UNITED
NATIONS

E

Economic and Social Council

Distr.
GENERAL

EB.AIR/WG.5/1999/8/Rev.1
23 July 1999

Original: ENGLISH

ECONOMIC COMMISSION FOR EUROPE

EXECUTIVE BODY FOR THE CONVENTION ON
LONG-RANGE TRANSBOUNDARY AIR POLLUTION

Working Group on Strategies
(Thirty-first session, 26 August - 3 September 1999)

Item 2 of the provisional agenda

CONTROL TECHNIQUES FOR PREVENTING AND ABATING EMISSIONS OF AMMONIA[*/]

Introduction

1. The purpose of this document is to provide guidance to the Parties to the Convention in identifying ammonia control options and techniques for reducing emissions from agricultural and other stationary sources in the implementation of their obligations under the Protocol.

2. It is based on information on options and techniques for ammonia emission reduction and their performance and costs contained in official documentation of the Executive Body and its subsidiary bodies.

3. The document addresses the control of ammonia emissions produced by agriculture and other stationary sources. Agriculture is the major source of ammonia, chiefly from livestock excreta, in livestock housing, during manure storage, processing and application to land and from excreta from animals at pasture. Emissions also occur from inorganic nitrogen (N) fertilizers when

____

*/ Prepared by the technical expert group during the thirtieth session of the Working Group on Strategies.

these are applied to land. Emissions could be reduced through abatement measures in all the above areas as well as by adjustments to livestock diets that result in less nitrogen in excreta available for ammonia formation. This document addresses the known potential abatement measures under the headings: slurry and manure application techniques; slurry storage techniques; livestock housing; feeding strategies and other measures; and non-agricultural stationary sources.

4. Abatement of ammonia emissions from agriculture differs fundamentally from the abatement of any industrial emissions because of the intrinsic difficulties entailed in regulating biological as opposed to engineering processes. Ammonia emissions depend largely on livestock type and management, soils and climate and these factors differ widely across the region of the United Nations Economic Commission for Europe (UN/ECE). While some of the techniques listed in this document are in commercial operation in some countries, their effectiveness has, for the most part, not been fully evaluated on working farms. Consequently, the efficiency of each of the abatement techniques for ammonia carry with them a degree of uncertainty and variability. The values used in this document should be regarded as indicative only.

5. It is possible to categorize many of the potential abatement techniques on the basis of the level of current knowledge and practicality. Techniques in this document are grouped into three categories:

(a) **Category 1 techniques**: they are well researched, considered to be practical, and there are quantitative data on their abatement efficiency, at least on the experimental scale;

(b) **Category 2 techniques**: they are promising, but research on them is at present inadequate, or it will always be difficult to quantify their abatement efficiency;

(c) **Category 3 techniques**: they have been shown to be ineffective or are likely to be excluded on practical grounds.

6. Options for ammonia reduction at the various stages of livestock manure production and handling are interdependent, and combinations of measures are not simply additive in terms of their combined emission reduction. Controlling emissions from applications of manures to land is particularly important, because these are generally a large component of total manure emissions and because land application is the last stage of manure handling. Without abatement at this stage, much of the benefit of abating during housing and storage may be lost.

7. Because of this interdependency, Parties will need to rely on additional modelling work before they can use the techniques listed here to develop an ammonia abatement strategy to meet their national emission targets.

8. The costs of the techniques will vary from country to country. A thorough knowledge of current husbandry practices is required to calculate the costs associated with any particular abatement technique. This calculation will involve an assessment of all the costs and financial benefits of each measure. Capital costs will need to be amortized at the standard UN/ECE rate of 4% and calculated separately from annual operating costs. Many measures may incur both capital and annual costs. For example, new livestock housing will incur the capital cost of the building itself plus potential annual costs of extra maintenance and/or energy. Costs in this document are shown for the Netherlands or the United Kingdom and are given as examples only. A fuller explanation of the means of calculating costs is provided in chapter VII.

9. Wherever possible, techniques listed in this document are clearly defined and assessed against a ‘reference’ or unabated situation. The ‘reference’ situation, against which percentage emission reduction is calculated, is defined at the beginning of each chapter. In most cases the ‘reference’ is the practice or design that gives rise to the highest ammonia emission: in many countries the ‘reference’ will be the most commonly practised technique, at present.

10. The document reflects the state of knowledge and experience of ammonia control measures which had been achieved by 1998. It will need to be updated and amended regularly, as this knowledge and this experience continuously expand, for example with new low-emission housing systems for pigs and cattle, as well as with feeding strategies for all livestock types.

I. GOOD AGRICULTURAL PRACTICE

11. The concept of ?good agricultural practice" aims to identify those measures to control ammonia emissions that protect the environment in the most cost-effective way. The set may comprise simple and highly cost-effective measures such as simple means of matching the protein in livestock diets as closely as possible to the animals’ requirements; regular cleaning of livestock collecting areas and the timing of applications of manures to land so as to maximize crop uptake of nutrients. It could also include more demanding measures such as techniques for slurry and manure application, slurry storage, livestock housing and other techniques, as listed below.

12. While some of the measures may provide highly cost-effective means of abating ammonia, they may be difficult to quantify and cost because there is

often a wide range of implementation already within the farming community and they cannot therefore easily be judged against a ‘worst case’ or ‘most commonly practised’ reference.

13. Good agricultural practice aims to achieve a compromise between economic farming and environmental protection. This compromise will differ from country to country depending on differing economic, environmental and farm structural conditions. Any statutory requirements to adhere to such advice will therefore necessarily vary from country to country.

II. SLURRY AND MANURE APPLICATION TECHNIQUES

14. Reference technique. The reference for manure application techniques is defined as emissions from untreated slurry or solid manure spread over the whole soil surface (‘broadcast’). For slurry, for example, this would be with a tanker equipped with a discharge nozzle and splash-plate. Ammonia emissions from slurry irrigation systems have been less studied but could be as high as the reference case. For solid manures, the reference case would be to leave the manure on the soil surface for a week or more. Emissions will vary with the composition of the slurry and manure and with prevailing weather and soil conditions. Abatement efficiencies will also vary relative to reference emissions depending on these factors, so figures quoted should be regarded as indicative only.

15. Lowering ammonia emissions may increase the amount of N available for plant uptake, so mineral N fertilizer application rates may need to be adjusted. Some techniques may temporarily decrease crop yield (especially of grass) through mechanical damage. There is also potential for increasing N losses by other pathways, e.g. nitrate leaching, nitrification or denitrification, the latter two processes resulting in greater emissions of nitrous oxide.

Category 1 techniques

16. Category 1 techniques include machinery for decreasing the surface area of slurries and burying slurry or solid manures through incorporation into the soil. The techniques included in category 1 are

(i) Band-spreading;
(ii) Trailing shoe or ‘sleigh-foot’ machines;
(iii) Injection - open slot;
(iv) Injection - closed slot;
(v) Incorporation of surface applied manure and/or slurry into soil.

17. The average ammonia abatement efficiency of category 1 techniques relative to the reference is given in table 1. The efficiency is valid for soil types and conditions that allow infiltration of liquid for techniques (i) - (iv) and satisfactory travelling conditions for the machinery. The table also summarizes the limitations that must be taken into account when considering the applicability of a specific technique and an indication of the cost.

18. A number of factors must be taken into account in determining the applicability of each technique. These factors include: soil type and condition (soil depth, stone content, wetness, travelling conditions), topography (slope, size of field, evenness of ground), manure type and composition (slurry or solid manure). Some techniques are more widely applicable than others. Because the manure is distributed through relatively narrow pipes in techniques (i) - (iv), even though most machines incorporate a device for chopping and homogenizing the manure, they are not suitable for very viscous slurries or those containing large amounts of fibrous material e.g. straw. Injection techniques are potentially very efficient but they do not work well on shallow, stony soils, which may result in damage to grass sward and increase the risk of soil erosion. Incorporation is not applicable on permanent grassland. Comments on applicability are included in the descriptions of the technique below and summarized in table 1.

19. Band-spreading, trailing shoe and injection machines are normally fitted to the rear of a slurry tanker, which is either towed by a tractor or is part of a self-propelled machine. An alternative is for the applicator to be attached to the rear of the tractors and slurry transported to it by a long ‘umbilical’ hose from a tanker or store located off the field. Such umbilical systems avoid the need to take heavy slurry tankers onto the land.

20. Band-spreading. Band-spreaders discharge slurry at or just above ground level through a series of hanging or trailing pipes. The width is typically 12 m with about 30 cm between bands. The technique is applicable to grass and arable land, e.g. for applying slurry between rows of growing crops. Because of the width of the machine, the technique is not suitable for small, irregularly shaped fields or steeply sloping land. The hoses may also become clogged if the straw content of the slurry is too high.

21. Trailing shoe. This technique is mainly applicable to grassland. Grass leaves and stems are parted by trailing a narrow shoe or foot over the soil surface and slurry is placed in narrow bands on the soil surface at 20 - 30 cm spacings. The slurry bands should be covered by the grass canopy so the grass height should be a minimum of 8 cm. The machines are available in a range of widths up to 7 - 8 m. Applicability is limited by size, shape and slope of the field and by the presence of stones on the soil surface.

22. Injection - open slot. This technique is mainly for use on grassland. Different shaped knives or disc coulters are used to cut vertical slots in the soil up to 5 - 6 cm deep into which slurry is placed. Spacing between slots is typically 20 - 40 cm and working width 6m. The application rate must be adjusted so that excessive amounts of slurry do not spill out of the open slots onto the surface. The technique is not applicable on very stony soil, nor on very shallow or compacted soils, where is impossible to achieve uniform penetration of the knives or disc coulters to the required working depth.

23. Injection - closed slot. This technique can be shallow (5 - 10 cm depth) or deep (15 - 20 cm). Slurry is fully covered after injection by closing the slots with press wheels or rollers fitted behind the injection tines. Shallow closed-slot injection is more efficient than open-slot in decreasing ammonia emission. To obtain this added benefit, soil type and conditions must allow effective closure of the slot. The technique is, therefore, less widely applicable than open-slot injection. Deep injectors usually comprise a series of tines fitted with lateral wings or ‘goose feet’ to aid lateral dispersion of slurry in the soil so that relatively high application rates can be achieved. Tine spacing is typically 25 - 50 cm and working width 2 - 3 m. Although ammonia abatement efficiency is high, the applicability of the technique is severely limited. The use of deep injection is restricted mainly to arable land because mechanical damage may decrease herbage yields on grassland. Other limitations include soil depth and clay and stone content, slope and a high draught force requiring a large tractor. There is also a greater risk of nitrogen losses as nitrous oxide and nitrates in some circumstances.

24. Incorporation. Incorporating manure spread on the surface by ploughing is an efficient means of decreasing ammonia emissions. The manure must be completely buried under the soil to achieve the efficiencies given in table 1. Lower efficiencies are obtained with other types of cultivation machinery. Ploughing is mainly applicable to solid manures on arable soils. The technique may also be used for slurries where injection techniques are not possible or unavailable. Similarly, it is applicable to grassland when changing to arable land (e.g. in a rotation) or when reseeding. Ammonia loss takes place quickly after manures are spread on the surface, so greater reductions in emissions are achieved when incorporation takes place immediately after spreading. This requires a second tractor to be used for the incorporation machinery, which must follow close behind the manure spreader. A more practical option might be incorporation within the same working day as spreading the manure, but this is less efficient in reducing emissions.

Category 2 techniques

25. Increasing rate of infiltration into the soil. When soil type and conditions allow rapid infiltration of liquid, ammonia emission decreases with decreasing slurry dry matter content. Dilution of slurry with water not only decreases the ammonium-N concentration but also increases the rate of infiltration into the soil following spreading on land. For undiluted slurry (i.e. 8 - 10% dry matter), dilution must be at least 1:1 (one part slurry to one part water) to achieve reduced emissions. A major disadvantage of the technique is that extra storage capacity may be needed and a larger volume of slurry must be applied to land. In some slurry management systems, slurry may be already diluted (e.g. where milking parlour or floor washings, rainfall, etc. are mixed with the slurry) and there may be only a small advantage in diluting further. When applying diluted slurries to land there may be a greater risk of surface run-off and leaching and this must be guarded against by paying attention to application rate, soil conditions, slope of the land, etc.

26. Another means of decreasing slurry dry matter content, and hence increasing the rate of infiltration into the soil, is to remove a proportion of the solids by mechanical separation. Using a mechanical separator with a mesh size of 1 - 3 mm lowers ammonia loss by a maximum of 50%. Disadvantages of the technique include the capital and operating costs of the separating machine and ancillary equipment, the need to handle both a liquid and a solid fraction, and emissions from the solids.

27. A third option for increasing infiltration rate is to wash slurry off grass and into the soil by applying water after spreading. A plentiful supply of water is needed, the application of which is an additional operation, but Canadian results have shown that 6mm of water can under some circumstances reduce ammonia losses by 50% compared to surface application alone.

28. Timing of application. Ammonia emissions are highest under warm, dry, windy conditions. Emissions can be reduced by choosing the optimum time of application, i.e. cool humid conditions, in the evenings, before or during rain and by avoiding spreading during June, July and August. Although it is not possible to quantify the efficiency of this technique, it is likely to be very cost-effective and to improve the efficiency of some other low-emission techniques in category 1. Conditions that favour low ammonia emissions (e.g. humid, no wind) may give rise to problems with offensive odours by preventing their rapid dispersion.

29. Pressurized injection. In this new technique, slurry is forced into the soil under pressure of 5 - 8 bars. Because the soil surface is not broken by

tines or discs the technique is applicable on sloping land and stony soils where other types of injector cannot be used. Emission reductions of up to 70% have been achieved in field trials, but further evaluation of the technique is needed.

Category 3 techniques

30. Acidified slurry. The equilibrium between ammonium-N and ammonia in solutions is dependent upon the pH. High pH favours loss of ammonia; low pH favours retention of ammonium-N. Lowering the pH of slurries to 4 - 5 by adding strong acids (e.g. nitric or sulphuric acid) decreases ammonia emission by 30 - 95%. Nitric acid has the advantage of increasing the slurry N content so giving a more balanced NPK fertilizer. Acidification has been carried out during storage of slurry and also during spreading using specially designed tankers. Although efficient, the technique has two major disadvantages. Firstly, handling strong acids on farms is very hazardous and, secondly, there is considerable potential for increasing the rate of nitrification/denitrification and emissions of nitrous oxide. Moreover, adding too much acid could produce hydrogen sulphide and worsen odour problems.

31. Other additives. Salts of calcium (Ca) and magnesium (Mg), acidic compounds (e.g. $FeCl_3$, $Ca(NO_3)_2$) and super-phosphate have been shown to lower ammonia emission, but the quantities required are too large to be practically feasible. Absorbent materials such as peat or zeolites have also been used. There is also a range of commercially available additives, but in general these have not been independently tested.

Table 1. Category 1 abatement techniques for manure application to land*

Abatement measure	Type of manure	Land use	Emission reduction (%)	Applicability[a]	Costs[b] (Euro per m^3)
Band-spreading	Slurry	Grass land	30 Emission reduction will be less if applied on grass >10 cm	Slope (<10% for tankers; <20% for umbilical systems); not for slurry that is viscous or has a high straw content, size and shape of field.	0.68
Band-spreading	Slurry	Arable	30	Slope (<10% for tankers; <20% for umbilical systems); not for slurry that is viscous or has a high straw content, size and shape of the field, possibility of applying to growing crop between rows.	0.68
Trailing shoe	Slurry	Mainly grass land	40	Slope (<10% for tankers; <20% for umbilical systems); not viscous slurry, size and shape of the field, grass height should be about 8 cm	1.33
Injection (open slot)	Slurry	Grass land	60	Slope < 12%, greater limitations for soil type and conditions, not viscous slurry.	2.51

Injection (closed slot)	Slurry	Mainly grass land, arable land	80	Slope < 12%, greater limitations for soil type and conditions, not viscous slurry.	2.51
Incorporation - immediate (costs for < 4h)	Solid manure and slurry	Arable land	80	Only for land that can be easily ploughed	Slurry 0.67 dairy; 0.53 other cattle; 1.05 pigs. Manure 1.32 dairy, other cattle, sheep and goats; 1.47 pigs; 3.19 layers; 6.19 broilers.
- within same working day	Solid manure and slurry		50-90 for manure depending on type; 40 for slurry		As above

*/ Emissions reductions are agreed as likely to be achievable across the UN/ECE.

a/ See text for details.

b/ Costs are for the United Kingdom. Costs are annual operating costs based on the use of contractors and depend on the application rate per hectare. See chapter VII for more information on costs.

C. SLURRY STORAGE TECHNIQUES

32. At present, there are no proven techniques for reducing ammonia emissions from stored solid manures. This chapter relates only to techniques for slurry storage. After removal from animal houses, slurry is stored either in concrete or steel tanks or silos or in lagoons, often with earth walls. The latter tend to have a relatively larger area per unit volume than the former.

33. Emissions from slurry stores can be reduced by decreasing or eliminating the airflow across the surface by installing a cover by allowing the

formation of a crust, or by reducing the surface per unit volume of the slurry store.

34. When using an emission abatement technique in manure stores, it is important to prevent loss of the conserved ammonia during spreading on land by using an appropriate low-emission application technique.

35. Reference technique. The baseline for estimating the efficiency of an abatement measure is the emission from the same type of store, without any cover or crust on the surface. Table 2 gives an overview of the different emission abatement measures for slurry tanks and their efficiency in reducing emissions.

Category 1 techniques

36. The best proven and most practicable technique to reduce emissions from stored slurry is to cover the slurry tanks or silos with a solid lid, roof or tent structure. Sealed tanks of canvas reinforced by glass fibre are also available for this purpose. While it is important to guarantee that covers are well sealed to minimize air exchange, there will always need to be some small openings or a facility for venting to prevent the accumulation of inflammable gases, such as methane.

Category 2 techniques

37. Aside from rigid covers and roofs (category 1), there is a range of flexible or floating covers that can also reduce ammonia emissions from stored slurries by preventing contact between the slurry and the air. However, the effectiveness and practicality of these covers are not well tested and are likely to vary according to management and other factors (category 2). Examples include flexible covers such as plastic sheeting placed on the surface of the slurry or a layer of oil floating on the surface. Similarly, the introduction of straw, peat, LECA balls (light expanded clay aggregates) or other floating material to the slurry surface in tanks or lagoons can reduce emissions by creating an artificial crust. These floating materials might hinder homogeneization of the slurry prior to spreading, or the spreading process itself, by clogging up machinery. This could cause problems on farms with frequent slurry spreading (e.g. to grassland).

38. Minimizing stirring of stored cattle slurry of a sufficiently high dry matter content will allow the build-up of a natural crust. If this crust totally covers the slurry surface and is thick enough, and slurry is introduced below the crust, such a crust can significantly reduce ammonia emissions at little or no cost. This natural crust formation is an option for farms that do not have to mix and spread slurry frequently. The emission

abatement efficiency will depend on the nature and duration of the crust. Due to this uncertainty this measure is also grouped in category 2.

39. If lagoons (or weeping wall stores) are replaced by tanks, emissions may also be reduced due to the lower surface area per unit volume. This could be an effective (though expensive) reduction option, particularly if the tanks are covered by rigid lids. However, the effectiveness of the option is difficult to quantify, as it is strongly dependent on the characteristics of the lagoon and the tank. It is therefore classed as category 2.

Table 2. Emission abatement measures for slurry storage

Abatement measure	**Livestock class**	**Emission reduction (%)**[a/]	**Applicability**	**Costs (Euro per m^3/yr)**[b/]
Rigid lid or roof (Cat. 1)	All	80%	Tanks and silos only	8.00
Flexible cover or floating (Cat. 2)	All	60		1.10 -tanks 1.25 - lagoons
Low technology covering (straw, peat, bark, LECA balls, etc.) (Cat. 2)	All	40	Probably not practicable on lagoons. Not on farms with frequent slurry spreading	1.10 - tanks
Natural crust (Cat. 2)	Cattle	35 - 50	Not on farms with frequent slurry spreading	0.00
Replacement of lagoon, etc. with **covered** tank (Cat. 2)	All			14.9 (cost of tank 6.94)

a/ Emission reductions are agreed best estimates of what might be achievable across UN/ECE. Reductions are expressed relative to emissions from an uncovered slurry tank/kilo.

b/ Costs are for the United Kingdom. Costs refer to the cost of the lid only, and do not include the cost of the silo.

D. LIVESTOCK HOUSING

40. Animal housing varies enormously across the UN/ECE region and ammonia emissions will vary accordingly. In general, emissions from livestock housing will be reduced if the surface area of the exposed slurry or manures is reduced and/or it is frequently removed and placed in covered storage outside the building. Emission reductions can also be achieved in poultry housing by drying manure and litter to a point where ammonia is no longer formed. Many of the options for reducing emissions from housing can be implemented only for newly built houses. Others require significant structural changes or energy inputs. For these reasons they are often more expensive than manure application or storage actions.

41. Reference techniques. The level of ammonia emission reduction achieved through new livestock housing designs will depend critically on the housing types currently in use and so can be calculated only in a matrix of change (see tables 4, 6 and 14).

A. Housing systems for dairy and beef cattle

42. There are currently no category 1 techniques available for abating ammonia from dairy and beef cattle housing.

Category 2 techniques

43. Straw-based systems. Research to date has not provided any proven low-ammonia emission housing techniques for beef or dairy cattle on straw-based or farm-yard manure systems. Ammonia emissions from straw-based housing may depend critically on the quantity of straw used: a high straw content in the manure can give rise to lower emissions than some traditional slurry-based housing, but there are currently insufficient data to prescribe specific quantities of straw per animal.

44. Slurry-based systems. A number of systems have been tried for slurry-based cattle housing, although none is sufficiently developed at present to be recommended as a category 1 technique. As with other livestock housing, current practice varies greatly between countries and farm types. The system most commonly researched is the “cubicle house” for dairy cows, where ammonia emissions arise from the manure pit, beneath the floor and from urine- and manure-fouled slatted and/or solid floors. In table 3, cubicle housing is considered to be the reference. Buildings in which the cattle are held in tied stalls tend to give rise to lower ammonia emissions than loose housing, because a smaller floor area is fouled with dung and urine. However, tied systems are not recommended because of animal welfare considerations.

45. Techniques to reduce ammonia emissions in cattle housing apply one or more of the following principles:

- Decreasing the surface area fouled my manure;
- Adsorption of urine(e.g. by straw);
- Rapid removal of urine; rapid separation of faeces and urine;
- Decreasing of the air velocity above the manure;
- Reducing the temperature of the manure and surfaces it covers.

46. Scraping and flushing systems. A number of systems have been tried involving the regular removal of the slurry from the floor to a covered store outside of the building. These involve either flushing with water, acid or diluted slurry, or scaping with or without water sprinklers. In general, these systems have proved to be ineffective or too difficult to maintain. The use of smooth and/or sloping floors to assist in scraping or flushing has given rise to problems with animal slipping and potentially injuring themselves.

47. The most promising system to date involves the use of a “toothed” scraper running over a grooved floor. This appears to produce a clean, and therefore lower-emitting floor surface, while still providing enough grip for the cattle to prevent any problems of slipping. This system is currently under evaluation in the Netherlands.

48. Table 3 gives emissions from different cattle housing in the Netherlands and an indication of the emissions reductions and costs which have been found in that country. Table 4 shows the applicability and advantages of adopting new housing designs relative to those in current use.

Tabel 3. Ammonia emissions and costs of different cattle housing in the Netherlands.

Code	Housing type	Reduction (%)	Ammonia emmission (kg/cow place/year)	Extra investments costs (Euro/cow place)	Extra costs (Euro/cow place/year)
1	Cubicle house (Reference)	0	13.0	Reference	Reference
2	Tied system[a/]	40	7.5	-/-	-/-[c/]
3	Tied system only during winter time[b/]	60	5.0	-/-	-/-[c/]
4	Grooved floor (Cat.2)	50	4.0	374	55
5	Flushing system without acid several times a day (Cat. 2) Scraper/slurry systems	50	4.0	217	31 102 - UK
6	Solid floor with straw bedding[b/]	0	0.60	-/-	-/-

a/ Tied systems are not favoured for animal welfare reasons.

b/ Systems with straw are favoured for animal welfare reasons. Emissions depend on the amount of straw used. Too little straw may increase emissions.

c/ Difficult to quantify. In any case, labour costs will be higher.

Table 4. Applicability of the different housing systems for cattle. (Read horizontally only)

System	Applicability of changing from one housing design to another	1	2	3	4	5	6
1	Cubicle house (Reference)		3	3	2	2	4
2	Tied system	4		4	4	3	4
3	Tied system only during winter time	4	4		1	3	4
4	Castellated floor	4	4	4		o/o	4
5	Flushing system without acid several times a day	4	4	4	o/o		4
6	Solid floor with straw bedding	4	4	4	4	4	

1 = highly applicable **4 = illogical, (NH_3 increase)**
2 = applicable **o/o = no difference in NH_3 emission**
3 = not applicable

B. Housing systems for pigs

49. Ammonia emissions from pig housing arise from the manure pit beneath the floors and from urine- and manure-fouled slatted and solid floors. Emissions from floors are influenced by the ratio of the slatted- to solid- floor area. Emissions from the pit can be decreased by quickly and completely removing the manure to an outdoor storage or by treating it (e.g. acidification or cooling).

50. Emissions from fully slatted pig houses are taken as the reference, although in some countries these systems are banned for animal welfare reasons. Pig housing with solid floors and straw bedding is favourable from an animal welfare point of view. However, these systems can give rise to ammonia emissions as high as or even higher than those from housing with fully slatted floors, particularly as they tend to allow more floor area (and therefore a larger emitting surface) per animal.

Category 1 techniques

51. Partly slatted floors (some 50% area), generally give rise to lower ammonia emissions, particularly if the slats are metal-or plastic-coated, allowing the manure to fall more rapidly and more completely into the pit below. Emissions from the solid part of the floor can be reduced by using an inclined or convex, smoothly finished surface, by appropriate siting of the feeding and watering facilities to prevent fouling the solid areas and by good climate control.

52. A number of manure removal or treatment systems can be used in conjunction with good floor design to further reduce ammonia emissions from pig housing:

(a) Flushing systems. There are many different types of flushing systems. Low-emission flushing systems remove the manure from the pit rapidly. The addition of acids also further reduces emissions, although this has other disadvantages (see para. 30).

(b) Vacuum systems. Rapid removal of manure from pits can be achieved by vacuum removal systems operated at least daily.

(c) Manure cooling. Cooling of the surface of the manure in the under-floor pit to 12°C or less by pumping groundwater through a floating heat exchanger can substantially reduce ammonia emissions. A readily available source of groundwater is required and the system may not be allowed where drinking water is extracted.

53. New designs for pig housing should, ideally, integrate the floor, manure pit and removal system with pen geometry to influence drinking and excreting areas in combination. Manure pit surface area can be reduced by using, for example, manure pans, manure gutters or small manure canals.

Category 2 techniques

54. Category 2 techniques for reducing ammonia include good climate control within the housing to ensure that temperature and ventilation rates do not get too high. Other systems which could reduce ammonia include lowering the under-floor manure pit further (suggest 1.2 m instead of 0.45 m) to maintain the slurry at a lower temperature and mixing bedding straw with peat. The use of peat, however, is considered unsustainable in many countries.

Category 3 techniques

55. It is possible to treat the ventilated air from the pig housing using a biological or organic matter (e.g. peat, bark) scrubber, but these systems are generally very expensive and have major practical drawbacks, such as clogging up and increasing the volume of waste. Also, they are not applicable to naturally ventilated buildings.

56. Table 5 shows the ammonia emissions for reference and category 1 housing types for fattening pigs in the Netherlands depending on the type of floor, the manure removal system, and the integrated design of pen and manure pit. Table 6 shows the applicability and advantages of adopting new housing designs over those in current use. Tables 7 to 12 show the applicability for sows and weaners.

Table 5. Techniques, reductions and costs of low-emission housing systems for fattening pigs[*/] (all techniques listed are category 1)

Code	Housing type	Reduction (%)	Ammonia emission (kg/pig place/year)	Extra investment costs (Euro/pig place)	Extra costs (Euro/pig place/year)
1	Fully slatted floor (Reference)	Reference	3.0	Reference	Reference
2	Partly slatted (some 50%) floor	20	2.5	5	-/- 8.27 - UK
3	Vacuum system	25	2.2	10	4
4	Partly slatted floor - metal slats	40	1.8	20 - NL 57.5 - UK	6 - NL 7.82 - UK
5	Partly slatted, external alleys (width 1.3 - 1.5 m)	20	2.5	5	4
6	Flushing system by gutters	45	1,6	50	17

7	Flushing system with acid	55	1.4	54	11
8	Flushing system with clarified aerated slurry	55	1.4	55	12 17.21 - UK
9	Manure cooling system (to 12° C max.)[a/]	60	1.2	56	9
10	Partly slatted floor - metal slats plus reduced manure pit surface to max. 0.18m[2]	65	1.0	5	0.2
11	Solid floor with straw bedding [b/]	0	3.0	-/-	-/-

*/ Emissions and reductions refer to experience in the Netherlands. Costs are for Netherlands (NL), unless stated that they are for the United Kingdom (UK).

a/ A readily available source of groundwater is required and the system may not be allowed where drinking water is extracted.

b/ Systems with straw are favoured for animal welfare reasons.

Table 6. Applicability of the different techniques of low-emission housing systems for fattening pigs. (Read horizontally only)

System	Applicability of changing from one housing design to another	1	2	3	4	5	6	7	8	9	10	11
1	Fully slatted floor (Reference)		2	1	2	1	1	1	1	1	2	o/o
2	Partly slatted (some 50%) floor	4		1	1	1	1	1	1	1	1	4
3	Vacuum system	4	4		1	4	3	1	1	1	1	4
4	Partly slatted floor - metal slats	4	4	4		4	1	1	1	1	1	4
5	Partly slatted, external alleys	4	4	1	1		3	3	1	2	1	4
6	Flushing system by gutters	4	4	4	4	4		3	3	3	1	4
7	Flushing system with acid	4	4	4	4	4	4		3	3	1	4
8	Flushing system with clarified aerated slurry	4	4	4	4	4	4	4		3	1	4
9	Manure cooling system to 12°C max.	4	4	4	4	4	4	4	4		3	4

10	Partly slatted floor - metal slats - reduced manure pit surface	4	4	4	4	4	4	4	4	4		4
11	Solid floor with straw bedding	3	3	3	3	3	3	3	3	3	2	

1 = highly applicable

2 = applicable

3 = not applicable

4 = illogical, (NH_3 increase)

o/o = no difference in NH_3 emission

Table 7. Techniques, reductions and costs of low-emission housing systems for pigs (farrowing sows including pigs)

Code	**Housing type**	**Reduction (%)**	**Ammonia emission (kg/pig place/year)**	**Extra investment costs Euro/pig place**	**Extra costs (Euro/ pig/place/ year)**
1	Fully slatted floor (Reference)	Reference	8.3	Reference	Reference
2	Partly slatted (some 50%) floor	30	6.0	-/-	-/-
3	Vacuum system	40	5.0	-/-	-/-
4	Water/manure channel plus reduced manure pit surface to max. 0.80 m^2	50	4.0	57	/
5	Flushing system with clarified aerated slurry	50	4.0	480	95
6	Flushing system by gutters	60	3.3	511	82
7	Flushing system with acid	60	3.1	469	83
8	Manure cooling system (to 12°C max.) [a/]	70	2.4	288	51
9	Solid floor with straw bedding [b/]	0	8.3	-/-	-/-

a/ A readily available source of groundwater is required and the system may not be allowed where drinking water is extracted.

b/ Systems with straw are favoured for animal welfare reasons. Emissions depend on the amount of straw use.

Table 8. Applicability of the different techniques of low-emission housing systems for farrowing sows including sucklings pigs. (Read horizontally only)

System	Applicability of changing from one housing design to another	1	2	3	4	5	6	7	8	9
1	Fully slatted floor (Reference)		2	1	1	1	1	1	1	4
2	Partly flatted (some 50%) floor	4		1	1	1	1	1	1	4
3	Vacuum system	4	4		1	1	3	1	2	4
4	Water manure, channel plus reduced manure pit surface to max.0.80 m^2	4	4	4		1	3	1	3	4
5	Flushing system with clarified aerated slurry	4	4	4	4		3	1	3	4
6	Flushing system by gutters	4	4	4	4	4		1	3	4
7	Flushing system with acid	4	4	4	4	4	4		3	4
8	Manure cooling system (to 12° C max.)	4	4	4	4	4	4	4		4
9	Solid floor with straw bedding	4	4	4	4	4	4	4	4	

1 = highly applicable 4 = illogical (NH_3 increase)
2 = applicable 3 = not or hardly applicable

Table 9. Techniques, reduction and costs of low-emission housing systems for pigs (mating and gestating sows)

Code	Housing type	Reduction (%)	Ammonia emission (kg/pig place/year)	Extra investment costs Euro/pig place	Extra costs (Euro/pig/ place/year)
1	Partially slatted with individual stall or group housing system without straw (Reference)	Reference	4.2	Reference	Reference
2	Partly slatted, external alleys (width 1.3-1.5 m)	30	3.0	5	-/-
3	Flushing system by gutters	40	2.5	154	26
4	Small channel, manure pit surface to max. 0.5 m^2 per sow with or without vacuum system	45	2.4	17	3
5	Flushing system with clarified aerated slurry	50	2.2	140	30
6	Manure cooling system (to 12°C max.) a/	50	2.2	107	19
7	Flushing system with acid	60	1.8	131	25
8	Solid floor with straw bedding b/	0	8.3	-/-	-/-

a/ A readily available source of groundwater is required and the system may not be allowed where drinking water is extracted.

b/ Systems with straw are favoured for animal welfare reasons. Emissions depending on the amount of straw use.

Table 10. Applicability of the different technics of low-emission housing systems for farrowing sows including suckling pigs. (Read horizontally only)

System	Applicability of changing from one housing to another	1	2	3	4	5	6	7	8
1	Partially slatted floor with individual stall or group housing system without straw (Reference)		3	1	3	1	1	1	4
2	Partly slatted, external alleys	4		2	2	1	2	1	4
3	Flushing system by gutters	4	4		1	1	3	1	4
4	Small channel, manure pit surface to max.0.5 m² per sow with or without vacuum system	4	4	4		1	3	1	4
5	Flushing system with clarified aerated slurry	4	4	4	4		B/B	1	4
6	Manure cooling system	4	4	4	4	B/B		3	4
7	Flushing system with acid	4	4	4	4	4	4		4
8	Solid floor with straw bedding	4	4	4	4	4	4	4	

1 = highly applicable
2 = applicable
3 = not or hardly applicable
4 = illogical (NH_3 increase)
B/B = no difference in NH_3 emission

Table 11. Techniques, reduction and costs of low-emission housing systems for weaners

Code	Housing type	Reduction (%)	Ammonia emission (kg/pig place/year)	Extra investment costs Euro/pig place	Extra costs (Euro/pig/ place/year)
1	Fully slatted floor (Reference)	Reference	0.60	Reference	Reference
2	Partly slatted (some 30%)	40	0.35	-/-	-/-
3	Vacuum system	40	0.35	-/-	-/-
4	Scrapers (with urine drainage)	50	0.30	65	12
5	Flushing system with gutters	45	0.30	250	4
6	Flushing system with acid	55	0.25	36	6
7	Water/manure channel, manure pit surface to max 0.15m^2	65	0.25		
8	Manure cooling system (to 12°C max.) a/	60	0.15	24	4
9	Solid floor with straw bedding b/	0	0.60	-/-	-/-

a/ A readily available source of groundwater is required and the system may not be allowed where drinking water is extracted.

b/ Systems with straw are favoured for animal welfare reasons. Emissions depending on the amount of straw use.

Table 12. Applicability of the different technics of low-emission housing systems for weaners. (Read horizontally only)

System	Applicability of changing from one housing system to another	1	2	3	4	5	6	7	8	9
1	Fully slatted floor (Reference)		3	1	2	1	1	1	1	B/B
2	Partly flatted (some 50%) floor	4		1	1	1	1	2	1	4
3	Vacuum system	4	4		1	3	1	1	1	4
4	Scrapers (with urine drainage)	4	4	4		4	1	1	3	4
5	Flushing system by gutters	4	4	4	4		1	1	3	4
6	Flushing system with acid	4	4	4	4	4		1	3	4
7	Water/manure channel, manure pit surface to max. 0.15m^2	4	4	4	4	4	4		1	4
8	Manure cooling system	4	4	4	4	4	4	4		4
9	Solid floor with straw bedding	4	4	4	4	4	4	4	4	

1 = highly applicable
2 = applicable
3 = not or hardly applicable
4 = illogical (NH_3 increase)
B/B = no difference in NH_3 emission

C. Housing systems for laying hens

57. Battery systems. The traditional deep-pit houses, where the manure falls and is stored often for a year or more in a pit beneath the surface of the house, is the highest emitting housing for intensive laying hens. It is therefore taken as the reference. However, free-range, barn and aviary-type housing can also give rise to high ammonia emissions and options for changing these systems will be different and probably more limited because of the need to take full account of welfare concerns.

58. Aviary and free-range systems. The same system of manure ventilation and removal can apply to some aviary systems where manure belts are placed under the tiers to collect the manure where the hens are free to walk around. In some countries the definition of "free range" includes such systems but with access to the outdoors. In other countries laying hens in?free-range systems" are housed on solid or partly slatted floors. In these systems the solid floor area is covered with litter and the hens have some access to the outdoors. Manure accumulates either on the solid floor or under the slatted area for the laying period (about 14 months). Currently there are no proven low-ammonia systems for these free-range houses.

Category 1 techniques

59. Ammonia emissions from battery deep-pit or canal systems (step deck, tier) can be lowered by reducing the moisture content of the manure through forced or unforced ventilation over the manure pit. So-called stilt houses, where the removal of side walls from the lower areas used to store manures, can provide a highly effective means of ventilation.

60. The collection of manure on manure belts and the subsequent removal of manure to covered storage outside the building can also reduce ammonia emissions, particularly if the manure is dried on the belts through forced ventilation. The manure should be dried to a dry-matter content of 70% to prevent the formation of ammonia. If the wastes from the manure belts are collected in an intensively ventilated drying tunnel, inside or outside the building house, the dry-matter content of the manure can reach 60 - 80% in less than 48 hours. Weekly removal from the manure belts to covered storage has been shown to reduce emissions by half compared to removal every two weeks. In general, the emission level from manure belt layer houses will depend on:

- The length of time that the manure is present on belts (long time = high emissions);

- The drying system;
- The poultry breed;
- The ventilation rate (low rate = high emissions).

D. Housing systems for broilers

61. Traditionally, broilers are kept in buildings with a solid, fully littered floor. This is taken as the reference. To prevent ammonia emission it is important to keep the litter as dry as possible. The dry-matter content and the emission of ammonia depend on, inter alia:

- The drinking-water system;
- The duration of the breeding period;
- The animal density and weight;
- The use of air purification systems;
- The use of floor insulation.

Category 1 technique

62. A simple way of maintaining dry manure is to reduce the spillage of water from the drinking system (e.g. using a nipple drinking system).

Category 2 techniques

63. There are no category 1 techniques for broiler houses beyond the simple measure mentioned in paragraph 62, though more effective emission reduction can be achieved through forced drying and several systems are currently being evaluated. In one Netherlands system ("floating floor system"), the litter is aerated by forcing air under the cloth ("floating") floor and the manure and litter. The system is very energy-intensive (double the electricity use of a conventional broiler house) and might increase dust emissions. However, the extra ventilation improves the distribution of heat, giving some savings on heating costs.

Category 3 techniques

64. It is possible, in forced ventilation poultry housing, to treat the ventilated air using a biological or organic matter (e.g. peat or bark) scrubber, but these systems are generally very expensive and have major practical drawbacks, such as clogging up and increasing the volume of waste.

65. Table 13 shows the techniques, potential reductions and costs of low-emission housing systems for laying hens and broilers as applied in the Netherlands. Table 14 shows the applicability and advantages of adopting different poultry housing designs over the type of housing currently in use.

Table 13. Reduction in ammonia emissions from different poultry systems relative to reference*/

Code	Housing type	Reduction (%)	Ammonia emission (g/animal place/year)	Extra investment costs (Euros/poultry/ place	Extra costs (Euros/ poultry/ place/year
Laying hens					
a Dry manure					
1	Deep pit and canal system	Reference	386	Reference	Reference
	Belt systems without drying	60	150		
2	Manure belt with forced drying and outside storage	80	85	-/-	0.68 - UK
3	Manure belt with forced drying with sealed storage	90	35	-/-	0.68 - UK
	Free-range system	20	315	0.56	0.26 - NL
4	Barn housing (slatted floor)	20	315	0.56	0.26 - NL
5	Aviary manure belt forced drying by ventilation	90	75	0.50	0.25 - NL
b Wet manure					
6	Open manure storage under the cage (flat deck, stair step, compact battery) with or without scraper	83	85	-/-	-/-
7	Removal of manure at least twice per week to a closed storage (manure belt)	90	35	0.09	-/-

Broilers					
1	Traditional (litter)	Reference	50	Reference	Reference
2	Floating floor with drying of litter (Cat. 2)	90	5	3.82	0.15 - NL
3	Perforated floor with forced drying of litter (Cat. 2)	85	14	4.64 - NL 3.71 - UK	0.10 - NL 0.09 - UK
	Air circulation in house				0.39 - UK
	Air circulation in pit				0.22 - UK

*/ Emissions refer to experience in the Netherlands. Costs are for the Netherlands (NL) and/or the United Kingdom (UK)

Table 14. Applicability of the different category 1 techniques of low-emission housing systems for laying hens and broilers. (Read horizontally only)

System	Applicability of changing from one housing design to another	1	2	3	4	5	6	7
Laying hens								
1	Deep pit, stilt house and canal system		2	1	3	3	1	1
2	Manure belt with forced drying	4		1	3	3	3	1
3	Manure belt with forced drying with sealed storage	4	4		3	3	2	2
4	Barn housing (slatted floor)	4	3	3		2	3	3
5	Aviary manure belt forced drying by ventilation	4	4	4	4		3	3
6	Open manure storage under the cage (flat deck, stair step, compact battery) with or without scraper	4	4	4	4	4		1
7	Removal of manure at least twice per week to a closed storage (manure belt)	4	4	4	4	4	4	

1 = highly applicable **3 = not applicable**
2 = applicable **4 = illogical (NH_3 increase)**

V. FEEDING STRATEGIES AND OTHER MEASURES

A. Feeding strategies

66. Adjusting livestock feed composition to decrease the amount of nitrogen excreted could be one of the most sustainable methods of reducing not only ammonia but also other forms of agricultural nitrogen emissions to water and air. Short of reducing livestock numbers, dietary manipulation is the only measure that actually seeks to reduce the total quantity of excreted nitrogen entering the environment. Abatement depends mainly on the reduction of soluble nitrogen excretion that usually corresponds with nitrogen excreted in the urine.

67. Reference technique. The extent to which ammonia emissions can be reduced through feeding strategies will be crucially dependent on current feeding practices (reference). The reference varies greatly across the UN/ECE and is in many cases not documented. In general, a 1 kg reduction in nitrogen excretion will result in an ammonia reduction of 0.3 - 0.5 kg N. Due to the uncertainty over the reference and its variable efficiency (due to ration composition and animal physiology), the feeding strategy option is allocated to category 2.

68. Measures to minimize protein over-consumption may be taken immediately and are usually very cost-effective. They usually aim at adjusting the protein content and quality of the ration as closely as possible to individual animal needs for all types of animals. This can reduce the nitrogen excreted in faeces and urine.

69. Phase feeding (different feed composition for different age or production groups) offers a cost-effective means of reducing nitrogen excretion in pigs and poultry and could mostly be implemented in the short term. Multi-phase feeding depends on computer-aided automated equipment.

70. For rations composed mainly of concentrates (especially for pigs and poultry) the crude protein content can be reduced if some essential amino acids are added in pure form (mainly lysine, methionine and threonine) to give an ideal protein diet.

71. For cattle fed mainly on roughage (grass, hay, silage, etc.) a certain protein surplus is often inevitable (mainly during summer) due to an imbalance between energy and protein in young grass. This surplus might be reduced by adding components with lower protein content to the ration (e.g. maize or hay) or by increasing the proportion of concentrate in the ration. The latter option will be limited in grassland regions where roughage is the only feed locally available.

72. Special combinations of components in concentrates can help to achieve the amino acid requirement of the animals with a lower crude protein content than otherwise necessary. As this strategy usually requires special components it can lead to extra costs and often cannot be recommended for the majority of the farms due to the limited local availability of the components. For pigs especially, this strategy will often also compete with the use of by-products from the food-processing industry.

B. Other measures

Mineral fertilizers

73. The proportion of nitrogen lost as ammonia is higher for urea than for other mineral nitrogen fertilizers. Therefore, the substitution of urea can reduce emissions by up to 90%, depending on the substituting fertilizer and on climatic and soil conditions. The implementation of this substitution is immediately possible without major restrictions. Its efficiency is well understood (category 1).

Grazing

74. Urine excreted by grazing animals often infiltrates into the soil before substantial ammonia emissions can occur. Therefore, ammonia emissions per animal are lower for grazing animals than for those in housing where the excrement is collected, stored and applied to land. The emission reduction achieved by increasing the proportion of the year spent grazing will depend on the baseline (emission of ungrazed animals), the time the animals are grazed, the fertilizer level of the pasture, etc. The potential for increasing grazing is often limited by soil type, topography, farm size and structure (distances), climatic conditions, etc. Due to its dependence on prevailing conditions and some uncertainties about other nitrogen emissions, additional grazing has to be grouped in category 2 in spite of its well documented effectiveness.

Manure treatment

75. Research on various options of reducing emissions by manure treatment are investigated or discussed. Some potentially promising options are:

(a) Composting of solid manure or slurry with added solids. Experimental results are very variable and sometimes even show increased emissions;

(b) Controlled denitrification processes in the slurry: pilot plants show that it might be possible to reduce ammonia emissions by transforming ammonium to nitrogen gas by controlled denitrification (alternating aerobic and anaerobic conditions). To achieve this a special reactor is necessary. The efficiency and the reliability of the system and its impact on other emissions need further investigation.

76. The efficiency of manure treatment options should generally be investigated under country- or farm-specific conditions. Apart from ammonia emissions, other emissions, nutrient fluxes and the applicability of the system under farm conditions should be assessed. Due to the mentioned uncertainties, these measures generally have to be grouped in category 2 or 3.

Non-agricultural manure use

77. If manure is used outside of agriculture, agricultural emissions may be reduced. Examples of such uses already common in some countries are the incineration of poultry manure and the use of horse and poultry manure in the mushroom industry. The emission reduction achieved depends on how fast the manure is taken away from the farm and how it is treated. An overall reduction of the emissions will only be achieved if the use of the manure itself does not generate high emissions (including other emissions than ammonia). For example, the use of manure in horticulture or the export of manure to other countries will not reduce overall emissions. There are also other environmental aspects to be considered, for example, poultry litter incineration is a renewable source of energy, but not all the nutrients in the litter will be recycled within agriculture.

Feed or manure additives

78. A wide variety of feed and manure additives have been suggested to reduce ammonia emissions. They mostly aim at reducing the ammonia content or the pH by chemical or physical processes. Their efficiency in reducing ammonia emissions depends on how well they achieve these aims and on where in the manure management process they are introduced. As most of the products available on the market have not been independently tested or the test results were not statistically significant and reproducible, they have to be grouped in category 3.

VI. NON-AGRICULTURAL STATIONARY SOURCES

Production of inorganic N fertilizers, urea and ammonia

79. The most important industrial sources of ammonia emissions are mixed fertilizer plants producing ammonium phosphate, nitrophosphates, potash and compound fertilizers and nitrogenous fertilizer plants manufacturing *inter alia* urea and ammonia. Ammonia phosphate production generates the most ammonia emissions from the sector. Ammonia in uncontrolled atmospheric emissions from this source has been reported to range from 0.1 to 7.8 kg N/ton of product.

80. Nitrogenous fertilizer manufacture covers plants producing ammonia, urea, ammonium sulphate, ammonium nitrate and/or ammonium sulphate nitrate. The nitric acid used in the process is usually produced on site as well. Ammonia emissions are particularly likely to occur when nitric acid is neutralized with anhydrous ammonia. They can be controlled by wet scrubbing to concentrations of 35 mg NH_3 [-N?]/m^3 [of air] or lower. Emission factors for properly operated plants are reported to be in the range 0.25 to 0.5 kg NH_3/ton of product.

81. Additional pollution control techniques beyond scrubbers, cyclones and baghouses that are an integral part of the plant design and operations are generally not required for mixed fertilizer plants. In general, an ammonia emission limit value of 50 mg NH_3-N/m^3 may be achieved through maximizing product recovery and minimizing atmospheric emissions by appropriate maintenance and operation of control equipment.

82. In a well operated plant, the manufacture of NPK fertilizers by the nitrophosphate route or mixed acid routes will result in the emission of 0.3 kg/ton NPK produced and 0.01 kg/ton NPK produced (as N). However, the emission factors can vary widely depending on the grade of fertilizer produced.

83. Ammonia emissions from urea production are reported as recovery absorption vent (0.1-0.5 kg NH_3/ton of product), concentration absorption vent (0.1-0.2 kg NH_3/ton of product), urea prilling (0.5-2.2 kg NH_3/ton of product) and granulation (0.2-0.7 kg NH_3/ton of product). The prill tower is a source of urea dust (0.5-2.2 kg NH_3/ton of product), as is the granulator (0.1-0.5 kg/ton of product as urea dust).

84. In urea plants, wet scrubbers or fabric filters are used to control fugitive emissions from prilling towers and bagging operations. This control equipment is similar to that in mixed fertilizer plants, and is an integral part of the operations to retain product. If properly operated, new urea

plants can achieve emission limit values of particular matter below 0.5 kg/ton of product for both urea and ammonia.

85. It should be noted that measured emissions of ammonia may be higher than calculations based on emission factors might suggest. In some countries, these emissions may be covered by regulations such as the EC Directive on Integrated Pollution Prevention Control, which requires the use of BAT to prevent or minimize emissions to air, soil and water.

VII. CALCULATING THE UNIT COST OF AMMONIA ABATEMENT TECHNIQUES FOR AGRICULTURE

86. The costs in this document were based on the following assumptions:

(a) UK costs. Costs for the United Kingdom are based on the year 1998, at which time the exchange rate was ECU 1.548/£. Machinery costs were amortized at 6% over 5 years, while the cost of buildings and other structures was amortized at 6% over 10 years;

(b) NL costs. Costs for the Netherlands are based on the year based on the year 1998, at which time the exchange rate was ECU 0.45/guilder. Machinery costs were based on a depreciation period of 8 years, an interest rate of 6% and 2.5% for maintenance. The costs of buildings and other structures were based on a depreciation period of 20 years, an interest rate of 6% and 1% for maintenance. The costs of equipment were further subdivided, depending on the type of equipment, but on average they were based on a depreciation period of 15 years (range: 8 to 20 years), an interest rate of 6% and 2.5% for maintenance (range 1 to 5%).

More detail on the method for arriving at these costs is given below.

87. Introduction Calculating the national cost of the introduction of ammonia abatement measures comprises two distinct phases. These are:

(a) Calculation of the unit cost of each of all the potential abatement measures;
(b) The use of the unit cost by the RAINS or other Integrated Assessment model.

This chapter sets out the methodology for the first phase.

88. Before carrying out any quantitative analysis of the implications of adopting measures to reduce ammonia emissions, it is necessary to have a thorough knowledge of:

- Husbandry practices common in the base year;
- The effects which the abatement measures will have on husbandry;
- Physical performance and management.

The measures may have implications for change beyond the farmer or landowner. Examples of such changes could include Governments considering the provision of grants to assist those faced with capital investment or machinery contractors that need to re-equip. In the context of the integrated assessment modelling it is necessary to consider the costs at the national level.

89. Calculation of the unit cost of individual abatement measures

The following steps should be followed to calculate national costs of abatement measures on a common basis. Explanatory notes and examples are provided to support the guidance.

Step	Details	
1.	**Objective**	List all the potential measures grouped by system.
Method		Separate by type of livestock, building, manure storage and spreading technique.
2.	**Objective**	Identify the implications of each measure for farmers and others.
Method		Understand current farming systems and define the changes resulting from implementation of the abatement measures. For each measure identify those areas where costs will be associated with the changes. Identify any areas where financial benefits may accrue from the changes.
3.	**Objective**	Separate those measures requiring capital expenditure from those involving only annual costs.

4. **Objective**		Identify the capital expenditure required to implement each measure identified at step 3.
Method		Separate those measures that can be implemented by retrofitting from those for which total replacement of facilities is necessary. Obtain the capital cost on a per unit basis for each item. National costs should be used wherever available. Where these are unavailable, international costs should be obtained.
5. **Objective**		Calculate the additional annual unit cost of each measure requiring capital expenditure.
Method		The annual charge for this element is derived by amortizing the capital cost over the economic life of the investment. The interest rate used for the calculation is the standard UN/ECE rate of 4%. Appropriate annual running costs should be added to the charge for capital to give the additional annual cost of the investment. Where existing assets are replaced before completing their economic life, account should be taken of any costs implications. Divide the net cost by the annual throughput to arrive at the annual cost per unit.
6. **Objective**		Calculate the additional annual unit cost of measures that do not involve capital expenditure.
Method		Obtain cost per unit of implementing the measure, subtracting the costs saved as a result of the cessation of current practice, to provide the net cost. Use national costs in preference to international costs. Take account of any benefits resulting from the measures, for example fertilizer savings.

Explanatory notes:

- The units may be per head for livestock systems or per cubic metre or per ton for manures. In the case of livestock, the per-head figure is based on the annual average population. In most livestock systems the occupancy is less than the theoretical capacity of the buildings.

- When considering changes to buildings and other fixed equipment, two circumstances need to be evaluated. These are:
  (i) The additional costs of replacement facilities;
  (ii) The modification of existing facilities;

- The choice will depend on building condition and suitability for modification, normally directly related to age and remaining economic life. Only the additional capital cost of providing those facilities that relate to the buildings' abatement capabilities should be costed. For example, when considering the modification of a building through retrofitting, calculate the capital cost of the modification and annualize this figure over its economic life on a per-head basis. When considering the cost implications of replacement facilities, it is necessary to exclude that part of the cost which relates to features with no abatement capability. Add to this figure an allowance for changes in running costs. (See example 3).

- The assessment of the annual cost implications of a rolling programme of investments, for example building replacement, needs to correspond with the assumptions on timing of emission abatement.

- For replacement assets account should also be taken of the remaining depreciation on the replaced assets less any allowance for any realized value on disposal.

- In the case of temporary coverings on slurry stores, the initial cost of the cover can normally be divided by its life to arrive at an annual cost. Changes to spreading techniques should be based on the amortized capital cost of the machine, plus an allowance for annual repair cost. Labour should be added at a rate appropriate to the work rate of the machine. The total annual cost is then divided by the throughput to arrive at a unit cost. Where necessary, costs saved should be deducted to provide the net annual unit cost. Examples 1 and 2 illustrate the application of this method. The assumptions on the phasing of changes needs to correspond with the assumptions on emission abatement.

<u>Examples</u>

90. The following examples are taken from recent costings in the Uniteid Kingdom and are included for illustrative purposes only.

Example 1. Calculation of additional costs associated with the incorporation technique - no capital expenditure

Incorporation of solid manure

Contractors will need to be used to incorporate solids in many situations as employed labour and machinery will be fully used on other tasks. Ploughing will be the usual method of incorporation. There will be a marginal cost saving because the operation will not need to be carried out by farm staff at a later time. Solids spread up to the equivalent of 250 kg total N per hectare per year specified in the United Kingdom’ s codes of good agricultural practice.

Additional costs incurred

	Unit	Additional cost (£)	Cost saved (£)
Ploughing Cost			
Contractor	ha	40	
Average farmer cost saving			
Fuel	ha		3
Repairs	ha		3
Net costs	ha	34	

Pig manures

	Unit	Number	Cost (£)
Application rate			
Pig manure	kg N/ton	7	
	ton/ha	36	
Cost			
Total	ha		34
	ton		0.95

Example 2. Calculation of additional costs associated with capital expenditure for a machine

High-efficiency application methods (injection)

Slurries will be injected where conditions permit. The extra costs are based on the purchase of an injector attachment for fitting to either the tanker or the tractor. The cost of such equipment varies from £3,500 for arable land to £8,000 for pasture use. Additional tractor power of about 35 kW is needed. Work rates of about 14 m^3 may be achieved compared to 17 m^3 (2½ loads per hour of 7 m^3) per hour using a tanker and splash plate system. This is based on a

6-minute discharge for a splash plate operation, being extended to 12 minutes when injecting. Capital cost amortized over 5 years at 4%.

Additional costs incurred

	Unit	Number	Cost (£)
Tractor			
Additional power requirement	kW	35	
Cost of additional power	£/hour		3
Additional cost of tractor	m^3		0.30
Labour			
Cost per hour	£/hour		6.10
Additional cost	m^3		0.10
Attachment			
Cost (average)			6000
Life	years	5	
Throughput	m^3/year	2000	
Annual cost			
Annual cost of investment	m^3		0.68
Repairs at 5%	m^3		0.15

Example 3. Calculation of additional costs associated with building changes

Air ducts in deep pit poultry housing

A simple polythene air duct is installed in the pit under the manure. This system is an ADAS development proposal. Applicable to cage systems without scraped trays. Such systems are estimated to apply to 20% of the laying flock. Such systems have additional running costs. The capital costs of the system are amortized over 10 years at 4%.

Stilt-type poultry housing

Stilt-type houses may be built in preference to deep-pit units. There are no additional running costs. The capital costs of new buildings are amortized over 20 years at 4%.

Additional costs of modifying an existing deep pit ventilation system

	Unit	Cost (£)
Base details		
Additional capital cost	bird place	0.20
Running costs for a year	bird place	0.10
Annual costs		
Annual cost of investment	bird place	0.02
Running costs	bird place	0.10
Total	bird place	0.12

Additional costs of stilt-house installations (compared with deep-pit systems)

	Unit	Cost £
Base details		
Additional capital cost	bird place	2.00
Running costs for a year	bird place	nil
Annual costs		
Annual cost of investment	bird place	0.15
Running costs	bird place	nil
Total	bird place	0.15