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GUIDANCE DOCUMENT ON CONTROL TECHNIQUES FOR PREVENTING AND ABATING EMISSIONS OF AMMONIA

Submitted by the Chairman of the Expert Group on Ammonia Abatement

1. Article 3, paragraph 8 (b) of the 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone requires each Party to “apply, where it considers it appropriate, best available techniques for preventing and reducing ammonia emissions, as listed in guidance document V (EB.AIR/1999/2, part V) adopted by the Executive Body at its seventeenth session (decision 1999/1)” and any amendments thereto. In line with the 2007 workplan (ECE/EB.AIR/2006/11, item 1.8), approved by the Executive Body at its twenty-fourth session (ECE/EB.AIR/87, para. 72), the Expert Group on Ammonia Abatement has updated the guidance document to provide an amended text as referred to above.

INTRODUCTION

2. The purpose of this document is to provide guidance to the Parties to the Convention in identifying ammonia (NH_3) control options and techniques for reducing emissions from agricultural and other stationary sources in the implementation of their obligations under the Protocol.

3. It is based on information on options and techniques for NH_3 emission reduction and their performance and costs contained in official documentation of the Executive Body and its subsidiary bodies.

4. The document addresses the abatement of NH_3 emissions produced by agriculture and other non-agricultural stationary sources. Agriculture is the major source of NH_3, 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 following their application 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 N in excreta available for NH_3 formation.

5. Abatement of NH_3 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 (UNECE). 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 NH_3 carries with it a degree of uncertainty and variability. The values used in this document should be regarded as indicative only.

6. 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***: These 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***: These are promising, but research on them is at present inadequate, or it will always be difficult to quantify their abatement efficiency. This does not mean that they cannot be used as part of an NH_3 abatement strategy, depending on local circumstances.

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

7. Separate guidance has also been prepared under the Integrated Pollution Prevention and Control (IPPC) Directive to reduce a range of polluting emissions from large pig and poultry units. The “Reference Document on Best Available Techniques (BAT) for Intensive Rearing of Poultry and Pigs”, the BREF (BAT reference) document, may be found at: http://eippcb.jrc.es/pages/FAbout.htm).

8. BAT take into account emissions to air, water and land and a range of other considerations including use of feed, water and energy, the need to minimize waste and the cost of each technique. However, NH_3 is a key emission and a key driver in assessing BAT for many techniques.

9. In this document, abatement methods are evaluated only on their demonstrated potential to reduce NH_3 emissions. For this reason, techniques which are regarded as category 1 techniques may not be BAT for purposes of IPPC; and BAT may include techniques categorized as only 2 in this document (category 3 technique cannot be BAT). However, in practice BAT will normally be an effective means of reducing NH_3 emissions. Reference is made to BAT, and the BREF, both in order to make this document concise and also to ensure consistency with the implementation of IPPC.

10. Options for NH_3 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 livestock 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.

11. Because of this interdependency, Parties will need to rely on additional modelling work before they can use the techniques listed here to develop an NH_3 abatement strategy to meet their national emission targets.

12. 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 UNECE rate of 4 per cent and calculated separately from annual operating costs.

13. It should be noted that, due to economies of scale, some of the abatement techniques may be more cost-effective on large farms than on small farms. This is especially so when an abatement technique requires the purchase of capital equipment, e.g. reduced-emission slurry applicators. In such cases, the unit costs increase as the volumes of manure decrease. A greater cost burden for smaller farms may also be the case for immediate incorporation of manures. On small farms, where labour or machinery are limited, immediate incorporation may only be achieved by hiring a contractor. For this reason the option of incorporating within 12 h is included, as this may be achievable on small farms without requiring excessive cost. (A split view is recorded in the BREF on whether 12 or 24 hours is BAT; thus 24 hours may be a more likely scenario on small farms).

14. Many measures may incur both capital and annual costs (see Table 1).

Table 1

(a) Capital costs (capital expenditure (CAPEX))

Consideration	Notes
Capital for fixed equipment or machinery.	Fixed equipment includes buildings, conversions of buildings, feed storage bins, or manure storage. Machinery includes feed distribution augers, field equipment for manure application or equipment for manure treatment.
Labour cost of installation.	Use contract charges if these are normal. If farm staff are normally used to install the conversion, employed staff should be costed at typical hourly rates. Farmers' input should be charged at the opportunity cost.
Grants	Subtract the value of capital grants available to farmers.

CAPEX (new) means the investment costs in new build situations, in contrast with CAPEX (retrofit) meaning rebuilding or renovation of buildings.

(b) Annual costs (operational expenditure (OPEX)): the annual cost associated with the introduction of a technique needs to be assessed

Consideration	Notes
Annualized cost of capital should be calculated over the life of the investment.	Use standard formula. [1] The term will depend on the economic life. Conversions need to take account of remaining life of original facility.
Repairs associated with the investment should be calculated.	A certain percentage of the capital costs.
Changes in labour costs.	Additional hours x cost per hour.
Fuel and energy costs.	Additional power requirements may need to be taken into account.
Changes in livestock performance.	Changes in diets or housing can affect performance, with cost implications.
Cost savings and production benefits.	In certain cases, the introduction of techniques will result in the saving of costs for the farmer. These should be taken into account only when they are the direct result of the measure**.** The avoidance of fines for pollution should be **excluded** from any costed benefits for these purposes.

15. 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 is the most commonly practised technique presently found on commercial farms and is used to construct baseline inventories.

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1) Formula of annual cost of capital:

$$C \times \left[\frac{r(1+r)^n}{(1+r)^n - 1} \right]$$

C = Costs are based on the purchase

R = Interest costs as percentage/100 (0.04; see para. 12)

n = Amortized years

16. The document reflects the state of knowledge and experience of NH_3 control measures which had been achieved by 2006. It will need to be updated and amended regularly, as this knowledge and this experience continuously expand, for example with new reduced-emission housing systems for pigs and cattle, as well as with feeding strategies for all livestock types.

I. GOOD FARMING PRACTICE

17. The concept of “good farming practice” aims to identify those measures to control NH_3 emissions that protect the environment in the most cost-effective way. These 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 reduced-emission manure application and storage, livestock housing and other techniques, as listed below.

18. While some of the measures may provide a highly cost-effective means of abating NH_3, 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.

19. Good farming 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. MANURE APPLICATION TECHNIQUES

20. *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”) and not followed by quick incorporation. 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 large 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 before incorporation. Emissions will vary with the composition of the slurry and solid 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.

21. Lowering NH_3 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 (N_2O).

Category 1 techniques

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

(a) Band-spreading slurry by trailing hose;
(b) Band-spreading slurry by trailing shoe or “sleigh-foot” machines;
(c) Injecting slurry – open slot;
(d) Injecting slurry – closed slot;
(e) Incorporation of surface-applied (broadcast) solid manure and slurry into soil within a few hours.

23. The average NH_3 abatement efficiencies of category 1 techniques relative to the reference are given in Table 1. Each 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.

24. 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 slurry is distributed through relatively narrow pipes in techniques (i) - (iv), even though most machines incorporate a device for chopping and homogenising slurry, they are not suitable for very viscous slurries or those containing large amounts of fibrous material e.g. straw. Closed-slot injection techniques are potentially very efficient but they do not work well on shallow, stony soils and, may also damage grass swards 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 2.

25. Band-spreading (trailing hose and 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 a tractor 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. Band spreading is more effective when slurry is applied to well-developed row crops, where the plant canopy increases the resistance to turbulent transfer, compared with bare soil. Emission reduction will be minimal if the crop is poorly developed or there is significant canopy contamination.

26. *Trailing hose.* These machines 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.

27. *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 or 8 m. Applicability is limited by size, shape and slope of the field and by the presence of stones on the soil surface.

28. *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 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 on very stony soil, nor on very shallow or compacted soils, where it is impossible to achieve uniform penetration to the required working depth. The slope of the field may also be a limitation to applicability of injection. There is also a greater risk of N losses as N_2O and nitrate in some circumstances.

29. *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 NH_3 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 large application rates can be achieved. Tine spacing is typically 25–50 cm and working width 2– 3 m. Although NH_3 abatement efficiency is great, 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 N losses as N_2O and nitrate in some circumstances.

30. *Incorporation.* Incorporating manure spread on the surface by ploughing is an efficient means of decreasing NH_3 emissions. The manure must be completely buried under the soil to achieve the efficiencies given in Table 2. Lesser 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 closely behind the manure spreader. A more practical option, especially for small farms, might be incorporation within 12 hours of spreading the manure, but this is less efficient in reducing emissions. Incorporation is only possible before crops are sown. Afterwards, if no crops are present to take up the readily available N, the risk of N leaching increases. Hence incorporation of manures involves a risk of exchanging air pollution for water pollution, but reduces the risk of surface run-off from subsequent rainfall events.

Table 2
(a) Category 1 abatement techniques for slurry application to land*

Abatement measure	Type of manure	Land use	Emission Reduction (%)	Applicability[a/]	Costs (OPEX)[b/] (Euro per m^3)
Trailing hose	Slurry	Grassland, arable land	30 Emission reduction may be less if applied on grass <10 cm.	Slope (<15% for tankers; <25% for umbilical systems); not for slurry that is viscous or has a large straw content, size and shape of field should be considered.	2.67 [c/]
Trailing shoe	Slurry	Mainly grassland	60**	Slope (<15% for tankers; <25% for umbilical systems); not viscous slurry, size and shape of the field, grass height should be > 8 cm.	2.45 [c/]
Shallow injection (open slot)	Slurry	Grassland	70**	Slope < 10%, greater limitations for soil type and conditions, not viscous slurry**.**	3.43 [c/]
Deep injection (closed slot)	Slurry	Mainly grassland, arable land	80	Slope < 10%, greater limitations for soil type and conditions, not viscous slurry.	2.89 [c/]
Broadcast application? and incorporation by plough in one process	Slurry	Arable land	80	Only for land that can be easily cultivated.	2.28
Broadcast application and incorporation by plough (costs for < 4 h)	Slurry	Arable land	80–90	Only for land that can be easily cultivated.	Slurry 2.28 Solid manure[b/] 1.32 dairy, other cattle, sheep and goats; 1.47 pigs; 3.19 layers; 6.19 broilers.
Incorporation by disc			60–80		
Broadcast application and incorporation by plough within 12 h	Slurry	Arable land	30	(according to § 10)	

(b) Category 1 abatement techniques for farmyard manure and poultry manure application to land*

Abatement measure	**Type of manure**	**Land use**	**Emission Reduction (%)**	**Applicability**[a/]	**Costs (OPEX)**[b/] **(Euro per m^3)**
Immediate incorporation by plough	solid manure (cattle, pigs)		90		
Immediate incorporation by plough	poultry manure		95		
Incorporation by plough within 12 h	solid manure	Arable land	50 for cattle and pig 70 for poultry		
Incorporation by plough within 24 h	solid manure	Arable land	35 for cattle and pig 55 for poultry		

*/ Emissions reductions are agreed as likely to be achievable across the UNECE region.

a/ 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.

b/ Costs are based on the data from the draft report from the concerted action ALFAM; Ammonia losses from field-applied animal manure, page 13. The costs of slurry manure application (€ per m^3) differ a lot depending the field sizes, tanker size, transport distance, road speed, etc. The ALFAM group made standardized cost calculations. The costs of the reference system are on average €4.84.

** Revised to incorporate conclusions of recent review.

Category 2 techniques

31. *Increasing rate of infiltration into the soil.* When soil type and conditions allow rapid infiltration of liquid, NH_3 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.

32. 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 or anaerobic digestion. Using a mechanical separator with a mesh size of 1–3 mm reduces NH_3 loss from the separated liquid by a maximum of 50 per cent. Another advantage lies in reduced soiling of grass swards. Disadvantages of the technique include the capital and operating costs of the separator and ancillary equipment, the need to handle both a liquid and a solid fraction, and emissions from the solids.

33. 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 6 mm of water can under some circumstances reduce NH_3 losses by 50 per cent compared to surface application alone.

34. *Timing of application.* Ammonia emissions are greatest under warm, dry, windy conditions. Emissions can be reduced by choosing the optimum time of application, i.e. cool humid conditions, in the evenings (although evening application may cause increased odour problems with neighbours), before or during light 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 reduced-emission techniques in category 1. Conditions that favour decreased NH_3 emissions (e.g. humid, no wind) may give rise to problems with offensive odours by preventing their rapid dispersion.

35. *Pressurized injection of slurry.* 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 on sloping land and stony soils where other types of injector cannot be used. Emission reductions of up to 60 per cent, similar to that for open slot injection, have been achieved in field trials, but further evaluation of the technique is needed.

36. *Application of slurry in addition to irrigation water.* Doses of slurry, calculated to match the nutrient requirement of crops, can be added to irrigation water to be applied onto grassland or growing crops on arable land. Slurry is pumped from the stores, injected into the irrigation water pipeline and brought to a sprinkler or travelling irrigator, which sprays the mix onto land. Data on air emissions during spreading are not reported, but positive benefits are expected because the infiltration of the slurry into soil increases and the dilution, up to 1:50, lowers the NH_3 concentration in the liquid and, consequently, the emission potential. However, due to the risk of contamination, this technique would not be appropriate for crops grown to be eaten raw.

Category 3 techniques

37. *Acidified slurry.* The equilibrium between ammonium-N and NH_3 in solutions depends on the pH (acidity). High pH favours loss of NH_3; low pH favours retention of ammonium-N. Lowering the pH of slurries to a stable level of 6 is commonly sufficient to reduce NH_3 emission by 50 per cent or more. When adding acids to slurry, the buffering capacity needs to be taken into account, usually requiring regular pH monitoring and acid addition to compensate for CO_2 produced and emitted during the preparation of the acidified slurry. Options to achieve acidified slurry are by adding organic acids (e.g. lactic acid) or inorganic (e.g. nitric acid, sulphuric acid, phosphoric acid) or by the addition in feed (e.g. benzoic acid) or slurry of components (e.g. lactic acid forming bacteria) that enhance pH reduction. A pH value of 4 - 5 is required when using nitric acid to avoid nitrification and denitrification, causing loss of nitrate and production of unacceptable quantities of N_2O. Organic acids have the disadvantage of being rapidly degraded

(forming and releasing CO_2); moreover, large quantities are required to achieve the desired pH level, since they are usually weak acids.

38. Nitric acid has the advantage of increasing the slurry N content so giving a more balanced NPK (nitrogen-phosphorus-potassium) fertilizer. Using sulphuric acid and phosphoric acid adds nutrients to the slurry that may cause over fertilization with S and P. Moreover, adding too much acid could produce hydrogen sulphide and worsen odour problems. Acidification preferably has to be carried out during storage of slurry and also during spreading using specially designed tankers. Although efficient, the technique has the major disadvantage that handling strong acids on farms is very hazardous.

39. When acidification is conducted in the animal house (see para. 96), frequent monitoring of the pH during storage until the moment of land spreading is needed to assure the lowered pH level of the slurry. Few successful results of farm integrated research have been shown as to date; additional research efforts are needed to upgrade this technique to category 2.

40. *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 NH_3 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.

III. MANURE STORAGE TECHNIQUES

41. At present, there are no proven techniques for reducing NH_3 emissions from stored cattle and pig farmyard manures. Where poultry manure is already dry (e.g. within poultry housing), for any further long term storage elsewhere, it is BAT to provide a barn or building with an impermeable floor with sufficient ventilation; this will keep the manure dry and prevent further significant losses.

42. After removal from animal houses, slurry is commonly stored in concrete or steel tanks or silos, or in an earth-banked lagoon (with an impermeable liner – clay or plastic). The latter tend to have a relatively larger surface area per unit volume than the former. Emissions from slurry stores can be reduced by decreasing or eliminating the airflow across the surface by installing a floating cover (different types), by allowing the formation of a surface crust, or by reducing the surface area per unit volume of the slurry store. Clearly, reducing the surface area is only a consideration at initial store design or at replacement.

43. When using an emission abatement technique for manure stores, it is important to prevent loss of the conserved NH_3 during spreading on land by using an appropriate reduced-emission application technique.

44. *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 3 gives an overview of the different emission abatement measures for slurry stores and their efficiency in reducing NH_3 emissions.

Category 1 techniques

45. The best proven and most practicable techniques to reduce emissions from slurry stored in tanks or silos is to provide a ‘tight’ lid, roof or tent structure. The application of these techniques to existing stores depends on the structural integrity of the stores and whether they can be modified to accept the extra loading. Plastic sheeting* (floating cover) is suitable for *small* earth-banked lagoons. Storage bags for slurry on small farms (e.g. < 150 fattening pigs) also provide a system that reduces emissions. While it is important to guarantee that such covers are well sealed or “tight” to minimize air exchange, there will always need to be some small openings or a facility for venting to prevent the accumulation of flammable gases, such as methane.

Category 2 techniques

46. There is a range of floating covers that can reduce NH_3 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, except for plastic sheeting on small earth-banked lagoons, and are likely to vary according to management and other factors. Examples include plastic sheeting, chopped straw, peat, LECA (light expanded clay aggregates) balls or other floating material applied to the slurry surface in tanks or earth-banked lagoons. Floating covers might hinder homogenization of the slurry prior to spreading; some of the materials used may hinder the spreading process itself, by clogging up machinery, or cause other slurry management problems.

47. 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 NH_3 emissions at little or no cost. This natural crust formation is an option for farms that do not have to mix and disturb the crust in order to spread slurry frequently. The emission abatement efficiency will depend on the nature and duration of the crust.

48. If shallow earth-banked lagoons are replaced by taller tanks or silos, emissions will be reduced due to the reduced surface area per unit volume. This could be an effective (though expensive) NH_3 reduction option, particularly if the tanks are covered by a lid, roof or tent structure (category 1 techniques). However, the effectiveness of this option is difficult to quantify, as it is strongly dependent on the characteristics of the lagoon and the tank.

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* Sheeting may be a type of plastic, canvas or other suitable material.

Table 3. Ammonia emission abatement measures for cattle and pig slurry storage

Abatement Measure	**NH_3 Emission reduction %)**[a/]	**Applicability**	**BAT for IPPC pig farms?**	**Costs (OPEX) (Euros per m^3/yr)** [c/]
'Tight' Lid, roof or tent structure (Cat. 1)	80	Concrete or steel tanks and silos. May not be suitable on existing stores.	Yes – but decisions taken on a case by case basis	8.00[b/]
*Plastic sheeting (floating cover) (Cat. 1)	60	Small earth-banked lagoons.	Yes – but decisions taken on a case by case basis	1.25
*Plastic sheeting (floating cover) (Cat. 2)	60	Large earth-banked lagoons and concrete or steel tanks. Management and other factors may limit use of this technique.	Yes – but decisions taken on a case by case basis	1.25
"Low technology" floating covers (e.g. chopped straw, peat, bark, LECA balls, etc.) (Cat. 2)	40	Concrete or steel tanks and silos. Probably not practicable on earth-banked lagoons. Not suitable if materials likely to cause slurry management problems.	Yes – but decisions taken on a case by case basis	1.10 – tanks
Natural crust (floating cover) (Cat. 2)	35–50	Higher dry matter slurries only. Not suitable on farms where it is necessary to mix and disturb the crust in order to spread slurry frequently.	Yes – but decisions taken on a case by case basis	0.00
Replacement of lagoon, etc. with covered tank or tall open tanks (H> 3 m) (Cat.1)	30– 60	Only new build, and subject to any planning restrictions concerning taller structures.	Not assessed	14.9 (cost of tank 6.94)
Storage bag (Cat. 1)	100	Available bag sizes may limit use on larger livestock farms.	Not assessed	2.50

* Sheeting may be a type of plastic, canvas or other suitable material.

a/ Emission reductions are agreed best estimates of what might be achievable across the UNECE region. Reductions are expressed relative to emissions from an uncovered slurry tank/silo.

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

c/ Based on a depreciation period of 10 years, and an interest rate of 6 per cent, and an additional cost of €12,000. (The cost €2.5 maybe adjusted)

IV. LIVESTOCK HOUSING

49. Animal housing varies enormously across the UNECE region and NH_3 emissions will vary accordingly. In general, emissions from livestock housing will be reduced if the surface area of exposed manures is reduced and/or such manures 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 NH_3 is no longer formed by hydrolysis of uric acid. 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 improved techniques for manure application to land and manure storage.

50. *Reference techniques*. The level of NH_3 emission reduction achieved through new livestock housing designs will depend critically on the housing types currently in use.

A. **Housing systems for dairy and beef cattle**

51. Techniques to reduce NH_3 emissions in cattle housing apply one or more of the following principles:

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

52. Housing systems for cattle are very varied across Europe. While loose housing is most common, dairy cattle are still kept in tied stalls in some countries. In these systems, all or part of the excreta is collected in the form of slurry. If solid manure is produced, it is removed from the house daily. Loose housing systems most commonly are slurry-based. The system most commonly researched is the “cubicle house” for dairy cows, where NH_3 emissions arise from fouled slatted and/or solid floors and from manure pits and channels beneath the slats/floor. In Table 4, cubicle housing is reference 1, while tied housing systems are reference 2. Buildings in which the cattle are held in tied stalls emit less NH_3 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.

Category 1 techniques

53. There is currently only one category 1 technique available for abating NH_3 from dairy and beef cattle housing, the use of a “toothed” scraper running over a grooved floor. Grooves should be equipped with perforations to allow drainage of urine. This appears to produce a clean, and therefore reduced-emission floor surface, while still providing enough grip for the cattle to prevent any problems of slipping. This system is implemented on several farms in the Netherlands.

Category 2 techniques

54. *Straw-based systems*. Straw-based systems are not very common for dairy cattle and data on NH_3 emissions is very limited. Research to date has shown that straw-based systems for beef cattle are likely to emit less NH_3 than slurry-based systems. Ammonia emissions critically

depend on the amount of straw per animal. In sloped floor systems, 5 kg straw lu^{-1}d^{-1} are sufficient to significantly reduce NH_3 emissions. It should be noted that straw-bedded systems commonly produce some slurry as well (from collection and dispersal yards at milking, and in the systems where they feed off the strawed areas i.e. on concreted areas).

55. Straw-based systems producing solid manure cannot only reduce housing emissions but also emissions after spreading the manure on the field. The total reduction (housing to field) has been shown to be up to 30 per cent and above, as compared with slurry systems.

Category 3 techniques

56. *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 flushing with water, acid, diluted or mechanically-separated 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 and/or sloping floors to assist in scraping or flushing has given rise to problems with animal slipping and potentially injuring themselves. None of these systems can therefore be considered as category 2 techniques at present.

57. Table 4 gives emissions from different cattle housing systems (reference systems and category 1 and 2 techniques).

Table 4. Ammonia emissions of different cattle housing systems (reference systems and category 1 and 2 techniques)

Housing type	Reduction (%)	[c] Ammonia emission (kg/cow place/year)
Cubicle house (reference 1)	0	11
Tied system[a] (reference 2)	60	4.4
Grooved floor (cat. 1)	25	8.3
Solid manure, sloped floor or deep litter system [with sufficient amount of straw (5–6 kg/cow/day] (cat. 2)[b]	30	7.5

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

b/ Systems in which all or most excreta are collected as solid manure. Emissions depend on the amount of straw used. Too little straw may increase emissions.

Systems with straw are favoured for animal welfare reasons.

c/ Emissions with full time housing of the animals. With grazing, emissions have to be reduced proportionally to the absence of the animals from the house.

B. Housing systems for pigs

58. Emissions from fully slatted pig houses with a storage pit underneath are taken as the reference, although in some countries these systems are banned for animal welfare reasons.

59. Designs to reduce NH_3 emissions from pig housing systems apply the following principles:

(a) Reducing emitting manure surfaces (soiled floor, slurry surface in channels);

(b) Removing the manure (slurry) from the pit frequently to an external slurry store;

(c) Additional treatment, such as aeration, to obtain flushing liquid;

(d) Cooling the manure surface;

(e) Changing the chemical/physical properties of the manure, such as decreasing pH, and/or;

(f) Using surfaces which are smooth and easy to clean;

(g) Treatment of exhaust air by acid scrubbers or biotrickling filters.

60. Designs to reduce all emissions from pig housing are also described in the BREF relating to intensive pig production (larger pig installations).

C. General measures for pig houses

61. Concrete, steel and plastic are used in the construction of slatted floors. Generally speaking, and given the same slot width, manure dropped on concrete slats takes longer to fall into the pit and this is associated with greater emissions of NH_3 than when using steel or plastic slats. It is worth noting that steel slats are not allowed in some member States.

62. Frequent removal of manure by flushing with slurry may result in a peak in odour emissions with each flush. Flushing is normally done twice a day: once in the morning and once in the evening. These peaks in odour emissions can cause nuisance to neighbours. Additionally treatment of the slurry also requires energy. These cross-media effects have been taken into account in defining BAT on the various housing designs.

63. With respect to litter, it is expected that the use of straw in pig housing will increase due to raised awareness of animal welfare. It may be applied in conjunction with (automatically) controlled naturally-ventilated housing systems, where straw would allow the animals to control the temperature themselves, thus requiring less energy for ventilation and heating. In systems where litter is used, the pen is divided into a dunging area (without litter) and a littered solid floor area. It is reported that pigs do not always use these areas in the correct way and dung in the littered area and use the slatted area to lie on. However, the pen design can influence the behaviour of the pigs, although it is reported that in regions with a warm climate this might not be sufficient. Integrated evaluation of straw use would include the extra costs for straw supply and mucking out as well as the possible consequences for the emissions from storage of farmyard manure and for the application onto land. The use of straw results in farmyard manure which will increase the organic matter of the soils.

Category 1 techniques

64. A number of manure removal or treatment systems can be used to reduce NH_3 emissions from pig housing:

(a) *Reducing the emitting manure surface*. Partly slatted floors (some 50% area), generally emit less NH_3, 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.

(b) *Flushing systems*. There are many different types of flushing systems. Low-emission flushing systems remove the manure from the pit rapidly.

(c) *Vacuum systems.* Rapid removal of manure from pits can be achieved by vacuum removal systems operated at least twice a week.

(d) *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 NH_3 emissions. A readily-available source of groundwater is required and the system may not be allowed where drinking water is extracted. There may be significant costs to setting up such a system.

65. A housing system has been developed incorporating manure surface cooling fins using a closed system with heating pumps. It performs well, but is a very costly system. Therefore, manure surface cooling fins are not category 1 for new housing systems, but when it is already in place, it is category 1. In retrofit situations this technique can be economically viable and thus can be category 1 as well, but this has to be decided on a case-by-case basis. It should be noted that energy efficiency can be less in situations where the heat that arises from the cooling is not used, e.g. because there are no weaners to be kept warm.

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

67. Treatment of exhaust air by acid scrubbers or biotrickling filters is another option that has proven to be practical and effective for large scale operations in Denmark, Germany and the Netherlands,. A number of manufacturers provide scrubber and trickling filters that are subject to field test and certification procedures in these countries to be admitted for practical use. They are most economically practical when installed into ventilation systems during the building of new houses. Application in existing housings demand high extra costs to modify ventilation systems, and is not considered category 1. So far, suitability for housing systems in South and Central Europe has not been tested.

68. Acid scrubbers mainly apply sulphuric acid in their recirculation water to bind ammonia as ammonium sulphate and have demonstrated ammonia removal efficiencies between 70 and 95 per cent, depending on their pH-set values. Nitrogen is removed out of the system by controlled discharge of recirculation water that contains an ammonium sulphate solution. In biotrickling

filters, ammonia is converted in nitrate by biomass on the synthetic package material and in the recirculation water. Ammonia removal efficiencies of 70 per cent can be guaranteed for properly designed filters. Operational costs of both acid scrubbers and trickling filters are especially dependent on the extra energy use by water recirculation and increased pressure differences. However, the high ammonia removal capacity of scrubbers enables in a number of regions scales of operations that outweigh the higher operational costs.

Category 2 techniques

69. Category 2 techniques for reducing NH_3 include good climate control within the housing to ensure that temperature and ventilation rates do not get too high. Other systems which could reduce NH_3 include increasing the depth of the under-floor manure pit further (1.2 m is suggested 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.

70. It is possible to treat the ventilated air from the pig/poultry housing using biofilters based on organic packing material such as wood chips or peat, without water recirculation. These systems can be remove up to 70 per cent of the $NH_{3,}$ but have major practical drawbacks for long-term use in animal housings because of high ammonia and dust loads. Systems suffer from clogging that increases energy consumption. Quick acidification by nitric acid accumulation and inhomogenuous humidification reduces and in the end eliminates the working capacity of the biomass.

D. Housing systems for growers/finishers

71. Growers/finishers are always housed in a group and most of the systems for group housing of sows apply here as well. The following techniques are compared against a specific reference system. The reference system for growers/finishers is a fully slatted floor with a deep manure pit underneath and mechanical ventilation. The associated emission level range is between 2.39 and 3.0 kg NH_3 per pig place per year. The system has been applied commonly throughout Europe.

Table 5. Category 1 techniques: reductions and costs of low-emission housing systems for fattening pigs.

Systems	**Emission reduction potential (%)**	**CAPEX (new) (cost relative to the reference (€))**	**OPEX new (cost relative to the reference (€))**	**BAT Assessment**
Group-housed on fully slatted floors: Reference*	0	0	0	
Fully slatted floor				
With vacuum system	25	8.60	4.30	BAT
With flush channels; no aeration	30	12.16	6.08	conditional BAT
Flush gutters/tubes; no aeration	40	2.44 to 8.54	1.22 to 4.27	conditional BAT
With flush channels; aeration	55	4.82	2.41	BAT, when it is already in place
flush gutters/tubes; aeration	55	0.56 to 5.54	0.28 to 2.77	BAT, when it is already in place
Partly slatted floors				
With scraper; concrete slats	40	no data	5.93	BAT, when it is already in place
With surface cooling fin; concrete slats	50	30.40	5.50	BAT, when it is already in place, and conditional BAT for retrofit
With surface cooling fin; steel slats	60	43.00	8.00	BAT, when it is already in place, and conditional BAT for retrofit
With flush channels; no aeration	50	no data	6.07	conditional BAT
With flush channels; aeration	60	no data	2.89	BAT, when it is already in place
With flush gutters/tubes; no aeration	60	59.00	9.45	conditional BAT
With flush gutters/tubes; aeration	60	161.80	57.40	BAT, when it is already in place
With channel/slanted walls/concrete slats	60	3.00	0.50	BAT
With channel/slanted walls/metal slats	65	23.00	5.44	BAT
With scraper; metal slats	50	no data	5.93	BAT, when it is already in place
Fully and partly slatted floors				
Acid scrubber, new building	90	32.30	11.40	
Briotrickling filter, new building	70	34.60	11.00	

*Reference system, a fully concrete slatted floor, has an NH_3 emission of 2.4 up to 3.0 kg NH_3 kg/year/place).

E. Housing systems for farrowing sows (including piglets)

72. Farrowing sows in Europe are generally housed in crates with steel and/or plastic slatted

floors. In the majority of the houses sows are confined in their movement, with piglets walking around freely. All houses have controlled ventilation and often a heated area for the piglets during the first few days. This system with a deep manure pit underneath is the reference system.

73. The difference between fully and partly slatted floors is not so distinct in the case of farrowing sows, where the sow is confined in its movement. In both cases, manuring takes place in the same slatted area. Reduction techniques therefore focus predominantly on alterations in the manure pit.

Table 6. Category 1 techniques: reductions and costs of low-emission housing systems for farrowing sows including piglets.

Systems	Emission reduction potential (%)	CAPEX (new) (cost relative to the reference (€))	OPEX new (cost relative to the reference (€))	BAT Assessment
Housing with confined movement: Reference*	0	0	0	
Fully slatted floor with plastic or steel slats				
With a board on a slope	30	260	29.50	BAT, when it is already in place
With water and manure channel	50	60	1.00	BAT
With flushing and manure gutters	60	535	86.00	BAT
With a manure pan	65	280	45.85	BAT
With surface cooling fins	70	302	51.20	BAT, when it is already in place, and conditional BAT in retrofit situations
Partly slatted floors with plastic or steel slats				
With a reduced manure pit	30	0	0	BAT, when it is already in place
Fully and partly slatted floors				
Acid scrubber, new building	90	107.60	38.00	
Briotrickling filter, new building	70	115.20	36.60	

*Reference system with steel or plastic slats, has an ammonia emission of 8.3 up to 8.7 kg NH_3 kg/year/place).

F. Housing systems for mating/gestating sows

74. Mating and gestating sows are housed individually or in a group. Group-housing systems require other feeding systems (e.g. electronic sow feeders) and a pen design that influences sow behaviour (use of manure and lying areas). Group housing is compulsory in new sow housing throughout EU Member States and in 2013 all mating and gestating sows, four weeks after being served or inseminated, will have to be housed in groups.

75. From the environmental point of view, submitted data did not report differences and seem to indicate that group-housing systems have similar emission levels to those from individual

housing, if identical emission reduction techniques are applied. The reference system for housing of mating and gestating sows is the fully slatted floor (concrete slats) with a deep pit.

Table 7. Category 1 techniques, reduction and costs of low-emission housing systems for mating and gestating sows.

Systems	**Emission reduction potential (%)**	**CAPEX (new) (cost relative to the reference (€))**	**OPEX new (cost relative to the reference (€))**	**BAT Assessment**
Individual housed on fully slatted floor:: Reference*	0	0	0	
Fully concrete slatted floor				
With vacuum system	25	8.60	4.30	BAT
With flush channels; no aeration	30	12.16	6.08	BAT, when it is already in place and conditional BAT for new buildings
With flush channels; aeration	55	4.82	2.41	conditional BAT
Flush gutters/tubes; no aeration	40	2.44 to 8.54	1.22 to 4.27	BAT, when it is already in place and conditional BAT for new build situations
Flush gutters/tubes; aeration	55	0.56 to -/- 5.54	0.28 to -/- 2.77	conditional BAT
Partly slatted floors				
With reduced manure pit	30	2.25	0.40	BAT
With manure surface cooling fins	50	112.75	20.35	BAT, when it is already in place and conditional BAT in retrofit situations
With vacuum system concrete slats	25	no data	-/-4,00	BAT
With vacuum system; metal slats	35	no data	-/-1.50	BAT
With flush channels; no aeration	50	no data	-/-6.07	BAT, when it is already in place and conditional BAT for new build situations
With flush channels; aeration	60	no data	-/-2.89	conditional BAT
With flush gutters/tubes; no aeration	50	-2 (59.00)	9.45	BAT, when it is already in place and conditional BAT for new build situations
With flush gutters/tubes; aeration	70	-2 (161.80)	57.40	conditional BAT
With scraper and concrete slats	30	no data	no data	BAT, when it is already in place
with scraper and metal slats	50	no data	no data	BAT, when it is already in place
Fully and partly slatted floors				
Acid scrubber, new building	90	64.60	22.80	
Biotrickling filter, new building	70	69.20	22.00	

*The reference system is individual housing with fully concrete slatted floor and has an ammonia emission of 3.12 up to 4.2 kg NH_3 kg/year/place).

G. Housing systems for weaners

76. Weaners are housed in a group in pens or flat decks. In principle, manure removal is the same for a pen and a flat deck (raised pen) design. The reference system is a pen or flat deck with a fully-slatted floor made of plastic or metal slats and a deep manure pit. It is assumed that in principle, reduction measures applicable to conventional weaner pens can also be applied to the flat deck. Straw-based systems with solid concrete floors are conditional BAT, but cannot be assigned to a category as no data on NH_3 emissions have been reported.

Table 8. Category 1 techniques: reduction and costs of low-emission housing systems for weaners.

Systems	Emission reduction potential (%)	CAPEX (new) (cost relative to the reference (€))	OPEX new (cost relative to the reference (€))	BAT Assessment
Pens or flat decks Fully Slatted Floor: Reference*	0	0	0	
Fully slatted floor				
with vacuum system	25	no data	no data	BAT
Partly slatted floor				
With a reduced manure pit included slanted walls	70	4.55	0.75	BAT
Fully slatted and partly slatted floor				
With manure scraper	35 – 70	68.65	12.30	BAT, when it is already in place
With flush gutters or flush tubes, no aeration	40 – 65	25.00	4.15	BAT, when it is already in place conditional BAT for new houses
With two-climate system	35	no data	no data	BAT
With sloped or convex solid floor	40	0.00	0.00	BAT
With manure pit + waste water channel	55	2.85	0.35	BAT
With triangle steel slats + manure channel with slanted walls	70	4.55	0.75	BAT
With manure surface cooling fins	75	24.00	9.75	BAT, when it is already in place and conditional BAT in retrofit situations
Acid scrubber, new building	90	11.10	3.80	
Biotrickling filter, new building	70	11.50	3.70	

*Reference system is a fully slatted floor with steel or plastic slats and has an ammonia emission of 0.6 up to 0.8 kg NH_3 kg/year/place).

H. Housing systems for poultry

Housing systems for laying hens

77. The evaluation of housing systems for layers should, in the European Union (EU) Member States, consider the requirements laid down by the European Directive 1999/74/EC, on housing of laying hens. These requirements prohibit the installation of new conventional cage systems and lead to a total ban on the use of such cage systems by 2012. One specific ongoing study is focused on the various systems of housing laying hens, and in particular on those covered by that Directive, taking into account, amongst others, the health and environmental impact of the various systems. The banning of conventional cage systems will require the use of the so-called enriched cage or of non-cage systems (alternative systems). Ammonia emissions from such systems have not been assessed. This has consequences for evaluating investments in refurbishing existing conventional cage systems and in the installation of new systems. For any investment in systems that will be banned by the Directive, an amortization period of 10 years for the associated costs would be advisable.

78. *Caged housing systems*. Most laying hens are still housed in conventional cages and most of the information on NH_3 emission reduction addresses this type of housing. The reference system used for the housing of layers in caged systems is open manure storage under the cages.

Category 1 techniques

79. Ammonia emissions from battery deep-pit or channel systems can be lowered by reducing the moisture content of the manure by ventilating 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 although no data are available to enable a categorization of this approach.

80. The collection of manure on belts and the subsequent removal of manure to covered storage outside the building can also reduce NH_3 emissions, particularly if the manure is dried on the belts through forced ventilation. The manure should be dried to a dry-matter content of 60–70 per cent to prevent the formation of NH_3. If the manure from the belts is collected in an intensively ventilated drying tunnel, inside or outside the building, the dry-matter content of the manure can reach 60 –80 per cent 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, emission from laying hen houses with manure belts will depend on:

(a) The length of time that the manure is present on the belts (long time = high emissions);
(b) The drying system;
(c) The poultry breed;

(d) The ventilation rate at the belt (low rate = high emissions);
(e) Feed composition.

Table 9. Caged housing systems for laying hens: techniques and associated NH_3 emission reduction potential

Category 1 techniques	NH_3 reduction potential (%)	BAT assessment
1. Non-aerated open manure storage under cages (RT)*	0*	Not applicable
2. Manure removal by way of scrapers to open storage	0	Not assessed
3. Aerated open manure storage under cages (deep-pit or high rise systems and channel house)	30	Conditional BAT. In regions where a Mediterranean climate prevails this system is BAT. In regions with much lower average temperatures, this technique can show a significantly greater NH_3 emission, but is considered BAT provided there is a mean of ventilating the manure store.
4. Manure removal by way of belts to closed storage	58–76	BAT
5. Vertical tiered cages with manure belts and forced air drying	55	BAT
6. Vertical tiered cages with manure belts and whisk-forced air drying	60	BAT
7. Vertical tiered cages with manure belts and improved forced air drying	70–88	BAT
8. Vertical tiered cages with manure belts and inside or outside drying tunnel	80	BAT

* Reference techniques (RT) and all the other reduction percentages of the other techniques are based on 0.083 kg NH_3/year x place. In the warmer regions of Europe, an emission of the RT of 0.220 kg NH_3/year x place has been measured.

81. *Non-caged housing systems.* In the EU, non-caged housing for laying hens is expected to attract more attention because of animal welfare considerations. In this section, techniques are compared against a specific reference system – the deep litter system (without aeration of the litter). This system has *approximately* 40 per cent greater emissions than the reference system for cages.

Table 10. Non-caged housing systems for laying hens: techniques and associated NH_3 emission reduction potential

Category 1 techniques	NH_3 reduction potential (%)	BAT assessment
Deep litter system (RT)*	0*	Not applicable
Deep litter with forced manure drying	60	BAT
Deep litter with perforated floor and forced manure drying	65	BAT
Aviary system	71	BAT

* Reference techniques (RT) and all the other reduction percentages of the other techniques are based on 0.315 kg NH_3/year x place.

82. The same system of manure ventilation and removal as in cage systems 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.

83. In some countries, the definition of “free range” includes such systems but with access to 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 reduced-NH_3 systems for these free-range houses.

Category 2 techniques

84. Treatment of exhaust air by acid scrubber or biotrickling filters is an option that has been applied on a very restricted scale in a few regions. Although highly effective in terms of ammonia removal (90%), the high dust loads in poultry housings complicate reliable long term functioning of current designs. Compared to pig production, the relatively high costs to treat the fully installed ventilation capacity have blocked wider application of the current generation of scrubbers.

I. Housing systems for broilers

85. Traditionally, broilers are kept in buildings with a solid, fully littered floor. This is taken as the reference. To minimize NH_3 emission, it is important to keep the litter as dry as possible. The dry-matter content and the emission of NH_3 depend on the:

(a) Drinking-water system (avoiding leakage and spills);
(b) Duration of the breeding period;
(c) Animal density and weight;
(d) Use of air purification systems;
(e) Use of floor insulation;
(f) Feed.

Category 1 technique

86. A simple way of maintaining dry manure and reducing NH_3 emission is to reduce the spillage of water from the drinking system (e.g. using a nipple drinking system). In Table 11, category 1 techniques are indicated which are BAT under all conditions. In contrast to other category 1 measures, no data are reported of reductions in NH_3 emissions. Nevertheless, the effectiveness of inhibiting uric acid hydrolysis in preventing emission is so well established that measures that keep manure dry may be considered as category 1.

Category 2 techniques

87. Effective emission reduction can be achieved through forced drying and several systems are currently being evaluated (Table 11). These systems are 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. The Combideck System can also be considered a category 2 technique because it is BAT only if local conditions allow its adoption.

Table 11. Housing systems for broilers: techniques and associated NH_3 emission reduction potential

	NH_3 reduction potential (%)	**BAT assessment**
Deep litter; fan ventilated house (RT)*	0*	Not applicable
Naturally-ventilated house with a fully littered floor and equipped with non-leaking drinking system (cat.1)	No data	BAT
Well-insulated fan ventilated house with a fully littered floor and equipped with non-leaking drinking system (cat.1)	No data	BAT
Perforated forced air drying (cat. 2)	82	BAT only for housing systems that are already in place
Tiered floor and forced air drying (cat. 2)	94	“ “ “ "
Tiered removable sides; forced air drying (cat.2)	94	“ “ “ "
Combideck System (cat. 2)	44	Conditional BAT. It can be applied if local conditions allow; e.g. if soil conditions allow the installation of closed underground storage of the circulated water. It is not yet known if this system performs equally well in locations where frosts are longer and harder and penetrate the soil or where the climate is much warmer and the cooling capacity of the soil might not be sufficient.

*Reference techniques (RT) and all the other reduction percentages of the other techniques are based on 0.080 kg NH_3/year x place.

88. For similar reasons as mentioned for laying hens, application of scrubber technology to treat ventilation air, although effective in ammonia removal, is only used incidentally.

J. Housing systems for turkeys and ducks

89. Traditionally, turkeys are kept in buildings with a solid, fully littered floor, very similar to the housing of broilers. Birds are housed in closed, thermally insulated buildings with forced ventilation or in open houses with open sidewalls. Manure removal and cleaning takes place at the end of each growing period. NH_3 emission has been measured under practical conditions in a

commonly used turkey house with a fully littered floor and has been found to be 0.680 kg NH_3 per turkey place per year.

90. The commonly applied duck house is a traditional housing system, very similar to the housing of broilers. Partly slatted/partly littered floor and fully slatted floor are other housing systems for fattening of ducks.

91. Techniques such as:

(a) Naturally-ventilated house with a fully littered floor and equipped with non-leaking drinking system;
(b) Well-insulated fan ventilated house with a fully littered floor and equipped with non-leaking drinking system;

can be considered BAT.

92. Techniques such as:

(a) Perforated forced air drying;
(b) Tiered floor and forced air drying;
(c) Tiered removable sides; forced air drying;

cannot yet be considered BAT, because data on emission reduction of NH_3 are not available.

93. For these livestock, there is no formal categorization of techniques due to lack of data on NH_3 emissions.

V. FEEDING STRATEGIES AND OTHER MEASURES

94. Feeding measures that reduce protein uptake will reduce N excretion of the animals and thereby reduce the need for abatement measures at housing and manure management. Nutritional management aims at matching feeds more closely to animal requirements at various production stages, thus decreasing the N excreted.

95. Feeding measures cover a wide variety of techniques that can be implemented individually or simultaneously to achieve the greatest reduction of nutrients excreted.

96. *Reference technique*. The extent to which NH_3 emissions can be reduced through feeding strategies will be crucially dependent on current feeding practices. The reference varies greatly across the UNECE and is in many cases not documented. In general, a 1 kg reduction in N excretion will result in an NH_3 emission 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 options are allocated to category 2.

A. Intensive rearing of pigs

97. Feeding measures in pig production include phase feeding, formulating diets based on digestible/available nutrients, using low-protein amino acid-supplemented diets. Further techniques are currently being investigated (e.g. different feeds for males and females) and might be additionally available in the future.

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

99. The crude protein content of the pig ration can be reduced if the amino acid supply is optimised through the addition of synthetic amino acids (e.g. lysine, methionine, threonine, tryptophan) or special feed components.

100. A crude protein reduction of 2 to 3 per cent (20 to 30 g/kg of feed) can be achieved depending on the species and the current starting point. The resulting range of dietary crude protein contents is reported in Table 11. The values in the table are only indicative and levels may need to be adapted to local conditions.

101. *Feed additives*. The addition of special components with high non-starch polysaccharide content (e.g. sugar beet pulp, soybean hulls) can reduce the pH of pig excreta and thus NH_3 emissions. These options need more research and can only be considered category 3 at present. The same effect can be achieved through the addition of acids to the feed. Recently, the potential of benzoic acid as additive in pig diet have been taken under study(in the Netherlands and Spain,),. Benzoic acid is degraded in the pig to hippuric acid, that lowers the urine pH and consequently the pH of the slurry stored in the pig house. Benzoic acid is officially allowed in the EU as acidity controlling agent (E210), and is also admitted as feeding additive for fattening pigs (1% dosage) and piglets (0.5% dosage; expected in the course of 2006) as calcium benzoate (registered trade mark: Vevovitall). Emission reductions of 25–30 per cent are expected at these dosages, to be confirmed in actual research. Based on the preliminary results, this technique could be category 2, whereas category 1 can be considered when transparent protocols become available for use by controlling agencies and (local) authorities.

Table 12. Indicative crude protein levels in feed for pig rations

Species	Phases	Crude protein content (% in feed)	Remark
Weaner	< 10 kg	19–21	
Piglet	< 25 kg	17.5–19.5	With adequately balanced and optimal amino acid supply
Fattening pig	25–50 kg	15–17	
	50–110 kg	14–15	
Sows	Gestation	13–15	
	Lactation	1 –17	

B. Intensive rearing of poultry

102. For poultry, the potential for reducing N excretion through feeding measures is more limited than for pigs because the conversion efficiency is already high and the variability within a flock of birds is greater. A crude protein reduction of 1 to 2 per cent (10 to 20 g/kg of feed) can usually be achieved depending on the species and the current starting point. The resulting range of dietary crude protein contents is reported in Table 12. The values in the table are only indicative and levels may need to be adapted to local conditions. Further applied nutrition research is currently being carried out in a number of EU Member States and may support further possible reductions in the future.

Table 13. Indicative crude protein levels in BAT-feeds for poultry

Species	Phases	Crude protein content (% in feed)	Remark
Broiler	Starter	20–22	With adequately balanced and optimal amino acid supply
	Grower	19–21	
	Finisher	18–20	
Turkey	< 4 weeks	24–27	
	5–8 weeks	22–24	
	9–12 weeks	19 –21	
	13+ weeks	16 –19	
	16+ weeks	14 –17	
Layer	18–40 weeks	15.5– 16.5	
	40+ weeks	14.5– 15.5	

C. Feeding for cattle

103. For cattle fed mainly on roughage (grass, hay, silage, etc.), a 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 of lesser 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.

VI. OTHER MEASURES

104. The proportion of nitrogen lost as NH_3 is greater for urea than for other mineral N fertilizers. Ammonia emissions can be reduced by either compliance with the UNECE

Framework Advisory Code of Good Agricultural Practice for Reducing Ammonia Emissions and related Guidelines, or the choice of a more suitable N-fertilizer adapted to climate and soil conditions unfavourable for urea. Ammonia losses from mineral fertilizers can be reduced by up to 90 per cent, depending on the substituting fertilizer and on climatic and soil conditions. The implementation of this substitution is immediately possible without major restrictions and the potential reduction in NH_3 emission is well documented (category 1).

105. Emissions from non-urea fertilizers such as ammonium nitrate and calcium ammonium nitrate occur partly as a result of direct fertilizer emission and partly from indirect emission resulting from plants as a consequence of fertilization. Grass cutting also contributes to the NH_3 emissions, with emissions arising from the re-growing sward as a consequence of cutting-induced N mobilization in the vegetation. Fertilizing grassland within the first few days after cutting provides surplus N resulting in a larger emission from the combined effects of cutting and fertilization. Delaying N fertilizer application following cutting allows the grass to recover thereby reducing NH_3 emissions. Model analysis found that a two-week delay in N fertilization reduced total (net annual) NH_3 emissions from cut and fertilized grassland by 15 per cent. Similar effects may be achieved with different timing depending on regional conditions. Given the interactions with weather and the need for further work to identify the optimum delay in relation to different management systems, this is classed as a category 2 technique.

Grazing

106. Urine excreted by grazing animals often infiltrates into the soil before substantial NH_3 emissions can occur. Therefore, NH_3 emissions per animal are less for grazing animals than for those housed where the excreta is collected, stored and applied to land. The emission reduction achieved by increasing the proportion of the year spent grazing will depend, inter alia, on the baseline (emission of ungrazed animals), the time the animals are grazed, and the N fertilizer level of the pasture. The potential for increasing grazing is often limited by soil type, topography, farm size and structure (distances), climatic conditions, etc. It should be noted that additional grazing of animals may increase other forms of N emission (e.g. N_2O, NO_3). However, given the clear and well quantified effect on NH_3 emissions, this can be classed as a category 1 technique (in relation to modification of the periods when animals are housed or grazed for 24 hours a day). The abatement efficiency may be considered as the relative total NH_3 emissions from grazing versus housed systems. The actual abatement potential will depend on the base situation of each animal sector in each country.

107. The effect of changing the period of partial housing (e.g. grazed during daytime only) is less certain and is rated as a category 2 technique. Changing from a fully housed period to grazing for part of the day is less effective in reducing NH_3 emissions than switching to complete (24 hour) grazing, since buildings and stores remain dirty and continue to emit NH_3.

Manure treatment

108. Research on various options of reducing NH_3 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 often show increased NH_3 emissions;

(b) Controlled denitrification processes in the slurry: pilot plants show that it might be possible to reduce NH_3 emissions by transforming ammonium to N_2 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.

109. The efficiency of manure treatment options should generally be investigated under country- or farm-specific conditions. Apart from NH_3 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 categories 2 or 3.

Non-agricultural manure use

110. 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 large emissions (including other emissions than NH_3). 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

111. A wide variety of manure additives has been suggested to reduce NH_3 emissions (see paragraph 34). They mostly aim at reducing the NH_3 content or the pH by chemical or physical processes. Their efficiency in reducing NH_3 emissions (up to 70% reduction reported) depends on how well they achieve these aims and on where in the manure management process they are introduced. The gain of N (less NH_3 lost) is equivalent to approximately 35 kg mineral N/ha (significantly more when nitric acid is used); when using pig manure, this represents €1.13 per kg N prevented to emit in the pig house and during storage (source: Danish Agricultural Advisory Service). 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.

VII. NON-AGRICULTURAL STATIONARY SOURCES

112. There are many non-agricultural sources of NH_3, including motor vehicles, waste disposal, residential solid-fuel combustion, and various industries, of which fertilizer production is likely to be the most significant across Europe. There is also a small, but collectively significant group of natural sources, including, for example, human breath and sweat and emissions from wild animals. The UNECE Protocols for reporting emissions do not currently distinguish between natural and anthropogenic sources in the same way that they do for volatile organic compounds (VOCs).

113. A common factor across many of these sectors is that NH_3 emissions have previously been ignored. This is most notable with respect to transport, as shown below. A first recommendation for reducing NH_3 emissions from non-agricultural sources is therefore to ensure that NH_3 is considered when assessing the performance of industry and other sources. Where NH_3 emissions are found to arise, or are likely to increase through some technical development, it will be appropriate for operators and designers to consider ways in which systems may be optimized to avoid or minimize emissions.

General techniques for NH_3 control

114. Venturi scrubbers are suitable for large gas flows bearing large concentrations of NH_3. Abatement costs are in the region of €3,500 /ton, excluding effluent treatment costs. As in all cases discussed in this section, the precise cost-effectiveness will vary according to the size of plant, NH_3 concentrations and other factors.

115. Dilute acid scrubbers, consisting of a tower randomly packed with tiles through which slightly acidic water is circulated, are suitable for dealing with flows of between 50 and 500 tons per year. Barriers to the technology include its limited suitability for large volume gas flows, potentially high treatment costs for effluents, and safety hazards linked to storage of sulphuric acid. Reported costs show much variability, from €180 to €26,000 /ton NH_3. Variation is again largely a function of plant size and NH_3 flow rate.

116. Regenerative thermal oxidation uses a supplementary fuel (typically natural gas) to burn NH_3 present in a gas stream, with costs reported in the range of €1,900 to 9,100 /ton of NH_3.

117. Biofiltration is suitable for low-volume gas flows with low concentrations of NH_3, abating emissions of around 1 ton per year. It is the least cost system for small sources. Abatement costs of €1,400 to €4,300 /ton have been reported, depending on sector.

118. Abatement efficiencies of the techniques described in this section are typically around 90 per cent.

Techniques specific to individual sectors

119. Emissions from road transport increased greatly in the 1990s as a result of the introduction of catalyst-equipped vehicles (an estimate for the United Kingdom shows a factor of 14 increase over this period). The problem is largely being resolved through the introduction of better fuel management systems, moving from carburettor control to computerized systems that exercise much tighter control over the ratio of air to fuel. Moves to reduce the sulphur content of fuels, some methods for NOx control from diesel-engine vehicles, and the use of some alternative fuels may start to increase emissions. Despite the consequences for NH_3 of all of these actions, it has not been considered as a priority pollutant by either vehicle manufacturers or by regulators. It is therefore important that for this and other sectors, account be taken of the impact of technological changes on NH_3 emissions. By doing so, actions can be undertaken to avoid or minimize emissions during the design phase, where potential problems are identified.

120. Non-evaporative cooling systems are applicable to the sugar beet industry. These systems are more than 95 per cent effective in reducing emissions. Costs are estimated at €3,500/ton NH_3 abated.

121. Emissions from domestic combustion can be reduced using a wide variety of techniques, ranging from the adoption of energy efficiency measures, to the use of better quality fuels, to optimization of burning equipment. There are significant barriers to the introduction of some of these options, ranging from the technical (e.g. lack of natural gas infrastructure) to the aesthetic (e.g. people liking the appearance of an open wood burning fire).

122. Waste disposal by landfilling or composting has the potential to generate significant amounts of NH_3. Actions to control methane emissions from landfill, such as capping sites and flaring or utilizing landfill gas are also effective in controlling $NH_{3.}$.

123. Biofiltration (see above) is effectively used at a number of centralized composting facilities, often primarily for control of odours, rather than NH_3 specifically. A more general technique, applicable to home composting as well as larger facilities, is to control the ratio of carbon to nitrogen, aiming for an optimum of 30:1 by weight.

124. Assessment needs to be undertaken of the extent to which emissions from horses are included in the agricultural and non-agricultural inventories. Many horses are kept outside of farms and so may be excluded. The most effective approach for reducing emissions from these sources is good housekeeping in stables, with provision of sufficient straw to soak up urine, and daily mucking out. More sophisticated measures for controlling emissions, such as the use of

slurry tanks are unlikely to be implemented at small stables, and in any case are described elsewhere in this document.

125. For a number of sectors, the most significant source of NH_3 release may be linked to the slippage of NH_3 from NOx abatement plant. Two types of technique are available, scrubbing NH_3-slip from the flue gases, which can reduce emissions from about 40 mg/m^3 by around 90 per cent, and more effective control of NOx control equipment. The potential for NH_3 emissions from this source will need to be considered carefully as NOx controls increase through wider adoption of BAT.

Production of inorganic N fertilizers, urea and ammonia

126. The most important industrial sources of NH_3 emissions are mixed fertilizer plants producing ammonium phosphate, nitrophosphates, potash and compound fertilizers, and nitrogenous fertilizer plants manufacturing, inter alia, urea and NH_3. Ammonia phosphate production generates the most NH_3 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.

127. Nitrogenous fertilizer manufacture covers plants producing NH_3, 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 NH_3. 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 0.25 to 0.5 kg NH_3/ton of product.

128. 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 NH_3 emission limit value of 50 mg $NH_3\text{-}N/m^3$ may be achieved through maximizing product recovery and minimizing atmospheric emissions by appropriate maintenance and operation of control equipment.

129. 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.

130. 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).

131. 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 NH_3.
