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DRAFT GUIDANCE DOCUMENT FOR PREVENTING AND ABATING AMMONIA EMISSIONS FROM AGRICULTURAL SOURCES

Submitted by the Co-chairs of the Task Force on Reactive Nitrogen

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)", the updated guidance document (ECE/EB.AIR/WG.5/2007/13) and any amendments thereto. In line with the decision of the Executive Body in 2008 to establish a Task Force on Reactive Nitrogen (TFRN) aiming at *"developing technical and scientific information, and options which can be used for strategy development across the UNECE to encourage coordination of air pollution policies on nitrogen in the context of the nitrogen cycle and which may be used by other bodies outside the Convention in consideration of other control measures"* the TFRN has updated the guidance document to provide an amended text. The TFRN will also organize a workshop on "The Costs of Ammonia abatement and the climate co-benefits", scheduled for 25-27 October (http://www.clrtap-tfrn.org/node/94), and the findings of this workshop together with other updates will be reported to the 48th session of the Working Group on Strategies and Review.

I. INTRODUCTION

1. The purpose of this document is to provide guidance to the Parties to the Convention in identifying ammonia (NH_3) control measures for reducing emissions from agricultural sources, taking account of the whole nitrogen cycle, and focusing on livestock feeding strategies. This guidance will facilitate the implementation of the Basic Obligations of the Protocol mentioned in Article 3, as regards NH_3 Emission, and more specifically will contribute to the effective implementation of the measures listed in Annex IX, and to achieving the national NH_3 emission ceilings listed in Table 3 (amended version of December 2005).

2. The document addresses the abatement of NH_3 emissions produced by agricultural sources. Agriculture is the major source of NH_3, chiefly from livestock excreta in livestock housing, during manure storage, processing, treatment and application to land, and from excreta from animals at pasture. Emissions also occur from inorganic nitrogen (N) fertilizers following their application to land and from crops and crop residues, including grass silage. Emissions can be reduced through abatement measures in all the above areas.

3. The first version of the Guidance document (EB.AIR/1999/2) provided general guidance on the abatement of NH_3 emissions. This version was revised in 2007 ECE/EB.AIR/WG.5/2007/13). The current version is further revised and addresses the provisions in the proposal for revision of the Annex IX of the 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (Gothenborg Protocol). Following a brief introduction to 'livestock production and development', this Guidance Document follows the order of the provisions in the proposal for revision of Annex IX.

4. In this document, strategies and techniques for the abatement of NH_3 emissions and N losses are grouped into three categories:

(a) ***Category 1 strategies***: 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 strategies***: 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 strategies***: These have been shown to be ineffective or are likely to be excluded on practical grounds.

5. Based on the available research, Category 1 techniques can be considered as already verified for use in abatement strategies. Category 2 and Category 3 techniques may also be used in abatement strategies. However, for these categories independent verfication should be provided by Parties using them in order to demonstrate the reductions in NH_3 emissions that they report. It should be noted that cost of a technique is *not* part of the definition of these categories. If a particular technique is well research and effective it may be classed as category 1. Information on costs is provided to support decisions on the use of the techniques.

6. 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/reference/irpp.html. There is only partial overlap between BAT and the present guidance document, since BAT only been defined for the pig and poultry sectors, and has not been defined for cattle, sheep or other livestock, nor for the land application of manures or fertilizers.

7. 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. Because of this interdependency, Parties should as far as

possible exploit models where the overall mass-flow of ammonia nitrogen is assessed, such as GAINS, in order to optimise their abatement strategies.

8. The costs of the techniques will vary from country to country. 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. Both for slurry application and manure incorporation, the costs for small farms will often be reduced by hiring a contractor with access to suitable equipment.

9. Many measures may incur both capital and annual costs (see Table 1). In addition to theoretical calculations based on capital and operating expenditure, actual data on costs (e.g. as charged by contractors) should be used where available. In addition to calculating the direct costs, the benefits of measures should as far as possible be calculated. In many cases, the benefits to the farmer (e.g., reduced mineral fertilizer need, improved agronomic flexibility, reduced emissions of other pollutants, less complaints due to odour) will outweigh the costs. A summary of the main interacting factors affecting net costs and benefits of ammonia mitigation has been provided as Informal Document 11 to the 46th Session of the Working Group on Strategies an Review [note: possible annex to this document]. Comparison of the net cost to the farmer (i.e. cost minus benefit) with other environmental benefits (e.g., improved air, water quality and soil quality, reduced biodiversity loss, reduced perturbation of climate) is beyond the scope of this document.

10. 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.

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.

Table 1(b): Annual costs (operational expenditure, OPEX): the annual cost associated with the introduction of a technique.

Consideration	Notes
Annualized cost of capital	Use standard formula. The term will depend on the economic life.

should be calculated over the life of the investment.	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.	The introduction of techniques will often result in the saving of costs for the farmer. These should be quantified as far as possible. Separate note should be taken of the avoidance of fines for pollution in costing benefits.

II. LIVESTOCK PRODUCTION AND DEVELOPMENTS

11. The livestock sector is an important contributor to the global food and agricultural economy, accounting for 40 percent of the value of world agricultural output and providing 10-15 percent of total food calories and one-quarter of dietary protein. In most of the developing country regions it is the fastest growing segment of the agricultural sector. The livestock sector is increasingly expected to provide safe and plentiful food and fibre for growing urban populations, livelihoods for almost one billion poor producers as well as global public goods related to food security, environmental sustainability and public health (Geers and Madec, 2006; FAO, 2010; Steinfeld et al., 2010).

12. While livestock provides various useful functions to society and the global demand for dairy, meat and egg products continues to increase for the next decades, there is also increasing pressure on (intensive) livestock production systems to produce more environmental friendly. The livestock sector is a major land user globally and has been implicated for deforestation and biodiversity loss (Steinfeld et al., 2006; FAO, 2010; Steinfeld et al., 2010). It is also a main user of fresh water, mainly through animal feed production, while fresh water resources become scarce in some areas. Livestock production is a main source of atmospheric ammonia (NH_3) and the greenhouse gases methane (CH_4) and nitrous oxide (N_2O). The emissions mainly originate from the nitrogen in manure of animals. Emissions of NH_3 from livestock production are related to the type, number and genetic potential of the animals, the feeding and management of the animals, and to the technology of animal housing and manure management (Bouwman et al., 1997; Steinfeld et al., 2006; Oenema et al., 2008).

13. Livestock production systems can broadly be classified in (i) grazing systems, (ii) mixed systems and (iii) landless or industrial systems (e.g. Seré and Steinfeld, 1996). Grazing systems are entirely land-based systems, with stocking rates less than one

livestock unit per ha. In mixed systems a significant part of the value of production comes from other activities than animal production while part of the animal feed often is imported. Industrial systems have stocking rates greater than 10 livestock units per ha and they depend primarily on outside supplies of feed, energy and other inputs. Less than 10% of the dry matter fed to animals is produced on the farm. Relevant indicators for livestock production systems are animal density in animals per ha (AU/ha) and kg milk/ha/year. A common and useful indicator for the pressure on the environment is the total N or P excretion of the livestock per ha per year (e.g., Menzi et al., 2009).

14. In each livestock category, a distinction can be made between conventional and organic farming. Further, there is often a distinction between intensive and extensive systems, which may coincide with the distinction between conventional and organic farming, but not necessarily. Intensive livestock production systems are characterized by a high output of meat, milk, and eggs per unit of agricultural land and per unit of stock (i.e. livestock unit), which usually coincides with a high stocking density per unit of agricultural land. This is generally achieved by high efficiency in converting animal feed into animal products. Because of their capacity to rapidly respond to a growing demand, intensive livestock production systems now account for a dominant share of the global pork, poultry meat and egg production (respectively 56, 72 and 61 percent) and a significant share of milk production (Steinfeld et al., 2006; FAO, 2009).

15. Traditionally, most animal products consumed by humans were produced locally on the basis on locally produced animal feeds. Increasingly, many animal products consumed by humans in urban areas are produced on the basis of animal feeds imported from elsewhere. This holds especially for pig and poultry products. Thereby, areas of animal feed production and pig and poultry production become increasingly disconnected from the site of animal product consumption. This disconnection has been made possible through the development of transport infrastructure and the relatively low price of fossil energy; the shipment of concentrated feed is cheap relative to other production costs. Transportation of meat and egg products has also become cheaper. However, the uncoupling of animal feed production from animal production has major consequences for the proper disposal and management of animal manure (FAO, 2009; Mooney et al., 2009 and references therein).

16. Increasingly, production chains are organized and regionally clustered in order to minimize production and delivery costs. Animal feed is the major input to livestock production, followed by labor, energy, water and services. Input costs vary substantially from place to place within countries as well as across continents. Access to technology and know-how is also unevenly distributed, as is the ability to respond to changing environments and to market changes. There are also institutional and cultural patterns that further affect production costs, access to technologies and transaction costs. The combination of these factors determines that livestock production systems become larger, specialized, and intensive (FAO, 2009; Mooney et al., 2009 and references therein).

17. Livestock production systems are dynamic systems because of continuous developments and changes in technology, markets, transport and logistics. Such

developments lead to changes in livestock production systems and in its institutional organization and geographical locations. Increasingly, livestock products become 'global commodities', and livestock production systems are producing in an 'open', highly competitive, global market. These developments are facilitated by the increasing demand for animal products because of the increasing urban population and the increasing consumption of animal products per capita, although there are large regional and continental differences. The additional demand for livestock products concentrates in urban centers. With high rates of consumption, rapid growth rates and a shift towards animal-derived foods, urban centers increasingly drive the sector. The retail, processing industry and suppliers of animal feed and technology greatly influence the sector, while the farmers, the livestock producers become increasingly dependent on the organization within the whole food chain (FAO, 2009; Mooney et al., 2009).

18. The rapid developments in livestock production systems have a strong effect on the emissions of NH_3, N_2O and CH_4 from these systems to the atmosphere and of the leaching of N to waters. Emission abatement strategies have to take such developments into account and to anticipate on these developments, so as to make these strategies effective and efficient.

III. NITROGEN MANAGEMENT, TAKING ACCOUNT OF THE WHOLE NITROGEN CYCLE

19. Management is commonly defined as 'a coherent set of activities to achieve objectives'. This definition applies to all sectors of the economy, including agriculture. Nitrogen management can be defined as 'a coherent set of activities related to nitrogen use in agriculture to achieve agronomic and environmental/ecological objectives (e.g., Oenema and Pietrzak, 2002). The agronomic objectives relate to crop yield and quality, and animal performance. The environmental/ecological objectives relate to nitrogen losses from agriculture. 'Taking account of the whole nitrogen cycle' emphasizes the need to consider all aspects of nitrogen cycling, also in 'NH_3 emissions abatement', to be able to consider all objectives in a balanced way and to circumvent 'pollution swapping'.

20. Nitrogen is a constituent of proteins (and enzymes) and involved in photosynthesis, eutrophication, acidification, and various oxidation-reduction processes. Through these processes, nitrogen changes in form (compounds), reactivity and mobility. Main mobile forms are the gaseous forms di-nitrogen (N_2), ammonia (NH_3), nitrogen oxides (NO and NO_2), and nitrous oxide (N_2O), and the water soluble forms nitrate (NO_3^-), ammonium (NH_4^+) and dissolved organically bound nitrogen (DON). In organic matter, most nitrogen is in the form of amides, linked to organic carbon (R-NH_2). Because of the mobility in both air and water, reactive nitrogen is also called 'double mobile'.

21. Depending on the type of farming systems, N management at farm level involves a series of management activities in an integrated way, including:

- Fertilization of crops;
- Crop growth and crop residue management;

- Growth of catch crops;
- Grassland management;
- Soil cultivation, drainage and irrigation;
- Animal feeding;
- Herd management, including animal housing
- Manure management, including manure storage and application;
- Ammonia emissions abatement measures;
- Nitrate leaching and runoff abatement measures;
- Nitrous oxide emissions abatement measures;
- Denitrification abatement measures;

To be able to achieve high crop and animal production with minimal N losses, all activities have to be considered in an integrated and balanced way.

22. Nitrogen is essential for plant growth. In crop production, it is often the most limiting nutrient, and therefore must be available in sufficient amount and in a plant-available form in soil to achieve optimum crop yields. To avoid the excess or untimely N applications, guidelines for site-specific best nutrient management practices should be adhered to, including:

- Nutrient management planning and record keeping, for all essential nutrients;
- Calculation of the total N requirement by the crop on the basis of realistic estimates of yield goals, N content in the crop and N uptake efficiency by the crop;
- Estimation of the total N supply from indigenous sources, using accredited methods:
    - mineral N in the upper soil layers at planting stage (by soil test);
    - mineralization of residues of the previous crops;
    - net mineralization of soil organic matter, including the residual effects of livestock manures applied over several years and, on pastures, droppings from grazing animals;
    - deposition of N from the atmosphere;
    - biological N_2 fixation by leguminous plants;
- Computation of the needed N application, taking account of the N requirement of the crop and the supply by indigenous N sources;
- Calculation of the amount of nutrients in livestock manure applications that will become available for crop uptake. The application rate of manure will depend on:
    - the availability of livestock manure;
    - the demands for nitrogen, phosphorus and potassium by the crops,
    - the immediately-available nitrogen, phosphorus and potassium contents in the manure;
    - the rate of release of slowly-available nutrients from the manure;
    - the nutrient that will be sufficiently supplied at the lowest application rate (to ensure no nutrient is over supplied);
- Estimation of the needed fertilizer N and other nutrients, taking account of the N requirement of the crop and the supply of N by indigenous sources and livestock manure;

- Application of livestock manure and/or N fertilizer shortly before the onset of rapid crop growth, using methods and techniques that prevent ammonia emissions;
- Where possible, application of N fertilizer in multiple portions (split dressings) with in-crop testing, where appropriate.

23. Nitrogen management which takes account of the whole nitrogen cycle aims at identifying measures for reducing all unwanted N emissions, including NH_3 emissions, in a cost-effective way, i.e., to a level where the value of marginal damages to human health and biodiversity is (approximately) equal to the marginal cost of achieving further reductions. Preferred measures for reducing NH_3 emissions are those that decrease other unwanted N emissions simultaneously, while maintaining or enhancing agricultural productivity (measures with synergistic effects). Conversely, measures aimed at reducing NH_3 emissions, which increase other unwanted emissions (antagonistic effects) should be modified to such extent that the antagonistic effects are nullified. Similarly, abatement measures avoid to increase other types of farm pollution (e.g., P losses, pathogens, soil erosion) or resource use (e.g., fuel), reduce the quality of food (e.g., increased antibiotics, hormones or pesticides) or the health and welfare of farm (e.g., by limiting barn size).

24. The effectiveness of nitrogen management can be evaluated in terms of (i) decreases of nitrogen losses, and (ii) increases of N use efficiency. Nitrogen use efficiency (NUE) indicators provide a measure for the amount of N that is retained in crop or animal products, relative to the amount of nitrogen applied or supplied. Management has a large effect on the nitrogen use efficiency (Tamminga 1996; Mosier et al., 2004).

25. Output / input ratios (mass/mass ratios) and balances (input minus output, in mass per unit surface area) are the best indicators for expressing overall N use efficiency (NUE) at farm level (Table 2). While the ratio of total N output (via products exported from the farm) and total N input (imported into the farm, including via biological N_2 fixation) is an indicator for the N use efficiency at farm level, the N surplus (or deficit) is an indicator for the N pressure of the farm on the wider environment, assuming that ultimately all surplus N is lost via either ammonia volatilization, N leaching and/or nitrification/ denitrification.

26. There are two well-established procedures for making nitrogen input-output balances, namely the farm-gate balance and the soil-surface balance (e.g., OECD, 2001; Oenema et al., 2003). Basically, the farm-gate balance records all N inputs and all N outputs of the farm, while the soil-surface balance records all N inputs to agricultural land and all N outputs in harvested crop products from agricultural land. The surface area of the farm-gate balance is the whole farm; the surface area of the soil-surface balance is an agricultural land (one field, all fields of a farm). However, both types of balances can be applied also at regional and country level. In general, it is easier to establish a farm-gate balance than a soil-surface balance, because of data availability. The results of the farm-gate balance and the soil surface balance should be similar, but may differ because of the use of correction factors for NH_3 volatilization from manure storages and the neglect of some input items. Hence, it is important to use standardized formats for making farm-gate balances and soil-surface balances.

27. Commonly, a distinction is made between N input-output balances and N input-output budgets. Balances and budgets apply similar input items; the main difference is that balances record the N output in harvested/marketable products only, while budgets records the N output via harvested/marketable products and losses. Hence, budgets provide a full record and account of all N flows.

28. A farm-gate nitrogen budget of a mixed crop-animal production farm is the most complex budget (figure 1). The main inputs are mineral/inorganic fertiliser, imported animal manure, fixation of atmospheric nitrogen by some (mainly leguminous) crops, deposition from the atmosphere and livestock feed. Inputs in seed and bedding used for animals are generally minor inputs, although the latter can be significant for some traditional animal husbandry systems. The main outputs are in crop and animal products, and in exported manure. Gaseous losses occur from manure in animal housing, in manure storage and after field application. Other gaseous losses occur from fields; from applied fertiliser, crops, soil and crop residues. Losses to ground and surface water occur via leaching or run off of nitrates, ammonium and dissolved organic nitrogen (DON).

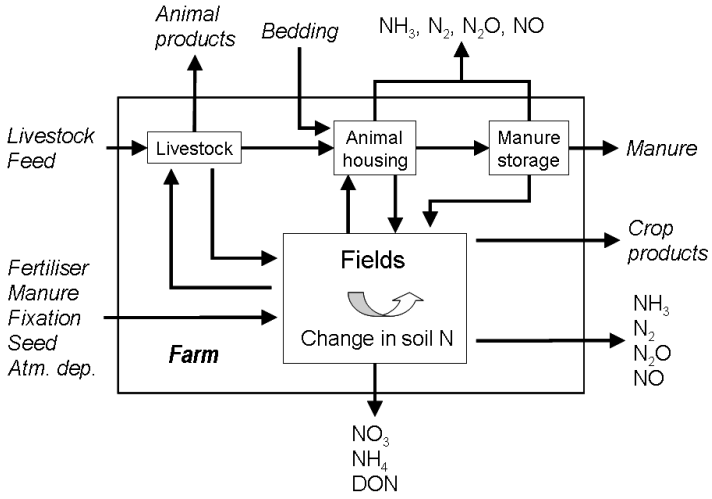


Figure 1. A farm nitrogen budget of a mixed crop-animal production farm.

29. The corresponding components of a farm nitrogen balance of a mixed crop-animal production farm are shown in Figure 2. Evidently, a farm N balance is much simpler than a farm-gate budget, as N losses to air, groundwater and surface waters are not included in the N balance. A farm N balance of a specialized crop production farm or a specialized animal production farm are much simpler than a farm gate-balance of a mixed crop-animal production farm, because of less N inputs and outputs.

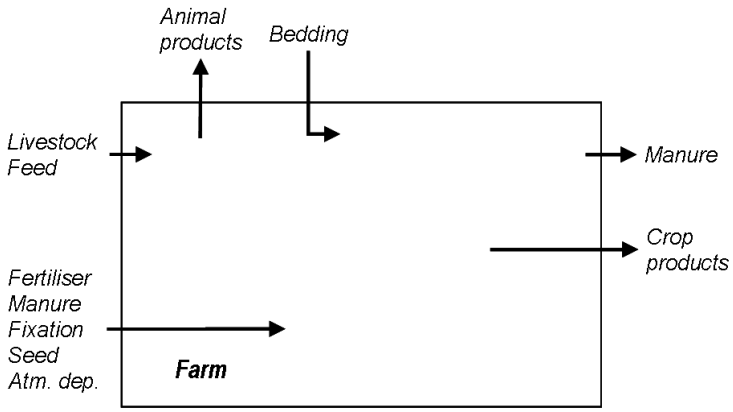


Figure 2: Components of a farm-gate nitrogen balance of a mixed crop-animal production farm.

30. A soil surface nitrogen balance of agricultural land is shown in figure 3. The main N inputs are mineral/inorganic fertiliser, animal manure, fixation of atmospheric nitrogen by some (mainly leguminous) crops and deposition from the atmosphere. Inputs in seed and composts are generally minor inputs. The main outputs are in harvested crop products. Note that animal products other than animal manure do not show up in the soil surface balance, as they do not pass the soil surface.

31. For using N balances and NUE as indicators at farm level, a distinction has to be made between:

(a) specialized crop production farms,
(b) mixed crop (feed) – animal production farms and
(c) specialized animal production farms.

Specialized crop production farms have relatively few NH_3 emission sources (possibly imported animal manure, urea and ammonium-based fertilizers, crops and residues). These farms can be subdivided according to crop rotation (e.g., areal percentage of cereals, vegetables and root crops). Specialized animal production farms produce only animal products (milk, meat, egg and animal manure) and all these products are exported from the farm. These farms can be subdivided according to animal categories (e.g., pig, poultry, and cattle). Mixed systems have both crops and animals; the crops produced are usually fed to the animals, while the manure produced by the animals is applied to the crop land. These farms can be subdivided according animal categories (e.g., dairy cattle, beef cattle, pigs, and) and livestock density (or feed self-sufficiency).

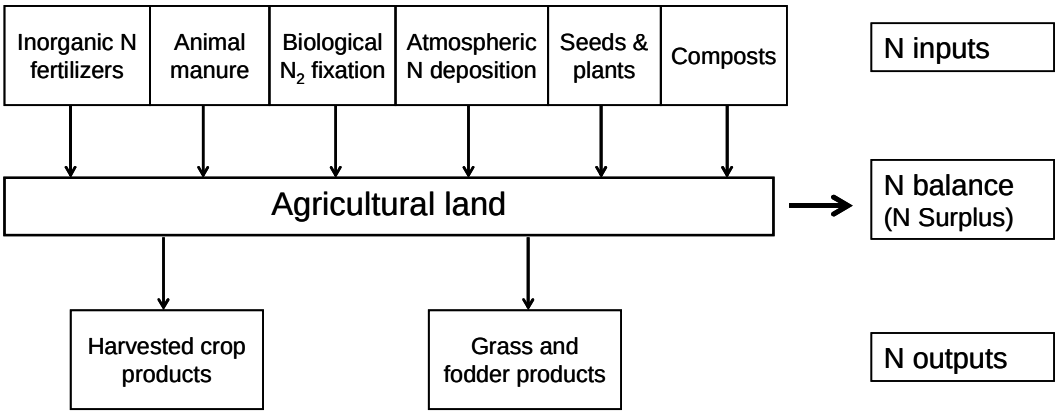
32. The variation between farms in NUE (output/input ratios) and N surpluses (input minus input) is large in practice, due to the differences in management and farming systems (especially as regards the types of crops and animals, and the livestock density). Indicative target values can be given for broad categories of farming systems (see Table 2).

33. Nitrogen balances and N input-put ratios can be made also for compartments within a farm, especially within a mixed farming system. For estimating NUE, three useful compartments or levels can be considered:

(a) feed N conversion into animal products (feed-NUE or animal-NUE),
(b) manure and fertilizer N conversion into crops (manure/fertilizer-NUE), and
(c) whole-farm NUE.

These NUEs are calculated as the percentage mass of N output per mass of N input:
- feed-NUE = [(N in milk, meat and eggs) / (N in feed and fodder)] x 100%
- manure/fertilizer-NUE = [N uptake by crops / N applied as manure/fertilizer] x 100%
- whole-farm NUE = [Σ(N exported off-farm) / Σ(N imported on to the farm)] x 100%

Indicative ranges of NUEs for dairy farms are shown below (Powel et al., 2010).



Input to output parameters	N input range	NUE range (%)	Source
Feed to milk (feed-NUE)	512–666 g cow^{-1} day^{-1}	26–33	Powell et al. (2006a)
	289–628 g cow^{-1} day^{-1}	22–29	Kebreab et al. (2001)
	200–750 g cow^{-1} day^{-1}	21–32	Castillo et al. (2000)
	496–897 g cow^{-1} day^{-1}	21–36	Chase (2004)
	838–1360 g cow^{-1} day^{-1}	16–24	Aarts et al. (2000)
Manure and fertilizer to crops and pasture (manure/fertilizer-NUE)	359–749 kg ha^{-1}	53–77	Aarts et al. (2000)
	Not available	16–57	Beegle et al. (2008)
Farm inputs to farm outputs (whole-farm NUE)	215–568 kg ha^{-1}	14–55	Rotz et al. (2006)
	150–370 kg ha^{-1}	39–47	Rotz et al. (2006)
	260–380 kg ha^{-1}	23–36	Rotz et al. (2005)
	240–423 kg ha^{-1}	34–46	Rotz et al. (1999)
	63–840 kg ha^{-1}	8–55	Ovens et al. (2008)
	Not available	25–64	Histov et al. (2006)

Figure 3: Components of a soil surface nitrogen balance of agricultural land (see OECD, 2001).

Table 2: Nitrogen surplus and nitrogen use efficiency indicators of farming systems, with typical values for specialized crop production farms, specialized animal production farms and mixed farms (see text).

Index	Calculation	Interpretation	Typical levels
N surplus = sum of all nitrogen inputs minus the nitrogen outputs that pass the farm gate, expressed in kg/ha/yr	N surplus = Σ ($Inputs_N$) – Σ ($outputs_N$)	•N surplus depends on types of farming system, crops and animals, and indigenous N supply, external inputs (via fertilizers and animal feed) management and environment •N surplus is a measure of the total N loss to the environment •N deficit [Σ ($Inputs_N$) < Σ ($outputs_N$] is a measure of soil N depletion •For specialized animal farming systems (land-loose), the N surplus can be very large, depending also on the possible N output via manure processing and export	Depends on types of farming systems, crops and animals: Crop: 0-50 kg/ha Mixed: 0-200 kg/ha Animal: 0-1000 kg/ha
NUE = nitrogen use efficiency, i.e., the N output in useful products divided by the total N input	NUE = Σ ($outputs_N$) / Σ ($Inputs_N$)	•N use efficiency depends on types of farming system, crops and animals, and indigenous N supply, external inputs (via fertilizers and animal feed) management and environment •For specialized animal farming systems (land-loose), there may be N output via manure processing and export	Depends on types of farming systems, crops and animals: Crop 0.6-1.0 Mixed: 0.5-0.6 Animal 0.4-0.6* Animal 0.8-0.95** *) no manure export **) landless farms; all manure exported off-farm

34. For assessing the feed-NUE or animal-NUE, the amounts of feed + fodder consumed and the N contents of the feeds + fodders have to be known. Also the amounts of N in animal products (protein in milk, meat and eggs) has to be known. Default values can be used for N in milk-protein, eggs and live-weight, carcass-weight and meat for cattle, pigs, and poultry.

35. For assessing the manure/fertilizer-NUE, it is useful to make a distinction between different N input sources. The 'fertilizer N equivalence value' indicates how well N from animal manures, composts and crop residues are used relative to the reference fertilizer (commonly NH_4NO_3 based fertilizers), which is set 1 (100%). A high value is indicative for a high N use efficiency. The fertilizer N equivalence value depends on the type (solid, slurry or liquid), origin (cattle, pigs, poultry) of manure and the time frame (year of application versus long-term effects. It also depends on crop type and environmental conditions (soil type, temperature, rainfall). A most decisive factor for a high fertilizer N equivalence value is management, i.e. the time and method of application. Table 3 gives target ranges of N fertilizer equivalence values for cattle, pig and poultry manure, slurries and liquids, as found in literature. Organic N sources usually contain a significant fraction organically-bound N, which becomes available to growing crops only after

mineralization. Therefore, a distinction is made between short-term (i.e. during the growing season immediately after application of the organic N source) and long-term fertilizer N equivalence values; the latter being higher than the former. Some organic N sources have only mineral N and easily mineralizable organic N, and as a consequence there is essentially no difference between short-term and long-term values.

Table 3: Ranges of short-term and long-term fertilizer nitrogen equivalence values (FNEV) of applied animal manures and crop residues, expressed in percentage of the reference fertilizer ammonium-nitrate. The manures are applied with common low-emission application techniques. The short-term fertilizer nitrogen equivalence values relate to the fertilizer nitrogen equivalence value of timely applications during the year of application. The long-term fertilizer nitrogen equivalence values include residual effects and assume repeated annual applications.

Nitrogen sources	**Fertilizer nitrogen equivalence values, %**	
	Short-term	**Long-term**
Separated cattle and pig liquids	70-100	70-100
Digested cattle and pig slurries	40-60	50-80
Cattle slurries	30-50	50-80
Pig slurries	30-65	50-80
Poultry slurries	30-65	50-80
Solid cattle, pig and poultry manures	20-40	40-60
Composts of cattle, pig and poultry manures	20-40	40-60
Urine and dung from grazing animals	10-20	20-40
Crop residues with more than 2.5% N	10-40	30-50
Crop residues with 1.5 – 2.5% N	0-30	20-40
Crop residues with less than 1.5% N	0	0-20

References: Berntsen et al., 2007; Bittman et al., 2007; Burton and Turner, 2003; Chadwick et al., 2000; Gutser et al., 2005; Hadas et al., 2002; Hart et al., 1993; Hatch et al., 2004; Janssen, 1984; Jenkinson and Smith, 1988; Kolenbrander and De La Lande Cremer, 1967; Langmeier et al., 2002; MacDonald et al., 1997; Mosier et al., 2004; Nevens and Reheul, 2005; Rufino et al., 2006; Rufino et al., 2007; Schils and Kok, 2003; Schroder et al., 2000; Schroder and Stevens, 2004; Schroder 2005; Schroder et al., 2005; Schroder et al., 2007; Sommerfeldt et al., 1988; Sorensen, 2004; Sorensen and Amato, 2002; Sorensen et al., 2003; Sorensen and Thomsen, 2005; Van der Meer et al., 1987; Velthof et al., 1998;

36. For whole-farms, the N surplus and NUE of specialized crop production farms are estimated as follows:

SurplusN = [FertN + ManureN + CompostN + BNF + Atm.N + SeedN] – [CropN] [1]

NUEcrop = [CropN] / [FertN + ManureN + CompostN + BNF + Atm.N + SeedN] [2]

Where,

SurplusN =	N Surplus at farm level, kg/ha
NUEcrop =	N use efficiency at farm level, mass/mass ratio (dimensionless)
FertN =	Amount of fertilizer N fertilizer imported to the farm, kg/ha
ManureN =	Amount of manure N imported to the farm, kg/ha
CompostN =	Amount of compost N imported to the farm, kg/ha
BNF=	Amount of biologically fixed N_2 by leguminous crops, kg/ha
Atm.N =	Amount of N from atmospheric deposition, kg/ha.
SeedN =	Amount of N imported via seed and plants, kg/ha.
CropN =	Net amount of N in harvested crop exported from the farm, including residues, kg/ha

There may be additional N inputs at the farm via for example autotrophic N2 fixation, crop protection means, irrigation water. These inputs are usually small relative to the former and are also difficult to manage. Therefore, these additional N inputs are often disregarded. However, when these inputs are a significant percentage of the total input (>10%), they should be included in the balance calculations.

37. For specialized landless animal production farms, the N surplus and NUE are estimated as follows:

SurplusN = [FeedN] – [AnimalN + ManureN] [3]

NUEanimal = [AnimalN + ManureN] / [FeedN] [4]

Where,

SurplusN =	N Surplus at farm level, kg
NUEanimal =	N use efficiency at farm level, mass/mass ratio (dimensionless)
FeedN =	Net amount of N in animal feed imported to the farm, kg
AnimalN =	Net amount of N in animals exported from the farm (i.e., including dead animals and corrected for imported animals), kg
ManureN =	Net amount of manure N exported from the farm (including feed residues, kg

There will be small additional N inputs at the farm via for example drinking and cleaning water, litter (bedding material) and medicines but these inputs are usually small (<5%) relative to the former and may be disregarded in this case.

38. For mixed crop – animal production farms, the N surplus and NUE are estimated as follows:

SurplusN = [FertN+ManureN+CompostN+BNF+Atm.N+SeedN]–[AnimalN + CropN + ManureN] [5]

NUEmixed=[AnimalN+CropN+ManureN]/[FertN+ManureN+CompostN+BNF+Atm.N+SeedN] [6]

Where,

SurplusN = N Surplus at farm level, kg/ha
FertN = Amount of fertilizer N fertilizer imported to the farm, kg/ha
FeedN = Amount of N in animal feed imported to the farm, kg/ha
ManureN = Amount of manure N imported to the farm, kg/ha
CompostN = Amount of compost N imported to the farm, kg/ha
BNF= Amount of biologically fixed N_2 by leguminous crops, kg/ha
Atm.N = Amount of N from atmospheric deposition, kg/ha.
SeedN = Amount of N imported via seed and plants, kg/ha.
CropN = Amount of N in harvested crop exported from the farm, including residues, kg/ha
AnimalN = Amount of N in animals exported from the farm (i.e., including dead animals and corrected for imported animals), kg
ManureN = Amount of manure N exported from the farm, kg/ha

39. A more accurate expression of the N use efficiency of specialized crop production farms takes into account the differences in fertilizer N equivalence values of manure, composts and BNF, and is estimated as follows:

NUEcrop = [CropN] / [FertN+(ManureN x FnevM)+(CompostN x FnevC)+(BNF)+Atm.N+ SeedN] [7]

Where,
FnevM = fertilizer N equivalence value for manure, kg/kg
FnevC = fertilizer N equivalence value for compost, kg/kg

40. Improvements in N management (and hence decreases in N losses) over time follow from decreases in N surpluses and increases in N use efficiencies over time. Progress in N management can thus be assessed through the monitoring of the annual N surplus and N use efficiency at farm level. To account for annual variations in weather conditions and incidental occasions, it is recommended to calculate five-year averages of N surplus and NUE.

41. The relative performance of the N management of farms can be assessed on the basis of comparisons with other farms, model farms or experimental farms. Target values for N surpluses and NUE of specialized crop production systems can be based on the performance of best managed (experimental/model) crop production systems in practice.

42. Crops differ in their ability to take up N from soil, due to differences in root length distribution and length of the growing season. Graminae (cereals and grassland) have a high uptake capacity; leafy vegetable (lettuce, spinach) a small uptake capacity. Target values for N surplus should be specified according to the areal fraction of cereals and grassland on the farm (e.g. in case of five classes: <25%; 25-50, 50 – 75, 75 - 90 and >90%).

43. For specialized crop production farms growing cereals on > 90% of the area, and using the input items of equation [7] and Fertilizer N equivalence values (FNEV) of table 3, the harvested N roughly equals the total effective N input and NUEcrop will be ~100%. With decreasing relative area of cereals in the crop rotation, target NUE will decrease and N surpluses will increase, depending also on the effective N input (Table 4).

Table 4: Target values for N use efficiency (NUE) and N surpluses of specialized crop production farms as function of the percentage of cereals in the crop rotation and mean total input of effective N (see text).

Cereals in rotation, %	Target NUE, %	N surpluses, in kg/ha/yr, at effective N inputs of 50, 100 and 200 kg/ha/yr		
		50	100	200
90 – 100	100	0	0	0
75 – 90	95	2.5	5	10
50 – 75	90	5	10	20
25 – 50	80	10	20	40
<25	70	15	30	60

44. The NUE of specialized animal farms and mixed farms depend in part on the 'unavoidable' gaseous N losses from animal manures in housing systems and manure storages due to NH_3 volatilization and nitrification-denitrification processes. Unavoidable N losses are N losses that occur when using best available technology (BAT). Hence, target values for NUEanimal should be based on considering the following equation:

$$TargetNUEanimal = [AnimalN + (ExcretedN - ManureNloss)] / [FeedN] \quad [8]$$

Where,

TargetNUEanimal =	N use efficiency at farm level, mass/mass ratio (dimensionless)
AnimalN =	Net amount of N in animals exported from the farm (i.e., including dead animals and corrected for imported animals), kg
FeedN =	Net amount of N in animal feed imported to the farm, kg
ExcretedN=	amount of N excreted by animals during confinement, kg
ManureNloss=	Unavoidable N losses from animal manure in animals housings and manure storages due to NH_3 volatilization and nitrification-denitrification processes, kg.

ExcretedN – ManureNloss = amount of manure N exported from the farm

45. ManureNloss values depend on the animal housing system and manure management systems. For cattle and pigs housed whole-year in slurry-based systems with covered manure storages, ManureNloss will be in the range of 5-20% of manure N excreted during confinement, with the lower value for low-emission housing systems and the higher value for houses with partially slattened floors, but depending also on climatic conditions. When animals are confined only during the winter season, less N will be excreted during confinement and ManureNloss per animal head will be lower. ManureNloss from housing systems with solid manure tend to be higher (20-40% when housed all-year), due to larger nitrification-denitrification losses during manure storage.

46. For poultry, ManureNloss is in the range of 10 to 50% of ExcretedN with the lower value for low-emission housing systems and the higher value for deep pits and ground-based litter systems without scrubbing and retaining NH_3 from exhaust air.

47. NUE of specialized animal production farms increases with increasing feed N retention and decreasing 'unavoidable gaseous N losses' (Table 5; Figure 4). Feed N retention depends on animal type, animal productivity and animal feeding. The 'unavoidable gaseous N losses' depend on housing system and animal manure

management, including low-emission management systems. Hence, NUE of specialized animal production farms is very responsive to gaseous N losses, including NH_3 volatilization losses; it is an integrated N management indicator.

Table 5: Calculated N use efficiency of specialized animal production farms as function of the feed N retention percentage and the percentage 'unavoidable N losses' according to equation [8]. It is assumed that all animal products, including animal manure, are exported from the farm (see text).

Feed N retention, %	N use efficiency, in %, as function of 'unavoidable N losses' of 5, 10, 20, 40 and 60% of N excreted				
	5	10	20	40	60
5	95	91	81	62	43
10	96	91	82	64	46
20	96	92	84	68	52
30	97	93	86	72	58
40	97	94	88	76	64

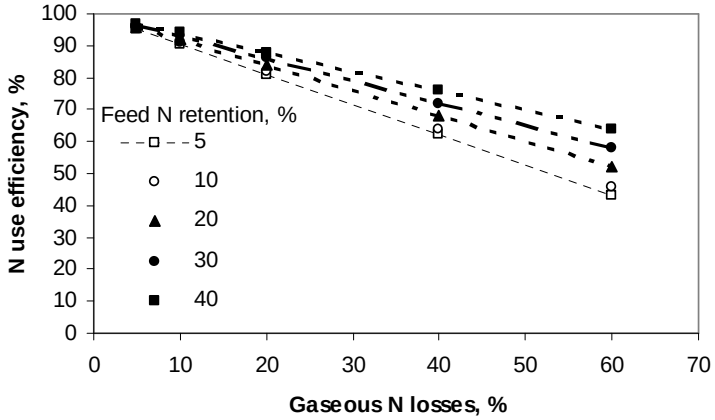


Figure 4: Calculated N use efficiency of specialized animal production farms as function of the feed N retention percentage and the percentage 'unavoidable N losses' according to equation [7]. It is assumed that all animal products, including animal manure, are exported from the farm (see text)

48. Whole farm N balances and N use efficiency are well-established indicators and used in many countries for estimating both the pressure of N on the environment and the N resource use efficiency. Currently, there is as yet little experience in many countries with these indicators for abating NH_3 emissions. However, there is solid theoretical and also empirical evidence that increases in NUE are associated with decreases in N losses per unit of produce. Similarly, increases in NUE of animal production systems and mixed production systems are typically associated with decreases in NH_3 losses per unit of produce, as shown for example in Denmark (Mikkelsen et al., 2010; Nørregaard Hansen et al., 2008; Anonymous, 2008) and the Netherlands (e.g., De Haan et al.).

49. Experiences in Denmark and the Netherlands show that most farmers are able to understand the N balance and NUE indicators easily and are also able to establish N balances and NUE indicators on the basis of bookkeeping records and default values for N contents in various products. However, training and participation in farmers-discussion

groups is helpful. Alternatively, N balances and NUE can be made by accountants, again on the basis of bookkeeping records and default values for N contents in various products. The annual costs for seeking the advice of accountants for establishing N balances and NUE indicators is in the range of 500-1500 euro per farm.

50. A simple Microsoft Excel spreadsheet program (NUE Calculator) is available for examining the effects of management factors on N surplus and NUE. This Excel spreadsheet program contains defaults values for various farming systems, and can be easily adjusted to farm-specific conditions.

IV. LIVESTOCK FEEDING STRATEGIES

General considerations

51. Gaseous nitrogen losses from livestock production originate from the feces (dung) and urine excreted by the livestock. The animal feed composition and the feed management has a strong influence on animal performance and on the composition of the dung and urine, and thereby also on the emissions of ammonia (NH_3). This section focuses on feeding strategies to reduce NH_3 emissions.

52. Animals require energy, protein, water, various nutrients including trace elements, and vitamins for their nutrition. The value of animal feed is usually defined by the quantity of energy and protein that can be metabolized by the animal after digestion of the feed in the gastrointestinal tract. The protein value of a diet is estimated by the fraction of protein that is absorbed from the gastrointestinal tract. For pig and poultry diets, the protein value is also defined by the quantity of individual amino acids absorbed in order to identify those amino acids that are most limiting protein deposition in animal products.

53. In practice, protein levels in animal feed are often higher than actually required. Safety margins in the protein content of the diet are used to account for: 1) suboptimal amino acid ratios; 2) variations in requirement between animals with different genotypes; 3) variations in requirement caused by differences in age or production stadiums; and 4) variations in the actual content and digestibility of essential amino acids in the diet. Protein content of the diet and N excretion can be reduced by matching the protein / amino acids content of the diet as close as possible to the animal's requirement.

54. The fraction of feed intake not digested, absorbed and retained by the animal is excreted via dung and urine. The excess N in the feed is excreted in the form of protein (organically bound nitrogen), urea, uric acid and ammonium. The partitioning of the N over these compounds together with the pH of the dung and urine greatly affects the potential for NH_3 loss.

Table 6: Ranges of N components in dung and urine of some animal species.

Animal Category	Dry matter g per kg	Total N g per kg dung/urine	Urea-N % of total N	Uric acid – N, % of total N	Protein-N, % of total N	Ammonium-N, % of total N
Dairy cattle						
- Dung	100-175	10-17	0	0	90-95	1-4
- Urine	30-40	4-10	60-95	0-2	0	1
Finishing pigs						
- Dung	200-340	8-10	0		86-92	8-14
- Urine	30-36	4-7	70-90		10-20	2-10
Chicken	200-300	10-20	5-8	35-50	30-50	6-8

55. There is a large variation in the composition of dung and urine from dairy cattle, fattening pigs and chicken. Table 6 provides ranges of values observed in literature (Canh et al., 1997; Bussink and Oenema, 1998; Whitehead, 2000).

56. The main options to influence the NH_3 emissions potential by livestock feeding are by (Aarnink and Verstegen, 2007):

(a) Lowering the ammonium, urea and uric acid contents of the urine and dung, through:
  (i) Lowering the crude protein intake;
  (ii) Increasing the non-starch polysaccharides intake (which shifts the nitrogen excretion from urea/uric acid in urine to protein in dung;

(b) Lowering pH of manure by:
  (i) lowering the pH of dung;
  (ii) lowering the pH of urine.

(c) Lowering the urease activty, and hence the ammonium concentrations in manure.

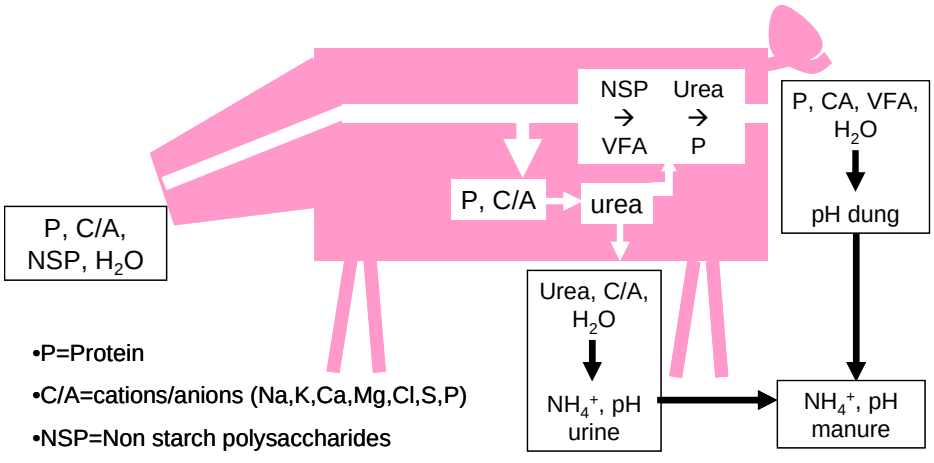


Figure 5: Schematic view of the main factors of the animal ration (protein content, cation-to-anion ratio and the content of non-starch polysaccharides) influencing the urea and ammonium contents and pH of the urine and dung excreted by animals.

Table 7: Present levels and minimum pH of urine of different livestock species. (Table to be completed and references added)

Species	Present pH urine	Minimum pH urine	Reference
Piglets			
Growing-finishing pigs	6.7-7.8	5.0	Canh et al. (1997)
Sows			
Cattle			

(Task to add target protein contents, cation-to-anion ratios and the non-starch polysacharides for having a – high, medium, low, very low nh3 volatilization potential in a table.)

57. The ammonium content of manure (dung + urine), following the hydrolysis of urea and the anaerobic digestion of protein in manure, can be calculated as follows (after Aarnink et al., 1992):

$[NH_4^+] = (dc*P_f - P_r + adc*(1-dc)*P_f) / (M_m)$

Where: dc = apparent digestibility coefficient of protein
P_f = protein in feed
P_r = protein retention
adc = anaerobic digestion coefficient for protein in manure
M_m = mass of manure

58. The pH of urine and manure can be estimated by making a complete cation-to-anion balance. In this estimation also the concentration of ammonium and carbonate has to be included. Table 7 provides an overview of the mean current pH levels of urine and of the minimum pH of urine of different livestock species.

59. Depending on enzyme activity, urea and uric acid are hydrolyzed into ammonium usually within a few hours to days. The mineralization of organic nitrogen (apparent undigested protein) in dung is a slow process. At a temperature of 18 ^oC it takes 70 days before 43% of the organic nitrogen in pig manure is mineralized to ammonia (Spoelstra, 1979). Therefore, by shifting N excretion in cattle and pigs from urine to dung, the N excretion via protein (organically bound nitrogen) is increased and the N excretion via urea, uric acid and ammonium is decreased. As a result, NH_3 emissions from the urine are reduced.

60. Livestock feeding strategies can influence the pH of dung and urine. The pH of dung can be lowered by increasing the fermentation in the large intestine. This increases the volatile fatty acids (VFA) content of the dung and causes a lower pH. The pH of urine can be lowered by lowering the electrolyte balance (Na + K – Cl) of the diet (Patience et al., 1987). Furthermore, the pH of urine can be lowered by adding acidifying components to the diet, e.g. $CaSO_4$, Ca-benzoate, benzoic acid. A low pH of the dung and urine excreted results also in a low pH of the slurry / manure during storage, also after a certain storage period. This pH effect can significantly reduce ammonia emissions from slurries during storage and also following application. These effects have been proven especially for pigs (Aarnink and Verstegen, 2007; Canh et al., 1998a; Canh et al., 1998c; Canh et al., 1998d; Canh et al., 1998e)

61. Several indicators are useful to indicate the efficiency of conversion of feed into animal product. They are defined as follows:

(a) Dietary crude protein (Nx6,25) content **(CP/DM)**. The requirement of crude protein (CP) as proportion of the dietary dry matter (DM) depends on animal species, type of production, digestibility of the diet DM and the quality (amino acid ratio) in the CP. Information on this indicator for concentrate feeds is usually available from the feed company. For forages, notably grazed forages, this may be more difficult, but the sward surface height (SSH) may be a helpful tool.

(b) Efficiency of N utilisation **(NUE = AY_N/F_N)**, where AY_N is the mass of N in animal products (in kg), F_N is the mass of N in the feed used (kg). This indicator requires information on the N content of animal products and animal feeds. Such figures have been extensively tabulated in recent years.

(c) Stocking density, the number of animal units (AU) per unit (ha) of land available for disposal of animal excreta **(AU/ha)**. (confirm what is meant by this last point)

62. Production of animal products (milk, meat, eggs) is not possible without first meeting the nutrient requirements to maintain the animals. Dietary protein levels required for maintenance are much lower than those needed for the synthesis of animal products. Hence, target levels of CP/DM vary with the proportion of ingested nutrients that is required for maintenance. This proportion is highest in slow growing animals, like replacement animals in cattle and lowest in rapidly growing animals like broilers. Target levels for NUE show the opposite.

Feeding strategies for ruminants (especially dairy and beef cattle)

63. Nitrogen use efficiency (NUE) in dairy production is limited by the biological potential of cows to transform feed N into milk and of crops and pasture to convert applied manure N and fertilizer N into grain, forage and other agronomic products. However, the disparity between actual NUE achieved by producers and potential NUE indicates that substantial improvements in NUE can be made on many commercial dairy farms. Although dairy producers can do little about the biological limitations of N use, practices such as appropriate stocking rates, manure N crediting and following recommendations to avoid wastage can substantially enhance NUE, farm profits and the environmental outcomes of dairy production. (Powell et al., 2009)

64. Lowering crude protein of ruminant diets is an effective and category 1 strategy for decreasing NH_3 loss. The following guidelines hold (Table 8):

- The average CP content of diets for dairy cattle should not exceed 150 g/kg DM (Broderick, 2003; Svenson, 2003). For beef cattle older than 6 months this could be further reduced to 120 g/kg DM.
- Phase feeding can be applied in such a way that the CP content of dairy diets is gradually decreased from 160 g/kg DM just before parturition and in early lactation to below 140 g/kg DM in late lactation and the main part of the dry period.

- Phase feeding can also be applied in beef cattle in such a way that the CP content of the diets is gradually decreased from 160 g/kg DM during the first 3 months to 120 g/kg DM thereafter.

Table 8: Target levels for crude protein (CP) content, in gram per kg of the dry mass of the ration, and efficiency of N utilisation (NUE), in mass fractions (kg/kg) **for cattle**

Cattle species	CP, g/kg	NUE, kg/kg
Milk + maintenance, early lactation	150-160	0.30
Milk + maintenance, late lactation	120-140	0.25
Replacement	120-130	0.10
Veal	170-190	0.45
Beef <3 months	150-160	0.30
Beef >6 months	120	0.20

65. In many parts of the world, cattle production is land-based or partly land-based. In such systems protein rich grass and grass products form a significant proportion of the diet. Such diets often contain a surplus of protein and the magnitude of the resulting high N excretion strongly depends on the proportions of grass, grass silage and hay in the ration and the protein content of these feeds. The protein surplus and the resulting N excretion and NH_3 losses will be highest for grass-only summer rations with grazing young, intensively fertilized grass or grass legume mixtures. However, urine excreted by grazing animals typically infiltrates into the soil before substantial NH_3 emissions can occur and NH_3 emissions per animal are therefore less for grazing animals than for those housed where the excreta is collected, stored and applied to land.

66. The NH_3 emission reduction achieved by increasing the proportion of the year the cattle spent grazing outdoors will depend on the baseline (emission of ungrazed animals), the time the animals are grazed, and the N fertilizer level of the pasture. The potential to increase grazing is often limited by soil type, topography, farm size and structure (distances), climatic conditions, etc. It should be noted that grazing of animals may increase other forms of N emissions (e.g. N_2O, NO_3). However, given the clear and well quantified effect on NH_3 emissions, increasing the period that animals are **grazing can be considered as a category 1 strategy** to reduce emissions. The actual abatement potential will depend on the base situation of each animal sector in each country. 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 strategy. 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. Grazing management (strip grazing, rotational grazing, continuous grazing) is expected to have little additional effect on NH_3 losses and is considered a category 3 strategy.

67. In general, increasing the energy/protein ratio in the diet by using ‘older’ grass (higher sward surface height, SSH) and/or supplementing grass by high energy feeds (e.g., silage

maize) is category 1 strategy. However, for grassland-based ruminant production systems, the feasibility of this strategy may be limited, especially when conditions for growing high energy feeds are poor and therefore have to be purchased, with as consequence that a full use of the grass production would no longer be guaranteed (under conditions of limited production, e.g. milk quotas or restrictions to the animal density). Hence, improving the energy/protein equilibrium on grassland-based farms with animal production constraints and no possibilities of growing high energy feeds is therefore considered a category 2 strategy.

68. The use of modern protein evaluation systems (e.g., PDI in France, MP in the UK, DVE/OEB in The Netherlands, AAT/PBV in Scandinavian countries) is recommended. In dairy cattle, the use of rumen protected limiting amino acids, like lysine and methionine may be helpful to better balance the amino acid composition of protein digested from the small intestine. Because for a successful introduction of this method detailed additional information on the behaviour of the feed in the digestive tract is required, this is considered a category 2 strategy.

69. Shifting N excretion from urea in urine to protein in dung is also an effective measure for decreasing ammonia loss. Dietary composition should be such that a certain degree of hindgut fermentation is stimulated, without disturbing rumen fermentation. This will shift the excretion of N from urine to dung. Hind gut fermentation can be stimulated by the inclusion of rumen resistant starch or fermentable fibre that escapes fermentation in the rumen (Van Vuuren et al., 1993). Because in the hindgut acetogenic rather than methanogenic bacteria are present, there is little risk of elevated CH_4 losses. Knowledge on factors responsible for shifting N excretion from urea in urine to protein in dung are as yet insufficient and this approach is considered a category 2 strategy.

70. The pH of freshly excreted urine ranges from 5.5-8.5 and mainly depends on the electrolyte content of the diet. Although the pH will eventually rise towards alkaline values due to the hydrolysis of urea irrespective of initial pH, it are the initial pH and the pH buffering capacity of urine which determine the rate of NH_3 volatilization from urine immediately following urination. Lowering the pH of urine of ruminants is theoretical possible. However, there are interactions with urine volume, ruminant performance, and animal welfare and it is therefore considered a category 3 technique. Similarly, lowering the pH of dung is theoretically possible, but this might easily coincide with disturbed rumen fermentation and is therefore not recommended. Because of the health risks involved this is considered a category 3 technique. Dung consistency could be used to monitor the adequacy of rumen fermentation.

71. Monitoring the protein status is possible with the (calculated) rumen degradable protein balance (e.g., PBV in Scandinavian countries, OEB in The Netherlands) and/or milk urea nitrogen (MUN) can be used too. MUN should preferably not exceed 10 mg/dl (milk urea below 22 mg/dl). Knowledge on factors responsible for variation in MUN is as yet insufficient and this approach is considered a category 2 strategy.

72. There are also herd management options to reduce NH_3 emissions. Firstly, by increasing the genetic potential of the cows (more milk per cow). This will lead to a higher NUE at herd level because of the lower share of maintenance energy. By equal total annual milk output per country the number of dairy cows and replacement cattle will consequently decrease. Secondly, by increasing the number of lactations per cow. This will reduce the number of replacement cattle. Finally, the actual number of replacement cattle per dairy cow should be optimized. All three options are a long term approach, but nevertheless represent category 1 techniques where to reduce overall ammonia emissions.

73. Rotational corralling of ruminants on crop land may reduce NH_3 emissions and increase N recovery from animal manure compared to the conventional practice of barn manure collection and land application of manure (Powell and Russelle, 2009). Overall results demonstrated that corralling dairy cattle on cropland improves urine N capture, reduces ammonia loss and enhances manure N recycling through crops.

74. Various feed strategies are able to reduce urinary N excretion from housed dairy cattle. A close matching of diets to animal nutritional requirements, feeding only enough RUP to meet cows' metabolizable protein requirements, reducing particle size to increase ruminal digestion of grain starch and increase microbial protein formation (so long as ruminal pH is not depressed) optimizes microbial protein synthesis, maximizes feed N conversion into milk and minimizes urinary N excretion.

Feeding strategies for pigs

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

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

77. 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.

78. A crude protein reduction of 2 to 3 per cent (20 to 30 g/kg of feed) can be achieved depending on pig production category and the current starting point. The resulting range of dietary crude protein contents is reported in Table 9. The values in the table are indicative target levels and may need to be adapted to local conditions.

Table 9: Target crude protein levels in feed for pig rations

Species	Phases	Crude protein content, % *)
Weaner	< 10 kg	19–21
Piglet	< 25 kg	17–19
Fattening pig	25–50 kg	15–17
	50–110 kg	14–15
	>110 kg	12-13
Sows	Gestation	13–15
	Lactation	15–17

*) With adequately balanced and optimal amino acid supply

79. For every 10 g/kg reduction in crude protein content of the diet a 10% lower TAN content of the pig slurry and 10% lower NH_3 emissions can be achieved in growing finishing pigs (Canh et al., (1998b). Currently, crude protein content of the diet of growing-finishing pigs is approximately 170 g/kg. In experiments, it has been demonstrated that decreases to 120 g protein per kg diet can be achieved without any effect on growth rate or feed efficiency when limiting amino acids are added (= 50% NH_3 emission reduction). In practice, 140 g protein per kg diet is economically feasible (= 30% NH_3 emission reduction, relative to the baseline value with a protein content of 170 g/kg). This can be achieved by phase feeding and adding the most limiting amino acids (Canh et al., 1998b; Dourmad et al., 1993; Lenis and Schutte, 1990). Although still some work needs to be done for the practical implementation, this is considered a category 1 technique for growing-finishing pigs. For sows and weaned piglets additional studies are needed, so for these categories it is considered a category 2 technique.

80. The addition of special components with high non-starch polysaccharide (NSP) content (e.g. sugar beet pulp, soybean hulls) can reduce the pH of pig excreta and thus NH_3 emissions. Increasing the amount of non-starch polysaccharides (NSP) in the diet increases the bacterial fermentation in the large intestine, which results in the immobilization of urea-N from the blood into bacterial protein. Ammonia emissions decrease by approximately 16 and 25% when NSP content of the diet increases from 200 to 300 and further to 400 g/kg diet, respectively. However, the effect on NH_3 emissions depends to a certain extent also on the kind of NSP in the diet. Increasing the level of NSP in the diet may also have negative impacts. At high NSP levels, nutrient digestibility decreases and this increases waste production, which is undesirable in animal dense areas. Furthermore, at increasing NSP levels in the diet volatile fatty acids (VFA) concentrations in the manure increases. Although VFA's are not the most important odorous compounds, increased VFA levels may increase odour release from the manure. At increasing NSP levels in the diet methane production from animal and manure may also increase (Kirchgessner et al., 1991). Because of all these reasons increasing the amount of NS P in the diet as means to decrease NH_3 emissions is considered a category 3 strategy in animal dense areas and a category 2 strategy in other areas.

81. Replacing $CaCO_3$ in the animal feed by $CaSO_4$, $CaCl_2$, or Ca-benzoate reduces the pH of urine and slurry and the NH_3 emission from the urine and slurry. By replacing calcium (6 g/kg) in the diet in the form of $CaCO_3$ by Ca-benzoate, urinary and slurry pH can be

lowered by more than 2 units. In that case NH_3 emission can be reduced up to 60%. 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) (registered trade mark: Vevovitall). Addition of 1% benzoic acid to th e diet of growing-finishing pigs lowers NH3 emissions by approximately 20% (Aarnink et al., 2008; Guingand et al., 2005). A similar replacement of CaCO3 by Ca-sulphate or Ca-chloride reduces the pH of slurry by 1.2 units and NH_3 emission by approximately 35% (Canh et al., 1998a; Mroz et al., 1996). Addition of benzoic acid is considered a category 1 technique for growing-finishing pigs and a category 2 technique for other pig categories. Replacement of $CaCO_3$ by $CaSO_4$, $CaCl_2$, or Ca-benzoate is considered a category 2 technique for all pig categories.

82. The effects of the feeding measures mentioned in paragraphs 61 to 63 have independent effects on NH_3 emission. This means that these effects are additive (at a relative scale) (Bakker and Smits (2002). Combined feeding measures are considered category 2 techniques for all categories of pigs.

Feeding strategies for poultry

83. 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 10. The values in the table are indicative target levels, which 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 10: Target crude protein levels in feed for poultry

Species	Phases	Crude protein content, % *)
Chicken, broilers	Starter	20–22
	Grower	19–21
	Finisher	18–20
Chicken, layers	18–40 weeks	15.5– 16.5
	40+ weeks	14.5– 15.5
Turkeys	< 4 weeks	24–27
	5–8 weeks	22–24
	9–12 weeks	19 –21
	13+ weeks	16-19
	16+ weeks	14 –17

*) With adequately balanced and optimal amino acid supply

Summary and synthesis and of feeding strategies

84. Low-protein animal feeding is one of the most cost-effective and strategic ways of reducing NH_3 emissions. For each percent (absolute value) decrease in protein content of the animal feed, NH_3 emissions from animal housing, manure storage and the application of animal manure to land are decreased by 5 to 15%, depending also on the pH of the urine and dung. Low-protein animal feeding also decreases N_2O emissions, and increases the efficiency of nitrogen use in animal production. Moreover, there are no animal health and animal welfare implications as long as the requirements for all amino acids are met.

85. Low-protein animal feeding is most applicable to housed animals and less for grassland-based systems with grazing animals, because grass in an early physiological growth stage and grassland with leguminous species (e.g. clover and lucerne) have a relatively high protein content. However, there are strategies to lower the protein content in herbage (balanced N fertilization, grazing/harvesting the grassland at later physiological growth stage, etc.) as well as in the ration of grassland-based systems (supplemental feeding with low-protein feeds), but these strategies are not always fully applicable.

86. Table 11 presents ranges of target crude protein values for various animal categories and for three 'ambition levels' of nitrogen mitigation. The 'high ambition values' relate to the lowest ranges of crude protein contents in the current guidelines for best feed management practices and low-protein feeding management. These values have been tested manifold in research and proven to be solid in practice. The medium and low ambition target crude protein values have been derived from the high ambition targets by simply increasing the target crude-protein content by 1 percent point. The achievable ambition levels for housed animals depend on the management skill of the farmer and the availability of the animal feedstuffs with low protein content, including synthetic amino acids.

87. The cost of synthetic amino acids supplementation relative to using soya beans depends on world market prices of these amino acids and soya bean, but the costs of amino acids supplementation tend to go down. The cost of supplementation of amino acids increases when the target protein content in the animal feed is lowered. This is show below for feed of fattening pits (personal communication Dr. Andre Aarnink, October, 2009)

Target protein content, %.	Extra costs, euro per 100 kg feed
15	0.00
13.5	0.90
12.7	3.10

Table 11: Possible crude protein levels (percent of dry feed with a standard dry matter content of 88%) for housed animals as function of animal category and for different ambition levels. These crude protein values can be used as annual mean targets in low-protein animal feeding strategies.

Animal type	**Mean crude protein content of the animal feed, %**		
	Low ambition	**Medium ambition**	**High ambition**
Dairy cattle, early lactation (>30kg/day)	17-18	16-17	15-16
Dairy cattle, early lactation (<30kg/day)	16-17	15-16	14-15
Dairy cattle, late lactation	15-16	14-15	12-14
Replacement cattle (young cattle)	14-16	13-14	12-13
Veal	20-22	19-20	17-19
Beef <3 months	17-18	16-17	15-16
Beef >6 months	14-15	13-14	12-13
Sows, gestation	15-16	14-15	13-14
Sows, lactation	17-18	16-17	15-16
Weaner, <10 kg	21-22	20-21	19-20
Piglet, 10-25 kg	19-20	18-19	17-18
Fattening pig 25-50 kg	17-18	16-17	15-16
Fattening pig 50-110 kg	15-16	14-15	13-14
Fattening pigs >110	13-14	12-13	11-12
Chicken, broilers, starter	22-23	21-22	20-21
Chicken, broilers, growers	21-22	20-21	19-20
Chicken, broilers, finishers	20-21	19-20	18-19
Chicken, layers, 18-40 weeks	17-18	16-17	15-16
Chicken, layers, >40 weeks	16-17	15-16	14-15
Turkeys, <4 weeks	26-27	25-26	24-25
Turkeys, 5-8 weeks	24-25	23-24	22-23
Turkeys, 9-12 weeks	21-22	20-21	19-20
Turkeys, 13 -16 weeks	18-19	17-18	16-17
Turkeys, >16 weeks	16-17	15-16	14-15

88. The high ambition values presented in Table 11 may be difficult to achieve when the feed quality is low (high fiber content and low digestibility of the feed). In these conditions, specific feed additives may help to increase the digestibility. Ruminants and also pigs (especially sows) need minimum fiber content in the feed for proper functioning of the rumen and for welfare reasons.

89. For producing special meat (and milk) products, the recommended protein content of the animal feed for a specific animal category may be slightly above the upper value of the indicated ranges in Table 11.

V. LIVESTOCK HOUSING

[Further updates on this section will include addition of references]

90. Animal housing varies enormously across the UN/ECE 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 livestock diets, manure storage and the application of manure to land.

91. *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. The reference techniques are described according to each livestock type.

A. Housing systems for dairy and beef cattle

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

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

93. 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 may be removed from the house daily. Loose housing systems are most commonly 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.

94. *Reference Systems:* Two references apply for cattle housing depending on national practices: the cubicle house and the tied animal house. In Table 12, cubicle housing is referred to as reference 1, while tied housing is 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.

95. *Animal welfare considerations* tend to lead to an increase of the soiled walking area per animal and a corresponding increase of emissions. Changes in building design to meet new animal welfare legislation in some countries (e.g. changing from tied stall to cubicle housing) will therefore increase NH_3 emissions unless other measures are introduced at the same time to combat this increase. Conversely, changes in building design to meet animal welfare requirements represent an important opportunity to introduce NH_3 mitigation measures in at the same time, thereby reducing the costs of the mitigation measures.

Category 1 techniques

96. *In the "grooved floor" system* for dairy and beef cattle housing, the use of a “toothed” scraper running over a grooved floor is a reliable technique to abate NH_3 emissions. Grooves should be equipped with perforations to allow drainage of urine. This results in 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.

97. In houses with traditional slats (either non-sloping, 1% sloping or grooved), an optimal barn climatization with roof insulation (RI) and/or automatically controlled natural ventilation (ACNV) can achieve a moderate emission reduction due to the decreased temperature (especially in summer) and reduced air velocities.

Category 2 techniques

98. *Different improved floor types* based on slats or solid, profiled concrete elements are being tested in the Netherlands. Emission reduction is achieved by a combination of emission reduction from the floor (increased run off of urine) and from the pit (reduction of air exchange by rubber flaps in the floor slots). The emission abatement efficiency depends on the specific technical characteristics of the system. Quantification is not yet possible. However, measurement programs to establish emission factors are implemented in the Netherlands.

99. *Solid versus slurry manure systems.* Research to date has shown that straw-based systems for cattle are not likely to emit less NH_3 in the animal houses than slurry-based systems. However, straw-based systems producing solid manure can give less emission than slurry after spreading the manure on the field. Similarly, the physical separation of faeces (which contains urease) and urine in the housing system can reduce both emissions during housing and emissions at the time of manure spreading. It may also be possible to further reduce ammonia emissions through alternative herd management. Verification of any NH_3 emission reductions from using solid-manure versus slurry-based systems and from solid-liquid separation should consider all the stages of emission (housing, storage, land application).

100. *Bedding material* in animal housing can have impacts on NH_3 emissions. The physical characteristics (urine absorbance capacity, bulk density) of bedding materials are of more importance than their chemical characteristics (pH, cation exchange capacity, carbon to nitrogen ratio) in determining ammonia emissions from dairy barn floors (Misselbrook and Powell, 2005). Ammonia emissions were significantly lower from sand (23% of applied urine N), followed by pine shavings (42% of applied urine N), than from the other four (straw, newspaper, cornstalks and recycled manure solids) bedding types (mean 63% of applied urine N). Ammonia emissions (g/cow/d) from manure solids (20.0), newspaper (18.9) and straw (18.9) were similar and significantly greater than emissions using pine shavings (15.2).

101. *Chemical air scrubbers* are also increasingly discussed for cattle housing. This approach applies only to cattle houses with forced ventillation (rather than natural ventillation). Although such systems have been demonstrated to be very effective for pig housing systems, due to the need for more research with cattle housing they are considered here as a category 2 technique.

Category 3 techniques

102. *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.

103. Table 12 gives emissions from different cattle housing systems (reference systems and category 1 and 2 techniques).

Table 12: 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	12[d/]
Tied system[a/] (Reference 2)	60	4.8
Grooved floor (Cat. 1)	25	9
Optimal barn climatization with roof insulation	20	9.6
Chemical air scrubbers (forced ventillation systems only)	70-95	1.2
Bedding of sand (solid manure system only)	60	4.8
Bedding of pine shavings (solid manure system only)	30	8.4

a/ Tied systems are not favoured for animal welfare reasons. Any conversion from tied stall to cubicle houses (e.g. to meet welfare requirements) should address the opportunity to include NH_3 emission mitigation measures at the same time.

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.

d/ Based on a walking area of 4-4.5 m^2 per cow and permanent housing.

B. Housing systems for pigs

104. *Reference system:* Emissions from fully slatted pig houses with a storage pit underneath are taken as the reference, although in some countries these systems are prohibited for animal welfare reasons.

105. 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.
(h) Lowering the indoor temperature as animal welfare and production allow.
(i) Reducing ventilation rate taking into account the minimum levels required for animal welfare reasons.
(j) Reducing air flow over the manure surface

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

i. General measures for pig houses

107. 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 countries.

108. 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.

109. 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 has the benefit of increasing the organic matter (carbon storage) of the soils.

Category 1 techniques

110. 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.

111. A housing system has been developed incorporating manure surface cooling fins using a closed system with heating pumps. It performs well (Category 1), but is a very costly system. In retrofit situations this technique can be economically viable, 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.

112. 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.

113. *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 housing demand extra costs to modify ventilation systems. Further information is desirable on the suitability of these systems for housing systems in South and Central Europe.

114. 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 several parts of Europe scales of farming operations that outweigh the higher operational costs.

Category 2 techniques

115. The ventilation system should be designed so that it has sufficient capacity to control the house temperature in warm summer months when the house is fully stocked with the heaviest animals, and to also have sufficient control to provide a minimum ventilation rate in colder winter months when the house is stocked with the lightest animals.

116. Significant reduction in power consumption and ammonia emission can be achieved by a combined system for controlling heating and ventilation systems that are optimally aligned to the requirements of the livestock. Ventilation control strategy must restrict ventilation rate according to the actual animal weight, outdoor temperature and desired indoor climate

117. 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 (or other substances). The use of peat, however, is considered unsustainable in many countries.

ii. Housing systems for growers/finishers

118. 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 13: Category 1 techniques: reductions and costs of low-emission housing systems for fattening pigs. [the units need to be clarified e.g. €/kg NH3-N abated?**]**

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).
The definition of BAT includes a non-quantified element of cost. Category 1 techniques may not, therefore, have been defined as BAT because of perception of costs, or may only have been defined as BAT where already fitted.

iii. Housing systems for farrowing sows (including piglets)

119. *Reference system:* Farrowing sows in Europe are generally housed in crates with steel and/or plastic slatted floors and a deep manure pit underneath. 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.

120. 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 14: Category 1 techniques: reductions and costs of low-emission housing systems for farrowing sows including piglets. [the units need to be clarified e.g. €/kg NH3-N abated?**]**

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).
The definition of BAT includes a non-quantified element of cost. Category 1 techniques may not, therefore, have been defined as BAT because of perception of costs, or may only have been defined as BAT where already fitted.

iv. Housing systems for mating/gestating sows

121. *Reference system:* The reference system for housing of mating and gestating sows is the fully slatted floor (concrete slats) with a deep pit.

122. 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. 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.

Table 15: Category 1 techniques, reduction and costs of low-emission housing systems for mating and gestating sows. [the units need to be clarified e.g. €/kg NH3-N abated?]

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).
The definition of BAT includes a non-quantified element of cost. Category 1 techniques may not, therefore, have been defined as BAT because of perception of costs, or may only have been defined as BAT where already fitted.

v. Housing systems for weaners

123. *Reference system:* 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.

124. 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. 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 16: Category 1 techniques: reduction and costs of low-emission housing systems for weaners. [the units need to be clarified e.g. €/kg NH3-N abated?**]**

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).
The definition of BAT includes a non-quantified element of cost. Category 1 techniques may not, therefore, have been defined as BAT because of perception of costs, or may only have been defined as BAT where already fitted.

C. Housing systems for poultry

i. Housing systems for laying hens

125. 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.

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

Category 1 techniques

127. 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.

128. 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% 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 % in less than 48 hours. Weekly removal from the manure belts to covered storage has been shown to reduce emissions by 50%

compared with 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 17: Caged housing systems for laying hens: techniques and associated NH_3 emission reduction potential

Category 1 & 2 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 (and increased moisture), this technique can show a significantly greater NH_3 emission, but is considered BAT provided there is a means 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
9. Chemical scrubbing of exhaust air	75-90	[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.
# The definition of BAT includes a non-quantified element of cost. Category 1 techniques may not, therefore, have been defined as BAT because of perception of costs, or may only have been defined as BAT where already fitted.

129. *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 18: Non-caged housing systems for laying hens: techniques and associated NH_3 emission reduction potential

Category 1 and 2 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
Chemical scrubbing of exhaust air	75-90	[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.
# The definition of BAT includes a non-quantified element of cost. Category 1 techniques may not, therefore, have been defined as BAT because of perception of costs, or may only have been defined as BAT where already fitted.

130. 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.

131. 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

132. Treatment of exhaust air by acid scrubber or biotrickling filters is an option that has been successfully applied on in several countries. Although highly effective in terms of ammonia removal (90%), the high dust loads in poultry housings can 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. [Note: there remains debate within the Task Force on whether acid scrubbing of exhaust air in poultry systems should be considered a category 1 method.]

ii. Housing systems for broilers

133. 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

134. 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 19, 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

135. 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. [Note: this should be reviewed]

Table 19: 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**			
Chemical scrubbing of exhaust air (cat. 2)	90	[BAT]			

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

The definition of BAT includes a non-quantified element of cost. Category 1 techniques may not, therefore, have been defined as BAT because of perception of costs, or may only have been defined as BAT where already fitted.

** 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.

136. Application of air scrubber technology to remove NH_3 from ventilation air of broiler houses, although effective in ammonia removal (e.g. 90% removal), has not yet been used widely. [Note: there remains debate within the Task Force on whether acid scrubbing of exhaust air in poultry systems should be considered a category 1 method.]

iii. Housing systems for turkeys and ducks

137. *Reference system turkeys:* 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.

138. *Reference system ducks:* 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.

139. Techniques that can be considered as category 1 (which are also considered as BAT) include:

(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;

140. The following techniques are considered as category 2, because data on NH_3 emission reduciton are not currently available.

(a) Perforated forced air drying;

(b) Tiered floor and forced air drying;

(c) Tiered removable sides; forced air drying;

141. [Note: As with other poultry, it remains a matter of discusion within the Task Force whether air scrubbing systems for turkeys, ducks and other poultry can be considered as category 1.]

VI. MANURE STORAGE TECHNIQUES

142. *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.

143. 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. Reducing the surface area is only a consideration at initial store design or at replacement.

144. 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.

145. 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.

Category 1 techniques

146. 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 sheeting may be a type of plastic, canvas or other suitable material) 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.

Table 20: 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)

The definition of BAT includes a non-quantified element of cost. Category 1 techniques may not, therefore, have been defined as BAT because of perception of costs, or may only have been defined as BAT where already fitted.

Category 2 techniques

147. 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.

148. 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.

149. 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.

150. There are few options for reducing NH_3 emissions from stored farmyard manures for cattle and pigs. Experiments have shown that covering farmyard manure piles with plastic sheeting can substantially reduce NH_3 emissions, and did not show any significant increase in methane or nitrous oxide emissions (T. Misselbrook, personal communication). At present, this is considered as a category 2 technique, due to the need for more general testing of the abatement efficiency.

VII. MANURE APPLICATION TECHNIQUES

151. *Reference technique*. The reference manure application technique is defined as untreated slurry or solid manure spread over the whole soil surface ("broadcast") and not followed by incorporation. For slurry, for example, this would typically consist of a tanker equipped with a discharge nozzle and splash-plate. For solid manures, the reference case would be to leave the manure on the soil surface without incorporation.

152. *Specification of abatement efficiency*. 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. For this reason, the figures quoted in Table 21 represent averages over a wide range of conditions. The absolute magnitude of ammonia emission levels of the reference techniques varies at a regional scale in response to variation in environmental conditions. While these factors also affect the absolute magnitude of ammonia emissions from low-emission approaches, the relative emission levels are comparable; for this reason the benefits of using low-emission approaches are expressed as percentage reduction compared with the reference.

153. Emissions of ammonia expressed as a percentage of the TAN (total ammoniacal nitrogen) applied are typically in the range of 40-60% following application using the reference technique, (although emissions outside this range are also common). Emissions will vary with the composition of the slurry or solid manure and with prevailing weather and soil conditions. Emissions of ammonia as a percentage of TAN applied are normally increased with increasing: evapotranspiration (air temperature, wind speed, solar radiation); and slurry DM concentration. Emissions of ammonia as a percentage of TAN applied are normally increased with decreasing: TAN concentration; and application rate. Emissions from different manure types will also vary. Emissions are also dependant on soil conditions that affect infiltration rates. For example, well draining, coarse textured, dry soils, which allow faster infiltration, will give rise to lower emissions than wet and compact soils with reduced infiltration rate (Søgaard et al., 2002). However, some soils may become hydrophobic when very dry, which can also reduce infiltration and therefore increase emissions.

Category 1 techniques

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

(a) Band-spreading slurry at or near the soil surface using trailing hose or trailing shoe methods;
(b) Injecting slurry – open slot;

(c) Injecting slurry – closed slot;
(d) Incorporation of surface-applied (broadcast) solid manure and slurry into soil;
(e) Dilution of slurry by at least 50% applied in water irrigation systems

155. The average NH_3 abatement efficiencies of category 1 techniques relative to the reference are given in Table 21. Each efficiency is valid for soil types and conditions that allow infiltration of liquid for techniques (a)–(c) 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 of each technique relative to the reference. [These costs estimates are subject to review by the TFRN.]

156. 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.

157. Techniques (a) - (c) operate on the basis that the surface area of slurry exposed to the prevailing weather conditions is reduced by at least 75% through confining the slurry to lines / bands which are approximately 250 (+/- 100) mm apart. The slurry is distributed through a number of relatively narrow pipes (usually 40-50 mm diameter). These machines usually incorporate systems for filtering, chopping and homogenising slurry, which minimise the occurrence of blockages in narrow pipes caused by slurries that are very viscous or that contain large amounts of fibrous material or foreign objects such as stones. Band-spreading and injection systems are normally fitted to the rear of a slurry tankers, which are either towed by a tractor or form parts of a self-propelled machines. An alternative is for the application system to be attached directly to the rear of a tractor and slurry transported to it by an ‘umbilical’ hose from a stationary tanker or store. Such umbilical systems can reduce soil compaction damage caused by heavy slurry tankers.

158. ***Band-spreading slurry at or above the soil surface.*** Band-spreading at or above the soil surface can be carried out using implements commonly referred to as ‘trailing hose’ (also known as ‘drag hose’ and ‘drop hose’)’ and ‘trailing shoe’ (also known as ‘drag shoe’ and ‘sleighfoot’). Trailing shoe and trailing hose systems are distinguishable from each other through the presence (trailing shoe) or absence (trailing hose) of a ‘shoe’ or ‘foot’ device at the outlet of each slurry distribution pipe which slides (or floats) on the surface of the ground with little or no penetration. The hose or shoe is intended to part of the herbage or any crop residue present to allow slurry placement directly on the soil surface. Greater efficiency generally reported with the sliding shoe (Webb et al. 2010) is attributed to manure being in narrower bands, having more contact with the soil and having less contact with live or dead vegetative material because it is better pushed aside by the shoe than the hose, even if the hose is very close to the ground. The benefit of the shoe

compared with the hose is greatest for taller canopies because of the reduced degree of canopy contamination.

159. ***Trailing hose:*** This technique discharges slurry at or just above ground level through a series of hanging or trailing pipes or flexible hoses, which either hang a short distance (<150 mm) above the soil or are dragged along the soil surface. The working width is typically between 6 and 12 m, although larger units of up to 24 m width are commercially available. The possible working width (requiring manual or powered swing arms for transport) is much larger than for the 'splash plate' reference system (6-9 m), representing a clear advantage of the trailing hose method. The spacing between bands (centre to centre) is typically 250-350 mm. The technique is applicable to grass and arable crops. The pipes may become clogged if the DM content of the slurry is high (>7-10%) or if the slurry contains large solid particles. However, the clogging of pipes is usually avoided by including a chopping and distribution system. This system improves spreading uniformity which improves nutrient use, but contributes signficantly to the cost and maintenance of the system.

160. ***Trailing shoe:*** This technique is mainly applicable to grassland [Insert: and arable crops with widely spaced rows. The machine working width is typically limited to 6 – 8 m, which, as with the reference system, is insufficient for practical operation in growing combinable crops, which are normally established in 12 m or 24 m tramline systems. The method is not recommended for growing solid seeded arable crops where the action of the shoe can result in excessive plant disturbance. 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. The spacing between bands is typically between 200 and 300 mm. Ammonia emission reductions are optimised when the slurry bands are partially sheltered by a grass canopy. Applicability is limited where there are significant stones on the soil surface. Large amounts of crop residue such as on untilled land will gather on the trailing shoes and interfere with their performance.

161. The ammonia emission abatement potential of trailing shoe or trailing hose machines is more effective when slurry is applied below well-developed crop canopies rather than on bare soil because the crop canopy increases the resistance to air turbulence from wind and shades the slurry from solar radiation. In general, ammonia emission reductions have typically been found to be larger from trailing shoe than from trailing hose, which is most likely due to the higher degree of canopy contamination resulting from certain types and implementation of the trailing hose methods. This emphasizes the need to avoid canopy contamination with slurry when using either method, which also has benefits for herbage quality.

162. ***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 50–60 mm deep into which slurry is placed. Spacing between slots is typically 200–400 mm and machine working width is typically ≤ 6 m. To be effective in both reducing ammonia emissions and increasing the availability of nitrogen to the crop, while also reducing crop injury, injection

should be to a depth of approximately 50-75 mm and the space between injector tines should be ≤ 300 mm. Also, 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, or on very shallow or compacted soils, where it is impossible to achieve uniform penetration to the required working depth. The method may not be applicable on very steeply sloping fields due to the risk of runoff down the injection furrows. Slurry injection systems will have a higher tractor power requirement than broadcast or band-spreading equipment.

163. ***Injection – closed slot.*** This technique can be shallow (50–100 mm depth) or deep (150–200 mm). 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. Some deep injectors comprise a series of tines fitted with lateral wings or "goose feet" to aid soil penetration and lateral dispersion of slurry in the soil so that relatively large application rates can be achieved. Tine spacing is typically 250–500 mm and working width, ≤ 4 m. Although NH_3 abatement efficiency is high, the applicability of the technique is mainly restricted mainly to pre-sowing application to arable land and widely spaced row crops (e.g. maize), while mechanical damage may decrease herbage yields on grassland or growing solid-seeded arable crops. Other limitations include soil depth, clay and stone content, slope and a high tractor power requirement.

164. ***Incorporation of surface-applied solid manure and slurry into soil***: Incorporating surface applied manure or slurry by either ploughing or shallow cultivation is an efficient means of decreasing NH_3 emissions. Highest reduction efficiencies are achieved when the manure is completely buried within the soil (Table 21). Ploughing results in higher emission reductions than other types of machinery for shallow cultivation. The applicability of this technique is confined to arable land. Incorporation is not applicable on permanent grassland, although it may be possible to use in grassland systems either when changing to arable land (e.g. in a rotation) or when reseeding pasture although nutrient requirements may be low at these times. It is also less applicable to arable crops grown using minimum cultivation techniques compared to crops grown using deeper cultivation methods. Incorporation is only possible before crops are sown. The technique is the main technique applicable to achieve emission reductions from to solid manures on arable soils. The technique is also effective for slurries where closed-slot injection techniques are not possible or available.

165. Ammonia loss takes place quickly (over several hours and days) after manures are spread on the surface, so greater reductions in emissions are achieved when incorporation takes place immediately after spreading. Immediate incorporation often requires a second tractor to be used for the incorporation machinery, which must follow closely behind the manure spreader. Where labour or machinery requirements limit this option, such as for small farms, manures should be incorporated within 4 hours of spreading the manure, but

this is less efficient in reducing emissions (Table 21). Incorporation within 24 hours of spreading will also reduce emissions to a smaller extent, but increases agronomic flexibility, which may be especially important for small farms. It is most important to incorporate rapidly when manure is applied near midday in hot conditions. It may be possible to spread and incorporate with a single implement. This can work well, provided that less than 25% of the manure is exposed to the atmosphere.

166. ***Slurry dilution for use in irrigation systems.*** Ammonia emissions from dilute slurries with low dry matter (DM) content are generally lower than for whole (undiluted) slurries because of faster infiltration into the soil (e.g. Stevens and Laughlin, 1998; Misselbrook et al., 2004). Doses of slurry, calculated to match the nutrient requirement of crops, can therefore 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. Dilution rates may be up to 50:1 water: slurry. This approach is included as a Category 1 method so far as this is an active dilution for use in water irrigation systems with a dilution of at least 50% (1:1 water:slurry) sufficient to reduce emissions by at least 30%, where there is a need for water irrigation. In the case of slurry with a DM content of 4%, this would need to be diluted to ≤ 2% DM content (see Figure 1). In order to be considered a category 1 method, the following conditions should apply:

i. The slurry is actively diluted for use in irrigation systems by at least the required amount of 1:1 dilution with water. By contrast, the slurry should not simply be dilute through poor management practice, such as because of slurry storage in shallow uncovered lagoons that collect a lot of rainwater. These storages are discouraged because they are in themselves potentially significant sources of emissions that are difficult to control with covers.
ii. Conditions are suitable for irrigation to meet crop water needs. Dilution of slurry without a water need adds to hauling costs and may exacerbate nitrate leaching.
iii. The amounts of slurry applied are calculated to match nutrient needs. The method should not be seen as an easy option for slurry disposal, with the possible risk of over fertilization and nitrate leaching.
iv. Soil conditions allow for rapid soaking of dilute slurries because there are no physical impediments to infiltration, such as high soil water content, poor soil structure, fine texture or other soil attributes that reduce infiltration rates of liquids in to soil, and that there is no decrease in infiltration rate due to high application volumes.

167. In addition to the specific dilution of slurry in irrigation systems, other methods of reducing slurry DM content can provide a useful means to reduce ammonia emissions. These include reducing DM levels through anaerobic digestion and by solid-liquid separation. Because such methods can tend to increase the pH of the low DM fraction and also produce a sludge with higher DM content, they are not included as Category 1 methods. Such methods can, nevertheless, provide a useful approach as part of Category 2 methods, where verification of the emission reductions should be provided.

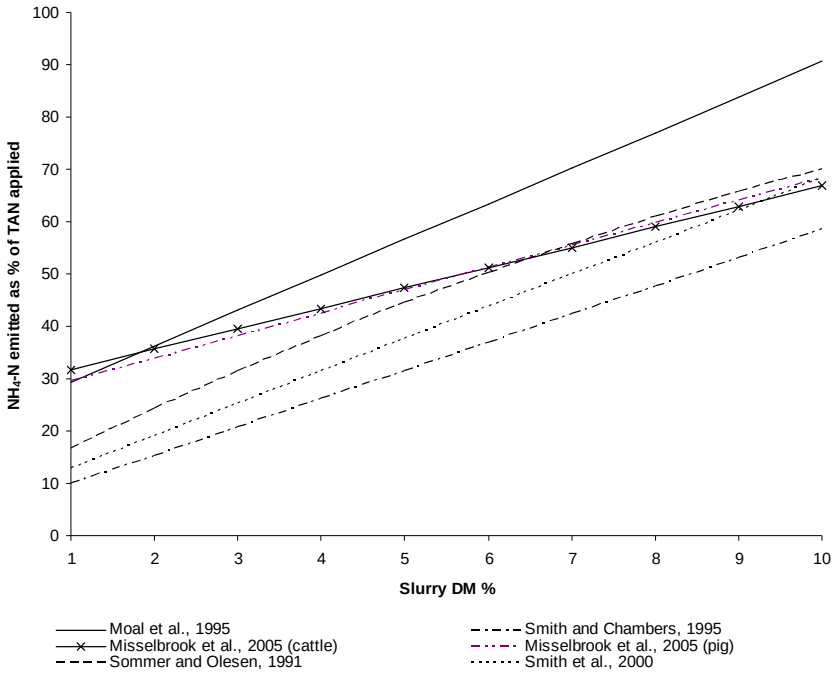


Figure 6: Relationship between the percentage of total ammoniacal nitrogen (TAN) emitted as ammonia during the land application of slurry and the dry matter content (DM % weight) of the slurry, according to six estimates. Even though ammonia emissions are still significant at 1% DM content (10-30% of TAN lost through volatilisation), a 50% reduction in DM content will achieve a 30% reduction in average ammonia emissions.

168. ***Additional benefits of techniques to reduce ammonia emissions from the land application of slurry and solid manure.*** The experimental quantification of N fertilizer benefits associated with reduced ammonia emissions has given variable results (Webb et al. 2010). This may be partly explained by the difficulty implicit in any attempt to detect a significant crop response to low N fertilizer additions against relatively large background soil N mineralisation rates. In practice, the reduction in ammonia emission translates into a relatively low application rate of additional N. Although the uptake of the ammonia-N by the crop will vary, the N that is not volatilised can be considered as potentially equivalent to chemical N fertilizer. Therefore, reduced ammonia losses can be considered to replace chemical fertilizer applications on a 1:1 ratio.

169. Band-spreading and injection techniques, as well as the rapid incorporation of solid manures, considerably reduce the odour associated with manure application. The reduction in odour emissions achieved by these techniques can allow application on areas or at times that may otherwise be unavailable due to complaints.

170. Band-spreading and injection techniques can allow more accurate slurry application rates than the reference technique, as the slurry should be distributed in equal proportions to pipes that are equally spaced apart along a fixed bout width. By comparison, the spatial distribution following application using the splashplate applicator (the reference system) is

often more variable, depending on the design and condition of the splashplate unit. Also, the bout width using splashplates can be more variable (e.g. affected by wind), resulting in imperfect alignment of adjacent bout strips and less accurate application along field boundaries. This potential improvement in accuracy of application increases efficiency of slurry as a nutrient source. The improvement in application accuracy also reduces the risk of nitrate pollution by avoiding spreading slurry onto adjacent areas such as near water courses.

171. The window of opportunity for slurry application using the reference technique (broadcast spreading) is restricted by the risk of crop quality deterioration or damage caused by slurry contamination. Band-spreading and injection reduce the occurrence of herbage contamination and therefore increase the crop canopy height onto which slurry can be applied without threatening crop quality. This is particular relevant to grassland, where slurry contamination can reduce grazing palatability or silage quality. These methods also allow slurry application on growing arable crops (particularly cereals) which are generally not considered suitable to receive slurry applied using splashplate. The use of low-emission techniques can therefore help to increase the flexibility of slurry application management by allowing more land area to be available on days when weather conditions are more suitable for reduced ammonia volatilisation and optimal slurry-N utilisation, and when soil moisture conditions are suitable to allow machinery traffic with minimal soil compaction.

172. ***Potential cost implications of abatement techniques.*** Cost increases associated with purchasing and maintaining, or hiring contractors with, new application machinery can be a disincentive to adoption. Injection techniques also require higher tractor power, further adding to the cost of adoption for those systems. These additional costs can be partially or totally outweighed by the financial benefit of improving yield and yield consistency, reducing nitrogen losses (by reducing mineral fertilizer requirements), by more precise delivery of manure nitrogen to the crop, by the increased agronomic flexibility and by other co-benefits such as reduction of odour and crop contamination (Webb et al. 2010). The overall benefit-cost ratio depends especially on equipment costs and abatement efficiency.

173. ***Impact of reduced ammonia losses on N cycle.*** If no crops are present, or growing, following manure application to take up the readily available N, the risk of N loss via leaching or gaseous N_2O increases. Hence incorporation and esp. injection of manures involves a risk of exchanging air pollution for water pollution, but reduces the risk of surface run-off from subsequent rainfall events. For this reason, the timing of slurry and solid manure application needs to balance the potential for low ammonia emissions against the other loss pathways, while considering the timing of crop needs. Ammonia mitigation makes an important contribution to the overall reduction of nitrogen losses from agriculture, thereby maximizing the agronomic benefits of applied mineral fertilisers. The financial benefit to the farmer of reducing the need for mineral nitrogen fertilizers is complemented by a regional-scale greenhouse gas benefit due to reduced mineral fertilizer needs, given the high energy costs of nitrogen fertilizer manufacture.

174. Results suggest that injection of slurry may either increase or have no impact on emissions of N_2O. The addition of readily-degradable C in slurry has been proposed as a mechanism for increasing emissions of N_2O by more than would be expected due to the additional N entering the soil as a result of ammonia abatement. This addition of readily-degradable slurry-C, without significantly aerating the soil, may increase denitrification activity. There are a number of reasons why reduced ammonia emission application techniques would not always lead to greater emissions of N_2O such as: (1) deeper injection (> 5 cm) or incorporation, by increasing the length of the diffusion path from the site of denitrification to the soil surface, may lead to a greater proportion of denitrified N being emitted as N_2; (2) the subsequent soil moisture status and hence aeration may not be suitable for increased N_2O production; (3) in soils already well-supplied with both readily-degradable C and mineral N any increase in N_2O emission may be too small to have a significant effect; and (4) the impact of subsequent weather on soil moisture content and water-filled soil pore space will also effect subsequent emissions of N_2O. The reflection of these interactions is that mitigation of ammonia emissions reduces the N_2O emissions associated with atmospheric nitrogen deposition to semi-natural ecosystems.

175. Incorporation of farmyard manure (FYM) appears to reduce or have no impact on N_2O emissions. In contrast to slurry, there is evidence that readily-degradable-C is lost as part of the effluent arising during storage of solid manures. Hence the C added to soil by incorporation of solid manures will have less effect on microbial metabolism.]

Category 2 techniques

176. ***Verification of Category 2 techniques.*** Category 2 techniques may form a useful part of a package of measures to reduce ammonia emissions, but may be more uncertain or the emission reductions inherently harder to generalize. For this reason, Annex IX [see the options for revision ECE/EB.AIR/WG.5/2010/14] specifies that, where Category 2 methods are used to achieve the specified emission reductions, details should be provided by parties to verify the reported emission reductions from the methods. Such verification should also be provided for Category 3 methods where these are used. For techniques based on a) increasing the rate of infiltration into the soil and b) presurized injection of slurry documentation should describe the practice used and give evidence from field or farmscale measurements demonstrating and justifying the emission reduction. Specific requirements apply to the verification of Atmospheric Timing Management Systems (ATMS) as described in the paragraph below.

177. ***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 by at least 30%. 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 actively diluting further.

Table 21(a): Category 1 abatement techniques for slurry* application to land.

Abatement measure	Land use	Emission reduction (%)†	Factors affecting emission reduction	Limitations to applicability compared with the reference	Estimated costs relative to reference
(a) Band-spreading slurry with a trailing hose	Grassland Arable	30-35%%	More crop canopy will increase reduction, depending on placement precision and the extent of herbage contamination.		1.3 May be cost neutral or net financial benefit if co-benefits considered.
Band spreading with trailing shoe	Grassland Arable (pre-seeding) and row crops	50-60%	More crop canopy will increase reduction, depending on placement precision and the extent of herbage contamination.	Not suitable for growing solid seeded crop or	1.5 May be cost neutral or net financial benefit if co-benefits considered.
(b) Injecting slurry (open slot)	Grassland	70%	Injection depth ≤ 5 cm	Unsuitable where: Slope >15%; High stone content; Shallow soils; High clay soils (>35%) in very dry conditions, Peat soils (>25% organic matter content).	1.9
(c) Injecting slurry (closed slot)	Grassland Arable	80 (shallow slot 5-10 cm) 90 (deep injection >15cm)	Effective slit closure		1.9
(d) Incorporation of surface applied slurry	Arable	Immediately by ploughing = 90%			2.0
		Immediately by non-inversion cultivation = 70%			1.8
		Incorporation after 4 hrs = 45-65%	Efficiency depends on application method and weather conditions between application and incorporation		1.5
		Incorporation within 24 hours = 30%			1.1
(e) Active dilution of slurry of >4% DM to <2% DM for use in water irrigation systems	Arable Grassland	30%	Emission reduction is proportional to the extent of dilution. A 50% reduction in dry matter (DM) content is necessary to give a 30% reduction in emission	Limited to water irrigation systems. Not appropriate where irrigation is not required.	~1.1

* slurry is defined as flowable manure usually less that 8-10% dry matter. Material with a higher dry matter content or containing high amounts of fibrous crop residue may require treatement (e.g. chopping or water addition) to be applied as a slurry, and should otherwise be handled as for solid manures (Table 1b).
† Average emission agreed to be achievable across the UNECE region.

Table 21 (b): Category 1 abatement techniques for solid manure application to land

Abatement measure	Land use	Emission reduction (%) †	Factors affecting emission reduction	Limitations to applicability compared with the reference	Estimated costs relative to reference
(d) Incorporation of surface applied manure	Arable	Immediately by ploughing = 90%	Degree of burying the manure		2.0
		Immediately by non-inversion cultivation = 60%	Degree of burying the manure		1.8
		Incorporation after 4 hrs = 45-65%	Degree of burying the manure Efficiency depends on time of day of spreading and weather conditions between application and incorporation;		1.5
		Incorporationwithin 12 hours = 50%			1.1
		Incorporation within 24 hours = 30%			1.1

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

178. 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. For these reasons, apart from the active dilution of slurry for irrigation (Category 1), this method is included as Category 2.

179. 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. Information to verify such systems should include demonstration of the overall ammonia emission reduction, taking account of the emissions from both the low DM and high DM fractions.

180. 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. Information to verify such systems should specify the time delay between slurry application and washing the grass with water, the amounts of water used, and the percentage emission reduction achieved.

181. ***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 typically 60 per cent, similar to that for open slot injection, have been achieved in field trials, but further evaluation of the technique is needed.

182. ***Application timing management systems (ATMS)***. Ammonia emissions are highest under warm, dry, windy conditions (i.e. when evapotranspiration rates are high). Emissions can be reduced by optimising the timing of application, i.e. cool humid conditions, in the evenings, before or during light rain and by avoiding spreading during warm weather conditions, particularly during periods when solar elevation, and hence solar radiation input, is most intense (June/July) (Riedy and Menzi 2007). This is potentially a cost-effective approach as it can be done using broadcast application equipment. Potential emission reductions achievable through these measures will vary depending on regional and local soil and climatic conditions, and therefore the suite of measures that may be included will be specific to regional conditions.

183. While the benefits of using such timing management practices has been long known, the main constraints are:

(a) the need to demonstrate that the approach can deliver a specified ammonia emission reduction target in practice,
(b) the need to carefully define what is meant by reference conditions (in order to ensure correct reporting of the outcomes), and
(c) the need to implement a system to manage this approach that verifies its efficacy and implementation.
(d) reduced flexibility when spreading manure with respect to soil trafficability, labour and equipment availability and consideration of other regulations.

184. This approach can be considered as rather different to the technical methods listed as Category 1, such as band spreading, manure incorporation, where the efficiencies reported in Table 21 are based on the average outcomes from many studies. In the case of ATMS the assessment uses the responses of models (based on many studies) to the actual timing practice.

185. In order to allow the benefits of timing practices to be included as an abatement measure, the above listed constraints must be addressed. This can be achieved through the use of an Application Timing Management System (ATMS), which is here defined as: *a verifiable management system for the direction and recording of solid and liquid manure application at different times, the adoption of which is demonstrated to show quantified farm scale reductions in ammonia emissions.* The use of any ATMS must demonstrate achievement of a specified ammonia emission reduction target, by comparison to the reference, in order for its benefit to be considered as part of international emission control strategies.

186. Application Timing Management Systems may be designed to exploit several principles in the variation of ammonia emissions, the benefits of which will vary with local climate, so that ATMS implementations will vary regionally. The following principles may be exploited in an ATMS:

(a) *Weather-determined variation in ammonia emissions.* Ammonia emissions tend to be smaller in cool and wet conditions and after light rain (though water-logging of

soils can make spreading conditions unfavourable). Ammonia emissions can therefore be forecasted by coupling ammonia emissions models with weather forecasting, as is already available in some countries, with land application timing restricted to forecasted periods of low ammonia emissions.

(b) *Seasonal variation in ammonia emissions.* Ammonia emissions can be estimated on a seasonal basis by generalising weather conditions for particular seasons. For example, seasonal variations lead to largest ammonia emissions in warm summer conditions and smaller emissions in cool moist winter conditions. Subject to other constraints, such as the objective to match manure application to the timing of crop needs, and the need to avoid water pollution, a targeted seasonal management of solid and liquid manure application has the potential to reduce overall annual ammonia emissions.

(c) *Diurnal variation in ammonia emissions.* Ammonia emissions tend to be smaller at night due to reduced windspeed, cooler temperatures and higher humidity.

(d) *The effect of timing of animal housing versus grazing on ammonia emissions.* Ammonia emissions from livestock allowed to range outdoors with sufficient foraging area (e.g. cattle grazing) tend to be much smaller than for housed livestock, since this practice avoids ammonia emissions associated with housing, manure storage and landspreading of slurries and solid manures. Therefore, subject to other constraints, such as water and soil quality issues arising from grazing during the winter, increasing the period in which animals are in the field (especially when 24 hours a day) can reduce ammonia emissions. Changes in timing practice may be included in an ATMS since these affects the total amounts of manure to be spread.

187. *Verification procedures for ATMS.* One of the main challenges for any ATMS is to demonstrate an appropriate verification of the approach, particularly given the requirement to demonstrate the achievement of a specified emission reduction. The ATMS approach is considered most relevant at a farm scale, as it results from the overall outcome of a package of timing practices. The emission reduction target should be applied on an annual scale as the emission reduction potential of this method is time dependent.

188. Verification of an ATMS should include each of the following steps:

(a) *Verification of the core biophysical modelling tool used.* A transparent description of the numerical model used should be provided, underpinned by appropriate independent verification from field measurements.

(b) *Verification of the effect of a specific timing management on ammonia emissions.* The degree to which the timing management leads to the target emission reduction required as compared as compared with the reference conditions for that region should be demonstrated for any ATMS being used.

(c) Verification that actual practices conform to those reported. Any ATMS should be implemented in conjunction with an appropriate recording system, to ensure and demonstrate that the timing management recorded in the ATMS is being fully implemented.

189. *Definition of the reference conditions for an ATMS.* In the case of most low emission techniques for land application, the percentage reduction achieved can be

generalized over a wide climatic area. By contrast, where an ATMS is used, a more detailed definition of the reference conditions is needed. Overall, the same *reference technique* applies (free broadcast surface application of slurries and solid manures), but where an ATMS is used, the reference must also be defined on a farm level according to existing practices. In order to account for regional variability in climate and inter-year variability in meteorological conditions, the reference condition for ATMS is extended to include: *"the combination of manure application management practices, and their timing, at a farm scale during a specified reference period, when using the reference application method (broadcast spreading), accounting for three-year variability in meteorological conditions"*.

190. The emission reduction potential of an ATMS should be verified for the region within which it is adopted. Numerical ammonia emission simulation models will, in general, need to be used as part of the verification of ATMS.

191. An ATMS may be used in combination with other measures for reducing ammonia emissions following land application of manures, such as slurry application technologies or incorporation of manures into soil. However, the additional absolute ammonia emission reduction of an ATMS will vary depending on the emission reduction potential of the accompanying application method. The joint contribution of both low emission application methods and an ATMS should be assessed to ensure that the overall farm-scale ammonia reduction target is met.

192. Depending on the type of ATMS to be implemented, the main additional costs will be associated with reduced flexibility in timing of manure application, and the associated administrative costs necessary for the verification. Potential cost savings may be found by combining ATMS approaches with advice on managing farm nitrogen stocks more effectively such as through a proven expert system.

193. Application prior to or during weather conditions that increase the risk of nutrient loss to waters should be avoided. Aspects of safety associated with machinery operation at certain times, particularly during hours of darkness, should also be considered when designing an ATMS. Conditions that favour reduced ammonia emissions (e.g. humid, no wind) may give rise to problems with offensive odours by preventing their rapid dispersion.

Category 3 techniques

194. *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 modifying or additing to feed (e.g. benzoic acid) (see section on Livestock Feeding Strategies) 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.

195. 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 and health and safety issues. 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.

196. When acidification is conducted in the animal house, 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.

197. *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.

VIII. FERTILIZER APPLICATION

(a) Urea-based fertilizers

198. Emission from fertilizer applications are dependant on fertilizer type, weather and soil conditions. Emissions from urea-based fertilizers are much greater than other fertilizer types because rapid hydrolysis of urea will cause localised rise in pH. Rapid hydrolysis often occurs in soils with a lot of urease enzyme due to an abundance of crop residue. Emissions from ammonium sulphate (and diammonium phosphate) are greater following application of these fertilizer types to calcareous (high pH) soils. Emission reduction techniques are therefore focussed on applications of urea-based fertilizers to all soil types and of ammonium sulphate (and diammonium phosphate) applications to calcareous soils. Emission reduction techniques rely on either slowing the hydrolysis of urea to ammonium carbonate, or encouraging rapid transfer of the fertilizer into the soil (Sommer et al., 2004).

199. The use of methods to reduce ammonia emissions from urea- and ammonium-based compounds makes an important contribution to overall ammonia emission reductions in agriculture. In particular it should be noted that ammonia emissions from urea-based fertilizers (typically 5-40% nitrogen loss as ammonia) are much larger than those based on ammonium nitrate (typically 0.5-5% nitrogen loss as ammonia). Although ammonium nitrate is the main form of nitrogen fertilizer used in Europe, there remains an ongoing risk for ammonia emission that its use might be restricted or prohibited in certain countries in the future. In the absence of measures to reduce ammonia emissions from urea-based fertilizers, such a change would be expected to significantly increase regional ammonia emissions.

200. *Reference technique.* The reference application technique is surface broadcast application of the nitrogen fertilizer.

Category 1 techniques

201. Category 1 techniques for urea-based fertilizers include: urease inhibitors, slow-release coatings, soil injection, rapid soil incorporation, and irrigation immediately following application. Of these, soil injection, rapid soil incorporation, and irrigation immediately following application would also apply to ammonium sulphate (and diammonium phosphate) applications to calcareous soils.

202. *Urease inhibitors* delay the conversion of urea to ammonium carbonate by directly inhibiting the action of the enzyme urease. This delayed/slower hydrolysis is associated with a much smaller increase in pH around the urea prill and, consequently, a significantly lower ammonia emission (Chadwick et al., 2005; Watson et al., 1994). The delay to the onset of hydrolysis also increases the opportunity for the urea to be washed into the soil

matrix, further reducing the potential for ammonia emissions. Approved urease inhibitors have been listed by the European Union (2008) (http://www.clrtap-tfrn.org/webfm_send/239)

203. *Polymer coated urea granules* provide a slow release fertilizer that may reduce ammonia emissions (e.g. Rochette et al., 2009), the extent to which will depend on the nature of the polymer coating and whether used with surface fertilizer application or combined with urea injection.

204. *Incorporation of fertilizer into the soil* either by direct closed-slot injection of by cultivation can be an effective reduction technique (Sommer et al., 2004). For urea prills, combining injection or incorporation with slow-release coatings may allow for a single fertiliser application prior to crop establishment negating the need for surface application at a later date. Depth of injection and soil texture will influence reduction efficiency. Mixing of the fertilizer with the soil through cultivation may be a less efficient reduction measure than injection to the same depth because a part of the mixed-in fertilizer will be close to the surface.

205. *Irrigation with at least 5mm water* immediately following fertilizer application has been shown to reduce ammonia emissions by up to 70% (Oenema and Velthof, 1993; Sanz-Cobeña, 2010). Water should not be applied to wet soils beyond field capacity. This is only considered a category 1 technique where there is a water need for irrigation, as the method may otherwise increase the risk of nitrate leaching.

206. *Switching from urea to ammonium nitrate* fertilizer is a rather easy way to reduce ammonia emissions, with an effectiveness of around 90%. The cost of this measure is simply the price differential between the two fertilizer types.

207. ***Potential cost implications.*** The increased cost of implementing these techniques will be offset to some extent (or provide a net benefit) by savings on fertilizer use to achieve the same yield as for the reference method, or an increased yield from the same rate of fertilizer application. Whether there is a net saving or cost to the farmer depends on the methods chosen and local agronomic conditions.

208. ***Impact on N cycle.*** If applied at agronomically sensible rates and times, improved crop nitrogen uptake will be the main benefit of mitigating ammonia emissions, with minimal increases via the other loss pathways (e.g. nitrate leaching, denitrification). In addition, by reducing ammonia emissions, a similar reduction in indirect nitrogen losses is expected (e.g. by reduced leaching and denitrification from forest soils). Considering the whole system (agricultural land, non agricultural land and transfers by atmospheric dispersion), these measures are not generally expected increase overall nitrate leaching or

nitrous oxide loss. The measures focus on retaining nitrogen in the farming system, thereby maximizing productivity.

Table 22: Mitigation options for reducing ammonia emissions from urea and ammonium based fertilisers.

Abatement measure	**Fertilizer type**	**Emission reduction (%)**	**Factors affecting emission reduction**	**Applicability**	**Estimated costs relative to reference***
Urease inhibitor	Urea-based	70% for solid urea, 40% for liquid urea ammonium nitrate		All	To be estimated
Slow release fertilizer (polymer coatings)	Urea	c. 30%	Polymer coating type and integrity; fertilizer application technique (surface or injected)	All	To be estimated
Closed-slot injection	All	80-90%	Depth of placement; soil texture; closure of slot (improperly closed slots may lead to high emissions due to high concentration of urea in the slot increasing pH)	Tilled or reduced-till land prior to seeding or during the seeding operation	To be estimated
Incorporation	All	50-80%	Depth of mixing; soil texture	Tilled land prior to crop establishment	To be estimated
Irrigation	All	40-70%	Irrigation timing and volume (immediate with c. 10mm is most effective)	Where crop irrigation is commonly practiced	To be estimated

* Local costs/benefits will vary, though trials have shown that the financial benefit of increased crop productivity can more than outweight the costs of the technique for some abatement measures.

Category 2 techniques

209. *Application timing management system (ATMS).* This represents a verified system to exploit the variation in ammonia emission potential based on environmental conditions, so as to use management of application timing to reduce overall emissions. Fertilizer applications under cooler conditions and prior to rainfall (although bearing in mind the need to avoid the associated risk of run-off to water bodies) are associated with lower ammonia emissions. If it is to be used, this strategy has to be associated with verification of the reference conditions and of the achieved reductions in emission, as discussed under the sand application section (Paragraphs 182-193).

210. *Mixing urea with acidified sulphate.* Co-granulation of urea and ammonium sulphate may reduce ammonia emissions compared with urea alone on certain soil types (Oenema and Velthof, 1993). Further studies are required across more soil types before recommendations can be made.

Category 3 techniques

211. *Band incorporation of urea.* This technique is not recommended on soils with high urease activity (e.g. with crop residue) and poor ability to adsorb urea as it can be

associated with increased ammonia emissions in comparison with the reference technique (e.g. Rochette et al., 2009).

(b) Ammonium based fertilisers

Category 1 techniques

212. Several of the techiques described above for urea can also be used to reduce ammonia emissions from ammonium based fertilizers. The highest risks apply to ammonium sulphate and ammonium phosphate based fertilizers when applied on calcareous or other high pH soils. Category 1 techniques for ammonium based fertilizers include: incorporation, injection, immediate irrigation and slow release fertilizers with polymer coatings (subject to the result of trials).

Category 2 techniques

213. 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 emissin 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. The approach may be integrated into Application Timing Management Systems.

IX. OTHER MEASURES RELATED TO AGRICULTURAL NITROGEN

(a) Grazing

214. 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.

215. 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.

(b) Manure treatment

216. Research on various options of reducing NH_3 emissions by manure treatment have been investigated. 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; for this reason, systems for composting of manure should consider the inclusion of additional methods to reduce NH_3 emissions from this source, such as air scrubbing systems.

(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.

217. 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. An exception is the use of air scrubbing systems for manure composting facilities (Category 1), which are well-tested but have significant costs.

(c) Non-agricultural manure use

218. 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.

(d) Manure additives

219. A wide variety of manure additives has been suggested to reduce NH_3 emissions. 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.

X. NON-AGRICULTURAL STATIONARY AND MOBILE SOURCES

220. 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 (Sutton et al. 2000). 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).

221. 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.

(a) General techniques

222. *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.

223. *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.

224. 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.

225. 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.

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

(b) Techniques suited to selected sectors

227. *Emissions of NH_3 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.

228. *Ammonia slippage in staionary catalytic reduction plant.* 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 NO_x control equipment. The potential for NH_3 emissions from this source will need to be considered carefully as NO_x controls increase through wider adoption of BAT.

229. *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.

230. *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).

231. *Capping landfill sites.* 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.

232. *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.

233. *Horses.* 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 from agricultural inventories. 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, but are described elsewhere in this document.

(c) Production of inorganic N fertilizers, urea and ammonia

234. 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.

235. 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.

236. 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-N/m^3 may be achieved through maximizing product recovery and minimizing atmospheric emissions by appropriate maintenance and operation of control equipment.

237. 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.

238. 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).

239. 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.

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