
UK	4.53	0.5 - 1	17 - 35
TOTAL	28	8 - 16	96 - 191

The countries for which the deviation between original estimates and those made here appear to be more significant for 2010 are Finland, Italy, Spain and Sweden. The new estimates predict larger emissions particularly from:

- ◆ wood combustion: Finland, Italy and Sweden
- ◆ horse manure and excreta: Spain and Italy
- ◆ sewage treatment and disposal: Italy

Table 18. EU15 non-agricultural ammonia emission estimates for 1999 and 2010.

	AEAT 1999 best estimate total non-agricultural emissions, kt/year	AEAT 2010 best estimate total non-agricultural emissions, kt/year	AEAT 2010 New non-agricultural total (omitting natural sources) kt/year
Austria	25.0	27.0	23.6
Belgium	11.0	10.0	8.0
Denmark	11.0	10.0	8.4
Finland	31.0	33.0	24.9
France	123.0	124.0	103.0
Germany	143.0	126.0	106.7
Greece	26.0	26.0	21.5
Ireland	10.0	9.0	7.2
Italy	111.0	105.0	90.2
Luxembourg	1.0	1.0	0.6
Netherlands	21.0	17.0	14.4
Portugal	28.0	28.0	24.1
Spain	84.0	82.0	64.0
Sweden	38.0	39.0	27.2
UK	63.0	51.0	36.8
Total	726.0	688.0	560.5

Table 19. Comparison between revised EU15 ammonia inventory, RAINs, UNECE and NECD values for 2010.

Country (EU15)	2010 New non-ag (omitting natural sources) kt/year	2010 Ceiling best estimate (new non-ag, non-natural + IIASA ag) kt/year	IIASA 2010 non-agricultural emissions (old transport factor) kt/year	IIASA 2010 agricultural emissions kt/year	RAINS 2010 Inventory (IIASA : old transport factor) kt/year	UNECE Emission levels 1990 kt/year	UNECE Emission ceilings 2010 kt/year	NECD Emission ceilings 2010 kt/year
Austria	23.6	84.4	6.1	60.8	66.9	81.0	66.0	66.0
Belgium	8.0	100.0	3.8	92.0	95.8	107.0	74.0	74.0
Denmark	8.4	79.5	0.6	71.0	71.7	122.0	69.0	69.0
Finland	24.9	55.2	0.8	30.3	31.1	35.0	31.0	31.0
France	103.0	852.9	30.0	750.0	780.0	814.0	780.0	780.0
Germany	106.7	667.1	11.1	560.4	571.5	764.0	550.0	550.0
Greece	21.5	94.8	0.7	73.3	74.0	80.0	73.0	73.0
Ireland	7.2	129.9	7.3	122.6	130.0	126.0	116.0	116.0
Italy	90.2	491.9	30.1	401.8	431.8	466.0	419.0	419.0
Luxembourg	0.6	7.3	1.8	6.7	8.5	7.0	7.0	7.0
Netherlands	14.4	146.9	8.9	132.6	141.4	226.0	128.0	128.0
Portugal	24.1	83.9	12.7	59.9	72.6	98.0	108.0	90.0
Spain	64.0	433.8	12.9	369.8	382.7	351.0	353.0	353.0
Sweden	27.2	84.0	4.2	56.8	61.1	61.0	57.0	57.0
UK	36.8	297.6	36.7	260.8	297.5	333.0	297.0	297.0
TOTAL	560.5	3609.2	167.8	3048.7	3216.4	3671.0	3128.0	3110.0

Table 20. Non-agricultural ammonia emissions (kt/year) for the EU15 by sector in 2010 (This study, best estimate).

Country (EC15)	Incineration (inc EfW)	Landfill	Sewage sludge production and disposal inc incineration	Horses mules and asses	Cigarette smoking	Household products	Domestic pets	Adult breath and sweat	Nappy emissions	Wild bird wastes	Other wild animals	Residential combustion - Wood	Residential combustion - anthracite	Residential combustion - coal	Residential combustion - coke
Austria	0.01	0.11	1.41	5.56	0.06	0.15	0.85	0.17	0.01	1.37	0.68	14.63	0.05	0.11	0.01
Belgium	0.02	0.12	0.58	1.88	0.07	0.19	1.05	0.21	0.01	0.50	0.25	2.14	0.06	0.13	0.01
Denmark	0.05	0.04	0.99	2.93	0.04	0.10	0.55	0.11	0.00	0.70	0.35	2.10	0.03	0.07	0.00
Finland	0.00	0.18	0.89	4.13	0.03	0.10	0.53	0.10	0.00	5.06	2.53	17.50	0.03	0.07	0.00
France	0.30	1.17	5.89	29.01	0.40	1.09	6.07	1.19	0.04	8.99	4.49	44.74	0.37	0.76	0.05
Germany	0.18	2.32	17.28	51.10	0.56	1.53	8.49	1.67	0.06	5.80	2.90	11.62	0.52	1.06	0.07
Greece	0.00	0.44	0.25	12.02	0.07	0.20	1.09	0.21	0.01	2.14	1.07	5.77	0.07	0.14	0.01
Ireland	0.00	0.18	0.19	5.03	0.03	0.07	0.38	0.08	0.00	1.14	0.57	0.27	0.02	0.05	0.00
Italy	0.04	2.94	22.24	27.73	0.39	1.07	5.96	1.17	0.04	4.88	2.44	22.49	0.36	0.74	0.05
Luxembourg	0.00	0.01	0.05	0.00	0.00	0.01	0.04	0.01	0.00	0.04	0.02	0.00	0.00	0.01	0.00
Netherlands	0.08	0.22	2.38	7.29	0.11	0.29	1.62	0.32	0.01	0.56	0.28	0.56	0.10	0.20	0.01
Portugal	0.00	0.44	2.37	16.16	0.07	0.19	1.03	0.20	0.01	1.52	0.76	2.77	0.06	0.13	0.01
Spain	0.02	1.44	2.64	30.81	0.27	0.74	4.10	0.81	0.03	8.29	4.15	15.34	0.25	0.51	0.03
Sweden	0.04	0.15	1.31	6.54	0.06	0.17	0.92	0.18	0.01	6.83	3.42	16.24	0.06	0.11	0.01
UK	0.06	2.67	7.07	13.00	0.40	1.10	6.10	1.20	0.04	4.00	2.00	1.12	0.37	0.76	0.05
TOTAL	0.80	12.43	65.53	213.18	2.54	6.99	38.79	7.63	0.25	51.83	25.92	157.30	2.35	4.83	0.32

Table 20 continued: Non-agricultural ammonia emissions (kt/year) for the EU-15 by sector in 2010 (This study, best estimate)

Country (EC15)	Solid smokeless fuel production	Fertiliser production	Chemical Industry	Paper and printing	Sugar Beet Processing	Cement	Field burning	Deer wastes	Domestic fertiliser use	Coke oven leakage	Transport	2010 Total kt/year
Austria	0.00	0.14	0.10	0.01	0.3	0.00	0.45	0.02	0.04	0.00	0.51	26.7
Belgium	0.01	0.22	0.60	0.00	0.9	0.08	0.26	0.01	0.05	0.21	0.56	10.1
Denmark	0.00	0.36	0.09	0.00	0.4	0.01	0.72	0.01	0.03	0.01	0.50	10.2
Finland	0.00	0.21	0.08	0.02	0.3	0.00	0.74	0.06	0.02	0.00	0.51	33.1
France	0.03	3.08	1.40	0.01	4.6	0.27	5.66	0.11	0.28	0.08	4.07	124.2
Germany	0.04	2.19	2.08	0.02	4.2	0.66	3.64	0.07	0.39	0.13	7.58	126.2
Greece	0.01	0.38	0.00	0.00	0.5	0.10	1.18	0.03	0.05	0.08	0.31	26.1
Ireland	0.00	0.48	0.15	0.00	0.2	0.02	0.28	0.01	0.02	0.00	0.24	9.4
Italy	0.03	1.12	0.86	0.01	2.3	0.45	3.30	0.06	0.27	0.13	3.99	105.1
Luxembourg	0.00	0.00	0.00	0.00	0	0.00	0.02	0.00	0.00	0.49	0.04	0.8
Netherlands	0.01	0.45	0.46	0.01	0.6	0.06	0.30	0.01	0.07	0.00	1.28	17.3
Portugal	0.01	0.14	0.06	0.00	0	0.04	0.88	0.02	0.05	0.00	0.74	27.6
Spain	0.02	1.27	0.52	0.01	2.1	0.23	5.79	0.10	0.19	0.07	1.89	81.6
Sweden	0.00	0.25	0.16	0.02	0.4	0.00	0.85	0.09	0.04	0.00	0.76	38.6
UK	0.03	1.53	1.03	0.01	0.9	0.20	1.94	0.05	0.28	0.10	4.53	50.5
TOTAL	0.19	11.82	7.57	0.12	17.70	2.14	25.99	0.65	1.78	1.30	27.52	687.5

5. Conclusions

1. The study has refined estimates of non-agricultural sources of ammonia to be emitted from the UK over the next 30 years. Significant improvements have been made to the inventory with respect to traffic and industrial sectors. The best estimate of these emissions for 2010 is 51kt.
2. Significant uncertainty remains in some parts of the inventory, particularly in sewage treatment and disposal, relating to the size of emissions in 2010 and technology penetration for the sector.
3. Some problems are experienced in developing the inventory of emissions because a number of sources are close to reporting thresholds (and hence are not included in e.g. the Pollution Inventory). As a result, these sources will report ammonia emissions in some years but not others (when they fall below the threshold). It should be considered whether the rules on reporting need to be changed (perhaps reduced thresholds, or a requirement to report every year if emissions have exceeded the threshold once in the last 5 years). Such changes would improve consistency in the inventory, and improve trends analysis.
4. It is anticipated that emissions will fall in several sectors as a result of existing actions, for example regarding the Landfill Directive and the implementation of IPPC. Regulations that are not yet in place, but which are expected, for example, limits on PAH and particulate emissions may also yield benefits in terms of reduced ammonia emissions, though these cannot be estimated ahead of any legislation.
5. The best estimate of total emissions from non-agricultural sources is 51 kt/y in 2010. Using the software package @RISK, the 90% confidence interval for total UK emissions of ammonia from non-agricultural sources in 2010 is between 50 kt and 77 kt. The uncertainty boundaries are dictated by the uncertainty in the trend in traffic emissions as this determines the direction of the overall trend. Refinement of the range should therefore initially concentrate on improvement in the emission factors for transport (see paragraph 7).
6. A total of 13.8 kt/year of ammonia is forecast to be emitted in the UK in 2010 by 'natural' sources (wildlife, human breath and sweat, etc. However, Article 2 of both the Gothenburg Protocol and NECD ceilings refer to anthropogenic sources. Excluding these natural sources gives an annual UK emission of ammonia from non-agricultural sources in 2010 of 37 kt.
7. Emissions from traffic will be less significant than previously thought, as a consequence of the use of improved engine and fuel management systems. The study includes application of new data on vehicle emissions. Earlier estimates for this sector were higher, through the use of emission factors from older vehicles with fuel control systems unrepresentative of the current and future fleet. An additional source identified here is the use urea (which reacts rapidly to form ammonia) in some types of NO_x control equipment used in diesel HGVs. However, such technologies should incorporate controls to minimise ammonia slip as part of the

original design. Options for control of emissions should be targeted at older vehicles, as it is anticipated that emissions from EURO-II vehicles will be minimal. These options include retro-fitting older vehicles with ammonia abatement equipment and introducing scrappage subsidies.

8. Emissions from combustion are dominated by small sources, as large combustion facilities are better optimised to run efficiently. Wood is the only source of ammonia in residential combustion for which emissions are growing. There is already growing concern over the small sources with respect to emissions of PAHs and fine particles, and these concerns may themselves lead to action. The main control options for the domestic emissions are:
 - ◆ Fuel switching
 - ◆ Improved efficiency of appliances and operating practices
 - ◆ Use of smokeless fuels.
9. Emissions from the treatment and disposal of sewage sludge have in recent years grown, as a result of the ban on dumping of the material at sea. However, they have now stabilised as a result of increased use of injection of sludge into soils, rather than simple spreading. The drivers for this change in practice relate to concerns over odour and the appearance of fields. The main abatement options for this sector are as follows:
 - ◆ Dilute wet acid scrubbers at treatment plant
 - ◆ Small wet scrubbers at smaller treatment plant
 - ◆ Activated carbon filtration at treatment plant
 - ◆ Biofiltration at treatment plant
 - ◆ Incineration of sludge
 - ◆ Injection of treated sludge to fields, as opposed to spreading.
10. Emissions from MSW (Municipal Solid Waste) Incineration arise firstly because of the difficulties of maintaining effective control over combustion when faced with material of extremely variable content and quality. Secondly, NO_x control equipment in the form of SCR and SNCR requires injection of ammonia or urea (which readily reacts to form ammonia), and some of the ammonia inevitably slips through the system. Control options include:
 - ◆ Use of wet scrubbing
 - ◆ Addition of methane to gases as an alternative to ammonia / urea.
 - ◆ For systems using SNCR and SCR, control of the system based on the NH₃ content in the flue gas, rather than the NO_x content.
11. Landfills typically generate ammonia from biodegradable materials at a rate of 0.73% of methane generation. The control options that are applicable largely reflect the provisions of the Landfill Directive, though will be limited in applicability for older facilities and those that are already closed:
 - ◆ Reduction of biodegradable wastes sent to landfill
 - ◆ Capping sites and fitting landfill gas collection equipment, followed by flaring or use of landfill gas
 - ◆ Treatment of landfill leachates, accompanied by systems for destroying any ammonia generated.

It is predicted that the ammonia emissions from landfill will drop from 4.7kt in 1999 to 2.67 in 2010, though there is a large uncertainty in the prediction ranging from 0.7 to 10.7kt

12. Given the generation of ammonia from landfills it is not surprising that it is also produced by composting. Rates can be minimised through:
 - ◆ The use of zeolites or biofiltration at large centralised composting facilities
 - ◆ Adjusting the carbon:nitrogen ratio to the optimum, which is 30:1.
13. Sugar beet processing emissions can be reduced per plant by 50% by replacing the existing evaporative cooling system with a non-evaporative cooling system and an effluent treatment plant. The cost per plant is high (around £5 million for installation) so penetration of this technology is likely to be slow.
14. Ammonia emissions arise in many parts of the chemical industry sector, such as the manufacture of fertiliser, sodium ferrocyanate, petrochemicals and pharmaceuticals. There will be significant reduction in these before 2010 as a consequence of the implementation of IPC and IPPC. The main abatement options for this sector relate to the use of various types of scrubber and regenerative thermal oxidation. The different techniques have similar efficiencies for reducing ammonia emissions, all around 90-99%.
15. For the cement and coking industries there is little that can be done to further reduce emissions beyond ensuring compliance with IPC and IPPC through the use of BAT.
16. Household products are a significant source of ammonia, the main emission in this group is from use of floor screeding latex solution. Replacement of this product with an ammonia free substitute would significantly reduce this sector's emissions.
17. Emissions from horses relate to waste production. Techniques for abating ammonia here are of course similar to those apply more widely in agriculture:
 - ◆ Ensuring that wastes are covered where possible
 - ◆ Maintaining bedding in good condition
 - ◆ Treatment of manure as silage, with subsequent injection to fields.
18. There is therefore clear pressure that will lead to a reduction in non-agricultural ammonia emissions. However, much of this pressure comes not from a desire to control ammonia specifically, but for other reasons.
19. The most practical abatement method for the majority of sectors is to use end of pipe technology such as gas scrubbers, a new non-evaporative cooling system would be needed to abate emissions in sugar beet processing and treating horse manure as silage is the best method of horse emission abatement. If all these technologies are applied the maximum feasible reduction (MFR) is 3.9kt in 2010, calculated with the @RISK technology penetration value (taken from best estimate for penetration in 2010). The MFR is 8% of the predicted 50.5kt total for 2010. If the maximum likely technology penetration is assumed then the MFR increases from 3.9kt to 5.4kt for 2010.

20. The most cost effective ammonia abatement measures are to fit dilute acid packed tile scrubbers to plants in the inorganic chemical process industry, the acid processes chemical process industry and the mineral fibre process industry. The cost of abatement per tonne for these three sectors is between £118/t and £361/t. The technology penetration by 2010 in these sectors for this scenario is between 60% and 83%, giving a maximum feasible reduction at 584 tonnes.
21. The Venturi Scrubber technology applied to the fertiliser plant emitting a high volume of flue gases containing high concentrations of ammonia is the 5th most cost effective abatement technique at £1021 per tonne. Even though the annualised cost is high (over £700,000) the cost per tonne is fairly low as a large tonnage of ammonia could be abated – MRF of 1,476 tonnes.
22. The high areas of uncertainty in input data to the cost curve have shown to be the emission per sector predicted in 2010 (due to the uncertain emission factors and projected behaviour of each industry sector). Another significant area of uncertainty is in the number of sewage treatment plants and the emissions from this sector in 2010.
23. The AEAT non-agricultural emission estimate total for the EU15 in 2010 is significantly higher than the IIASA non-agricultural inventory for the EU15. We consider that the difference is due to the AEAT inventory being more comprehensive; it incorporates sectors such as horses that have a very significant emission of 213kt for all of the EU15, the largest emission for a sector by a large margin. Our projections estimate the second largest sector to be 157kt emitted from residential wood combustion.
24. The estimates for EU15 non agricultural ammonia emissions for 1999 and 2010 indicate a decrease over the next 10 years from 727kt to 688kt or 561 kt/year excluding 'natural sources'. This is mainly due to the decrease in transport emissions resulting from the uptake of EURO II/III standard catalyst cars that emit less ammonia.

6. References

@RISK – Advanced risk analysis for spreadsheets. Palisade Corporation, New York, USA.

BAT Reference Notes for the Cement Industry, March 2000

Bates J, et al 1999 *Cost effectiveness of options for reducing UK methane emissions*, AEA Technology Report for BG plc.

Baum M C et al, Multi-component Remote Sensing of Vehicle Exhaust by dispersive absorption spectroscopy.1. Effect of fuel type and catalyst

BRC, April 2000, The Safe Sludge Matrix: Guidelines for the application of sewage to agricultural land, ADAS Gleadthorpe Research Centre

British Standards Institution, Smoke reducing solid fuel burning domestic appliances, June 1969

Burnley *et al* 1999, *The impact of the landfill directive in municipal waste management in the UK*, Proceedings Sardinia 99, Seventh International Waste Management and Landfill Symposium.

COPERT III, Computer programme to calculate emissions from road transport, Version 2.1, Eggleston et al, November 2000, European Environment Agency DTI data for sector fuel demand into the future

Economic Evaluation of Air Quality Targets for PAHs for the European Commission DG Environment January 2001 (AEA Technology, Holland *et al*)

EFMA (European Fertiliser Manufacturers Association). Best Available Techniques for Pollution Prevention and Control in the European Fertiliser Industry – Production of Ammonium Nitrate, Nitrate and Calcium Ammonium Nitrate.

Environmental Protection Act 1990, Authorisation number AN 9751, British Chrome and Chemicals, Eggescliffe, 16 December 1994

Environmental Protection Act 1990, *Authorisation Number AI0292*, Rockwool 06 August 1993 - 2001

ERG (Air pollution Control ltd) , 'Odour control for the Water Industry, 2001' Environment, Foundry Lane, Horsham, West Sussex, RH13 5QG

ETSU 1996 A review of landfill gas collection methods and efficiencies, ETSU B/LF/00472/REP for Landfill Gas Services, Wake J K

Eurostat '96, Eurostat Yearbook, A statistical view on Europe 1985-1995, Office for Official Publications of the European Communities

Final Report

Eurostat '97, Panorama of EU Industry 1997, Volume 1, European Commission, Office for Official Publications of the European Communities, ISBN 92 – 827 – 9304 - 4

Fraser M P et al, Detection of excess ammonia Emissions from In-use Vehicles and the Implications for fine particle control, California USA, Environmental Science and Technology, 1998, 32 1053 – 1057

HMIP Report - Abatement of ammonium salts in stack gases, HMIP/CPR2/41/1/152

Holland, M.R., Jones, H., Visschedijk, A., Berdowski, J. and Bleekers, A. (2001) Economic Evaluation of Air Quality Standards for PAHs. Draft final report to European Commission DG Environment, January 2001.

Hori S et al - Ministry of transport, Japan, 1990, Analysis of NH₃ emission characteristics from 3 way catalyst cars, Int. Journal of Vehicle Design, vol 11 no 2 1990

IPC Incineration Guidance 1996 – Processes subject to Integrated Pollution Control – Waste Incineration, The Environment Agency, 1996

IPC Carbonisation Processes: Coke Manufacture Guidance, Fuel production and combustion sector (including power generation), S2 1.06 HMSO September 1995

IPC Guidance Note S2 4.03, Inorganic acids and halogens, Environment Agency 1999

Kean A J et al - University of California, On -road measurement of Ammonia and other motor vehicle exhaust emissions, Environmental Science and Technology, 01/09/2000 3535-3539

MARACCAS 1999 – Model for the Assessment of Regional Ammonia Cost Curves for Abatement Strategies, Version 1.0 for MS Windows 95/98, NT and MARACCAS Manual. David Cowell, Imperial College 1999.

MARACCAS Version 1.1 – Model up date provided by Imperial College (Warren R) 2001

Martin (1991) Biological degradation of Wastes. ISBN 1851666354 Elsevier Applied Science

Metcalf and Eddy, inc, *Wastewater Engineering – Treatment, disposal and reuse* 3rd Edition, McGraw-Hill, Inc. 1991 ISBN 0-07-041690-7

Moeckli M A - Zurich, Switzerland, Emission Factors for Ethene and Ammonia from a tunnel Study with a Photoacoustic trace gas detection system, Environmental Science and Technology, Vol 30, No 9 1996 2864 - 2867

National Atmospheric Emission Inventory (NAEI). 1999 Ammonia Inventory. Published 2001.

OECD 1999, OECD (Organisation for Economic Co-operation and Development, Environmental Data, Compendium 1999, ISBN 92-64-05879-6

Office for National Statistics 1999. Annual abstract of statistics, 1999 edition.
Publication of the government statistical service

PENTEC Products, technologies and services for process and environmental management, The ENDAT Group Ltd, Ochil House, Springkerse Business Park, Stirling FK7 7XE

Pollution Inventory 1999 – What's in you Backyard? Accessed January 2001
http://146.101.4.38/wiyby/asp/pi_substance.asp?id=5
www.environment-agency.gov.uk

Richard T, 2000, Cornell Composting Science and Engineering
<http://www.cfe.cornell.edu/compost/odors/odortreat.html>

Rototest AB June 1998, Ammonia emissions from cars with three-way catalytic converters

SEPA Authorisation APCN20246, United fish products, Aberdeen, 30 June 2000

STEEDS, Transport model, Projections for the European Commission, DG TREN, 2001

Sutton, Theobald and Dragosits, December 2000 *Inventory of ammonia emissions from non-agricultural sources in the UK 1999*, Interim report for MAFF Contract AM0108, CEH

Sutton, Dragosits, Tang and Fowler 1999, Ammonia emissions from non-agricultural sources in the UK, *Atmospheric Environment* 34 (2000) 885-869

TRL Report, Barlow T J, Exhaust emission factors 2000: Light-duty emission tests (Unpublished Report)

UBA/AECC (1989) Emission nichtlimitierter Abgasbestandteile aus Ottomotoren mit Abgaskatalysatoren.

Volkswagen ~1988, Nicht limitierte Automobil-Abgaskomponenten,

WRc Report 1997, UK Sewage Sludge Survey, R & D Technical Report P165, Gendebien A et al, Environment Agency

Appendix 1

Contacts made during the study, by sector

- ❖ Cement works
 - Keith Brierley, Environment Agency
 - Les Parrot, British Cement Association
- ❖ Cokeries and steel works
 - Paul Brooks, CORUS
 - Ian Taylor, Environment Agency
- ❖ Composting
 - The Composting Association
 - Tom Richard, Iowa State University
- ❖ Explosives factories
 - Robert Brown, SEPA
- ❖ Fertiliser factories
 - ABB Environmental Ltd
 - Brian Audley, Kemira Agro
 - European Fertiliser Manufacturers Association (EFMA)
 - Don Martin, Hydro Agri
 - Kish Shah, Terra Nitrogen UK
- ❖ Horses
 - British Equestrian Trade Association (BETA) (Claire Williams – involved in BETA survey)
 - Dave Chadwick, Institute of Grasslands Research, Northwick
 - Dodson and Horell Ltd
 - Ian Davidson, MAFF
 - Jane James, Celina Randall, Environment Agency
- ❖ Incineration
 - SELCHP (South East London Combined Heat and Power MSW incinerator)
 - G. Jones, consultant
- ❖ Industrial combustion
 - Ian Taylor, Environment Agency

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- ❖ Landfill
 - AEA Technology, Waste team
 - Organics Ltd
- ❖ MSW (Municipal Solid Waste) incineration
 - Ian Taylor, Environment Agency
- ❖ Other chemical industry, including petrochemicals and pharmaceuticals
 - Anguil Environmental Europe
 - Ian Taylor, Environment Agency
- ❖ Residential combustion
 - Hwam Heat Design AS
- ❖ Sewage sludge treatment, incineration and spreading
 - British Lime
 - B Chambers, ADAS
 - Environment Agency
 - John Lester, Imperial College
 - Northumbrian Water
 - North West Water
 - Shell Green Sludge Incinerator
 - South West Water
 - Thames Water
- ❖ Sodium ferrocyanate manufacture
 - Geoff Whitehorn, Degussa Huls
- ❖ Sugarbeet processing
 - British Sugar
- ❖ Transport
 - Vehicle component manufacturers

Appendix 2

Glossary

@RISK – Advanced risk analysis for spreadsheets
 BAT – Best available techniques
 BRC – British Retail Consortium
 COPERT III - Computer programme to calculate emissions from road transport
 ECU – Engine control unit
 EfW – Energy from Waste
 IGER – Institute of Grassland and Environmental Research
 IPC – Integrated pollution control, UK precursor to IPPC
 IPPC – Integrated Pollution Prevention Control
 MAFF – Ministry of Agriculture, Fisheries and Food
 MARACCAS – Model for the Assessment of Regional Ammonia Cost Curves for Abatement Strategies
 MFR – Maximum feasible reduction
 MSW – Municipal solid waste
 NAEI – National Atmospheric Emissions Inventory
 SCR – Selective Catalytic Reduction (Uses a catalyst to reduce NO_x and controlled amounts of reducing agent such as ammonia)
 SELCHP – South East London Combined Heat and Power. MSW incineration plant.
 SEPA – Scottish Environmental Protection Agency
 SNCR - Selective Non-catalytic Reduction (Injection of ammonia or urea into the flue gas to reduce NO_x)
 λ – Air to Fuel optimum ratio $\text{Air/Fuel} = 14.5 = \lambda$

@RISK – Advanced @RISK analysis for spreadsheets. The computer package can be used to evaluate uncertain situations. @RISK uses Monte Carlo analysis simulation to view the most probable model result from thousands of scenarios. It also identifies the critical factors that cause risk, using a sensitivity analysis.

Ammonia slip – ammonia escaping in the flue gas that is left unreacted after it (or urea) was injected for NO_x abatement.

Anthracite – A type of coal with the lowest volatile matter (under 6%), the highest fixed carbon and thus the greatest calorific value of all coal types.

Biofilter – A series of layers of gravel, vegetation and plastic beads to biologically degrade gases blown through the system, such as ammonia and hydrogen sulphide.

Bunding – Low lying wall surrounding a storage tank to catch liquid spillage

Dilute acid scrubber – Packed tile scrubber, using water containing dilute sulphuric acid to scrub out gases such as ammonia

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Effectiveness (cost curve) - % of emissions abated by technology

Glass fibre candles – Fibre glass candle shaped filters irrigated with slightly acidic water used to abate ammonium nitrate emissions (also abate ammonia emissions)

Mineral fibres – chemically made fibres such as fibre glass

ODOURGUARD – Catalytically enhanced chemical scrubber

Regenerative thermal oxidation –flaring system, with a supplementary fuel to flare (oxidise) gases such as ammonia

Venturi Scrubber – large cyclone scrubber for high gas flows (often used for removing particulates)

Appendix 3

Summary sheets of ammonia abatement by sector

Sector: Traffic*Sub – sector: Catalyst vehicles to EURO IV (petrol driven)***Description of source**

Ammonia emissions are close to zero in non-catalyst vehicles (pre EURO – I). The ammonia is formed from the hydrogen produced when the engine is fuel rich and NO_x when the catalyst has warmed up.

Trend

Year	1990-1998	1999	2000	2005	2010	2015	2020	2025	2030
Emission (kt) – low		4.06	4.17	3.20	1.51	0.82	0.72	0.74	0.74
Emission (kt) – best	0.85('90) –12.17('98)	12.19	12.5	9.59	4.53	2.46	2.16	2.23	2.23
Emission (kt) – high		19.19	20.86	28.33	31.31	33.52	35.39	36.76	38.00

Basis for projections: Traffic forecast from DETR. Assumed no progress beyond EURO IV.

Abatement options

Option	Efficiency	Penetration	Cost/tonne ammonia	Secondary effects	Comments
Engine Control Unit improvements of 80-95% of fuel rich reduction	80-95% abatement of ammonia emissions	2000 – 5% 2005 – all new cars produced with ECU 2010 – 50% 2015 – 95% 2020 –30 –100%	Cost attributed to other pollutants as they are the driver for ECU development	2 conflicting directives – NO _x limits may increase NH ₃ emissions if gasoline direct injection is used in petrol cars (with NO _x traps) and urea injection in diesel cars	Euro II and onwards – engine control will see NH ₃ emissions decreasing
Diesel NH ₃ clean up box (after urea injection)	99.9% efficiency	2008 – introduction of urea injection 100% penetration of NH ₃ clean up box	Clean-up box total cost £143 28.65µg/m ³ ammonia abated	2008 legislation on heavy duty diesel vehicles leads to urea injection – clean up box prevents ammonia slip	

List of contacts

1. Tim Murrells – AEA Technology (personal communication 2000)

Sector: Combustion*Sub – sector: Residential combustion - Coal, anthracite and coke wood***Description of source**

Chemical reduction area in flame causes N in fuel to be converted into NH₃. Higher average fire temperatures and better air circulation will lead to more efficient combustion and will reduce the production of ammonia.

Trend

Year	1999	2000	2005	2010	2015	2020	2025	2030
Emission (kt) – low	0.48	0.41	0.26	0.18	0.13	0.10	0.05	0.03
Anthracite Emission (kt) - best	0.97	0.82	0.52	0.37	0.27	0.20	0.10	0.05
Emission (kt) – high	1.93	1.64	1.04	0.73	0.53	0.39	0.20	0.10
<i>Emission (kt) – low</i>	<i>0.85</i>	<i>0.85</i>	<i>0.54</i>	<i>0.38</i>	<i>0.28</i>	<i>0.20</i>	<i>0.18</i>	<i>0.15</i>
Coal Emission (kt) – best	1.70	1.70	1.08	0.76	0.55	0.41	0.35	0.30
<i>Emission (kt) – high</i>	<i>3.40</i>	<i>3.40</i>	<i>2.15</i>	<i>1.52</i>	<i>1.11</i>	<i>0.82</i>	<i>0.70</i>	<i>0.60</i>
Emission (kt) – low	0.06	0.05	0.03	0.02	0.02	0.01	0.01	0.01
Coke Emission (kt) - best	0.11	0.10	0.06	0.05	0.03	0.02	0.02	0.02
Emission (kt) – high	0.23	0.20	0.13	0.09	0.07	0.05	0.04	0.03
<i>Emission (kt) – low</i>	<i>0.45</i>	<i>0.45</i>	<i>0.50</i>	<i>0.56</i>	<i>0.63</i>	<i>0.70</i>	<i>0.70</i>	<i>0.70</i>
Wood Emission (kt) – best	0.89	0.90	1.01	1.12	1.25	1.40	1.40	1.40
<i>Emission (kt) – high</i>	<i>1.78</i>	<i>1.80</i>	<i>2.01</i>	<i>2.25</i>	<i>2.51</i>	<i>2.80</i>	<i>2.80</i>	<i>2.80</i>

Basis for projections: fuel switching away from traditional fuel to natural gas etc. Increase in wood burning.

Shape of distribution: fairly flat normal distribution

Abatement options

Option	Efficiency	Penetration	Cost/tonne ammonia	Timing	Secondary effects	Comments
Fuel switching from solid fuel to oil or gas powered central heating	100%	2000 – High 2005 – Limited?	Requires an economically attractive alternative fuel source to be available	Long term	Reduction of PAH and PM ₁₀ emissions	
Replace open fire with optimised stoves	>50%	2000 – 0% 2005 – 10% 2010 – 20% 2020 – 30% 2030 – 35%	£315 per stove	Long term	Reduction of PAH and PM ₁₀ emissions	Good for new houses – slow uptake in old stock
Prohibition: Target wood burning for aesthetic purposes Must be an alternative source of fuel available	Up to 100%	2010 – 20% Must find fuel alternatives 2010 – 10%		Medium term Long term	Reduction of PAH and PM ₁₀ emissions	
Leaflet campaign on best practice for fireplace use	Up to 30%?	2005 – 50% 2010 – 75% 2030 – 100%		Short term	Reduction of PAH and PM ₁₀ emissions	

List of contacts

AEA Technology NAEI group
DTI projections for fuel switching

Sector: Combustion*Sub – sector: Coal use in industry - including power stations***Description of source**

Large industrial coal burners are fitted with NO_x abatement technologies, which use ammonia to reduce NO_x. Ammonia slip and leaks may occur. Incomplete combustion leads to minimal amounts of N in coal being emitted as ammonia.

Trend

Year	1990-1998	1999	2000	2005	2010	2015	2020	2025	2030
Emission (kt) – low		0.006	0.006	0.003	0.002	0.001	0.001	0.001	0.00
Emission (kt) - best	Decreasing	0.012	0.011	0.006	0.004	0.002	0.001	0.001	0.000
Emission (kt) - high		0.024	0.022	0.012	0.008	0.004	0.002	0.002	0.001

Basis for projections: Assume trend from 1995 continues, at a 10% decrease each year. Reduction in coal use, improvements in efficiency and abatement will mean emissions are insignificant by 2030.

Abatement options

Abatement not considered for industrial coal use as the sector has low emissions that are declining

List of contacts

NAEI team, AEA Technology

Sector: Waste

Sub – sector: Municipal Solid Waste Incineration in Energy from Waste plants

Description of source

Incinerators are fitted with NO_x abatement technologies, which use ammonia to reduce NO_x. Ammonia slip and leaks may occur.

Trend

Year	1990-1998	1999	2000	2005	2010	2015	2020	2025	2030
Emission (kt) – low – 50%		0.01	0.01	0.012	0.02	0.04	0.05	0.055	0.06
Emission (kt) - best	Decrease	0.022	0.023	0.035	0.063	0.146	0.158	0.16	0.17
Emission (kt) – high +50%		0.1	0.1	0.12	0.2	0.4	0.5	0.55	0.6

Basis for projections: Increase due to trends in MSW incineration (Burnley *et al*, 1999) 1% waste growth scenario, Uncertainty based on Sutton *et al* 1999

Abatement options

Option	Efficiency	Penetration	Cost/tonne ammonia	Timing	Secondary effects	Comments
Selective catalytic reduction replacing selective non-catalytic reduction	80% (All injected NH ₃ converted as SCR far smaller volume for injection cf SNCR) (Private consultant)	50% long term	Not a direct cost	Long term future	Higher NO _x abatement	The Netherlands and Sweden already have NO _x limits that require SCR technology – UK will eventually follow
Fluidised bed incinerators do not require NH ₃ injection	Up to 100%	Low, only one fluidised bed MSW incinerator in UK	Not a direct cost	Long term		Mass burn incineration is likely to be chosen over fluidised bed incineration in future

List of contacts

Private consultant (Previously managed pollution abatement technology company)

Sutton *et al*, 1999

Burnley *et al*, 1999

Sector: Waste*Sub – sector: Sewage Sludge Incineration (+ electricity generation)***Description of source**

Sewage sludge incinerators are fitted with NO_x abatement technologies, which use ammonia to reduce NO_x: ammonia slip and leaks may occur. Incomplete sludge combustion leads to N in waste being emitted as ammonia.

Trend

Year	1990-1998	1999	2000	2005	2010	2015	2020	2025	2030
Emission (kt) – low – 50%		0.01	0.01	0.016	0.026	0.03	0.035	0.037	0.04
Emission (kt) – best	Increase	0.043	0.047	0.069	0.069	0.07	0.08	0.09	0.1
Emission (kt) – high +50%		0.1	0.1	0.16	0.26	0.28	0.3	0.31	0.32

Basis for projections: Ban on dumping sewage sludge at sea and a move away from spreading on land as sewage sludge contains metal contaminants etc. will cause increases in sludge incinerated.

Abatement options

Option	Efficiency	Penetration	Cost/tonne ammonia	Timing	Secondary effects	Comments
Dry and pellet sewage sludge and sell as fertiliser - divert from incinerator	Medium to low depending on scrubbing of drying stage gases & on speed/depth of pellet incorporation with earth	Low penetration – high initial investment in plant required	Potential income from fertiliser pellets offsets annual costs but not initial costs	Slow up take due to new processing plant requirement	Increase in fertiliser pellets use would displace conventional fertilisers.	Little information currently available on the potential of this technology

List of contacts

Haydn Jones – AEA Technology
 Shell Green sewage sludge incinerator
 North West Water

Sector: Waste*Sub – sector: Landfill***Description of source**

Nitrogen in proteins in organic waste is broken down by bacteria, which convert the nitrogen into ammonia.

Trend

Year	1990-1998	1999	2000	2005	2010	2015	2020	2025	2030
Emission (kt) – low		1.12	1.11	0.86	0.67	0.58	0.55	0.525	0.5
Emission (kt) – best	Constant	4.69	4.45	3.45	2.67	2.3	2.2	2.1	2
Emission (kt) – high		17.9	17.81	13.78	10.66	9.2	8.8	8.4	8

Basis for projections: Landfill tax waste leading to waste stream diversion, composting of organic waste (diversion from landfill). Uptake of flaring difficult to predict. Uncertainty based on Sutton *et al*, 1999

Abatement options

Option	Efficiency	Penetration	Cost/tonne ammonia	Timing	Secondary effects	Comments
Landfill directive – flaring of landfill gas	Up to 99.9% ammonia combustion	Under landfill directive up to 70% - large landfills (high uncertainty)	About £100,000 installation cost and £5,000 operating cost PA, though fitted to control methane rather than ammonia	Medium to long term	Main purpose for flare is to combust the methane	Heat supply / electricity generation from landfill gas can generate income
Diversion of organic waste to centralised composting, using a large, open, turned windrow	Significantly less ammonia produced with composting of landfill – see section	Up to 2 million tonnes of waste composted per year by 2010	£600,000 instalment. Recurring cost £20,000 to £35,000(with income from compost)	From about 0.5million tonnes waste (1998) to 2 million tonnes 2010 (Burnley et al 1999)	Reduces methane emissions	Would still be a small proportion of waste stream in 2010

List of contacts

Burnley S et al 1999

Organics Ltd – a landfill technology company

Judith Bates, AEA Technology 1999

Sector: Waste*Sub – sector: Sewage treatment and disposal***Description of source**

Sludge spreading on land releases ammonia (injection into the soil reduces this). Sewage treatment works using lime, aerobic and anaerobic digestion also emit ammonia.

Trend

Year	1990-1998	1999	2000	2005	2010	2015	2020	2025	2030
Treatment, Emission (kt) – low		1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Treatment, Emission (kt) - best		5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Treatment, Emission (kt) - high		12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7
Disposal, Emission (kt) – low		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Disposal, Emission (kt) - best		1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Disposal, Emission (kt) - high		4	4	4	4	4	4	4	4

Basis for projections:**Abatement options**

Option	Efficiency	Penetration	Cost/tonne ammonia	Timing	Secondary effects	Comments
Dilute acid wet scrubber to abate ammonia emissions (from chemical treatment tanks primarily)	99.9%	2001 – 25%? 2005 – 40% 2010 - 50% 2015 – 52% 2020 – 55% 2025 – 57% 2030 – 60%	£50 - £1000 / tonne (6% DR) depending on ammonia emission size from source	Medium term	Capture of gases from sewage treatment would abate others such as hydrogen sulphide	Uptake is very uncertain as no data – estimates based on response from producers of technology and water industries

List of contacts

ERG (Air Pollution Control) Ltd - Personal Communication 2001. ADAS – Sewage sludge expert. MAFF.

Forbes Ltd – ammonia scrubber production

Sector: Other Industrial sources

Sub – sector: Fertiliser manufacture

Description of source

Ammonia is a raw material for fertiliser production and thus end of pipe emissions are significant. Ammonia is formed when reducing NOx emissions.

Trend

Year	1990-1998	1999	2000	2005	2010	2015	2020	2025	2030
Emission (kt) – low -50%		1.30	1.24	0.96	0.765	0.76	0.755	0.755	0.75
Emission (kt) - best	'98=6.5kt	2.61	2.48	1.92	1.53	1.52	1.51	1.51	1.5
Emission (kt) – high +50%		3.91	3.71	2.87	2.295	2.28	2.265	2.265	2.25

Basis for projections: time series showed an overall gradual decrease in emissions (with high fluctuation). Competition and general industry emission reduction will result in further NH₃ emission reduction.

Abatement options

Option	Efficiency	Penetration	Cost/tonne ammonia	Timing	Secondary effects	Comments
Reduction in fertiliser purchased – organic farming, best practice fertiliser application	Approximately 90% NH ₃ abatement	IPPC will mean Venturi scrubbers are necessary for the larger plants 2004 – 25% 2010 – 100%	£1600 /tonne (6% DR)	After IPPC in force 2004 onwards		
Glass Fibre ‘candles’ (Hydro Agri)	Remove ammonium nitrate and SOME of the ammonia. Estimate 95% abatement.	IPPC will encourage uptake. Candles are mainly for ammonium nitrate abatement	£2,000/tonne (6% DR)	Already in use in some / all plants Increase in uptake level after IPPC in force. 2004 onwards	Very efficient for ammonium nitrate abatement	

List of contacts

Hydo Agri - Don Martin, Environmental Manager

Kemira Agro – Environmental Manager

Environment Agency – Technical Adviser

ABB Environmental – Venturi Scrubber Producers – Personal Communication 2001

Sector: Other industrial Sources

Sub – sector: Sugar Beet Processing

Description of source

The nitrogen content in sugar beet is emitted during processing as ammonia. It is produced at 22 points in the process, the largest source to air is the cooling tower, emitting 50% of total plant emissions.

Trend

Year	1990 – 98	1999	2000	2005	2010	2015	2020	2025	2030
Emission (kt) – low		0.78	0.78	0.78	0.78	0.6	0.5	0.4	0.3
Emission (kt) – best	~constant	0.95	0.9	0.9	0.9	0.8	0.7	0.6	0.5
Emission (kt) – high		1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46

Basis for projections: British Sugar, personal communication (production likely to be constant short term, with a longer term decrease due to increased competition)

Abatement options

Option	Efficiency	Penetration	Cost/tonne ammonia	Timing	Secondary effects	Comments
Non-evaporative cooling system	Up to 100%	2000 – 0 2005 – 15% 2010 – 30% 2015 – 45% 2020 – 60% 2025 – 60% 2030 – 60%	£6,000 / tonne	Medium to long term – high investment (£5M per plant) will mean step changes as each plant fitted	Will reduce local impacts of ammonia e.g. on SSSI	IPPC is likely to lead to 2 out of 6 plants fitting cooling system.

List of contacts

Sutton, Theobald et al 2000

British Sugar 2001 (Environmental Manager and Cantley plant representative)

AEA Technology – NAEI team

Sector: Other Industrial Sources*Sub – sector: Paper and printing***Trend**

Year	1990 - 98	1999	2000	2005	2010	2015	2020	2025	2030
Emission (kt) – low -25%		0.00375	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375
Emission (kt) – best		0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Emission (kt) – high +25%		0.00625	0.00625	0.00625	0.00625	0.00625	0.00625	0.00625	0.00625

Basis for projections: Emission is small and from a single plant, so the trend is assumed to be constant.

Abatement options

The emissions are very low and thus not considered in detail for abatement. Good practice and overall impact of IPPC result in no increase being predicted.

List of contacts

Pollution Inventory
NAEI

Sector: Other Industrial Sources*Sub – sector: Chemical Industry – acid and halogen production***Description of source****Trend**

Year	1990 - 98	1999	2000	2005	2010	2015	2020	2025	2030
Emission (kt) – low –25%		0.09	0.09	0.12	0.15	0.19	0.25	0.32	0.40
Emission (kt) – best	5% PA growth 95-98	0.12	0.12	0.16	0.20	0.26	0.33	0.42	0.54
Emission (kt) – high +25%		0.15	0.16	0.20	0.25	0.32	0.41	0.53	0.67

Basis for projections: Increased production countered by better operational practises**Abatement options**

Option	Efficiency	Penetration	Cost/tonne ammonia	Timing	Secondary effects	Comments
Regenerative Thermal Oxidiser	98% abatement	Fast if required by legislation – initial costs at £100,000 may be an economic barrier	£591/tonne (6% DR)	Technology currently in use and in demand for smaller flues	Can also be used to destroy VOCs (will oxidise them at the same time as ammonia)	Suitable for gas flows 400 – 80,000 m ³ per hour

List of contacts

Anguil Environmental Europe Ltd (Manufacturers and suppliers of oxidisers)

Environment Agency – Technical Adviser

Neil Passant – AEA Technology

Sector: Other Industrial Sources*Sub – sector: Solid smokeless fuel production***Description of source****Trend**

Year	1990 - 98	1999	2000	2005	2010	2015	2020	2025	2030
Emission (kt) – low -25%		0.030	0.026	0.023	0.021	0.019	0.017	0.015	0.014
Emission (kt) – best	Decreasing at 10% PA	0.039	0.035	0.031	0.028	0.025	0.023	0.021	0.018
Emission (kt) – high +25%		0.050	0.043	0.039	0.035	0.032	0.028	0.026	0.023

Basis for projections: past time series shows 10% decrease in emissions each year**Abatement options**

Option	Efficiency	Penetration	Cost/tonne	Timing	Secondary effects	Comments
Reduction in fugitive emissions from kiln	Presently ~99% of emissions prevented. Aim for >99%	2010 – 50%?	Low cost though small emission reduction	Medium term	Reduction in particulate and PAH emissions	Implementation due to IPPC and for PAH reduction not NH ₃

ContactsEnvironment Agency
CORUS

Sector: Other Industrial Sources

Sub – sector: Coke Production

Description of source

The coke ovens are the source of ammonia. The controls on the ovens are straight-forward door lid controls and top lid controls (they control the seals), the ammonia leaks out through the seals when the kiln is firing.

Trend

Year	1990 - 98	1999	2000	2005	2010	2015	2020	2025	2030
Emission (kt) – low –25%		0.08	0.08	0.08	0.08	0.07	0.06	0.05	0.04
Emission (kt) – best	constant	0.11	0.10	0.10	0.10	0.09	0.08	0.07	0.05
Emission (kt) – high +25%		0.13	0.13	0.13	0.13	0.11	0.10	0.09	0.06

Basis for projections: constant emissions based on 1990-98 flat trend. In the longer term a decrease in coke demand is likely to decrease emissions.

Abatement options

Option	Efficiency	Penetration	Cost/tonne ammonia	Timing	Secondary effects	Comments
door lid controls and top lid controls (seal control)	99.5 % (BAT option)	BAT already so most coke ovens should have them	Low-medium cost with small emission reduction	Medium term	Reduction in PAH emissions and particulates	CORUS already has the seals at 99.5% efficiency

List of contacts

CORUS – Paul Brooks, Environmental Manager
 IPC Coke production Guidance Note

Sector: Other Industrial Sources

Sub – sector: Cement industry

Description of source

Ammonia is released from the raw materials used to make the cement. The mill on the cement works abates the majority of these emissions.

Trend

Year	1990 - 98	1999	2000	2005	2010	2015	2020	2025	2030
Emission (kt) – low -25%		0.16	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Emission (kt) – best	Constant emissions	0.21	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Emission (kt) – high +25%		0.26	0.25	0.25	0.25	0.25	0.25	0.25	0.25

Basis for projections: no change in cement production predicted in future (BCA)

Abatement options

Option	Efficiency	Penetration	Cost/tonne	Timing	Secondary effects	Comments
Reduce mill down time when kiln is firing	Highly Variable 20 – 50%	5 - 20% - 2010 due to IPPC	Low	Immediate	Reduction in particulates etc.	Depends on plant set up (mill / kiln combination) may apply to few plants
Glass fibre candles (see fertiliser production)	95% NH ₃ abatement	Low – emissions of ammonia are disperse and very low per plant – industry would be reluctant to take up technology	High cost of equipment and low emissions leads to costs over £3000/tonne	~0/1 plant by 2010		Implemented to abate ammonium sulphate salts not specifically NH ₃

List of contacts

Environment Agency – Cement technical Adviser

Blue Circle Cement

British Cement Association

Sector: Other industrial sources*Sub – sector: Processes in inorganic chemical industry***Description of source****Trend**

Year	1990 - 98	1999	2000	2005	2010	2015	2020	2025	2030
Emission (kt) – low		0.39	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Emission (kt) - best	Decrease	0.52	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Emission (kt) - high		0.65	0.63	0.63	0.63	0.63	0.63	0.63	0.63

Basis for projections: assume any increases in production counteracted by increased emission control with IPPC**Abatement options**

Option	Efficiency	Penetration	Cost/tonne	Timing	Secondary effects	Comments
Biofilter	96.5% (90 – 97.5)	2010 - 50% (10-70%)	£32,000	Medium term		High cost per tonne as applied to very low ammonia emission sources
Regenerative thermal oxidiser (see acid and halogen production)						

List of contacts

AGM – Environmental Equipment Suppliers

Anguil Environmental

Sector: Other industrial sources*Sub – sector: Mineral fibre production***Description of source**

Ammonia is a raw material used in mineral fibre production and end of pipe emissions of unreacted ammonia are significant.

Trend

Year	1990 - 98	1999	2000	2005	2010	2015	2020	2025	2030
Emission (kt) – low		0.26	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Emission (kt) - best	Constant	0.35	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Emission (kt) - high		0.43	0.38	0.38	0.38	0.38	0.38	0.38	0.38

Basis for projections: past time series constant and no change in production predicted**Abatement options**

Option	Efficiency	Penetration	Cost/tonne	Timing	Secondary effects	Comments
Dilute acid wet scrubber to abate ammonia emissions	99.9%	2010 - 70% (20 – 90% uncertainty)	£50 – 1000 / tonne (6% DR)	Medium term. 1 or 2 plants may install scrubber as a result of IPPC		
Regenerative thermal oxidiser for smaller plant	See acid and halogen production	50% (10 – 70%)				

List of contacts

Rockwool Plant (Wales). Environment Agency (Wales)

Sector: Other Industrial sources*Sub – sector: Processes in organic chemical industry***Description of source**

Ammonia impurities in raw materials may be released during processing.

Trend

Year	1990 - 98	1999	2000	2005	2010	2015	2020	2025	2030
Emission (kt) – low		0.12	0.10	0.05	0.02	0.02	0.02	0.02	0.02
Emission (kt) - best	15% decrease PA	0.16	0.14	0.06	0.03	0.03	0.03	0.03	0.03
Emission (kt) - high		0.20	0.17	0.08	0.04	0.04	0.04	0.04	0.04

Basis for projections: past time series 15% decrease PA, assume trend continues. Long term trend stabilises to constant emission.**Abatement options**

Option	Efficiency	Penetration	Cost/tonne	Timing	Secondary effects	Comments
Regenerative thermal oxidiser	See acid and halogen production	50% (10-70%)				
Biofilter	See inorganic chemical production	50% (10-70%)				

List of contacts

Environment Agency.

IPC Guidance Notes Organic Chemicals.

Anguil environmental.

AGM Environmental equipment suppliers.

Sector: Household Products

Description of source

The main source of ammonia from household products is emitted from floor screeding latex solution (Sutton et al 1999).

Trend

Year	1990 - 98	1999	2000	2005	2010	2015	2020	2025	2030
Emission (kt) - low		0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
Emission (kt) - best	N.A.	1.14	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Emission (kt) - high		5.02	5.02	5.02	5.02	5.02	5.02	5.02	5.02

Basis for projections: Assume similar use of household cleaning products with time.

Shape of distribution:

Abatement options

Option	Efficiency	Penetration	Cost/tonne	Timing	Secondary effects	Comments
Switching to alternative products from ammonia based ones	100%	Between 10% and 50%	Unknown	Short to medium term		Further research needed in order to produce abatement strategy

List of contacts

Sutton *et al*, 1999

Sector: Horses

Description of source

Ammonia is emitted from horse manure solids and urine when exposed to the air.

Trend

Year	1990 - 98	1999	2000	2005	2010	2015	2020	2025	2030
Emission (kt) – low /2		6.13	6.13	6.13	6.13	6.13	6.13	6.13	6.13
Emission (kt) – best	Constant	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00
Emission (kt) – high x2		23.19	23.19	23.19	23.19	23.19	23.19	23.19	23.19

Basis for projections: assumed to be constant with time as no major changes in horse numbers predicted

Abatement options

Option	Efficiency	Penetration	Cost/tonne	Timing	Secondary effects	Comments
Maintain dry bedding, good ventilation and extra straw	Approximately 10 to 40%	Potentially high	Information not available	Short term		
Treat and bag manure as silage and then immediate ploughing into field	Apply to 50% of horses (4 or more in stable) 80-90% abatement possible	Applies to 50% horses. Group penetration 2010 - 20% (10-40%)	About £800 per year for 8 horse stable (inc. bags, staff-time, muck spreading and ploughing)	Short to Medium term	Leachate collection system may be additional cost to abate NH ₃ to water.	

List of contacts

IGER, MAFF, Environment Agency – technical adviser for IPPC on pigs and poultry
British Equestrian Trade Association (BETA) – Claire Williams

Sector: Biomass*Sub – sector: Field burning***Description of source**

The nitrogen in cereals is released to the air as ammonia, due to inefficient burning

Trend

Year	1990 - 98	1999	2000	2005	2010	2015	2020	2025	2030
Emission (kt) – low		0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
Emission (kt) - best	Decrease 90-92	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94
Emission (kt) – high		8	8	8	8	8	8	8	8

Basis for projections: Flat trend, as it is assumed stubble burning will continue at current levels.

Abatement options

Option	Efficiency	Penetration	Cost/tonne	6.1.1.1 Timing	Secondary effects	Comments
Tighter enforcement of stubble burning ban	Unknown	Low to medium (farms still burning stubble may resist change / see no alternative)	Regulation already in place (low additional cost)	Short to medium term	Reduced PM ₁₀ and other emissions	

List of contactsSutton *et al* 1999

NAEI team

Appendix 4

EU15 emission estimates

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Netherlands	Portugal	Spain	Sweden	UK
Incineration (inc EFW) (OECD 1999)	Incineration 1996	Incineration 1996	Incineration 1997	Incineration 1994	Incineration 1995	Incineration 1996	Incineration 1997	Incineration 1995	Incineration 1997	Incineration 1996	Incineration 1996	Incineration 1997	Incineration 1996	Incineration 1996	Incineration 1996
1996/7 Activity	431	715	1602	50	10352	6429	0	0	1400	98	2693	0	705	1300	2200
2010 Emission (kt)	0.01	0.02	0.05	0.00	0.30	0.18	0.00	0.00	0.04	0.00	0.08	0.00	0.02	0.04	0.06
1999 Emission (kt)	0.00	0.01	0.02	0.00	0.11	0.07	0.00	0.00	0.01	0.00	0.03	0.00	0.01	0.01	0.02
Landfill (OECD 1999)	Landfill 1996	Landfill 1996	Landfill 1997	Landfill 1994	Landfill 1995	Landfill 1996	Landfill 1997	Landfill 1995	Landfill 1997	Landfill 1996	Landfill 1996	Landfill 1997	Landfill 1996	Landfill 1996	Landfill 1996
1996/7 activity (1000 tonnes)	887	939	343	1500	9593	18978	3561	1432	24000	94	1768	3610	11758	1200	21800
2010 Emission (kt)	0.11	0.12	0.04	0.18	1.17	2.32	0.44	0.18	2.94	0.01	0.22	0.44	1.44	0.15	2.67
1999 Emission (kt)	0.19	0.20	0.07	0.32	2.06	4.08	0.77	0.31	5.16	0.02	0.38	0.78	2.53	0.26	4.69
Sewage sludge production and disposal (OECD 1999)	Sewage sludge production and disposal (includes incineration of sludge) 1997	Sewage sludge production and disposal (includes incineration of sludge) 1995	Sewage sludge production and disposal (includes incineration of sludge) 1997	Sewage sludge production and disposal (includes incineration of sludge) 1997	Sewage sludge production and disposal (includes incineration of sludge) 1995	Sewage sludge production and disposal (includes incineration of sludge) 1995	Sewage sludge production and disposal (includes incineration of sludge) 1997	Sewage sludge production and disposal (includes incineration of sludge) 1995	Sewage sludge production and disposal (includes incineration of sludge) 1991	Sewage sludge production and disposal (includes incineration of sludge) 1997	Sewage sludge production and disposal (includes incineration of sludge) 1996	Sewage sludge production and disposal (includes incineration of sludge) 1996	Sewage sludge production and disposal (includes incineration of sludge) 1994	Sewage sludge production and disposal (includes incineration of sludge) 1995	Sewage sludge production and disposal (includes incineration of sludge) 1996
1996/7 activity (1000 tonnes)	216	88	151	136	900	2642	38	29	3400	8	364	363	404	200	1081
2010 Emission (kt)	1.41	0.58	0.99	0.89	5.89	17.28	0.25	0.19	22.24	0.05	2.38	2.37	2.64	1.31	7.07
1999 Emission (kt)	1.44	0.59	1.01	0.91	5.99	17.60	0.25	0.19	22.65	0.05	2.42	2.42	2.69	1.33	7.20

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Netherlands	Portugal	Spain	Sweden	UK
Horses mules and asses (OECD 1999)	Horses and mules 1998	Horses and mules 1998	Horses 1998	Horses 1998	Horses mules and asses 1998	Horses 1998	Horses mules and asses 1998	Horses mules and asses 1998	Horses mules and asses 1998	Horses mules and asses 1998	Horses 1998	Horses mules and asses 1998	Horses mules and asses 1998	Horses 1998	Horses mules and asses 1998
1998 activity (1000 heads)	74	25	39	55	386	680	160	67	369	0	97	215	410	87	173
2010 Emission (kt)	5.56	1.88	2.93	4.13	29.01	51.10	12.02	5.03	27.73	0.00	7.29	16.16	30.81	6.54	13.00
1999 Emission (kt)	5.56	1.88	2.93	4.13	29.01	51.10	12.02	5.03	27.73	0.00	7.29	16.16	30.81	6.54	13.00
	Cigarette smoking	Cigarette smoking	Cigarette smoking	Cigarette smoking	Cigarette smoking	Cigarette smoking	Cigarette smoking	Cigarette smoking	Cigarette smoking	Cigarette smoking	Cigarette smoking	Cigarette smoking	Cigarette smoking	Cigarette smoking	Cigarette smoking
Population 1998 (1000)	8210	10200	5300	5156	58800	82300	10551	3700	57700	426	15700	10000	39754	8900	59100
2010 Emission(kt)	0.06	0.07	0.04	0.03	0.40	0.56	0.07	0.03	0.39	0.00	0.11	0.07	0.27	0.06	0.40
1999 Emission (kt)	0.06	0.07	0.04	0.04	0.42	0.58	0.07	0.03	0.41	0.00	0.11	0.07	0.28	0.06	0.42
	Household products	Household products	Household products	Household products	Household products	Household products	Household products	Household products	Household products	Household products	Household products	Household products	Household products	Household products	Household products
Population 1998 (1000)	8210	10200	5300	5156	58800	82300	10551	3700	57700	426	15700	10000	39754	8900	59100
2010 Emission (kt)	0.15	0.19	0.10	0.10	1.09	1.53	0.20	0.07	1.07	0.01	0.29	0.19	0.74	0.17	1.10
1999 Emission (kt)	0.16	0.20	0.10	0.10	1.13	1.59	0.20	0.07	1.11	0.01	0.30	0.19	0.77	0.17	1.14
	Domestic fertiliser use	Domestic fertiliser use	Domestic fertiliser use	Domestic fertiliser use	Domestic fertiliser use	Domestic fertiliser use	Domestic fertiliser use	Domestic fertiliser use	Domestic fertiliser use	Domestic fertiliser use	Domestic fertiliser use	Domestic fertiliser use	Domestic fertiliser use	Domestic fertiliser use	Domestic fertiliser use
Population 1998 (1000)	8210	10200	5300	5156	58800	82300	10551	3700	57700	426	15700	10000	39754	8900	59100
2010 Emission (kt)	0.04	0.05	0.03	0.02	0.28	0.39	0.05	0.02	0.27	0.00	0.07	0.05	0.19	0.04	0.28
1999 Emission (kt)	0.04	0.05	0.03	0.02	0.28	0.39	0.05	0.02	0.27	0.00	0.07	0.05	0.19	0.04	0.28

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Netherlands	Portugal	Spain	Sweden	UK
OECD 1999	Domestic pets	Domestic pets	Domestic pets	Domestic pets	Domestic pets	Domestic pets	Domestic pets	Domestic pets	Domestic pets	Domestic pets	Domestic pets	Domestic pets	Domestic pets	Domestic pets	Domestic pets
Population 1998 (1000)	8210	10200	5300	5156	58800	82300	10551	3700	57700	426	15700	10000	39754	8900	59100
2010 Emission (kt)	0.85	1.05	0.55	0.53	6.07	8.49	1.09	0.38	5.96	0.04	1.62	1.03	4.10	0.92	6.10
1999 Emission(kt)	0.85	1.05	0.55	0.53	6.07	8.49	1.09	0.38	5.96	0.04	1.62	1.03	4.10	0.92	6.10
OECD 1999	Adult breath and sweat	Adult breath and sweat	Adult breath and sweat	Adult breath and sweat	Adult breath and sweat	Adult breath and sweat	Adult breath and sweat	Adult breath and sweat	Adult breath and sweat	Adult breath and sweat	Adult breath and sweat	Adult breath and sweat	Adult breath and sweat	Adult breath and sweat	Adult breath and sweat
Population 1998 (1000)	8210	10200	5300	5156	58800	82300	10551	3700	57700	426	15700	10000	39754	8900	59100
2010 Emission (kt)	0.17	0.21	0.11	0.10	1.19	1.67	0.21	0.08	1.17	0.01	0.32	0.20	0.81	0.18	1.20
1999 Emission (kt)	0.17	0.21	0.11	0.11	1.21	1.70	0.22	0.08	1.19	0.01	0.32	0.21	0.82	0.18	1.22
	Infant emissions from nappies	Infant emissions from nappies	Infant emissions from nappies	Infant emissions from nappies	Infant emissions from nappies	Infant emissions from nappies	Infant emissions from nappies	Infant emissions from nappies	Infant emissions from nappies	Infant emissions from nappies	Infant emissions from nappies	Infant emissions from nappies	Infant emissions from nappies	Infant emissions from nappies	Infant emissions from nappies
Population 1998 (1000)	8210	10200	5300	5156	58800	82300	10551	3700	57700	426	15700	10000	39754	8900	59100
2010 Emission (kt)	0.01	0.01	0.00	0.00	0.04	0.06	0.01	0.00	0.04	0.00	0.01	0.01	0.03	0.01	0.04
1999 Emission (kt)	0.01	0.01	0.00	0.00	0.04	0.06	0.01	0.00	0.04	0.00	0.01	0.01	0.03	0.01	0.04
	Wild birds wastes	Wild birds wastes	Wild birds wastes	Wild birds wastes	Wild birds wastes	Wild birds wastes	Wild birds wastes	Wild birds wastes	Wild birds wastes	Wild birds wastes	Wild birds wastes	Wild birds wastes	Wild birds wastes	Wild birds wastes	Wild birds wastes
Land area 1997 (km ²)	82520	30280	42390	304590	541480	349090	128900	68890	294060	2570	33880	91550	499440	411620	240940
2010 Emission(kt)	1.37	0.50	0.70	5.06	8.99	5.80	2.14	1.14	4.88	0.04	0.56	1.52	8.29	6.83	4.00
1999 Emission (kt)	1.42	0.52	0.73	5.25	9.33	6.01	2.22	1.19	5.06	0.04	0.58	1.58	8.60	7.09	4.15

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Netherlands	Portugal	Spain	Sweden	UK
OECD 1999	Deer wastes	Deer wastes	Deer wastes	Deer wastes	Deer wastes	Deer wastes	Deer wastes	Deer wastes	Deer wastes	Deer wastes	Deer wastes	Deer wastes	Deer wastes	Deer wastes	Deer wastes
Land area 1997 (km ²)	82520	30280	42390	304590	541480	349090	128900	68890	294060	2570	33880	91550	499440	411620	240940
2010 Emission (kt)	0.02	0.01	0.01	0.06	0.11	0.07	0.03	0.01	0.06	0.00	0.01	0.02	0.10	0.09	0.05
1999 Emission (kt)	0.02	0.01	0.01	0.06	0.11	0.07	0.03	0.01	0.06	0.00	0.01	0.02	0.10	0.09	0.05
OECD 1999	Other wild animal wastes	Other wild animal wastes	Other wild animal wastes	Other wild animal wastes	Other wild animal wastes	Other wild animal wastes	Other wild animal wastes	Other wild animal wastes	Other wild animal wastes	Other wild animal wastes	Other wild animal wastes	Other wild animal wastes	Other wild animal wastes	Other wild animal wastes	Other wild animal wastes
Land area 1997 (km ²)	82520	30280	42390	304590	541480	349090	128900	68890	294060	2570	33880	91550	499440	411620	240940
2010 Emission (kt)	0.68	0.25	0.35	2.53	4.49	2.90	1.07	0.57	2.44	0.02	0.28	0.76	4.15	3.42	2.00
1999 Emission (kt)	0.75	0.28	0.39	2.77	4.92	3.17	1.17	0.63	2.67	0.02	0.31	0.83	4.54	3.74	2.19
Assume proportional to fuel wood & charcoal produced per country (OECD 1999)	Residential combustion - Wood	Residential combustion - Wood	Residential combustion - Wood	Residential combustion - Wood	Residential combustion - Wood	Residential combustion - Wood	Residential combustion - Wood	Residential combustion - Wood	Residential combustion - Wood	Residential combustion - Wood	Residential combustion - Wood	Residential combustion - Wood	Residential combustion - Wood	Residential combustion - Wood	Residential combustion - Wood
Fuelwood and charcoal production(1000m ³) late '90s	3423	500	491	4094	10466	2719	1350	63	5262		131	648	3588	3800	262
2010 Emission (kt)	14.63	2.14	2.10	17.50	44.74	11.62	5.77	0.27	22.49	0.00	0.56	2.77	15.34	16.24	1.12
1999 Emission (kt)	11.63	1.70	1.67	13.91	35.55	9.24	4.59	0.21	17.87	0.00	0.45	2.20	12.19	12.91	0.89

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Netherlands	Portugal	Spain	Sweden	UK
Assume residential anthracite burning proportional to population (OECD 1999)	Residential combustion - anthracite	Residential combustion - anthracite	Residential combustion - anthracite	Residential combustion - anthracite	Residential combustion - anthracite	Residential combustion - anthracite	Residential combustion - anthracite	Residential combustion - anthracite	Residential combustion - anthracite	Residential combustion - anthracite	Residential combustion - anthracite	Residential combustion - anthracite	Residential combustion - anthracite	Residential combustion - anthracite	Residential combustion - anthracite
Population 1998 (1000)	8210	10200	5300	5156	58800	82300	10551	3700	57700	426	15700	10000	39754	8900	59100
2010 Emission (kt)	0.05	0.06	0.03	0.03	0.37	0.52	0.07	0.02	0.36	0.00	0.10	0.06	0.25	0.06	0.37
1999 Emission (kt)	0.13	0.17	0.09	0.08	0.97	1.35	0.17	0.06	0.95	0.01	0.26	0.16	0.65	0.15	0.97
assume residential coal burning proportional to population	Residential combustion - coal	Residential combustion - coal	Residential combustion - coal	Residential combustion - coal	Residential combustion - coal	Residential combustion - coal	Residential combustion - coal	Residential combustion - coal	Residential combustion - coal	Residential combustion - coal	Residential combustion - coal	Residential combustion - coal	Residential combustion - coal	Residential combustion - coal	Residential combustion - coal
Population 1998 (1000)	8210	10200	5300	5156	58800	82300	10551	3700	57700	426	15700	10000	39754	8900	59100
2010 Emission (kt)	0.11	0.13	0.07	0.07	0.76	1.06	0.14	0.05	0.74	0.01	0.20	0.13	0.51	0.11	0.76
1999 Emission (kt)	0.24	0.29	0.15	0.15	1.69	2.37	0.30	0.11	1.66	0.01	0.45	0.29	1.14	0.26	1.70
assume residential coke burning proportional to population	Residential combustion - coke	Residential combustion - coke	Residential combustion - coke	Residential combustion - coke	Residential combustion - coke	Residential combustion - coke	Residential combustion - coke	Residential combustion - coke	Residential combustion - coke	Residential combustion - coke	Residential combustion - coke	Residential combustion - coke	Residential combustion - coke	Residential combustion - coke	Residential combustion - coke
Population 1998 (1000)	8210	10200	5300	5156	58800	82300	10551	3700	57700	426	15700	10000	39754	8900	59100
2010 Emission (kt)	0.01	0.01	0.00	0.00	0.05	0.07	0.01	0.00	0.05	0.00	0.01	0.01	0.03	0.01	0.05
1999 Emission (kt)	0.02	0.02	0.01	0.01	0.11	0.15	0.02	0.01	0.11	0.00	0.03	0.02	0.07	0.02	0.11

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Netherlands	Portugal	Spain	Sweden	UK
Assume SSF production proportional to population (used as residential fuel) (OECD 1999)	Solid smokeless fuel production	Solid smokeless fuel production	Solid smokeless fuel production	Solid smokeless fuel production	Solid smokeless fuel production	Solid smokeless fuel production	Solid smokeless fuel production	Solid smokeless fuel production	Solid smokeless fuel production	Solid smokeless fuel production	Solid smokeless fuel production	Solid smokeless fuel production	Solid smokeless fuel production	Solid smokeless fuel production	Solid smokeless fuel production
Population 1998 (1000)	8210	10200	5300	5156	58800	82300	10551	3700	57700	426	15700	10000	39754	8900	59100
2010 Emission (kt)	0.00	0.01	0.00	0.00	0.03	0.04	0.01	0.00	0.03	0.00	0.01	0.01	0.02	0.00	0.03
1999 Emission (kt)	0.01	0.01	0.00	0.00	0.04	0.06	0.01	0.00	0.04	0.00	0.01	0.01	0.03	0.01	0.04
assume production of nitrogenous fertilisers proportional to consumption ratio	Fertiliser production	Fertiliser production	Fertiliser production	Fertiliser production	Fertiliser production	Fertiliser production	Fertiliser production	Fertiliser production	Fertiliser production	Fertiliser production	Fertiliser production	Fertiliser production	Fertiliser production	Fertiliser production	Fertiliser production
Nitrogenous fertiliser consumption 1997(1000 tonnes)	112	176	291	175	2518	1788	307	395	915		370	116	1042	206	1251
2010 Emission (kt)	0.14	0.22	0.36	0.21	3.08	2.19	0.38	0.48	1.12	0.00	0.45	0.14	1.27	0.25	1.53
1999 Emission (kt)	0.23	0.37	0.61	0.37	5.25	3.73	0.64	0.82	1.91	0.00	0.77	0.24	2.17	0.43	2.61
Chemical Industry (acid and halogen production)+ Mineral fibre production+ inorganic chemical processes+organic chemical processes (Eurostat 97)	Chemical Industry	Chemical Industry	Chemical Industry	Chemical Industry	Chemical Industry	Chemical Industry	Chemical Industry	Chemical Industry	Chemical Industry	Chemical Industry	Chemical Industry	Chemical Industry	Chemical Industry	Chemical Industry	Chemical Industry
Chemical Industry turnover % 1994	1.3	7.9	1.2	1	18.5	27.4		2	11.3		6.1	0.8	6.8	2.1	13.6
2010 Emission (kt)	0.10	0.60	0.09	0.08	1.40	2.08	0.00	0.15	0.86	0.00	0.46	0.06	0.52	0.16	1.03
1999 Emission (kt)	0.11	0.67	0.10	0.08	1.56	2.32	0.00	0.17	0.96	0.00	0.52	0.07	0.58	0.18	1.15

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Netherlands	Portugal	Spain	Sweden	UK
Eurostat '97	Paper and printing	Paper and printing	Paper and printing	Paper and printing	Paper and printing	Paper and printing	Paper and printing	Paper and printing	Paper and printing	Paper and printing	Paper and printing	Paper and printing	Paper and printing	Paper and printing	Paper and printing
Paper and Board production 1994	3603	1247	311	10877	8678	14457	347	37	6719		3010	949	3501	9284	5829
2010 Emission (kt)	0.01	0.00	0.00	0.02	0.01	0.02	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.02	0.01
1999 Emission (kt)	0.01	0.00	0.00	0.02	0.01	0.02	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.02	0.01
	Sugar Beet Processing	Sugar Beet Processing	Sugar Beet Processing	Sugar Beet Processing	Sugar Beet Processing	Sugar Beet Processing	Sugar Beet Processing	Sugar Beet Processing	Sugar Beet Processing	Sugar Beet Processing	Sugar Beet Processing	Sugar Beet Processing	Sugar Beet Processing	Sugar Beet Processing	Sugar Beet Processing
Areas under beet 1994/96	0	101	67	34	406	506	40	36	285	0	115	0	178	54	170
2010 Emission (kt)	0.00	0.53	0.35	0.18	2.15	2.68	0.21	0.19	1.51	0.00	0.61	0.00	0.94	0.29	0.90
1999 Emission (kt)	0.00	0.56	0.37	0.19	2.27	2.83	0.22	0.20	1.59	0.00	0.64	0.00	0.99	0.30	0.95
	Cement	Cement	Cement	Cement	Cement	Cement	Cement	Cement	Cement	Cement	Cement	Cement	Cement	Cement	Cement
Ready mixed Concrete production 1994 (Million m ³)		9.3	1.2		30.4	74.1	11.5	2.3	50		7	4.1	26		22.3
2010 Emission (kt)	0.00	0.08	0.01	0.00	0.27	0.66	0.10	0.02	0.45	0.00	0.06	0.04	0.23	0.00	0.20
1999 Emission (kt)	0.00	0.09	0.01	0.00	0.29	0.70	0.11	0.02	0.47	0.00	0.07	0.04	0.24	0.00	0.21

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Netherlands	Portugal	Spain	Sweden	UK
Coke oven leakage: coke used in steel making Eurostat '97	Coke oven leakage	Coke oven leakage	Coke oven leakage	Coke oven leakage	Coke oven leakage	Coke oven leakage	Coke oven leakage	Coke oven leakage	Coke oven leakage	Coke oven leakage	Coke oven leakage	Coke oven leakage	Coke oven leakage	Coke oven leakage	Coke oven leakage
First processing of steel (1000 t) 1994		1.9	0.1		0.7	1.2	0.7		1.2	4.4			0.6		0.9
2010 Emission (kt)	0.00	0.21	0.01	0.00	0.08	0.13	0.08	0.00	0.13	0.49	0.00	0.00	0.07	0.00	0.10
1999 Emission (kt)	0.00	0.23	0.01	0.00	0.09	0.15	0.09	0.00	0.15	0.54	0.00	0.00	0.07	0.00	0.11
Field burning emission	Field burning emission	Field burning emission	Field burning emission	Field burning emission	Field burning emission	Field burning emission	Field burning emission	Field burning emission	Field burning emission	Field burning emission	Field burning emission	Field burning emission	Field burning emission	Field burning emission	Field burning emission
Arable and permanent crop land (km ²)	14790	8700	23730	24600	187510	120590	39150	9140	109270	670	9820	29000	191640	27990	64250
2010 Emission (kt)	0.45	0.26	0.72	0.74	5.66	3.64	1.18	0.28	3.30	0.02	0.30	0.88	5.79	0.85	1.94
1999 Emission (kt)	0.45	0.26	0.72	0.74	5.66	3.64	1.18	0.28	3.30	0.02	0.30	0.88	5.79	0.85	1.94
Transport (STEEDS)	Transport	Transport	Transport	Transport	Transport	Transport	Transport	Transport	Transport	Transport	Transport	Transport	Transport	Transport	Transport
Petrol catalyst car activity 2010 (billions vehicle km)	39.1	42.8	38.2	38.9	309.6	577.2	23.6	17.9	303.8	2.8	97.4	56.6	144.2	57.7	344.8
Emission 2010	0.51	0.56	0.50	0.51	4.07	7.58	0.31	0.24	3.99	0.04	1.28	0.74	1.89	0.76	4.53
Petrol catalyst car activity 1999	28.5	35.4	27.7	28.9	163.6	407.5	9.8	11.9	176.6	2.3	79.4	16.2	78.0	40.3	227.0
1999 Emission (kt)	1.53	1.90	1.49	1.55	8.79	21.89	0.52	0.64	9.48	0.12	4.26	0.87	4.19	2.16	12.19
Non-agricultural total 2010	26.4	9.7	10.1	33.0	121.7	124.6	25.8	9.4	104.3	0.8	17.3	27.6	80.5	38.5	50.5
Non-agricultural total 1999	25.0	11.3	11.2	31.3	123.0	143.3	26.0	10.5	110.8	0.9	21.2	28.1	83.6	37.7	63.4

Appendix 5:

UK 1999 NH₃ Inventory

Introduction

The following sections outline the methodology employed for the compilation of the UK NH₃ emissions estimates that were submitted to UN/ECE and EMEP as the formal submission in 2001. These emission estimates include data for 1990 to 1999.

The purpose of this appendix is to ensure that the methodology that has been used is transparent, and therefore allow an understanding of the conclusions that have been reached in the report. This is essential as there are a number of different ways of compiling NH₃ estimates- even from similar datasets.

The following sections explain the methods and data sources used for each SNAP sector.

1. Combustion in Energy Production & Transformation

1.1 Power Stations- Coal Combustion

The CORINAIR Atmospheric Emissions Inventory Guidebook (CORINAIR 1999) gives a range of NH₃ emissions factors from industrial combustion of coal (0.01-0.86 g/GJ). An emission factor at the lower end of this range was assumed for the power stations in the UK. This was converted into an emission per unit mass of coal consumed to give 0.0003 kt NH₃/Mt of coal. There are large uncertainties associated with this factor, and it was assumed to be constant across the 1990 to 1999 time series.

The coal consumption for all UK power stations was taken from the Digest of UK Energy Statistics (DUKES) series of publications produced by the DTI.

1.2 Power Stations- MSW Combustion

Where incinerators include energy recovery (i.e. are “waste to energy plant”), the CORINAIR reporting structure requires that they are classified under the power station sector.

The emission factor for NH₃ emissions from MSW combustion are derived from point source data. Plant reporting annual emissions of NH₃ and the mass of MSW consumed allow an emission factor to be generated for the UK. The calculated emission factor for each year is then applied to the total UK consumption of MSW in this sector. It should be noted that the emission factor falls by over an order of magnitude between 1996 and 1999 due to the introduction of new stringent legislation.

The mass of MSW used to generate electricity is taken directly from DUKES.

1.3 Collieries- Coal Combustion

Emissions estimates for NH₃ are included from this sector in the NAEI inventory because emission factor and activity data are available. However, the emissions are not significant.

2. Combustion in Commercial Institutional Residential & Agricultural Fuel Combustion

2.1 Commercial and institutional- Coal Combustion

These sectors are insignificant with respect to NH₃ emissions, but have been included because data is available. The emissions factor used is the same as that identified for the power stations, fuel consumption data is taken from DUKES.

2.2 Domestic Combustion- Various Fuels

Lee and Dollard (1994) concluded that the most reliable emission factor was 1 kg NH₃ per tonne of coal. No data are currently available for the domestic combustion of coke, anthracite or wood and consequently the coal emission factor was used for these fuels.

Detailed consumption data of different fuel types in the domestic sector are available indirectly from DUKES, and these were used for the time series.

2.3 Cigarette Smoking

The emission factor used in the NAEI estimates are taken from Martin *et al* (1997). This gives 4.13 mg NH₃ per cigarette.

The number of cigarettes released for consumption (for 1990 to 1999) is available from the H M Customs and Excise Annual Report (1999). This gives the number of cigarettes, cigars and hand rolled tobacco released each year. The hand rolled tobacco was converted into cigarettes and the data summed to obtain a total cigarette consumption for each year. However, consultation with ASH (*pers. comm.*) indicated that up to an additional 30% may be being consumed in the UK illegally- this was not taken into account as it was not possible to confirm.

2.4 Combustion in the Agriculture Sector

Emissions estimates for NH₃ are included from this sector in the NAEI inventory because emission factor and activity data are available. However, the emissions are not significant.

3. Combustion in Industry

3.1 Iron and Steel/Other Industry- Coal Combustion

The emission factor for power stations was used as there was no other suitable data.

The consumption of coal in these sectors can be determined from the DUKES time series, and the resulting emissions are small.

3.2 Cement- Clinker Production

This sector is a large consumer of coal for combustion. It has been possible to determine an emission factor by using point source emissions data reported to the Environment Agency's Pollution Inventory (Pollution Inventory 1999). The resulting emission factors are therefore similar, but different for each year in the time series. The calculated emission factor for 1996 was 0.027 kt NH₃ per Mt of coal- considerably larger than the emission factor calculated from the power station data. The emissions from this sector give 0.31 ktonnes of NH₃.

Coal consumed in this sector can be calculated from a range of data held by the NAEI.

4. Production Processes

4.1 Coke Production

Emissions from this sector arise from door leakage during coke production. Emission factors have been calculated by compiling the available data from the Pollution inventory (1999), from Scotland and Northern Ireland. The Pollution Inventory encompasses England and Wales. In the vast majority of cases presented in this report, the presence of point sources in Scotland and Northern Ireland is also known from other data sources. Hence a total UK figure can be compiled. This has enabled a typical emission factor to be determined for individual years (although the same factor is applied across different years in this case).

The amount of coke made is available from DUKES. The emissions from this source are approximately 0.1 ktonnes of NH₃.

4.2 Solid Smokeless Fuel Production

The emission factor used for this sector has been taken from a USEPA publication (USEPA: AP42 Compilation of Air Pollutant Emission Factors).

The amount of coal used in this production process can be determined indirectly from data available from DUKES. The total emission is not large- approximately 0.05 ktonnes of NH₃.

4.3 Inorganic Chemical Industry

The emission reported in this sector comprises a sum of the Emissions reported in the Pollution Inventory, and individual plant from Scotland and Northern Ireland. All of the inorganic chemistry industry is included with the exception of fertiliser manufacture and sugar production from beet.

The NAEI emission estimate of 0.8 ktonnes in 1996 does not agree well with 3.0 ktonnes proposed by Sutton *et al* (2000a) . This may occur due to one of several reasons. First the reference is given as the Chemical Release Inventory (CRI) which is an old version of the Pollution Inventory, although emissions are not expected to be greatly changed retrospectively (and later work- Sutton *et al* (2000b) indicate the use of the Pollution Inventory). Secondly all sources obtained from the CRI (England and Wales) have been scaled by population to account for Northern Ireland and Scotland. The NAEI has used point source specific information to include these regions. Finally it is possible that the data has simply been disaggregated in a different way, and differing assumptions made about whether reported data is considered to be reliable.

An important point is made by Sutton *et al* (2000a)- that there is a reporting threshold for the Pollution Inventory. Therefore it is possible for plant to fall marginally below this threshold, and not report NH₃ emissions. This can result in significant variation between different years, and a general under representation of the NH₃ emissions from the relevant sectors.

4.4 Chemical Fertiliser Production

The NAEI estimate emissions from this sector in 1996 to be 5.5 ktonnes, with data being taken from the Pollution Inventory (1999) and other sources or Scotland and Northern Ireland.

4.5 Organic Chemical Industry

The NAEI estimate emissions from this sector in 1996 to be 0.3 ktonnes, with data being taken from the Pollution Inventory (1999) and other sources or Scotland and Northern Ireland.

4.6 Other Chemical Industry Processes

There are a number of production processes in the chemical industry which are listed in the Pollution Inventory, but which have not been individually included in the sectors above. These remaining smaller processes are aggregated into "Production processes: Chemical Industry" in the NAEI. The sources in this sector include: acid processes, petrochemical processes, processes involving halogens and a number of other minor source groups included as process emissions.

4.7 Paper and Printing

The emissions in this sector are taken directly from the Pollution Inventory (1999). There is one plant reporting NH₃ emissions in 1998 only. It has been assumed that these emissions are constant with time, and consequently the same value (has been entered for 1990 to 1999). Emissions from this sector are very small.

4.8 Sugar Beet Processing

The emission factor for this sector was taken from a personal communication with staff at British Sugar (the only sugar beet processors in the UK). British Sugar have been conducting extensive studies of their environmental emissions and note that the emissions per mass of beet vary across different seasons depending on the growing conditions. However, the quoted emission factor of 0.1 tonnes of NH₃ per ktonne of beet sliced is considered to be a reliable average value.

Data on the mass of the annual sugar beet crop has been provided by British Sugar for the period of 1990 to 1999. The mass of beet that has been washed and topped/tailed has been used, i.e. the mass being sliced. This varies by year, but is generally a little less than 10 Mtonnes of beet.

4.9 Other Industry Processes

Emissions from this sector represent the emissions from the mineral fibre industry. Emissions of NH₃ have been taken directly from the Pollution Inventory (1999).

5. Extraction/Distribution of Fossil Fuels

No sources are included in the 1999 inventory under this source sector.

6. Solvent Use

The sources included in this sector are emissions from non-aerosol household products used for cleaning and hair applications and leakage of NH₃ refrigerant. The emissions given by the NAEI have been taken directly from Sutton *et al* (2000a) as these were considered to be the most reliable data that are currently available. The emission quoted for 1996 (1.14 kTonnes of NH₃) has been applied to all years as it is considered reasonable for the emissions to be constant with time until annual activity data is obtained.

7. Road Transport

The data given here is taken from the NAEI Road Transport Emissions Model which gives the official UK estimates of pollutants for the UK. The methodology of this model is too complex to be given in any detail here. However the following parameters are taken into account when pollutant estimates are made: vehicle types, distances driven, vehicle speed, vehicle age and therefore associated abatement technology, petrol or diesel vehicles, road type and engine size.

The emissions reported from this road transport model are generally considered to be the most reliable estimates for UK emissions that are available. Although agriculture dominates the total NH₃ emissions, road transport is a significant proportion.

Further developments in transport ammonia emission factors have been made, based on new information. The emission factors used for the ammonia abatement report are thus lower than those used in the inventory, this is discussed in detail in section 2.

8. Other Transport & Machinery

There are currently no emissions included in the inventory. Emissions from diesel powered vehicles are small (see sector 7), but estimates will be included in the next version of the inventory.

9. Waste Treatment & Disposal

9.1 MSW and Domestic Waste Incineration

The emissions factors for this sector have been determined from reported point source data. The mass of waste being incinerated can be determined from DUKES and accompanying information. This is conducted in the NAEI on a routine basis to enable the calculation of a number of pollutants. It should be noted that emissions from this sector fall to zero after 1996. This is because all plant are reallocated to SNAP1- the Electricity Generating source sector.

9.2 Sewage Sludge Incineration

Emissions from this source can be calculated in the same way as those from MSW incineration, the amount of sewage sludge incinerated being available from the DUKES. The value given by the NAEI for 1996 is very small at 0.018 ktonnes of NH₃.

9.3 Landfill

Emissions from landfill have been highlighted as the most uncertain of the potentially significant sources. The calculations outlined by Sutton *et al* (2000a) are based on work done by Eggleston (1992) and Munday (1990). This assumes a constant ratio with CH₄ emissions from landfill. However, using CH₄ emissions from landfill reported by the NAEI (the 1999 version of the National Atmospheric Emissions Inventory), it was not possible to resolve the NH₃ emissions reported by Sutton. For consistency the emissions estimates reported by Sutton were used in the NAEI, but more work is needed to arrive at a more reliable estimate for the emissions from this sector.

9.4 Infant Emissions from Nappies

Emission factors and population data has been taken from Sutton *et al* 2000b. The emissions from this sector are very small (0.037 ktonnes of NH₃).

9.5 Waste Water/Sewage Sludge Treatment and Disposal

This sector includes waste water treatment and the disposal of sewage sludge to land. Data provided from a number of waste water treatment plant have not given any reason to doubt the estimated emissions given by Sutton *et al* (2000a), which draws on the data of Lee and Dollard (1994) and Sutton *et al* (1995). Therefore this value (1.46 ktonnes of NH₃) has been used for 1996. Limited data has meant that it has not been possible to determine any variation of this emission across the time series and so this value has been applied to all years since 1990.

Disposal of sewage sludge to land has varied across the time series. The emission factor used here has incorporated the revisions suggested by Sutton *et al* (2000a). The activity data applied to the different years has been determined from the observed trend in the mass of sewage sludge disposed of to land (which has been greatly affected by the ban of disposal to sea).

10. Agriculture, Forestry & Land Use Change

10.1 Emissions from Farmed Animals and Soils

Emissions from agriculture have been taken directly from the NH₃ emission inventory compiled for MAFF by a number of institutes. This includes estimates from manure and excreta of a variety of farmed animals and emissions from agricultural soils.

10.2 Domestic Fertiliser Application

The use of domestic fertiliser has been included in this sector as requested by MAFF. The estimates are taken directly from Sutton *et al* (2000a) as they are currently considered to be the most reliable information available. This gives an emission of 0.28 ktonnes of NH₃.

10.3 Field Burning

Estimates of the emissions of NH₃ from field burning were made by Lee and Atkins in 1994 and gave a UK total of 4 ktonnes of NH₃ prior to the banning of field burning. Sutton *et al* (2000a) has made a more recent estimate of 1.9 ktonnes of NH₃ from biomass burning. Both sources of data have been combined to generate a time series from 1990 to 1999 which is likely to represent the transition which occurred when agricultural burning was significantly reduced.

11. Nature

11.1 Domestic Pets

Emission factors for domestic cats and dogs have been taken directly from Sutton *et al* (2000a), although there are large uncertainties associated with these emission factors as indicated.

The numbers of domestic cats and dogs was taken from the Pet Food Manufacturers Association, which gives animal numbers in the UK from 1979. The NAEI emission estimates are 4.8 and 1.0 ktonnes of NH₃ for dogs and cats respectively.

11.2 Horses

Emissions from horses have been included under the “Nature” sector as requested by MAFF. However this is currently inconsistent with emissions of other pollutants from the same source. This will be addressed during the compilation of the next inventory.

The emissions estimates from this sector have undergone a significant revision since Sutton *et al* 2000a. The latest figures (Sutton *et al* 2000b) indicate that the emission from race horses and other horses sum to 13.0 ktonnes of NH₃. This revision is explained by Sutton as arising from a re-evaluation of the population data. In trying to source data, the NAEI team have come across similar difficulties. The available horse census data shows a significant increase in the horse population across the two most recent surveys. At present it is not known for certain whether this is a real change with time, or an artefact arising from the change in the census methodology—although the latter is strongly suspected. Consequently generating a time series from this data is difficult. The most sensible approach was considered to be to take the most recent population data (also used by Sutton) and to apply this to all years in the time series. This assumes a constant

horse population across 1990 to 1999, but with the currently available data it is not realistic to estimate time resolved emissions.

11.3 Wild Birds

The emissions from this source have been taken directly from Sutton *et al* (2000b) and applied across the time series.

11.4 Other Wild Animals

The emissions from this source have been taken directly from Sutton *et al* (2000b).

11.5 Adult Breath and Sweat

Emission factors for these sectors were taken from Sutton (2000b).

To ensure consistency with other pollutants reported in the NAEI, population data was taken from a different source, but the resulting difference in emissions is insignificant. The total emissions from these two sources sum to 1.2 ktonnes in 1996.

12 Sectors investigated but not included

The following sectors were investigated for significant sources of NH₃. In both cases the calculated NH₃ emissions were small, and therefore not included in the NAEI 1999 emission inventory. However, due to the lack of data availability from both of these sectors the calculated emission was very high in uncertainty. Therefore it is expected that emissions from both sources will be reassessed and calculated with more certainty for the next version of the UK emissions inventory, and will be included.

12.1 Maggot Farming

There are a significant number of maggot farms still operating in the UK (36 known operators), however the industry has gone through significant decline in recent years. Although the NH₃ production from the maggot farming is significant, all operators consulted indicated that abatement measures were in place, and therefore the estimated emissions from the individual installations were small. However, more information is required to determine an emission, which may be reported.

12.2 Fish Processing

There are only five fish meal processing plant known to exist in the UK. Local authorities were consulted regarding the NH₃ emissions occurring from these plant. Where data were available, the emissions of NH₃ were small, being abated by the more modern plant. Local authorities commented that there were significant odour issues associated with the plant operations, but that significant NH₃ emissions were not apparent from the reported emissions data.

13. References

CORINAIR (1999): Atmospheric Emissions Inventory Guidebook. Second Edition. Published and compiled by EMEP, CORINAIR and the European Environment Agency.

DUKES: Digest of United Kingdom Energy Statistics. Historic annual series of publications- the most recent being DUKES 2000. Published by the DTI, by the Stationary Office, London.

Eggleston H S (1992) An Improved UK Ammonia Emissions Inventory. In Klaassen G, Ammonia Emissions in Europe: Emission Coefficients and Abatement Costs. IIASA, A-2361 Laxenbuerg, Austria 95-107.

H M Customs and Excise Report 1998-1999 (1999). The Stationary Office, November 1999.

Lee D and Atkins D (1994) Atmospheric Ammonia Emissions from Agricultural Waste Combustion, *Geophys. Res. Lett.* **21**, 281-284.

Lee D and Dollard G (1994): Uncertainties in Current Estimates of Emissions of Ammonia in the United Kingdom. *Environ. Poll.* **86**, 267-277.

Martin P, Heavner D L, Nelson P R, Maiolo K C, Risner C H, Simmons P S, Morgam W T and Ogden M W (1997): Environmental Tobacco Smokes (ETS): A Market Cigarette Study. *Environ International* **23**, 75-90.

Munday P K (1990) UK Emissions of Air Pollutants 1970-1988. Report LR764. Warren Spring Laboratories UK.

Pollution Inventory (1999). Pollution Inventory compiled and published by the UK Environment Agency.

Sutton MA, Place C J, Eager M, Fowler D, Smith R I (1995) Assessment of the Magnitude of Ammonia Emissions in the United Kingdom. *Atmos. Env.* **29**, 1393-1411.

Sutton M A, Dragosits U, Tang Y S and Fowler D (2000a). Ammonia Emissions from Non-Agricultural Sources in the UK. *Atmos. Env.* **34** 855-869.

Sutton M A, Theobald M R, Dragosits U (2000b). Inventory of Ammonia Emissions from Non-Agricultural Sources in the UK 1999. Interim report for MAFF Contract AM0108. Centre for Ecology and Hydrology Edinburgh, Bush Estate.

USEPA: AP42 Fifth Edition (1999). Compilation of Air Pollutant Emission Factors. Available from USEPA web site: <http://www.epa.gov/ttn/chief/ap42/>

SNAP	SNAP NAME	SOURCE NAME	"FUEL"		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
SNAP1														
010101	Combustion plants >= 300 MW	POWER STATIONS	COAL	kt	0.0248	0.0246	0.0231	0.0192	0.0182	0.0174	0.0160	0.0136	0.0140	0.0117
010102	Combustion plants >=50< 300MW	POWER STATIONS	MSW	kt	0.0976	0.0986	0.1201	0.1666	0.2687	0.2779	0.2873	0.3613	0.0541	0.0224
0105	Coal mining, oil / gas extraction etc	COLLIERIES	COAL	kt	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SNAP	SNAP NAME	SOURCE NAME	"FUEL"		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
SNAP2														
0201	Commercial and institutional plants	MISCELLANEOUS	COAL	kt	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000
0201	Commercial and institutional plants	PUBLIC SERVICES	COAL	kt	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
0201	Commercial and institutional plants	Railways (Stationary sources)	COAL	kt	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0202	Residential plants	DOMESTIC	ANTHRACITE	kt	1.1801	1.6117	1.2900	1.9107	1.9721	1.4365	1.3573	1.2652	0.9504	0.9653
0202	Residential plants	DOMESTIC	COAL	kt	3.0165	3.1185	2.8245	2.6819	1.8899	1.2266	1.3217	1.2959	1.3880	1.7008
0202	Residential plants	DOMESTIC	COKE	kt	0.3752	0.3099	0.2604	0.2168	0.1832	0.1723	0.1792	0.0822	0.1139	0.1148
0202	Residential plants	DOMESTIC	WOOD	kt	0.8910	0.8910	0.8910	0.8910	0.8910	0.8910	0.8910	0.8910	0.8900	0.8900
020205	Other equipment	Cigarette Smoking	Cigarette	kt	0.4492	0.5273	0.5123	0.4973	0.4641	0.4135	0.4389	0.4223	0.4391	0.4189
0203	Plant in agri., forestry etc.	AGRICULTURE	COAL	kt	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SNAP	SNAP NAME	SOURCE NAME	"FUEL"		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
SNAP3														
0301	Comb. in boilers etc.	Iron and Steel	COAL	kt	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0301	Comb. in boilers etc.	Other industry	COAL	kt	0.0012	0.0013	0.0016	0.0013	0.0012	0.0010	0.0008	0.0007	0.0004	0.0005
030311	Cement	Cement	Clinker Production	kt	0.3501	0.2877	0.2619	0.2652	0.3056	0.3016	0.3079	0.3221	0.3282	0.2102

SNAP	SNAP NAME	SOURCE NAME	"FUEL"		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
SNAP4														
04	Production Processes	Chemical Industry	NON FUEL PROC.	kt	0.1030	0.1030	0.1030	0.1030	0.1030	0.1030	0.0774	0.0984	0.1112	0.1189
04	Production Processes	Other industry	NON FUEL PROC.	kt	0.3259	0.3259	0.3259	0.3259	0.3259	0.3537	0.3173	0.3638	0.4103	0.3474
040201	Coke oven (door leakage)	COKE PROD.	COKE MADE	kt	0.1387	0.1289	0.1175	0.1097	0.1116	0.1121	0.1120	0.1122	0.1119	0.1057
040204	Solid smokeless fuel	SSF PRODUCTION	COAL	kt	0.0926	0.0901	0.0791	0.0797	0.0714	0.0589	0.0568	0.0518	0.0381	0.0386
0404	Processes in inorganic chemical industries	Chemical Industry	NON FUEL PROC.	kt	0.7893	0.7893	0.7893	0.7893	0.7893	0.7893	0.7604	0.6581	0.4990	0.5188
040407	NPK fertilisers	Chemical industry (Fertilizer production)	NON-FUEL FERTILIZER	kt	4.7946	4.7946	4.7946	4.7946	4.7946	4.7946	5.5321	3.9308	6.6270	2.6071
0405	Proc. in organic chemical industr. (bulk prod	Chemical Industry (NH3 from Organics)	NON FUEL PROC.	kt	0.4832	0.4832	0.4832	0.4832	0.4832	0.2853	0.3381	0.2493	0.2311	0.1611
0406	Processes in wood, paper pulp, food, drink an	PAPER AND PRINTING	NON FUEL PROC.	kt	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050
0406	Processes in food etc.	Sugar Beet processing	NON FUEL PROC.	kt	0.7900	0.7700	0.9300	0.9000	0.8000	0.8000	0.8800	1.0000	0.8900	0.9500
SNAP	SNAP NAME	SOURCE NAME	"FUEL"		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
SNAP6														
060408	Domestic solvent use (non paint application)	non-aerosol products (household products)	NON-FUEL DOMESTIC	kt	1.1414	1.1414	1.1414	1.1414	1.1414	1.1414	1.1414	1.1414	1.1414	1.1414

SNAP	SNAP NAME	SOURCE NAME	"FUEL"	UNITS	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
SNAP7														
070101	Highway driving	Road transport (All cars)	DERV	kt	0.0015	0.0018	0.0022	0.0029	0.0039	0.0049	0.0057	0.0066	0.0070	0.0078
070101	Highway driving	Road transport (cars cat)	PETROL	kt		0.0187	0.1373	0.4992	0.9546	1.4536	1.9281	2.5430	3.0803	3.5228
070101	Highway driving	Road transport (cars non cat)	PETROL	kt	0.0930	0.0931	0.0967	0.0938	0.0865	0.0797	0.0701	0.0626	0.0525	0.0424
070102	Rural driving	Road transport (All cars)	DERV	kt	0.0045	0.0053	0.0065	0.0083	0.0106	0.0127	0.0146	0.0163	0.0172	0.0190
070102	Rural driving	Road transport (cars cat)	PETROL	kt		0.0562	0.4135	1.4178	2.5969	3.7505	4.9542	6.2949	7.5497	8.5667
070102	Rural driving	Road transport (cars non cat)	PETROL	kt	0.2752	0.2796	0.2912	0.2666	0.2353	0.2057	0.1802	0.1550	0.1286	0.1031
070103	Urban driving	Road transport (All cars)	DERV	kt	0.0050	0.0058	0.0070	0.0093	0.0123	0.0148	0.0168	0.0181	0.0189	0.0210
070103	Urban driving	Road transport (cars cat)	PETROL	kt		0.0581	0.3632	1.1816	2.1782	3.1147	4.0580	4.9429	5.8497	6.6494
070103	Urban driving	Road transport (cars non cat)	PETROL	kt	0.3015	0.2891	0.2557	0.2222	0.1974	0.1708	0.1476	0.1217	0.0996	0.0801
070201	Highway driving	Road transport (All LGVs)	DERV	kt	0.0019	0.0021	0.0024	0.0027	0.0032	0.0038	0.0044	0.0050	0.0055	0.0065
070201	Highway driving	Road transport (LGVs cat)	PETROL	kt				0.0000	0.0001	0.0003	0.0005	0.0007	0.0010	0.0013
070201	Highway driving	Road transport (LGVs non cat)	PETROL	kt	0.0074	0.0068	0.0065	0.0062	0.0059	0.0055	0.0050	0.0044	0.0039	0.0031
070202	Rural driving	Road transport (All LGVs)	DERV	kt	0.0058	0.0071	0.0078	0.0083	0.0094	0.0108	0.0121	0.0133	0.0146	0.0159
070202	Rural driving	Road transport (LGVs cat)	PETROL	kt				0.0000	0.0002	0.0007	0.0013	0.0019	0.0027	0.0031
070202	Rural driving	Road transport (LGVs non cat)	PETROL	kt	0.0232	0.0227	0.0212	0.0189	0.0175	0.0156	0.0138	0.0117	0.0103	0.0076
070203	Urban driving	Road transport (All LGVs)	DERV	kt	0.0060	0.0072	0.0077	0.0087	0.0099	0.0111	0.0122	0.0128	0.0142	0.0157
070203	Urban driving	Road transport (LGVs cat)	PETROL	kt				0.0000	0.0003	0.0007	0.0013	0.0018	0.0026	0.0031
070203	Urban driving	Road transport (LGVs non cat)	PETROL	kt	0.0239	0.0233	0.0212	0.0198	0.0185	0.0159	0.0139	0.0113	0.0100	0.0075
070301	Highway driving	Road transport (coaches)	DERV	kt	0.0016	0.0014	0.0015	0.0015	0.0014	0.0014	0.0014	0.0017	0.0015	0.0016
070301	Highway driving	Road transport (HGV Artic)	DERV	kt	0.0140	0.0138	0.0131	0.0133	0.0150	0.0155	0.0175	0.0185	0.0217	0.0204
070301	Highway driving	Road transport (HGV rigid)	DERV	kt	0.0108	0.0100	0.0097	0.0101	0.0107	0.0106	0.0105	0.0112	0.0108	0.0125
070302	Rural driving	Road transport (coaches)	DERV	kt	0.0051	0.0046	0.0043	0.0039	0.0039	0.0040	0.0041	0.0043	0.0043	0.0047
070302	Rural driving	Road transport (HGV Artic)	DERV	kt	0.0132	0.0135	0.0134	0.0135	0.0139	0.0142	0.0152	0.0155	0.0120	0.0165
070302	Rural driving	Road transport (HGV rigid)	DERV	kt	0.0216	0.0215	0.0211	0.0207	0.0216	0.0207	0.0204	0.0210	0.0204	0.0212
070303	Urban driving	Road transport (buses)	DERV	kt	0.0077	0.0088	0.0086	0.0089	0.0093	0.0093	0.0095	0.0093	0.0095	0.0094
070303	Urban driving	Road transport (HGV Artic)	DERV	kt	0.0037	0.0036	0.0032	0.0032	0.0032	0.0033	0.0035	0.0038	0.0042	0.0034
070303	Urban driving	Road transport (HGV rigid)	DERV	kt	0.0145	0.0143	0.0141	0.0140	0.0152	0.0145	0.0147	0.0150	0.0139	0.0130
0704	Mcycles<50 cm3	Road Transport: Mopeds (<50cc, 2st)	PETROL	kt	0.0010	0.0009	0.0006	0.0005	0.0005	0.0004	0.0004	0.0003	0.0003	0.0004
070501	Highway driving	Road Transport: M/cycle (>50cc, 4st)	PETROL	kt	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0006	0.0007	0.0006	0.0008
070502	Rural driving	Road Transport: M/cycle (>50cc, 2st)	PETROL	kt	0.0010	0.0010	0.0008	0.0007	0.0006	0.0006	0.0006	0.0005	0.0004	0.0005
070502	Rural driving	Road Transport: M/cycle (>50cc,	PETROL	kt	0.0029	0.0031	0.0027	0.0025	0.0025	0.0026	0.0028	0.0028	0.0028	0.0033

		4st)												
070503	Urban driving	Road Transport: M/cycle (>50cc, 2st)	PETROL	kt	0.0013	0.0011	0.0009	0.0008	0.0008	0.0007	0.0007	0.0006	0.0005	0.0005
070503	Urban driving	Road Transport: M/cycle (>50cc, 4st)	PETROL	kt	0.0036	0.0034	0.0029	0.0028	0.0031	0.0030	0.0031	0.0031	0.0030	0.0035

SNAP	SNAP NAME	SOURCE NAME	"FUEL"		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
SNAP9														
090201	MSW/Domestic Incineration	INCINERATION	MSW	kt	0.48242	0.48136	0.45986	0.4134	0.31133	0.30207	0.29613	0	0	0
090205	Incineration of sludges from water treatment	INCINERATION	Sewage Sludge Combustion	kt	0.015	0.0138	0.0144	0.0168	0.0144	0.0164	0.0176	0.0162	0.03811	0.04305
090401	Managed Waste Disposal on Land	LANDFILL	NON-FUEL	kt	4.687	4.687	4.687	4.687	4.687	4.687	4.687	4.687	4.687	4.687
0910	Other waste treatment	Infant Emissions from Nappies	Population	kt	0.03663	0.03663	0.03663	0.03663	0.03663	0.03663	0.03663	0.03663	0.03663	0.03663
091002	Waste water treatment in resid/comm sector	SEWAGE-SLUDGE DISPOSAL	NON FUEL PROCESSES	kt	5.56	5.97	6.38	6.78	7.19	7.6	8.01	7.73	7.45	7.16
SNAP	SNAP NAME	SOURCE NAME	"FUEL"		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
SNAP10														
1001	Cultures with fertilizers	AGRICULTURAL SOILS	NON-FUEL FERTILIZER	kt	50	54	41	37	35	30	24	28	26.7584	29.803
100104	Market gardening	DOMESTIC HOUSE&GARDEN	Domestic Fertilizer	kt	0.27929	0.27929	0.27929	0.27929	0.27929	0.27929	0.27929	0.27929	0.27929	0.27929
100301	Cereals	FIELD BURNING	NON-FUEL AGRICUL	kt	4	4	2.97	1.94	1.94	1.94	1.94	1.94	1.94	1.94
1005	Manure management - organic compounds	Pigs Wastes	Manure & Excreta	kt	32.7	33.1	33.29	33.66	33.13	31.51	30.67	32.74	39.5625	35.473
100501	Dairy cows	Dairy Cattle Wastes	Manure & Excreta	kt	90.57	89.43	88.08	87.93	87.35	85.86	84.83	82.16	80.1726	96.293
100502	Other cattle	Other Cattle Wastes	Manure & Excreta	kt	61.38	59.66	59.17	59.47	62.4	60.57	62.43	61.09	61.5335	46.275
100505	Ovines	Sheep&Goats Wastes	Manure & Excreta	kt	17.32	17.24	17.27	17.31	17.44	17.31	16.98	17.2	18.1767	18.336
100507	Laying hens	Laying Hens Wastes	Manure & Excreta	kt	19.47	13.63	13.6	13.44	13.49	13.25	13.34	14.21	12.6335	11.679
100508	Broilers	Broilers Wastes	Manure & Excreta	kt	19.47	20.02	18.96	20.56	19.57	19.14	19.14	19.34	21.4266	22.464
100509	Other poultry	Other Poultry Wastes	Manure & Excreta	kt	16.57	14.14	14.03	13.95	15.12	16.12	16.12	18.6	16.8239	17.56

100515	Other	Deer Wastes	Manure & Excreta	kt	0.05	0.06	0.06	0.06	0.05	0.04	0.04	0.04	0.0478	0.0491
SNAP	SNAP NAME	SOURCE NAME	"FUEL"		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
SNAP11														
110702	Mammals	Domestic Pets	Manure & Excreta	kt	6.3	6.24	6.25	5.97	5.8	5.74	5.83	5.84	6.1	6.1
110702	Mammals	Horses Wastes	Manure & Excreta	kt	13.0171	13.0171	13.0171	13.0171	13.0171	13.0171	13.0171	13.0171	13.0171	13.0171
110703	Other animals	Wild Birds Wastes	Manure & Excreta	kt	4.154	4.154	4.154	4.154	4.154	4.154	4.154	4.154	4.154	4.154
110703	Other animals	Wild Other Animal Wastes	Manure & Excreta	kt	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.1857	2.1857
1125	Other	Adult Breath & Sweat	Population	kt	1.18823	1.19332	1.19741	1.20123	1.20543	1.20979	1.20967	1.21811	1.21811	1.21811

