

Notes on the 2002 NAS Study:

Air Emissions from Animal Feeding Operations: Current Knowledge, Future Needs

William J. Weida

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Please Note: the following synopsis has been taken directly from the 2002 pre-publication version of Air Emissions from Animal Feeding Operations: Current Knowledge, Future Needs by the National Academy of Sciences (NAS). All quotes and paraphrases of this document are cited with the page number of their location. Some quotes and paraphrases have been underlined by this author for emphasis. All bolded comments are interpretations made by this author and are not from the NAS.

Chapter 2:

Chapter 2 provides statistics to characterize the livestock industry and it includes a number of opinions about the nature and competitiveness of a livestock industry that is rapidly becoming specialized. (pages 21-27) It defines an AFO using the EPA definition of “a lot or facility where animals have been, are, or will be stabled and confined and fed or maintained for a total of 45 days or more in any 12 month period and where crops, vegetation forage growth, or post harvest residues are not sustained in the normal growing season over any portion of the lot or facility.” (40 CFR, part 122.23(b)(1)) This leads directly into a discussion of animal units. Here, the NAS finds:

Finding and Recommendation 1: Much confusion exists about the use of the term "animal unit" because EPA and USDA define animal unit differently. Both EPA and USDA should agree to define animal in terms of animal live weight rather than an arbitrary definition of animal unit. (page 28)

Thus, the NAS finds that the fundamental definition of an animal unit—from which all calculations about the emissions from an AFO stem—is “arbitrary.” This means that all calculations based on these units must also be “arbitrary.”

The chapter then describes the specifics of each type of AFO including weights, feed, and manure management practices. (page 28-33)

In a discussion of the economics of emissions and manure management, the NAS notes that “a product that costs more to use than the value of benefits generated by its use is a waste. Once a product is identified as a waste, profit-maximizing behavior seeks the least cost (total cost minus total revenue) option for waste disposal...Emissions and manure management become a policy issue when not all costs and benefits of livestock production are realized by the farmer...Policy is generally designed to maximize social welfare by maximizing total benefits (private and public) minus total costs (private and public)...Thus, the policy objective with respect to emissions and manure management on livestock farms may be to limit emissions to the rate at which the...marginal health and environmental damage avoided is greater than or equal to the marginal cost of emissions mitigation to farmers, the community, and consumers...”(page 34) **Thus, it is necessary to know the costs imposed by the emissions to**

make this calculation. If you can't make the calculation, you can't make the policy.

According to the NAS, to make the calculation you would need:

1. accurate estimates of emissions.
2. accurate measures of environmental quality and public health related to emissions.
3. accurate knowledge of the dollar value society places on (2) and on the dollar costs to farmers. (page 35)

Of course, we don't know any of these things. As a result, the NAS goes on to note that:

“Where manure is considered a waste product or a product of little positive value, farm practices to limit emissions and to manage manure are driven by regulatory requirements (such as the EPA CAFO rule and state rules) and non-regulatory guidelines (such as NRCS standards and Cooperative Extension Service recommendations).” (page 35) **Unfortunately, as this report notes, there are no scientifically supportable methods for determining emissions and thus, no supportable methods for enforcing either the guidelines or the regulations. As the NAS puts it:**

“Information needs arising from the economics of emissions and manure management are substantial....Accurate measurement of emissions from current and proposed livestock production and manure management systems is one of the most critical components. The economic basis for measurement of emissions is that society cannot rationally decide how much cost to incur to decrease emissions without knowing the extent to which emissions will be decreased and value of the benefits that will be generated by that decrease.” (page 36)

The NAS study then lists a number of alternative manure management and emission strategies. (page 36-40) However, the NAS notes that “currently available options for control or mitigation of air emissions from livestock and poultry operations are limited.” (page 36)

In sum, a number of methods for decreasing odor are being studied, but none are effective enough to warrant a NAS designation as either “effective” or scientifically supportable.

Chapter 3:

This chapter covers the chemical constituents of air emissions from AFOs and the conditions that contribute to their spread. 50% of US emissions of nitrogen and 25% of US emissions of Nitrous Oxide come from animal manure (Table 3-1, page 42).

On a global and national scale, the main concern is the role of nitrogen in the formation of ammonia which is the key element in a “nitrogen cascade” in the atmosphere. This “cascade” of ammonia can, in sequence, lower atmospheric visibility, raise soil acidity, decrease forest productivity, decrease ecosystem biodiversity, increase stream acidity, and decrease coastal productivity. In addition, Nitrous Oxide has a global warming potential that is about 300 times as great as carbon dioxide (page 43).

On a regional scale, hydrogen sulfide emissions could be important contributors to atmospheric sulfur in areas with a high concentration of AFOs (page 45).

On a local scale, odor is the result of a large number of compounds and, given its subjective nature, measurement by human panels will be the method of choice for the foreseeable future. Odor must be quantified to calculate the local impacts of AFOs (page 46).

Factors affecting air emissions: Emissions are affected by differences in rainfall, temperature, wind speed, topography and soils as well as the mean ambient temperature and moisture in an area. “Averaging reported emission factors does not remove these climate factors,

especially if the emission factors selected were determined mostly in one climatic region of the country. This bias remains when emission factors for one species are applied to others by adjusting them only to reflect differences in excretion rates.” (page 47) Differences in emissions can also result from land availability for manure or lagoon use, evaporation rates, differences in soil textures and drainage, differences in soil microbial action, differences in the way the breed of a given animal species will respond to feed, and geographic and climate differences (page 47). **This means current methods of permitting based only on a general number of animal units are biased and not applicable to any area other than the specific locale where the average readings were generated. The NAS study goes on to note that:**

“differences may not be as important for annual emissions of major gaseous species (e.g., NH₃, CH₄) as for shorter-term emissions of [particulate matter] and odors.” (page 48) **These underlined items, where the bias is likely to be the greatest, are precisely the things that local permitting authorities are supposed to protect off-site residents against.**

Hourly, daily and seasonal changes: Changes in emissions at individual AFOs from these factors are specifically discussed in the study because “Failure to account for short-term cycles in an experimental design could result in significant systematic error in a derived annual emission factor.”(page 48) “The impact of daily cycles and upsets on the estimates of annual emissions may not be important, provided a sufficient number of observations are made to account for them. However, given the current paucity of emissions data for the development of emission factors for AFOs, it is not possible to determine to what extent such cycles and upsets may have impacted published emission measurements...averaging does not compensate for the systematic bias that may be present as a result of a failure of experimental design to account adequately for such events.” (page 49)

This states that the improperly designed experiments on which all animal unit calculations currently used in permitting are based may result in a bias that affects all emission calculations. It doesn’t take much imagination to realize that there was an incentive to make emission calculations as favorable to the AFOs as possible when they were first developed. This could easily have been done by taking measurements at times and under conditions when emissions would be lower. These experimental errors cannot be removed by averaging and they would bias all future calculations of emissions to the low side.

The NAS then goes on to show (Figure 3-1) that nitrogen emissions from hogs do not increase in a linear manner with age. Instead, they increase in significant jumps every 20 days—from 40 to 120 days—and nearly double during the last half of the finishing period. As a result, nitrogen emissions cannot be validly calculated for a hog operation by simply averaging together the emissions from each weight—this would significantly underestimate the emissions from larger animals and over estimate the emissions from smaller animals (page 50). **This means that all emission figures that come from general tables (such as those in the USDA Waste Management Handbook) are inaccurate—and that they probably overestimate the emissions from a farrowing operation and underestimate the emissions from a finishing operation. Accurate emissions can only be calculated by knowing the specific number of hogs in each age group at a specific location—and even then you must take all the terrain and atmospheric conditions into account.**

The chemical compounds that result in odor have life spans in the atmosphere of from one day to many months, depending on the compound. These life spans affect the range over which the odor travels. As these compounds rise above the lower layers of the atmosphere, their

life spans and ranges may be much greater. When estimating emissions, one must account for the roughness of the terrain, the wind direction and strength, and the amount of surface heating. “[E]xtreme local pollution episodes generally occur ...when ground level inversions are strongest...Local orographic conditions, such as lying in a valley, can exacerbate inversions and dictate the wind fields.” (page 54, 55). However, the complexities of various kinds of air emissions and time and space of their distribution make direct measurement at an individual AFO impractical. (page 55)

Thus, the factors needed to determine the air pollution from an AFO cannot now be measured or modeled. As a result, there is no way to determine how much air pollution will come from an AFO without massive research into this area. This means that any permitting process is essentially operating without the information necessary to grant the permit.

Chapter 3 then discusses at length the many health and environmental impacts of air pollution from AFOs. It finishes this discussion by ranking the effects of air pollution using three levels of concern: major, significant, and insignificant. (page 55-59) Out of nine items ranked, only two are given the highest rank—ammonia on a global, national and regional level and odor on a local level. (Table 3-7, page 59) **Thus, one of the two most important effects of AFOs on health and the environment—odor—cannot be properly measured at this time and cannot be accurately determined by the use of current methods based on animal units. Without these measurements, this factor can neither be regulated nor controlled by the permitting authority. This invalidates the entire permitting process which proceeds on the assumption that the requirements specified in the permit can be inspected and enforced. The result of this is three findings in the NAS report:**

Finding and Recommendation 2. Air emissions from animal feeding operations are of varying concern at different spatial scales, and as a result, USDA and EPA should first focus their efforts on the measurement and control of those emissions of major concern. (page 59)

This says that the effect of odor on the local environment should be a priority concern for the USDA and EPA.

Finding and Recommendation 3. Measurement protocols, control strategies and management techniques must be emission and scale specific. For ammonia, methane, and nitrous oxide, the aim is to control emissions per unit of food produced rather than emissions per farm. For air emissions important on a local scale—hydrogen sulfide, particulate matter, and odor—the aim is to control ambient concentrations at the farm boundary and/or nearest occupied dwelling. Monitoring should be conducted to measure concentrations of air pollutants of possible health concern at times when they are likely to be highest and in places where the densities of animals and humans, and typical meteorological conditions, are likely to result in the highest degree of human exposure. (page 60)

This says that all monitoring must be modified to each specific AFO—there is no such thing as a general monitoring protocol. It further says that emissions will vary over time and that monitoring should be done at those time that the emissions are highest.

Finding and Recommendation 4. There is little credible scientific information on the effects of mitigation technology on concentrations, rates, and fates of air emissions from AFOs. Best management practices (BMPs) aimed at mitigating AFO emissions should continue

to be improved and applied as new information is developed on their character, amount, and dispersion of these air emissions, and on their environmental and health effects.

Finding 4 says that there is little or no scientifically credible information on which to base an evaluation of the likely effects of the emissions, even if one could measure the emissions (which Finding 3 and Chapter 4 say you can't.)

Chapter 4:

This chapter deals with measurement of emissions. It notes that measurement of AFO emissions is complicated by the fact that they arise from multiple area sources and not distinct point sources. This causes emissions to vary through time and over space, and emissions are further affected by local or regional meteorological conditions. This creates the fundamental problem—measurement of off-property impacts from every AFO is not practical, but local, state and federal agencies need some way to estimate emissions. (page 61-63) Unfortunately, the NAS study finds that “In the case of odor, no formal effort to standardize methodology [to measure odor emissions] has occurred in the United States.” (page 63) **Because there are no recognized standards for odor emissions, there are also no standards for permitting of AFO facilities and no standards that can be applied to protect neighbors of the facilities.**

The NAS report then goes into a detailed discussion of measuring and monitoring the concentrations and compositions of the various AFO emissions. A fairly extensive section on measuring odor is included in this section. Specifications of the recently adopted European standard for odor are discussed and the NAS finds that for the US: (pages 64-72)

Finding and recommendation 5. Standardized methodologies for odor measurement have not been adopted in the United States. A standardized methodology should be developed in the U.S. for objective measurement of odors and a standardized unit of measurement of odor concentration should be adopted in the U.S. (page 71)

This chapter then devotes considerable space to discussing the measurement of emissions. The NAS notes that “To determine emissions from area sources, it is necessary to take into account the local meteorology and the wind field.” (page 75) The NAS finds:

Finding and recommendation 6. The complexities of various kinds of air emissions and the temporal and spatial scales of their distribution make direct measurement at the individual farm level impractical other than in a research setting. The EPA should develop and carry out intensive field campaigns to evaluate the extent to which ambient atmospheric concentrations of the various species of interest are consistent with estimated emissions and to understand how transport and chemical dynamics shape the local and regional distribution of these species. (page 79)

Finding and recommendation 7. Scientifically sound and practical protocols for measuring air concentrations, emission rates, and fates are needed for the various elements (nitrogen, carbon, sulfur), compounds (e.g., ammonia [NH₃], CH₄, H₂S), and particulate matter. Reliable and accurate calibration standards should be developed, particularly for ammonia. Standardized sampling and compositional analysis techniques should be provided for PM, odor, and their individual components. The accuracy and precision of

analytical techniques for ammonia and odor should be determined, including intercomparisons on controlled (i.e., synthetic) and ambient air.

In summary, this chapter finds that although there is a significant need for measurement of concentrations of substances and estimates of emissions from AFOs, there is very little information on this subject. The NAS attributes this to a lack of research. It then goes on to note:

“The availability of concentration measurement methods is a prerequisite for emission rate determination. Many of the emission rate methods used for other sources could be adapted to determine emission rates of substances from AFOs. Given the variability in types of AFOs, configurations, populations, climate and so forth, the variability of emission rates is expected to be great temporally, spatially, and from one AFO to another. (page 80)

Thus, it is possible to measure most of the emissions using techniques from other areas—it just hasn’t been done. However, if it is ever accomplished, every measurement will be unique to the specific AFO where the measurement occurred and it should neither be generalized to other AFOs or averaged with other AFO emission measurements to create a general model.

Chapter 5:

This chapter first discusses the way emissions are currently calculated by the EPA using the “emission factors” approach. This approach is based on observed air emissions from a set of “average” AFOs that are supposed to represent all AFOs. Emission factors are then based on mass of each substance emitted per animal or animal-based unit per unit of time. The NAS feels this approach has a number of weaknesses, among which are the difficulty of selecting the AFOs deemed to be representative of the entire industry and the use of data “which do not exist today in sufficient numbers to provide reasonable confidence in the results.” (page 81)

The NAS critique of the “emissions factors” model currently used by the EPA is devastating:

- a. The emissions factor model EPA (2001) does not provide a methodology to adequately determine air emissions from individual AFOs.
- b. Both the model farm construct and the data are inadequate.
- c. The model farm construct used by EPA (2001) cannot be supported for estimating air emissions from an individual AFO.
- d. There is a great deal of variability among AFOs that cannot be accounted for using the emission factors approach.
- e. Additional factors not included in the EPA model that affect emissions include animal feeding and management; animal productivity; housing, including ventilation rate and confinement area; use of abatement strategies such as sprinklers to decrease dust; and physical characteristics of the site such as soil type and whether the facility is roofed.
- f. Emissions are likely to differ for different climatic (long-term) and weather (short-term) conditions including temperature, wind, and humidity.
- g. Improvements in the model farm construct are needed for both discrete variables (e.g., management, confinement conditions, location) and continuous variables (e.g., nutrient input, productivity, meteorology).
- h. Concerns about the quality of data (use of non-peer-reviewed data), lack of data, inappropriate use of data, and representativeness of data. (page 83)

In sum, the current method of calculating emissions used by EPA is worthless for making any type of estimate of emissions from an AFO. As a result, the NAS found:

Finding and recommendation 8. Estimating air emissions from AFOs by multiplying the number of animal units by existing emission factors is not appropriate for most substances. The science for estimating air emissions from individual AFOs should be strengthened to provide a broadly recognized and acceptable basis for regulations and management programs aimed at mitigating the effects of air emissions.

With the current methods regarded as inadequate, the rest of the chapter investigates regression analysis and process-based models. The NAS feels that process based models provide the greatest chance of yielding scientifically sound estimates. (page 84-85) The NAS finds:

Finding and recommendation 9. Use of process-based modeling will help provide scientifically sound estimates of air emissions from AFOs for use in regulatory and management programs. EPA and USDA should use process-based mathematical models with mass balance constraints for nitrogen-containing compounds, methane, and hydrogen sulfide and should investigate the potential use of a process-based model to estimate mass emissions of odorous compounds and potential management strategies to decrease their impacts. (page 85)

In addition to their concern with direct emissions from AFOs, the NAS is also concerned with the total emission load from livestock operations. This includes the emissions that come from raising the crops that feed the livestock and other livestock-related activities. The total amount of these emissions is important from a global perspective. (page 85-94) Here the NAS finds:

Finding and recommendation 10. A systems approach, which integrates animal and crop production systems both on and off (imported feeds and exported manure) the AFO, is necessary to evaluate air emissions from the total animal production system. Regulatory and management programs to decrease air emissions should be integrated with other environmental (e.g., water quality) and economic considerations to optimize public benefits. (page 94)

Finding and recommendation 11. Nitrogen emissions from AFOs and total animal production systems are substantial and can be quantified and documented on an annual basis. Measurements and estimates of individual N species components (i.e., NH₃, molecular nitrogen [N₂], N₂O and nitric oxide [NO]) should be made in the context of total N losses. Control strategies aimed at decreasing emissions of reactive nitrogen compounds (Nr) from total animal production systems should be designed and implemented now. These strategies can include both performance standards based on individual farm calculations of nitrogen balance, and technology standards to decrease total system emissions of reactive N compounds (Nr) by quantifiable amounts. (page 95)

Chapter 6:

This chapter covers government regulations and programs. While the chapter is mostly descriptive, in its characterization of the permitting process the NAS notes:

“The state permitting process is designed to protect the public by ensuring that pollutant concentrations downwind from agricultural sources do not violate the ambient air quality standards established to protect human health (the NAAQS). These standards protect human health by prescribing maximum ambient concentrations and averaging time periods for criteria pollutants...if modeling of emissions demonstrates that a proposed facility will comply with the NAAQS, the facility can receive a permit that allows emission at the modeled emission rate (the allowable emission rate, or AER). However, emission rates are often determined from emission factors. If emission factors do not exist or are incorrect, the permitting process is flawed.” (page 113)

Thus, the purpose of the permitting process—to protect the public—cannot be fulfilled if the emission factors are incorrect. The previous chapters have stated that the emission factors are, indeed, incorrect. This leads to the obvious conclusion that permitting processes are currently incapable of protecting the public from air pollution emissions from AFOs. As a result, it is no surprise that: The NAS specifically notes that “because the Clean Air Act and its regulations generally rely on objective measures of pollutants, the regulatory process has not been effective in controlling odors, which are difficult to measure objectively.” (page 114)

Chapter 7:

Chapter 7 deals with ways to achieve reductions in atmospheric emissions and to reduce all emissions from AFOs. It does so with recommendations for both the short term (five years or less) and the long term (20-30 years). The NAS states that both the USDA and the EPA must change their priorities if air emissions are to be addressed with an adequate base of scientific information. (pages 126, 127)

This chapter is already in almost an outline form and the reader is advised to pay close attention to the improvements suggested. Of particular note are the following findings and suggestions:

Finding and recommendation 12. USDA and EPA have not devoted the necessary financial or technical resources to estimate air emissions from AFOs and develop mitigation technologies. EPA and USDA should form a continuing research coordinating council (1) to develop a national research agenda on issues related to air emissions from AFOs in the context of animal production systems and (2) to provide continuing oversight on the implementation of this agenda. This council should have authority to advise on research priorities and funding. For the short-term, USDA and EPA should initiate and conduct a coordinated research program designed to produce a scientifically sound basis for measuring and estimating air emissions from AFOs on local, regional, and national scales.

Finding and recommendation 13. Setting priorities for both short- and long-term research on estimating air emission rates, concentrations, and dispersion requires weighing the potential severity of adverse impacts, the extent of current scientific knowledge about them, the potential for advancing scientific knowledge, and the potential for developing successful mitigation and control strategies. Short-term research priorities should improve estimates of emissions on individual AFOs including the effects of different control technologies:

1. Priority research for emissions important on a local scale should be conducted on odor, PM, and H₂S (also see Finding 2).
2. Priority research for emissions important on regional, national, and global scales should be conducted on ammonia, N₂O, and methane. (pages 127, 128)

The NAS states specifically that:

“The primary emissions of local concern are PM and odor. The overall goal of the research is to provide information that can help decrease the emissions of PM and odors to minimize impacts on the public near the sources of the emissions...For local impacts, ambient concentrations near the ‘fence line’ or the nearest occupied residence are important because they may be associated with health effects and are now used in the regulatory process...Directly measuring emissions from every AFO poses both serious technical problems and prohibitive costs. Nevertheless, there is a need for an approach that can be used by state and federal agencies to estimate emissions from individual AFOs.” (page 128, 129)

Thus, the first priority for research on emissions should be to solve local problems. This is necessary because the capability to estimate the emission required to grant permits does not currently exist.

For the long run, the NAS suggests expanding the definition of an AFO to include remote locations where feed is grown and to which wastes are transferred. This expanded definition is necessary to ensure that all emissions of waste to the environment are accounted for. (page 135)

Air Emissions from Animal Feeding Operations: Current Knowledge, Future Needs

This pre-publication version of Air Emissions From Animal Feeding Operations, Current Knowledge, Future Needs has been provided to the public to facilitate timely access to Be committee's findings. Although the substance of the report is final, minor editorial charges may be made throughout the text and citations will be checked prior to publication. The final report is anticipated to be available in February 2003.

Ad Hoc Committee on Air Emissions from Animal Feeding Operations Committee on
Animal Nutrition

Board on Agriculture and Natural Resources
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Executive Summary

Public concerns about the environmental effects and, to a lesser extent, the possible health effects of air emissions from animal feeding operations (AFOs, See Glossary) have grown with the increasing size and geographic concentration of these operations. This intensification has been driven by the economics of domestic and export markets for meat, poultry, milk, and eggs. Public concerns have also grown as the population, both exurbanites and expanding urban centers, have moved into what had been largely rural farming areas. Objectionable odors from AFOs are a significant concern not only to the new residents in these areas but also to many long-time residents.

Prompted by legislation, especially the Clean Air Act (CAA), as well as by public concerns, the U.S. Environmental Protection Agency (EPA) has been considering what information is needed to define and support feasible regulation of air emissions from AFOs. At the same time, the U.S. Department of Agriculture (USDA) has been using its authority to aid farmers in mitigating the effects of air emissions with modified agricultural practices. Acting jointly, these two agencies asked the Board on Agriculture and Natural Resources (BANR) to evaluate the scientific information needed to address these issues. A 16-person ad hoc committee was appointed, the Committee on Air Emissions from Animal Feeding Operations, which has been guided by a Statement of Task that was agreed upon by the National Academies and the sponsoring agencies (Appendix A).

The Statement of Task directed the committee to:

- review and evaluate the scientific basis for estimating the emissions to the atmosphere of various specified substances from confined livestock and poultry operations;
- review the characteristics of the agricultural animal industries, methods for measuring and estimating air emissions, and potential best management practices for mitigating emissions;
- evaluate confined animal feeding production systems in terms of biologic systems; and
- identify critical short- and long-term research needs and recommend methodologic and modeling approaches for estimating and measuring air emissions and potential mitigation technologies.

Making scientifically credible estimates of air emissions from AFOs is complicated by various factors that affect the amounts and dispersion of emissions in the atmosphere. Such factors include the kinds and numbers of animals involved, their diets and housing, the management of their manure (feces and urine, which may also include litter or bedding materials), topography, climatic and weather conditions, and actions taken to mitigate the emissions and their effects. Estimates of emissions generated for one set of conditions or for a single type of AFO may not translate readily into others.

Accurate estimation of air emissions from AFOs is needed to gauge their possible adverse impacts and the subsequent implementation of control measures. For example, increasing pressure is being placed on EPA to address these emissions through the Clean Air Act (CAA) and other federal laws and regulations. EPA is under court order to establish new water quality rules for AFOs by December 2002. The need to understand the relationship between actions to mitigate the effects of manure management on water quality and its related effects on air quality prompted EPA to ask for an interim report several months in advance of this final report.

The committee's findings in the interim report are encompassed and extended by the findings and recommendations in this report.

Findings From the Interim Report (NRC, 2002a)

- Finding 1: Proposed EPA regulations aimed at improving water quality may affect rates and distribution of air emissions from animal feeding operations.
- Finding 2: In order to understand health and environmental impacts on a variety of spatial scales, estimates of air emissions from AFOs at the individual farm level, and their dependence on management practices, are needed to characterize annual emission inventories for some pollutants and transient downwind spatial distributions and concentrations for others.
- Finding 3: Direct measurements of air emissions at all AFOs are not feasible. Nevertheless, measurements on a statistically representative subset of AFOs are needed and will require additional resources to conduct.
- Finding 4: Characterizing feeding operations in terms of their components (e.g., model farms) may be a plausible approach for developing estimates of air emissions from individual farms or regions as long as the components or factors chosen to characterize the feeding operation are appropriate. The method may not be useful for estimating acute health effects, which normally depend on human exposure to some concentration of toxic or infectious substance for short periods of time.
- Finding 5: Reasonably accurate estimates of air emissions from AFOs at the individual farm level require defined relationships between air emissions and various factors. Depending on the character of the AFOs in question, these factors may include animal types, nutrient inputs, manure handling practices, output of animal products, management of feeding operations, confinement conditions, physical characteristics of the site, and climate and weather conditions.
- Finding 6: The model farm construct as described by EPA (2001a) cannot be supported because of weaknesses in the data needed to implement it.
- Finding 7: The model farm construct used by EPA (2001a) cannot be supported for estimating either the annual amounts or temporal distributions of air emissions on an individual farm, sub-regional, or regional basis because the way in which it characterizes feeding operations is inadequate.
- Finding 8: A process-based model farm approach that incorporates "mass balance" constraints for some of the emitted substances of concern, in conjunction with estimated emission factors for other substances, may be a useful alternative to the EPA model farm construct defined by EPA (2001a).

The contents, including the findings and recommendations, of this report represent the consensus views of the committee and have been formally reviewed in accordance with National Research Council procedures. In addressing its Statement of Task, the committee has come to consensus on 13 major findings, each accompanied by one or more related recommendations. The basis of these findings is discussed more extensively in the body of the report.

FINDINGS AND RECOMMENDATIONS

Animal Units

EPA defines animal units differently than USDA. An EPA animal unit is equal to 1.0 slaughter and feeder cattle, 0.7 mature dairy cows, 2.5 pigs weighing more than 55 pounds, 10 sheep or lambs, and 0.5 horses. USDA defines animal unit as 454 kg (1000 pounds) of animal live weight regardless of species. A consistent

basis for defining animal unit will decrease confusion that may exist because of the differing definitions. The process-based model described in this report is better suited for using a continuous variable (e.g., 500-kg live weight) versus a discrete variable (e.g., a dairy cow).

Finding 1: Much confusion exists about the use of the term "animal unit" because EPA and USDA define animal unit differently.

***Recommendation:* Both EPA and USDA should agree to define animal in terms of animal live weight rather than an arbitrary definition of animal unit.**

Spatial Distribution of Effects

The various substances that together make up the total air emissions from animal feeding operations differ in quantity, the potential severity of their effects, and the spatial distribution of these effects. Ammonia, whose environmental impacts are reasonably well understood, has relevant impacts that have to be addressed at regional, national, and global scales. On the other hand, the effects of odor, whose composition is not well known in scientific terms and whose impacts on the public are difficult to judge, are important mainly at a very local level.

Table ES-1, which supports and elaborates Finding 2 below, represents the reasoned judgment of the committee on the relative importance of each substance at the relevant spatial scales strictly for emissions from AFOs. For example, VOCs play an important role in tropospheric ozone formation, yet such emissions from AFOs are likely insignificant compared to other sources.

Finding 2: Air emissions from animal feeding operations are of varying concern at different spatial scales, as shown in Table ES-1.

TABLE ES-1. Committee's Ranking of the Potential Importance of AFO Emissions at Different Spatial Scales

	Global, National,	Local, Property Line, Nearest	Primary Effects of
Emissions	Regional	Dwelling	Concern
NH ₃	Major	Minor	Atmospheric deposition
N ₂ O	Significant	Insignificant	Global climate change
NO _x	Significant	Minor	Haze
CH ₄	Significant	Insignificant	Global climate change
VOC _s ^b	Insignificant	Minor	Quality of human life
H ₂ S	Insignificant	Significant	Quality of human life
PM ^c 10	Insignificant	Significant	Haze
PM2.5	Insignificant	Significant	Health, haze

Odor **Insignificant** **Major** **Quality of life**

Relative importance of emissions from AFOs at spatial scales based on committee's informed judgment on known or potential impacts from AFOs. Rank order from high to low importance are major, significant, minor, insignificant. While AFOs may not play an important role for some of these, emissions from other sources alone or in aggregate may have different rankings. For example VOCs and NO_x play important roles in the formation of tropospheric ozone, however the role of AFOs is likely insignificant compared to other sources.

^bVolatile organic compounds

^cParticulate matter

Recommendation: These differing effects, concentrations, and spatial distributions lead to a logical plan of action for establishing research priorities to provide detailed scientific information on the contributions of AFO emissions to potential effects and the subsequent implementation of control measures. USDA and EPA should first focus their efforts on the measurement and control of those emissions of major concern.

Measurement Protocols and Control Technologies

Achieving the overall goal of decreasing the adverse impacts of air emissions from AFOs will require attention to the differences in the character of the various emissions (e.g., their persistence in the atmosphere), in the way they are dispersed, in their environmental effects, and in the effectiveness of various control and management strategies. As noted above, it will also require attention to priorities based on the geographic scale at which impacts are of greatest concern. The local scale is considered the AFO boundary or nearest occupied dwelling. The regional scale may be as small as a single topographic land feature (e.g., a stream valley) to as large as multi-state airsheds.

Finding 3. Measurement protocols, control strategies and management techniques must be emission and scale specific.

Recommendations:

For air emissions important on global, or national scale (i.e., ammonia and the greenhouse gases methane [CH₄] and nitrous oxide [N₂O₃]), the aim is to control emissions per unit of production (kg of food produced) rather than emissions per farm. Where the environmental and health benefits outweigh the costs of mitigation it is important to

decrease the aggregate emissions. In some geographic regions, aggregate emission goals may limit the number of animals produced in those regions.

For air emissions important on a local scale (hydrogen sulfide [H₂S], particulate matter [PM], and odor), the aim is to control ambient concentrations at the farm boundary and/or nearest occupied dwelling. Standards applicable to the farm boundary and/or nearest occupied dwelling must be developed.

Monitoring should be conducted to measure concentrations of air pollutants of possible health concern at times when they are likely to be highest and in places where the densities of animals and humans, and typical meteorological conditions, are likely to result in the highest degree of human exposure.

Current Best Management Practices

As noted in the committee's interim report, available estimates of emission factors, rates and concentrations are sufficiently uncertain and provide a poor basis for regulating or managing air emissions from AFOs. Nevertheless, some best management practices to mitigate the adverse effects of air emissions appear at face value to warrant their use, even as new information on mitigation and best management practices is being developed. While the committee favors a strong focus on research to develop needed new information, the use of clearly effective measures should be continued while new information is being developed.

Finding 4. There is a general paucity of credible scientific information the effects of mitigation technology on concentrations, rates, and fates of air emissions from AFOs. However, the implementation of technically and economically feasible management practices (e.g., manure incorporation into soil) designed to decrease emissions should not be delayed.

Recommendation: Best management practices (BMPs) aimed at mitigating AFO emissions should continue to be improved and applied as new information is developed on their character, amount, and dispersion of these air emissions, and on their environmental and health effects. A systems analysis should include impacts of a BMP on other parts of the entire system.

Odors

Odors associated with AFOs are often regulated in response to nuisance complaints rather than demonstrated health effects. The measurement of odor concentrations downwind from AFOs is based on olfactometers that relate odor strength to a standard (usually n-butanol) or uses the judgment of panels of experts trained to distinguish odor strengths. While standardized terminology and measures have been developed in Europe, similar effort has not occurred in the scientific community in the United States.

Odors continue to be a problem with AFOs at the local level. Continuing research into the constituents of odor with a goal of providing a basis for scientific agreement or standards is needed.

Finding 5. Standardized methodologies for odor measurement have not been adopted in the United States.

Recommendations:

Standardized methodology in the U.S. should be developed for objective measurement of techniques of odors to correspond to subjective human response.
A standardized unit of measurement of odor concentration should be adopted in the U.S.

Dispersion Modeling

Finding 6. The complexities of various kinds of air emissions and the temporal and spatial scales of their distribution make direct measurement at the individual farm level impractical other than in a research setting. Research into the application of advanced three-dimensional modeling techniques accounting for transport over complex terrain under thermodynamically stable and unstable planetary boundary layer (PBL) conditions offers good possibilities for improving emissions estimates from AFOs.

Recommendation: EPA should develop and carry out one or more intensive field campaigns to evaluate the extent to which ambient atmospheric concentrations of the various species of interest are consistent with estimated emissions and to understand how transport and chemical dynamics shape the local and regional distribution of these species.

Measurement Protocols

Accurate measurement of air emissions is dependent on the availability and use of protocols that are both technically sound and practical for use in field as well as laboratory. Such measurement protocols are available for measuring nitrous oxide (N₂O) and nitric oxide (NO). Improved measurement protocols are needed for other substances. Particulate matter, odor, and volatile organic compounds (VOCs) are important emissions at the local level, but pose some special problems because their constituents and emission rates vary widely among AFOs and their locations.

Finding 7. Scientifically sound and practical protocols for measuring air concentrations, emission rates, and fates are needed for the various elements (nitrogen, carbon, sulfur), compounds (e.g., ammonia [NH₃], CH₄, H₂S), and particulate matter.

Recommendations:

Reliable and accurate calibration standards should be developed, particularly for ammonia. Standardized sampling and compositional analysis techniques should be provided for PM, odor, and their individual components.
The accuracy and precision of analytical techniques for ammonia and odor should be determined, including intercomparisons on controlled (i.e., synthetic) and ambient air.

Emission Factors

The “emission factors” approach for estimating air emissions is based on measuring emissions from a set of defined AFOs to obtain an “average” emission per unit (e.g., per animal units or per units of production). These “emission factors” can then be used to estimate emissions for other AFOs by multiplying the emissions factor by the number of observed units in the category to which the “average” applies. As noted in the committee’s interim report, the existing emission factors for AFOs are generally inadequate because of limited number of measurements on which they are based, as well as the limited generality of the models for which the emission factors have been developed (see Appendix L). Improving existing emission factors to the point where they could provide scientifically credible estimates of either emission rates or concentrations would require major efforts in getting sufficient observations to characterize the variability among and within AFOs.

The committee, in finding 9 and in Chapter 5) suggests that an alternative approach for estimating emissions, a process-based modeling approach, can provide more useful estimates for most of the air emission substances of concern. Particulate matter is the main exception and may require additional efforts to improve emission factors. Allocation of overall resources for improving and evaluating emission estimates should focus on the committee’s recommended process-based modeling approach for all emissions mentioned, except for particulate matter.

Finding 8. Estimating air emissions from AFOs by multiplying the number of animal units by existing emission factors is not appropriate for most substances.

Recommendation: The science for estimating air emissions from individual AFOs should be strengthened to provide a broadly recognized and acceptable basis for regulation and management programs aimed at mitigating the effects of air emissions.

Process Based Model

To counter the tendency to consider only on-farm inputs and outputs from AFOs, to ensure more accurate accounting of the flow of chemicals and other air emission substances from the operation, and to provide a “mass balance” control for the total flow of inputs to and outputs from the operation, the committee recommends a “process-based modeling” approach for estimating air emissions.

The process-based modeling approach can be used to estimate the flows of elements (nitrogen, sulfur, carbon) and of compounds containing these elements. The committee believes, with some reservations, that this approach might be used for estimating odor emissions. The only substance of direct concern to the committee for which this approach may not be well suited is particulate matter.

This approach involves the specification of mathematical models that describe the movement of various substances of interest at each major stage of the process of producing livestock products: movement into the next stage, movement in various forms to the environment, and ultimately, movement into products used by humans. Mass balance constraints serve as a check on the whole system to ensure that estimates of movements of substances out of the system do not exceed the amounts available within the system.

Finding 9. Use of process-based modeling will help provide scientifically sound estimates of air emissions from AFOs for use in regulatory and management programs.

Recommendations:

- EPA and USDA should use process-based mathematical models with mass balance constraints for nitrogen-containing compounds, methane, and hydrogen sulfide to identify, estimate, and guide management changes that decrease emissions for regulatory and management programs.
- EPA and USDA should investigate the potential use of a process-based model to estimate mass emissions of odorous compounds and potential management strategies to decrease their impacts.
- EPA and USDA should commit resources and adapt current or adopt new programs to fill identified gaps in research to improve mathematical process-based models to increase the accuracy and simplicity of measuring and predicting emissions from AFOs (see short-term and long-term research recommendations).

Systems Analysis

The emission factors approaches in current use focus on the "on-farm" inputs to and outputs from an AFO. This ignores the potential environmental effects associated with "off-farm" production of feed and other materials used in an AFO. Since some of the feed for typical AFOs is imported from other farms and a portion of the manure is often exported from the AFO for use on other farms (some regional and species differences exist), restricting consideration of inputs and outputs to a single AFO may not completely represent the full environmental effects of the operation. A "systems approach" that considers both the on-farm and the off-farm inputs and outputs of the AFO would provide a more accurate description of overall impacts.

Finding 10. A systems approach, which integrates animal and crop production systems both on and off (imported feeds and exported manure) the AFO, is necessary to evaluate air emissions from the total animal production system.

Recommendation: Regulatory and management programs to decrease air emissions should be integrated with other environmental (e.g., water quality) and economic considerations to optimize public benefits.

Nitrogen Emissions

Because of its potential environmental impacts at regional, national, and global scales, instituting control strategies for nitrogen should be assigned [a] high priority. Sufficient information is currently available to do this at all geographic scales.

Finding 11. Nitrogen emissions from AFOs and total animal production systems are substantial and can be quantified and documented on an annual basis. Measurements and estimates of individual N species components (i.e., NH₃, molecular nitrogen [N₂], N₂O and nitric oxide [NO]) should be made in the context of total N losses.

Recommendation: Control strategies aimed at decreasing emissions of reactive nitrogen compounds (Nr) from total animal production systems should be designed and implemented now. These strategies can include both performance standards based on individual farm calculations of nitrogen balance, and technology standards to decrease total system emissions of reactive N compounds (Nr) by quantifiable amounts.

Research

The two major federal agencies with regulatory or management responsibilities relative to air emissions from AFOs are EPA and USDA. Each agency also has research responsibilities. In support of its action programs, responsibilities that are typically serviced through "in-house" research staffs. Close cooperation is needed between the two major agencies in setting and supporting research priorities relative to air emissions. Inputs and participation from the full range of state, private, and research institutions with relevant interests are needed to ensure that concerns about air emissions are addressed with the full complement of needed expertise.

The importance of food production from AFOs coupled with the potential environmental effects from air emissions demand substantial research efforts in both the short and long-term. These issues will not be resolved without addressing the appropriate funding of these efforts. Current allocations of funding aimed at AFO air emissions are not adequate or appropriate in view of the amount of concern about these emissions and the recent increases in AFO animal production.

Research in the short-term (4-5 years) can significantly improve the capability of the process-based modeling approach for estimating air emissions. A long-term (20-30 years) research program that encompasses overall impacts of animal production on the environment, as proposed here, can have even more substantial results decreasing overall impacts on the environment while sustaining production at a high level.

Finding 12. USDA and EPA have not devoted the necessary financial or technical resources to estimate air emissions from AFOs and develop mitigation technologies. The scientific knowledge needed to guide regulatory and management actions requires close cooperation between the major federal agencies (EPA, USDA), the states, industry and environmental interests, and the research community, including universities.

Recommendations:

EPA and USDA should cooperate in forming a continuing research coordinating council (1) to develop a national research agenda on issues related to air emissions from AFOs in the context of animal production systems and (2) to provide continuing oversight on the implementation of this agenda. This council should include representatives of EPA and USDA, the relevant research community, and other relevant interests. It should have authority to advise on research priorities and funding.

Exchanges of personnel among the relevant agencies should be promoted to encourage efficient use of personnel, broadened understanding of the issues, and enhanced cooperation among the agencies.

For the short-term, USDA and EPA should initiate and conduct a coordinated research program designed to produce a scientifically sound basis for measuring and estimating air emissions from AFOs on local, regional, and national scales.

For the long-term, USDA, EPA, and other relevant organizations should conduct coordinated research to determine which emissions (to water and air) from animal production systems are most harmful to the environment and human health and to develop technologies that decrease their releases into the environment. The overall research program should include research to optimize inputs to AFOs, optimize recycling of materials, and significantly decrease releases to the environment.

The reality of budget constraints in allocating research funds to address problems of air emissions requires a careful weighing of several factors, including those that affect both the implementation costs and societal benefits. Finding 2 proposes a way of ranking both action and research opportunities among the emission substances based on amounts of concern or impacts and geographic scale of impacts. A more complete listing of factors is needed for setting both short- and long-term research priorities and allocating research funds.

Finding 13. Setting priorities for both short- and long-term research on estimating air emission rates, concentrations, and dispersion requires weighing the potential severity of adverse impacts, the extent of current scientific knowledge about them, the potential for advancing scientific knowledge, and the potential for developing successful mitigation and control strategies.

Recommendations:

Short-term research priorities should improve estimates of emissions on individual AFOs including the effects of different control technologies:

2. Priority research for emissions important on a local scale should be conducted on odor, PM, and H₂S (also see Finding 2).
3. Priority research for emissions important on regional, national, and global scales should be conducted on ammonia, N₂O, and methane (also see Finding 2).

Long-term research priorities should improve understanding of animal production systems and lead to development of new control technologies.

SUMMARY

These findings and recommendations, taken together, point to two major changes in direction for improving basic information needed for dealing with the adverse effects of air emissions from AFOs. One is to replace the current "emissions factor" approach for estimating and tracking the rates and amount of air emissions with a "process-based modeling" approach with mass balance constraints. The second is to initiate a substantial long-term research program on the overall system of producing food from animal feeding operations with the goal of eliminating the release of undesirable air and other emissions into the environment.

Facing the need for defensible information on air emissions from AFOs in a timely manner is a major challenge for EPA and USDA. Neither has yet addressed the need for this

information in defining high priority research programs. Each has pursued its regulatory and farm management programs under the assumption that the best currently available information can be used to implement its program goals.

The scope and complexity of the information needed by these agencies, as well as the potential environmental impacts of air emissions from AFOs, require a concentrated, focused, and well funded research effort. Such an effort is described in this report.