UNITED
NATIONS

E

Economic and Social
Council

Distr.
GENERAL

EB.AIR/WG.6/1998/10
19 May 1998

Original: ENGLISH

ECONOMIC COMMISSION FOR EUROPE

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

Working Group on Abatement Techniques
(Sixth session, Geneva, 2-3 July 1998)
Item 7 of the provisional agenda

CONTROL OPTIONS/TECHNIQUES FOR PREVENTING AND ABATING EMISSIONS OF REDUCED NITROGEN

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led by the United Kingdom[1]

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.

GE.98-31172

[1] At a meeting held in London (United Kingdom) from 14 to 15 January 1998 with the participation of experts from Italy, the Netherlands, Switzerland, the United Kingdom, the International Institute for Applied Systems Anallysis (IISA), Imperial College and the UN/ECE secretariat and based on documents previously submitted to the Working Group (e.g. EB.AIR/WG.6/R.28, EB.AIR/WG.6/R.35 and EB.AIR/WG.6/R.36).

3. The document addresses the control of ammonia emissions produced by agriculture and other stationary sources. Ammonia from agriculture is emitted chiefly from livestock excreta, in livestock housing and during manure storage, processing and application to land as well as from excreta from animals at pasture. Emissions also occur from inorganic N fertilizers when 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 which 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 interact strongly with livestock type and management, soils and climate, and these factors differ widely across the UN/ECE region. While some of the techniques listed here are in commercial operation in some countries, their effectiveness, for the most part, has not been fully evaluated on working farms. It follows that the efficiency of abatement techniques for ammonia carry with them a high degree of uncertainty and variability. The values used should therefore be regarded as indicative.

5. It is possible to categorize many of the potential abatement techniques on the basis of the level of current knowledge and practicality. The techniques described below are grouped into three categories:

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

(b) **Category 2 techniques** - which are promising, but where research is at present inadequate, or where it always be difficult to quantify abatement efficiency;

(c) **Category 3 techniques -** which 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 manure 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 benefit of abatement during housing and storage may be lost.

7. Because of this interdependency of techniques described above, Parties will need to employ additional modelling work before the techniques listed

here can be used to develop an ammonia abatement strategy to meet national emission targets.

8. The techniques listed are those which can be clearly defined and assessed against a ‘reference’, unabated situation. The ‘reference’ situation, against which the percentage emission reduction is calculated, is defined at the beginning of each section. In most cases the ‘reference’ is the practice or design which gives rise to the greatest ammonia emission: in many countries the ‘reference’ will be the current most commonly practised technique.

9. Some ammonia reduction techniques cannot easily be judged against a ‘worst case’ or ‘most commonly practised’ reference because of the wide range of practices within the farming community. Such techniques often relate to ‘good nutrient management’ and include fundamental measures such as simple means of matching the protein in livestock diets as closely as possible to requirements. Though not listed here, ‘good nutrient management’ and ‘good housekeeping’ measures may provide highly cost-effective means of abating ammonia.

10. The costs of the techniques will vary from country to country. A thorough knowledge of current husbandry practices is required before the costs associated with any particular abatement technique can be calculated. Calculating the costs will involve assessing all the implications of each measure in terms of both costs and financial benefits. Capital costs will need to be calculated separately from annual costs and amortized at the standard United Nations Economic Commission for Europe rate of 4 %. Many measures may incur both capital and annual costs. For example, slurry injection will incur the capital cost of the machinery purchase plus annual costs of extra labour and tractor power. Examples of costs in the Netherlands and the United Kingdom are given as examples only. As stated above, both the absolute costs and the relative cost-efficiency of measures may differ between countries.

11. This document reflects the state of knowledge and experience of ammonia control measures which had been achieved by 1997. 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.

A. Slurry and manure application techniques

12. 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 splashplate. Ammonia emissions can be reduced during manure applications by using techniques which decrease contact with the air by reducing the surface area of the manure and/or increasing infiltration into the soil.

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

<u>Category 1 techniques</u>

14. Category 1 techniques include machinery for decreasing the surface area of slurries and burying slurry or solid manures through incorporation into the soil. They are:

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

15. 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 which allow infiltration of liquid (for techniques (i)-(iv) and satisfactory travelling conditions for the machinery. The table also summarizes the limitations which must be taken into account when considering the applicability of a specific technique and an indication of the cost.

16. A number of factors must be taken into account in determining the applicability of each technique, for instance: 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), they are not suitable for very viscous slurries or those containing large amounts of fibrous material, e.g. straw, even though most machines incorporate a device for chopping and homogenizing the manure. 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 to permanent grassland. Comments on applicability are included in the descriptions of the technique below and summarized in table 1.

17. 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 obviate the need to take heavy slurry tankers onto the land.

18. <u>Band-spreading</u>. 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 and its use is also limited by the slope of the land.

19. <u>Trailing shoe.</u> 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 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 the size, shape and slope of the field and by the presence of stones on the soil surface.

20. 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 cm and working width 6 m. 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 to very stony soil nor to very shallow or compacted soils, where is impossible to achieve uniform penetration of the knives or disc coulters to the required working depth.

21. 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 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.

22. 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 if 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 is lost rapidly once the manure is spread on the surface, so greater reductions in emissions are achieved when incorporation takes place immediately after spreading. This requires the use of a second tractor, which must follow closely behind the manure spreader. A more practical option might be to incorporate the manure on the same day as it is spread, but this is less effective.

Category 2 techniques

23. Increasing the 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 already be diluted (e.g. where milking parlour or floor washings, rainfall, etc. are mixed with the slurry) and there may be no advantage in diluting it further. When applying diluted slurries to land, there may be a greater risk of surface run-off and leaching. This must be guarded against by paying attention to application rate, soil conditions, slope of the land, etc.

24. 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 needed.

25. 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, and its application is an additional operation.

26. Timing of application. Ammonia emissions are highest in 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 (e.g. humid, no wind) which favour low ammonia emissions may give rise to problems with offensive odours by preventing their rapid dispersion.

27. Pressurized injection. In this 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 to sloping land and stony soils, where other types of injector cannot be used. Emission reductions of 60 % have been achieved in field trials, but further evaluation of the technique is needed.

Category 3 techniques

28. Acidified slurry. The equilibrium between ammonium-N and ammonia in solutions is dependent on 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 is 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 denitrification and emissions of nitrous oxide.

29. Other additives. Salts of calcium (Ca) and magnesium (Mg), acidic compounds and superphosphate have been shown to lower ammonia emissions, but the quantities required are too large to be practicable. 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/] **ECU per m^3**
Band-spreading	Slurry	Grass-land	10	Slope (tankers <20%, umbilical <30%), not viscous slurry, size and shape of field	0.68
Band-spreading	Slurry	Arable	30	Slope (tankers <20%, umbilical <30%), not viscous slurry, size and shape of the field, possibility of applying to growing crop between rows	0.68
Trailing shoe	Slurry	Mainly grass-land	40	Slope (tankers <20%, umbilical <30%), not viscous slurry, size and shape of the field, grass height should be about 10 cm	1.33
Injection (open slot)	Slurry	Grass-land	60	Slope <12%, greater limitations for soil type and conditions not viscous slurry	1.95
Injection (closed slot)	Slurry	Grass-land and arable land	80	Slope <12%, greater limitations for soil type and conditions, not viscous slurry	1.95
Incorporation - immediate (costs for < 4h)	Solid manure	Arable land	80	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 day	and slurry		40		As above

*Emission reductions are likely to be achieved across the UN/ECE.

a/ See text for details.
b/ Costs are for the United Kingdom. Costs are based on the use of contractors (1.548 ECU/£).

B. Slurry storage techniques

30. At present, there are no proven techniques for reducing ammonia emissions from stored solid manure. This section consequently relates only to techniques for slurry storage. After the 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.

31. 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.

32. 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.

33. 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

34. The most well proven and practicable technique to reduce emissions from stored slurry is to cover the slurry tanks or silos with a solid lid, roof or tent structure. Whilst it is important to guarantee that covers are well sealed to minimize air exchange, there will always need to be some small openings to prevent the accumulation of inflammable gases, or a facility for venting to prevent build-up of methane, etc.

Category 2 techniques

35. There is a range of flexible or floating covers which 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. 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 latter floating solid materials might hinder the spreading process (clogging up) or the homogenization of the slurry prior to spreading, which could cause problems on farms with frequent slurry spreading (e.g. to grassland).

36. Minimizing stirring of stored cattle slurry of 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, it can significantly reduce ammonia emissions at little or no cost. This natural crust formation is an option for farms which do not have to mix and spread slurry frequently. The emission abatement efficiency will depend on the nature of the crust. Due to this uncertainty this measure is also grouped in category 2.

37. 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, (ECU per m^3/yr)[b]
Rigid lid or roof (CAT 1)	All	80	Tanks and silos only	7.59
Flexible cover or floating sheet (CAT 2)	All	60		1.10 - tanks 1.55 - lagoons
Artificial crust (straw, peat, bark, LECA balls, etc.) (CAT 2)	All	40	May not be practicable on lagoons . Not on farms with frequent slurry spreading	
Natural crust (CAT 2)	Cattle	35	Not on farms with frequent slurry spreading	
Replacement of lagoons, etc. with covered tanks (CAT 2)	All			14.5

[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/ silo.(1.548 ECU/£)

[b] Costs are for the United Kingdom.

C. Livestock housing

38. 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 and manure is reduced and/or if they are 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 options.

39. The level of ammonia emission reduction achieved by adopting 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 8).

1. Housing systems for laying hens

40. Battery systems. The traditional deep-pit stilt houses where the manure falls and is stored, often for a year or more, in a ventilated pit beneath the surface of the house is the highest emitting housing for intensive laying hens and 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.

41. Ammonia emissions from deep-pit stilt houses or canal systems (step deck, tier) can be reduced by reducing the moisture content of the manure through forced or unforced ventilation over the manure pit. Removing the side

walls from the lower areas used to store manure can be a highly effective means of ventilation.

42. 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 to an intensively ventilated drying tunnel, inside or outside the building, 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 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 air capacity (low air capacity = high emissions).

43. Aviary and free-range systems. The same system of manure ventilation and removal can apply to some aviary systems with manure belts placed under the tiers to collect the manure where the hens are free to walk around. Laying hens in free-range systems are housed on solid or partly slatted floors. 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 free-range houses.

2. Housing systems for broilers

44. Traditionally, broilers are kept in buildings with a solid fully littered floor. 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 occupation density and weight;
- The use of air purification systems;
- The use of floor insulation.

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).

45. There are no category 1 techniques for broiler houses, beyond this simple measure, though more effective emission reduction can be achieved through forced drying, and several systems are currently being evaluated. In one system (“floating floor system”) in the Netherlands, the litter is aerated by forcing air under the cloth (“floating”) floor. The system is very energy-intensive (double the electricity use of a conventional broiler house), although the extra ventilation improves the distribution of heat, thus offsetting some heating costs.

46. Table 3 shows the techniques, potential reductions and costs of low-emission housing systems for laying hens and broilers as applied in the Netherlands. Table 4 shows the applicability and advantages of adopting category 1 housing designs in relation to the type of housing currently in use.

Table 3. Reduction in ammonia emissions from different poultry systems relative to reference*

Code	**Housing type**	**Reduction (%)**	**Ammonia emission (g/animal place/ year)**	**Extra invest-ments (ECU/ poultry place)**	**Extra Costs (ECU poultry/ year)**
Laying hens					
a	**Dry manure**				
1	Deep pit, tilt house and canal system	Reference	386	Reference	Reference
2	Manure belt with forced drying	80	85	-/-	-/-
3	Manure belt with forced drying with sealed storage	35	90	-/-	-/-
	Free ange system				
4	Barn housing (slatted floor)	20	315	0.56	0.26
5	Aviary manure belt forced drying by ventilation	90	75	0.50	0.25
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 a 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
3	Perforated floor with forced drying of litter (CAT. 2)	85	14	4.64 - NL 3.71 - UK	0.10 - NL 0.56 - UK

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

Table 4. The applicability of the different category 1 techniques of low-emission poultry housing systems (Read in one direction only: horizontally)

Code	System ⇒ rebuild into system ⇒	1	2	3	4	5	6	7
	Laying hens							
1	Deep-pit, tilt 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 a week to a closed storage (manure belt)	4	4	4	4	4	4	

1 = highly applicable **4 = illogical (NH_3increasing)**
2 = applicable

3. Housing systems for pigs

47. 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 slatted to solid floor area. Emission from the pit can be decreased by quickly and fully removing the manure to an outdoor storage or by treating it (e.g. acidification or cooling).

48. Emissions from fully slatted pig houses are taken as the reference, although in some countries these systems are not allowed for animal welfare reasons. Pig housing with solid floors and straw bedding are favourable from an animal welfare point of view, but can give rise to ammonia emissions as high as those from housing with fully slatted floors.

49. Partly slatted floors (c50% area) generally give rise to reduced ammonia emissions, particularly if the slats are metal- or plastic-coated, allowing the manure to fall more rapidly and more fully 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.

50. 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:

- Flushing systems. There are many different types of flushing system. Low-emission flushing systems remove the manure from the pit rapidly. The addition of acids further reduces emissions.

- Vacuum systems. Rapid removal of manure from pits can be attained by vacuum removal systems operated at least daily.

- Manure cooling. Cooling of the surface of the manure in the floor pit to 12 ^{0}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.

51. 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. The manure pit surface area can be reduced by using, for example, manure pans, manure gutters or small manure canals.

52. Category 2 techniques for reducing ammonia include good climate control within the housing to keep the temperature and ventilation rates down. It is also possible to treat the ventilated air from pig housing using a biological or organic (e.g. peat, bark) scrubber, but these systems are generally very expensive and unpractical.

53. Table 5 shows the different housing systems and their ammonia emissions 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 relative to those in current use. Similar tables could be constructed for sows and weaners.

Table 5. Techniques, reductions and costs of low-emission housing systems for pigs (fatteners)*

code	Housing type	Reduction (%)	Ammonia emission (kg/pig place/ year)	Extra invest ments (ECU/pig place)	Extra costs (ECU/ pig-place/ year)
1	Fully slatted floor (Reference)	Reference	3.0	Reference	Reference
2	Partly slatted (c50%)floor	20	2.5	5	-/- 8.20 - 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. 0.18m2	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 the Netherlands (NL) and/or 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. The applicability of different low-emission housing systems for fatteners. (Read horizontally only)

Code	System ⇒ rebuild into system ⇒	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 (c50%)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 12^0 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$_2$,(NH_3 increasing)
o/o = no difference in NH_3 emission

4. Housing systems for dairy and beef cattle

54. Straw-based systems. There are no proven low ammonia emission techniques for beef or dairy cattle in straw-based or farm-yard 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 compared to some traditional slurry-based housing.

55. 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 solid floors. Buildings in which the cattle is held in tied stalls have tended to give rise to lower ammonia emissions because a smaller floor area gets fouled with dung and urine. However, tied systems are not recommended because of animal welfare considerations.

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

- Decreasing the surface area fouled by manure;
- Adsorption of urine (e.g. straw);

- Rapid removal of urine; rapid separation of faeces and urine;
- Decreasing the air velocity above the manure;
- Reducing the temperature of the manure and of the surfaces it covers.

57. 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 scraping with or without water sprinklers. In general, these systems have proved to be ineffective or too difficult to maintain. The use of smooth or sloping floors to assist in scraping or flushing has given rise to problems with animals slipping and potentially injuring themselves.

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

59. Table 7 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 7. Ammonia emissions and costs of different cattle housing systems in the Netherlands

Code	Housing type	Reduction (%)	Ammonia emission (kg/cow place/ year)	Extra invest-ments (ECU/cow place)	Extra costs (ECU/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 wintertime [b/]	60	5.0	-/-	-/- [c/]
4	Castellated floor (CAT.2)	50	4.0	374	55
5	Flushing system without acid several times a day (CAT.2)	50	4.0	217	31
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 use. Too little straw may increase emissions.

[c/] Difficult to quantify. In any case the labour costs will be higher

Table 8. The applicability of different housing systems for cattle. (Read horizontally only)

Code	System ⇒ rebuild into system ⇒	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 wintertime	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 increasing)**
2 = applicable **o/o = no difference in NH_3 emission**
3 = not applicable

D. Feeding strategies and other measures

Feeding strategies

60. 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 which actually seeks to reduce the total quantity of excreted nitrogen entering the environment. Abatement depends mainly on the reduction of soluble nitrogen excretion, which usually corresponds with nitrogen excreted in the urine.

61. The extent to which ammonia emissions can be reduced through feeding strategies will be crucially dependent on current feeding practices (baseline). The baseline 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 baseline and its variable efficiency (due to ration composition and animal physiology), the feeding strategy option falls in category 2.

62. Measures to minimize protein over consumption may be taken immediately and are usually very cost-effective. They usually aim at adjusting the protein content of the ration as closely as possible to individual animal needs for all types of animals.

63. 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.

64. 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.

65. 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.

66. 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 can often not be recommended for the majority of the farms because the components may not be locally available. Especially for pigs this strategy will often also compete with the utilization of by-products from the food- processing industry.

Other measures

67. Apart from the measures described for animal housing, manure storage and application and special feeding strategies, other measures can help to minimize ammonia emissions by reducing the amount of manure, its content of volatilizable nitrogen or the contact between excrement and the atmosphere.

Mineral fertilizers

68. 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 substitute 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

69. Urine excreted by grazing animals can often infiltrate 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 level of 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 of 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

70. Some potentially promising options for reducing emissions by manure treatment are:

- Separation of the slurry by screening, sedimentation or centrifugation: emissions after application of the resulting liquid fraction are lower than from the original slurry, thanks to a more rapid penetration into the soil and less soiling of plants. Emissions from the resulting solid fraction depend on how these are processed and utilized;

- Composting of solid manure or slurry with added solids: emission reduction depends on a wide variety of factors. Experimental results are very variable and sometimes even show increased emissions;

- 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). A special reactor is necessary to achieve this. The efficiency and the reliability of the system and its impact on other emissions need further investigation.

71. 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 have to be generally grouped in category 2 or 3.

Non-agricultural manure use

72. If manure is used outside of agriculture, agricultural emissions will 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 in emissions will be achieved only if the utilization 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.

Feed or manure additives

73. 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 2.

E. Non-agricultural stationary sources

Production of inorganic N fertilizers, urea and ammonia

74. 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 sourcehas been reported to range from 0.1 to 7.8 kg N/ton of product.

75. Additional pollution control techniques beyond scrubbers, cyclones and baghouses that are an integral part of plant design and operations are generally not required for mixed fertilizer plants. In general, an ammonia emission limit value of 50 mg/m^3 (as N) may be achieved by maximizing product

recovery and minimizing atmospheric emissions through appropriate maintenance and operation of control equipment.

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

77. 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/m^3 or lower. Emission factors for properly operated plants are reported to be in the range of 0.25 to 0.5 kg NH_3/ton of product.

78. 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).

79. 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 an emission limit value of particular matter below 0.5 kg/t of product for both urea and ammonia.

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