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CAFOs: Issues and Development of New Waste Treatment Technology

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CAFOs: Issues and Development of New Waste Treatment Technology

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1. The author recently served on two separate initiatives to develop and co-author comprehensive reports related to some topics of this paper. Some edited excerpts from those reports, "Considerations for waste treatment technology conversion by the North Carolina swine industry" and "Framework for the conversion of anaerobic lagoons and spray-fields—technology panel final report," are utilized throughout this paper. Both reports are recommended for additional information.

I. Introduction

The impact of animal agriculture on the environment and health effects attributed to concentrated animal feeding operations (CAFOs) are significant issues facing the livestock industry, intensive swine production in particular. In the United States and elsewhere, researchers give considerable attention relative to procurement of objective data and efforts to develop new animal waste treatment technologies to address these issues. This paper discusses several environmental issues relevant to CAFOs; emphasis is on swine production and associated aerial emissions and issues related to the potential regulation of those emissions via existing federal laws. Efforts by some university and industry groups to develop new animal waste treatment technology are also discussed. Particular detail is devoted to initiatives in North Carolina and Missouri to develop innovative animal waste treatment technologies in compliance with Agreements and Consent Decrees between the Attorneys General in those states and major swine-producing companies.

II. Issues Surrounding CAFO Operations

Predominant issues associated with concentrated animal feeding operations (CAFOs) are arguably centered on water and air quality concerns associated with current waste treatment systems and nuisance and health effects of aerial emissions from CAFOs. Specific concerns have been identified to be direct discharge of waste treatment lagoons to surface waters, lagoon leakage to ground waters, nutrient loading resulting from land application and the fate and effect of nitrogen, phosphorus (P), and metals. Potential health effects from aerial emissions and the fate and effect of pathogenic bacteria contained in land applied manure effluent are relatively new issues of concern. Specific air quality issues identified include emissions of ammonia, hydrogen sulfide, volatile organic compounds (VOCs), greenhouse gases, dust, and odor. Collectively, these issues may challenge the sustainability of many aspects of worldwide agribusiness more so than any issue facing animal production agriculture in recent decades.

A. Groundwater Impacts

Groundwater contamination by manure nutrients and/or pathogens is a serious issue, especially if drinking water supplies are affected. Such contamination may occur from any type of farming operation, septic system, or other land uses under certain environmental conditions. Regarding waste treatment lagoons for CAFOs, the risk of groundwater contamination is related to lagoon construction, sprayfield management, soil and geologic conditions, and climate. A 1998 study in North Carolina found evidence of leaching from some clay-lined lagoons.[2] The executive summary of the study noted that because there were relatively few sites included in this study, only limited conclusions could be drawn concerning the adequacy of the lagoon construction standards and the validity of the groundwater vulnerability assessment methodology. Huffman reported results for a study designed to determine the extent to which animal waste lagoons pose a threat to groundwater in North Carolina.[3] This study focused on swine waste lagoons that were constructed prior to 1993 when more restrictive regulations were mandated that required lagoon construction to meet design requirements of the United States Department of Agriculture (USDA) and Natural Resources Conservation Service (NRCS).[4] Seepage assessments on 34 lagoons were conducted using ammonia and nitrate nitrogen gases as environmental indicators of contamination in shallow groundwater.[5] Using the United States Environmental Protection Agency (EPA) drinking water standard as a benchmark for the evaluation, one third of the sites met the standard at 125 feet (review boundary) and two thirds met the standard at 250 feet (compliance boundary).[6] These two studies illustrate that lagoons can impact groundwater, but provide limiting information regarding the magnitude of associated environmental impacts.

B. Surface Water Impacts

Direct discharge to surface waters from a CAFO liquid waste treatment system, such as lagoons, as well as runoff of liquid manure applied to crops also represent environmental hazards. To effectively address these hazards, consideration of the number of discharges, the amount of waste reaching surface waters, the environmental impact and reasons for the discharges, and annual trends in discharges in relation to changes in inspection and enforcement policies should be documented. Although some such studies resulted from a 1995 swine lagoon rupture in North Carolina,[7] information in this subject area is limited.

2.. *See* NORTH CAROLINA DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES, IMPACT OF ANIMAL WASTE LAGOONS ON GROUNDWATER QUALITY (Groundwater Section, N. C. Dep't of Env't & Natural Res., on file with A. Mouberry, 1998).

3. *See* R.L. HUFFMAN, GROUNDWATER IMPACTS OF LAGOONS (N. C. St. Univ. Coll. of Agric. & Life Sci., on file with Rodney Huffman, 1999).

4. *Id.*

5. *Id.*

6. *Id.*

7. *See* J.M. Burkholder et al., *Impacts to a Coastal River and Estuary from Rupture of a Large Swine Waste Holding Facility*, 26 J. ENVTL. QUALITY 1451-66 (1997).

C. *Nutrient Loading (Soil/Water) Impacts*

Nutrient loading within a geographical region is ecologically important and impacts the diversity and productivity of living organisms within that region.[8] This issue has become more complex due to increased human populations and trends to produce food and fiber more efficiently under conditions of CAFOs as well as concentrated cropping operations. Grain is often imported into regions where CAFOs are located to meet feed requirements. Like all members of the animal kingdom, livestock and poultry are not capable of converting 100% of the nutrients in their feed to meat, milk, eggs, or other tissue. Regarding pig nutrient-conversion efficiency, Dourmad et al. reported that approximately two thirds of the nitrogen and P consumed by pigs is excreted in the manure (feces and urine).[9] Most manure by-products are managed and spread over land near the facilities in which CAFOs are located. Under these conditions, nutrient imbalances are likely, and adverse environmental impacts may occur when land application of manure nutrients exceeds crop utilization potential, or if poor management is used during the manure application, resulting in nutrient loss due to environmental factors such as soil erosion or surface runoff during rainfall.

Nitrogen in animal waste is influenced by the technology used to treat the waste. The biochemical cycle of nitrogen is very dynamic, and nitrogen contained in manure may be removed in a number of ways. For example, nitrogen may be removed by crop harvest; or it may leave the animal production facility, waste treatment lagoon, or application field as a gas (NH_3, NO, NO_2, N_2O or N_2); or, due to its mobility in soil, nitrogen may be transported as organic or inorganic nitrogen forms in the liquid state via surface runoff or leaching into groundwater.

Unlike nitrogen, P is very immobile in soil and must first be transported to a surface water environment to have an environmental impact. It has historically been accepted that this nutrient affects receiving waters via transport in eroding soil or in surface runoff as soluble inorganic or organic phosphorus. However, P leaching to shallow groundwater and lateral losses of P via export in subsurface runoff may be significant under certain soil conditions.[10] Soils

8. *See* P. Gundersen, *Mass Balance Approaches for Establishing Critical Loads for Nitrogen in Terrestrial Ecosystems*, *in* PROCEEDINGS OF A WORKSHOP IN LOCKEBERG, SWEDEN 56-81 (Nordic Council of Ministers Report, Copenhagen, Den. (1992).

9. *See* J.Y. Dourmad et al., *Nitrogen and Phosphorus Consumption, Utilization and Losses in Pig Production*, Presented at the 48th Meeting of the EAAP in Vienna (Aug. 1997).

10. *See* J.T. Sims et al., *Phosphorus Loss in Agricultural Drainage: Historical Perspective and Current Research*, 27 J. ENVTL. QUALITY 277-93 (1998).

containing P concentrations that greatly exceed the agronomic potential of crops may require years or even decades of nitrogen leaching to return to levels that are crop limiting for this nutrient.[11] Commercial fertilizer-P use has increased only slightly over the past decade; however, the growth of CAFOs has resulted in substantial increases in the application of animal manure P in some areas.[12] Environmental concerns include the capacity of such soils to adsorb new P and the amount of P loss from these soils due to erosion, runoff, drainage, or leaching to groundwater. An interagency committee has recently developed a P loss assessment method[13] to assess the risk of manure P delivery to surface and groundwater, as required by changes mandated by recent NRCS policy and Nutrient Management Standard 590.[14]

Although much focus is currently placed on nitrogen and P and their importance as environmental nutrients of concern, certain metals such as copper and zinc contained in animal feed should also be considered for long-term comprehensive sustainable nutrient balance planning in watersheds containing CAFOs.[15]

III. Using Aerial Emissions of Key Compounds as Indicators of CAFO Pollution

Air pollutant emissions from CAFOs are a subject of interest and debate by impacted stakeholders and some state and federal regulatory agencies. One issue central to the debate includes consideration that some CAFOs are subject to federal reporting and permit requirements such as those mandated by Title V of the Clean Air Act,[16] the EPA Comprehensive Environmental Response, Compensation, and Liability Act,[17] and the Emergency Planning and Community Right-to-Know Act.[18] Air pollutants described in these regulations that can be emitted

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11. *See* R.E. McCollum, *Buildup and Decline in Soil Phosphorus: 30-Year Trends on a Typic Umprabuult*, 83 AGRONOMY J. 77-85 (1991).

12. *See* B.L TERRY & B.J. KIRBY, COMMERCIAL FERTILIZERS—2000, (The Fertilizer Institute, 2000).

13. *See* J. Havlin et al., *Assessing the Risks of Phosphorus Delivery to North Carolina Waters*, *in* PROCEEDINGS OF INT'L SYMPOSIUM—ADDRESSING ANIMAL PROD. & ENVTL. ISSUES § 6 (G.B. Havenstein ed., Oct. 3-5, 2001).

14. *See* NATURAL RESOURCES CONSERVATION SERVICE, UNITED STATES DEPARTMENT OF AGRICULTURE, NUTRIENT MANAGEMENT, CODE 590 (1999), *at* http://www.nrcs.usda.gov/technical/ecs/nutrient/590.html.

15. *See* J. Zublena, *Excess Soil Levels of Copper Zinc and Phosphorus Due to Poultry Manure Applications*, *in* PROCEEDINGS, 21ST ANNUAL CAROLINA POULTRY NUTRITION CONFERENCE 17-25 (Charlotte, N.C., Dec. 7-8, 1994).

16. *See* Clean Air Act, 42 U.S.C. 7401 et seq. (2002).

17. *See* Comprehensive Environmental Response, Compensation, and Liability Act, 42 U.S.C. § 9658 (2002).

18. *See* Emergency Planning and Community Right-to-Know Act, 42 U.S.C. 11046

from CAFOs include such compounds as ammonia, hydrogen sulfide, volatile organic compounds (VOCs), as well as particulate matter.[19]

A. Ammonia Emissions

Nitrogen is a component element of proteins, nucleic acids, and other important bio-molecules necessary for life. Livestock and poultry, like humans, must consume nitrogen nutrients to support metabolic activities necessary for growth and nutritional maintenance. However, animals are not capable of converting all of the nitrogen consumed in their diets to meat or other tissue. Waste products of nitrogen metabolism excreted in urine and feces are predominately in the form of organic nitrogen and under the biological treatment or storage conditions of most CAFO waste management practices, it is rapidly converted to ammonia (NH_3). The amount of ammonia that is actually emitted into the atmosphere, however, is dependent upon many variables including climate, the animal building design, manure storage and treatment facilities, as well as waste management treatment strategies and methods employed for land application of manure.[20] These and other topics are addressed in much detail in a white paper (currently in review) containing over two hundred references prepared for the National Center for Manure and Animal Waste Management to summarize the state of knowledge about ammonia emissions from animal operations.[21] Much of the information in the white paper was also recently published.[22]

Reported values of excreted nitrogen in fresh swine manure, as Total Kjeldahl nitrogen (organic nitrogen + ammonia) and ammonia nitrogen, are .52 kilograms (kg) and .29 kg, respectively, per 1000 kg live animal mass per day.[23] Utilizing these values, it is calculated that up to approximately 29 pounds of ammonia are capable of being produced per pig-finishing space per year. However, caution must be exercised in predicting ammonia emission inventories based simply on the number of animals at any given CAFO and selected published excretion and/or emission values. This is illustrated by the fact that examination of published data shows that emissions from swine buildings and waste

(2002).

19. *See supra* notes 15-17 and accompanying text.

20. *See* H. Leneman et al., *Focus on Emission Factors: A Sensitivity Analysis of Ammonia Emission Modeling in the Netherlands*, 102 ENV'T POLLUTION 205-10 (1998).

21. *See* NATIONAL CENTER FOR MANURE & ANIMAL WASTE MANAGEMENT, UNITED STATES DEPARTMENT OF AGRICULTURE, FUND FOR RURAL AMERICA GRANT (2002), *at* http://www.cals.ncsu.edu/waste_mgt/natlcenter/center.htm.

22. *See* J. Arogo et al., *Ammonia in Animal Production—A Review*, ASAE—Am. Soc'y Agric. Eng'r Paper No. 01-4089, St. Joseph, Mich. (2001).

23. ASAE—American Society of Agricultural Engineers, *Manure Production Characteristics*, Standard D384.1 (2001); *see* infra Table 1, Appendix.

treatment facilities can vary significantly.[24] Reported building emissions range from approximately 1 to 6 grams NH_3/day/pig and approximately 0.2 to 5 kg NH_3/year/pig space. Emissions from treatment lagoons range from 1 to 2.2 kg NH_3/year/pig. Emission studies that included lagoons, houses, and surrounding crops reported values that ranged from approximately 3 to 10 kg NH_3/year/pig.

Variations in methodology and instrumentation for measuring ammonia emissions have also impacted reported ammonia emission values. Ammonia measuring techniques vary from simple acid traps to complex Open-Path Fourier Transform Infrared Technology.[25] The appropriate methodology for measuring ammonia emissions and the determination of ammonia flux from the surface of waste treatment systems, systems utilizing lagoons or open storage basins in particular, is one area receiving considerable attention. Misunderstandings persist regarding the design objectives of lagoon treatment technology relative to ammonia emission. Contrary to assumptions made by some researchers, lagoons were not specifically designed to volatilize ammonia. The literature shows that lagoon-design criteria were based on operational needs to manage odor, biosolids, and organics as well as nitrogen.[26] There is little doubt that ammonia is volatilized from an open lagoon, storage basin, or during land application; however, the quantity of ammonia emitted is unresolved.[27]

Researchers have reported that up to 90% of the input nitrogen to anaerobic lagoons is emitted to the atmosphere as ammonia,[28] and

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24. *See infra* Table 2, Appendix.

25. *See* J.Q. Ni & A.J. Heber, *Sampling and Measurement of Ammonia Concentration at Animal Facilities—A Review*, ASAE Paper No. 01-4090 (2001).

26. *See* ASAE—American Society of Agricultural Engineers, *Design of Anaerobic Lagoons for Animal Waste Management*, Standard EP403.2. 543-46 (1993); J.C. Barker, *Lagoon Design and Management for Livestock Waste Treatment and Storage*, EBAE—Biological and Agricultural Engineering Department, N. C. St. Univ., Raleigh, N.C. (1983); MIDWEST PLAN SERVICE, SWINE HOUSING AND EQUIPMENT HANDBOOK (MWPS-8, Iowa St. Univ., 1985).

27. *See* R.R. Sharpe & L.A. Harper, *Ammonia and Nitrous Oxide Emissions from Sprinkler Irrigation Application of Swine Effluent*, 26 J. ENVTL. QUALITY 1703-06 (1997); D.B. Harris & E.L. Thompson, *Evaluation of Ammonia Emission from Swine Operations in North Carolina*, *in* PROCEEDINGS OF EMISSION INVENTORY—LIVING IN A GLOBAL ENVIRONMENT, VIP-88, 420-29 (Air & Waste Mgmt. Assoc., 1998); L.A. Harper et al., *Gaseous Nitrogen Emissions from Anaerobic Swine Lagoons: Ammonia, Nitrous Oxide, and Dinitrogen Gas*, 29 J. ENVTL. QUALITY 1356-1465 (2000); W.P. Robarge, *Ammonia Emissions*, *in* CONSIDERATIONS FOR WASTE TREATMENT TECHNOLOGY CONVERSION BY THE NORTH CAROLINA SWINE INDUSTRY (2000); W.P. Robarge et al., *Atmospheric Concentrations of Ammonia and Ammonium Aerosols in Eastern North Carolina*, AM. SOC. AGRIC. ENG'G PROCEEDINGS 10-18 (2000); V.P. Aneja et al., *Measurement and Analysis of Atmospheric Ammonia Emissions from Anaerobic Lagoons*, 35(11) ATMOSPHERIC ENV'T 1949-58 (2001).

28. J.C. Hatfield et al., *Swine Manure Management*, *in* AGRIC. UTILIZATION OF

approximately one third of the total ammonia emission from swine facilities in North Carolina has been reported to originate from lagoons.[29] Other studies, however, have shown that lagoons may emit less ammonia than previously reported and that a significant portion of the nitrogen emissions occurs in the form of environmentally inert di-nitrogen gas.[30] While it may be difficult to explain conventional mechanisms of nitrification and denitrification under typical lagoon conditions, Jones et al. describes alternative mechanisms of di-nitrogen gas formation in lagoons.[31]

Some scientists hypothesize that such discrepancies in ammonia emissions data results from different manure management practices, variable climatic conditions, and inappropriate measurement technologies. Recent work to address some of the challenges associated with emission quantification from swine facilities has been published.[32] These researchers devised four classification categories for swine manure and storage systems based on gas emission characteristics and system effluent concentrations of total P and total sulfur.[33] A total of 29 swine manure management systems were studied in Iowa, Oklahoma, and North Carolina.[34] Results showed that emission rates of ammonia, methane, and VOCs were dependent upon manure-loading rate and indirectly influenced by the number of animals.[35] Emission rates for ammonia and corresponding site characteristics are shown in Table 2.[36] It was concluded that the methods employed provide an efficient process by which to identify swine facilities that may represent potential air quality or nuisance concerns as well as a method to assess swine manure management technology and best management practices.

Collectively, the variability in ammonia emissions data as well as unresolved issues related to measurement technologies illustrate that it is incorrect to assume that all nitrogen excreted at CAFOs is emitted to the

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MUN., ANIMAL, AND INDUS. WASTE, 40-57 (USDA-ARS, 1993).

29. A.P. Aneja et al., *Characterization of Atmospheric Ammonia Emissions from Swine Waste Storage and Treatment Lagoons*, 105 J. GEOPHYSICAL RES. 11,535-45 (2000).

30. L.A. Harper et al., Gaseous Nitrogen Emissions from Anaerobic Swine Lagoons: Ammonia, Nitrous Oxide, and Dinitrogen Gas. 29 J. ENVTL. QUALITY 1356-1465 (2000).

31. *See* M.L. Jones et al., *Mechanisms of Dinitrogen Gas Formation in Anaerobic Lagoons*, 4 ADVANCES ENV'T RES. 133-9 (2000).

32. *See* J.A. Zahn et al., *Functional Classification of Swine Manure Management Systems Based on Effluent and Gas Emission Characteristics*, 30 J. ENVTL. QUALITY 635-47 (2001).

33. *Id.*

34. *Id.*

35. *Id.*

36. *See infra* Table 2, Appendix.

atmosphere as ammonia.[37] As such, standardization of measurement techniques and development of objective ammonia emission factors are critically needed. Such an effort would be beneficial not only regarding the appropriate application of permit requirements according to state and federal policy, but also for determining the effect of various technologies currently available or under development that focus on ammonia abatement strategies. While considerable work has been done to develop ammonia emission factors in Europe,[38] it is widely recognized in the scientific community that emission factor estimates need significant refinement in both Europe and the United States. Such refinement needs to reflect subclasses within animal species, dietary variation, building design, and waste treatment system options selected or designed to abate ammonia emissions.

B. *Hydrogen Sulfide Emissions*

Hydrogen sulfide (H_2S) is generated from the anaerobic microbial fermentation of sulfur-containing metabolites present in manure. H_2S is acutely dangerous to humans at air concentrations exceeding 200 (ppm); the United States Occupational Safety and Health Administration (OSHA) has implemented a 10-ppm limit for 8 hour exposure to protect worker health.[39] Emissions concentrations of H_2S are usually low in CAFO manure management systems as compared to concentrations of ammonia. Excreted sulfur and H_2S emission data for swine are shown in Tables 1 and 3, respectively.[40]

Mean H_2S concentrations in finishing pig buildings have been shown to range between 0.1 to 0.3 ppm;[41] however, much higher concentrations can be emitted when the manure slurry is agitated.[42]

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37. *See supra* notes 31-37 and accompanying text.

38. K.W. Vander Hoek, *Estimating Ammonia Emission Factors in Europe: Summary of the Work of the UNECE Ammonia Expert Panel*, 32 ATMOSPHERIC ENV'T 315-16 (1998).

39. *See* J.M. SWEETEN ET AL., ODOR MITIGATION FOR CONCENTRATED ANIMAL FEEDING OPERATIONS: WHITE PAPER AND RECOMMENDATIONS, *available at* National Center for Manure & Animal Waste Management, United States Department of Agriculture, Fund for Rural America Grant (2002), http://www.cals.ncsu.edu/waste_mgt/natlcenter/center.htm.

40. *See infra* Tables 1 and 3, Appendix.

41. A.J. Muehling, *Gases and Odors from Stored Swine Waste*, 30 J. ANIMAL SCI. 526-30 (1970); A.J. Heber et al., *Manure Treatment to Reduce Gas Emissions from Large Swine Houses*, INT'L SYMPOSIUM ON AMMONIA & ODOR CONTROL FROM ANIMAL PROD. FACILITIES 449-457 (Vinkeloord, Neth., Oct. 6-10, 1997); J.Q. Ni et al., *Hydrogen Sulfide Emissions from Two Large Swine Finishing Buildings with Long-Range High Frequency Measurements*, 138 J. AGRIC. SCI. 227-36 (2001).

42. *See* N.K. Patni & S.P. Clarke, *Transient Hazardous Conditions in Animal Buildings Due to Manure Gas Released During Slurry Mixing*, 7(4) APPLIED ENG'G

Emission data for swine facilities is available,[43] but the reported results are highly variable. Heber et al. reported a mean H_2S emission rate of 0.90 grams per day per Animal Unit (g/d-AU) from two finishing houses in winter,[44] as compared to 8.26 g/d-AU reported from a finishing unit during 193 days of summer.[45] Mean H_2S emission rates from three deep-pit finishing facilities in Minnesota ranged between 0.12 to 2.3 grams per day per square meters (g/d-m^2).[46] Zhu et al. reported a mean H_2S emission rate of 0.57 g/d-m^2 from two swine finishing facilities.[47] In a study conducted under pilot scale conditions, Heber et al. reported mean H_2S emission rates of 0.11, 0.37, and 0.91 g/d-AU (0.01, 0.05, and 0.13 g/d-m^2) for daily flush, and 14- and 42-day pull-plug waste management strategies, respectively.[48]

The emission classification analysis by Zahn et al. conducted on four varying swine manure management systems showed emission rates between 0.6 to 1.0 kilograms per site per day (kg/site/d)(sites described

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AGRIC. 478-84 (1991).

43. *See* G.L. Avery et al., *Hydrogen Sulfide Production in Swine Confinement Units*, 18(1) TRANSACTIONS OF THE ASAE 149-51 (1975); A.J. Heber et al., *Manure Treatment to Reduce Gas Emissions from Large Swine Houses*, INT'L SYMPOSIUM ON AMMONIA & ODOR CONTROL FROM ANIMAL PROD. FACILITIES 449-457 (Vinkeloord, Neth., Oct. 6-10, 1997); J.Q. Ni et al., *Hydrogen Sulfide Emissions from a Mechanically-Ventilated Swine Building During Warm Weather*, *in* ASAE ANNUAL INT'L MEETING, 13 (Paper No. 984050 Orlando, Fla., July 11-16, 1998); J.Q. Ni et al., *Burst Releases of Hydrogen Sulfide in Mechanically Ventilated Swine Buildings, in* ODORS AND VOC EMISSIONS 2000 (Paper No. Session 8-c, Hyatt Regency, Cincinnati, Ohio, Apr. 16-19, 2000); L.D. Jacobson et al., *Comparison of Hydrogen Sulfide and Odor Emissions from Animal Manure Storages*, *in* PROC. OF THE INT'L. SYMPOSIUM ON ANIMAL & ODOR CONTROL FROM ANIMAL PROD. FACILITIES 6-10 (J.A.M. Voermans & G.T. Monteny eds., Dutch Soc. of Agric. Eng'g, Vinkeloord, Neth., Oct. 1997); L.D. Jacobson et al., *Odor and Gas Emissions from Animal Manure Storage Units and Buildings*, ASAE Paper No. 99-4004 (1999); B.R. Bicudo et al., *Odor, Hydrogen Sulfide and Ammonia Emissions from Swine Farms in Minnesota, in* ODORS AND VOC EMISSIONS 2000 (Hyatt Regency, Cincinnati, Ohio, Apr. 16-19, 2000); J. Zhu et al., *Daily Variations in Odor and Gas Emissions from Animal Facilities*, 16(2) APPLIED ENG'G AGRIC. 153-8 (2000); J.A. Zahn et al., *Functional Classification of Swine Manure Management Systems Based on Effluent and Gas Emission Characteristics*, 30 J. ENVTL. QUALITY 635-47 (2001).

44. A.J. Heber et al., *Manure Treatment to Reduce Gas Emissions from Large Swine Houses*, INT'L SYMPOSIUM ON AMMONIA & ODOR CONTROL FROM ANIMAL PROD. FACILITIES 449-457 (Vinkeloord, Neth., Oct. 6-10, 1997).

45. J.Q. Ni et al., *Hydrogen Sulfide Emissions from Two Large Swine Finishing Buildings with Long-Range High Frequency Measurements*, 138 J. AGRIC. SCI. 227-36 (2001).

46. L.D. Jacobson et al., *Odor and Gas Emissions from Animal Manure Storage Units and Buildings*, ASAE Paper No. 99-4004 (1999).

47. J. Zhu et al., *Daily Variations in Odor and Gas Emissions from Animal Facilities*, 16(2) APPLIED ENG'G AGRIC. 153-8 (2000).

48. A.J. Heber et al., *Odor, Ammonia and Hydrogen Sulfide Emission Factors for Finishing Buildings*, FINAL REPORT TO THE NAT'L PORK PRODUCERS COUNCIL (Apr. 2, 2001).

in Table 3).[49] However, unlike the results for ammonia, methane, and VOCs, the emission rate of hydrogen sulfide was independent of the 4 types of manure management systems studied.[50] Still, these collective studies show that the amount of H_2S that is actually emitted from a swine production facility is dependent upon many variables. Differences among emission rates reported in the literature are probably due to several factors including building types, pig size, season, measurement equipment, and sampling procedure. Again, this illustrates the need for standardization of measurement techniques and development of objective emission factors.

C. *Volatile Organic Compound Emissions*

The metabolic catabolism or breakdown of nutrients contained in manure by naturally occurring indigenous bacteria results in a variety of end products, including VOCs that can be emitted from CAFOs. Until the early 1990's, characterization data of the chemical composition of VOCs contained in the ventilation air exhausted from livestock buildings was limited. O'Neill and Phillips published a review showing results of twelve such studies conducted largely on swine facilities.[51] The results showed that phenol was the most frequently reported VOC measured in 5 of the 12 studies. Other compounds, as noted by the authors, were not necessarily absent as they may have been missed or excluded due to sampling or analytical techniques utilized.

Improvements during the past decade in methodology to measure air phase emissions from CAFO sources have resulted in a more comprehensive characterization of emitted VOCs. Zahn et al. characterized 27 VOCs that contributed to decreased air quality near a "high odor" swine production facility (some emission data for total non-methane VOCs that they measured in this study is shown in Table 3).[52] This effort represented an initial attempt to develop reliable emission-

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49. *See* J.A. Zahn et al., *Functional Classification of Swine Manure Management Systems Based on Effluent and Gas Emission Characteristics*, 30 J. ENVTL. QUALITY 635-47 (2001); *see also supra* notes 31-36 and accompanying text; *see infra* Table 3, Appendix.

50. *See* J.A. Zahn et al., *Functional Classification of Swine Manure Management Systems Based on Effluent and Gas Emission Characteristics*, 30 J. ENVTL. QUALITY 635-47 (2001).

51. *See* D.H. O'Neill & V.R. Phillips, *A Review of the Control of Odor Nuisance from Livestock Buildings: Part 3, Properties of the Odorous Substances Which Have Been Identified in Livestock Wastes or in the Air Around Them*, 53 J. AGRIC. ENG'G RES. 23-50 (1992).

52. *See* J.A. Zahn et al., *Characterization of Volatile Organic Emissions and Wastes from a Swine Production Facility*, 26 J. ENVTL. QUALITY 1687-96 (1997); see infra Table 3, Appendix.

testing techniques for quantifying VOCs from swine facilities. The more recent work by Zahn et al., previously discussed in this paper, to address the challenges associated with classifying swine waste management systems based on effluent chemical properties and gaseous emission rates also included VOC measurements.[53] Some VOC emission data for the four classification categories for swine manure and storage systems devised are shown in Table 3.[54] This study showed that waste treatment lagoons with established anoxic bacterial photosynthetic populations emitted less VOCs as compared to the other manure management systems studied.[55]

These studies indicate that VOC emission from manure is a highly dynamic process dependent upon biological and chemical transformation processes occurring in the manure slurry and at the manure slurry-air interface. As such, it is logical to anticipate varying VOC emission rates associated with differing geographic locations and different types of swine waste management systems.

D. *Particulate Matter (Dust) Emissions*

Dust emitted from CAFOs is primarily composed of feed components and dried fecal material. Other components may include dander (hair and skin cells), bacteria, endotoxin, viruses, molds, pollen, grains, mites, insect parts, and mineral ash.[56] Studies conducted in Europe and the United States show particulate matter emission inventory numbers in a range of less than 1 to over 11 pounds per finishing pig per year (lbs/finishing pig/yr).[57] A European study, which included participants from England, the Netherlands, Denmark, and Germany, showed 2.0 lb/yr-pig.[58] This study also showed that nursery buildings had emission rates higher than finishing buildings and the mean dust emission rate for all pig buildings in the summer was about 30% higher than in the winter. In an American study conducted in Indiana and

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53. *See supra* note 50.
54. *See infra* Table 3, Appendix.
55. *See supra* note 50.
56. *See* K.J. Donham et al., *Characterization of Dusts Collected from Swine Confinement Buildings*, 47 AM. INDUS. HYGIENE ASSOC. J. 404-10 (1986); A.J. Heber et al., *Influence of Environmental Factors on Concentrations and Inorganic Content of Aerial Dust in Swine Finishing Units*, 31(3) TRANSACTIONS OF ASAE 875-881 (1988).; G.A. Carpenter, *Dust in Livestock Buildings—Review of Some Aspects*, 33 J. AGRIC. ENG'G RES. 227-41 (1986); D.J. Cole et al., *Health, Safety, and Environmental Concerns of Farm Animal Waste*, 14(2) OCCUPATIONAL MED.: ST. OF THE ART REVS. 423-48 (1999).
57. *Infra* Table 3, Appendix.
58. Takai et al., *Concentrations and Emissions of Airborne Dust in Livestock Buildings in Northern Europe*, 70 J. AGRIC. ENG'G RES. 59-77 (1998).

Illinois, Heber et al. measured an average of 3.2 miligrams per cubic meter (mg/m^3) dust concentrations inside two buildings in the winter with mean pig weights of 180 pounds.[59] Results measured during the summer showed an average of 1.8 mg/m^3 with mean pig weights of 79 pounds.[60] The emission rates per Animal Unit (AU = 500 kg) were 282 and 3,429 miligrams per hour per Animal Unit (mg/h-AU) (0.75 and 9.1 lb/yr-pig), respectively.[61]

Particulate matter emission rates are generally estimated by multiplying dust concentrations measured at the animal building ventilation fan by the building ventilation rate. Emission rates are highly variable dependent upon climate (e.g., summer ventilation rates in northern Europe are much lower than those recommended for North America due to the cooler climate), building design, feed consistency (e.g., dry, wet, or pellet), and control mechanisms to prevent dust dispersion.[62] From a health perspective, the size of emitted particles is also important. Airborne particulates are classified as inhalable or respirable. The human nose and mouth trap inhalable particulates, whereas respirable particulates are less than 5 µm in diameter and are able to penetrate deep into the lungs.[63] Heber et al. conducted a study to determine particle size distribution of swine finishing house dust.[64] The results showed that approximately 72% of settled dust mass contained particles between 10-40 µm and 21% of the dust mass were less than 10 µm.[65] Aerial dust mass contained approximately 63% particle size between 8-25 µm and 32% contributed by particles less than 10 µm.[66] These studies show that particulate matter emissions is not uniform for swine facilities and varies dependent upon housing type, animal size, and climate.

E. Odor Emissions

Odor is a subjective human olfactory response that varies from one person to another. Airborne compounds emitted from CAFOs can elicit

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59. A.J. Heber et al., *Odor Emission Rates from Swine Confinement Buildings, in* ANIMAL PROD. SYS. & THE ENV'T, (Int'l Conference on Odor, Water Quality, Nutrient Management, & Socioeconomic Issues, Des Moines, Iowa, July 20-22, 1998).

60. *Id.*

61. *Id.*

62. *See Infra* Table 3, Appendix.

63. *See* D.J. Cole et al., *Health, Safety, and Environmental Concerns of Farm Animal Waste*, 14(2) OCCUPATIONAL MED.: ST. OF THE ART REVS. 423-48 (1999).

64. *See* A.J. Heber et al., *Effect of Particle Size on Deposition of Piggery Dust, in* PROCEEDINGS OF THE FIFTH ANNUAL CONFERENCE OF THE AEROSOL SOCIETY (Loughborough Univ. of Tech., Mar. 26-27, 1991).

65. *Id.*

66. *Id.*

the human olfactory response. Defined as odorants, these compounds can occur in gaseous (vapor), liquid, or solid form, with dust particles representing a source of odorants in the solid phase. Odorant emissions from concentrated swine operations have been reported to involve more than 400 compounds.[67] Odor is generally quantified in terms of Odor Units (OU) defined as the amount of odorant(s) contained in one cubic meter of air at the odor detection threshold (ODT) as determined by using sensory methods with human observers. ODT is defined as the dilution factor at which the sample has a 50% probability of being detected under the conditions of the sensory method employed. While there are national air quality standards and individual State Implementation Plans that regulate compounds that contribute to odor (as odorants), there are currently no federal guidelines that regulate odors.[68] Odor emission characteristics reported for some swine facilities are shown in Table 3.[69]

Management, fate, and effect of odor emissions from animal operations represents a complex set of scientific, economic, social, and political issues[70] and there are a variety of challenges associated with this widely controversial topic. A white paper recently prepared for the National Center for Manure and Animal Waste Management addresses many of these issues.[71]

An emerging issue of importance is the impact of odor emissions on human health. There is limited information in the scientific literature showing risks to physical health downwind of animal confinement facilities; however, a report by Schiffman et al. that summarized current state of knowledge on this subject suggests that it is possible for odorous emissions from CAFOs to impact physical health.[72] Wing and Wolf have also reported that odor may affect the quality of life of those living

67. *See* S.S. Schiffman et al., *Quantification of Odors and Odorants from Swine Operations in North Carolina,* 108 Agric. Forest Meterol. 213-40 (2001).

68. *See* R.I. Mackie et al., *Biochemical Identification and Biological Origin of Key Odor Components in Livestock Waste.* 76 J. ANIMAL SCI. 1331-42 (1998).

69. *Infra* Table 3, Appendix.

70. *See* NORTH CAROLINA AGRICULTURAL RESEARCH SERVICE, CONTROL OF ODOR EMISSIONS FROM ANIMAL OPERATIONS (N. C. St. Univ. Coll. of Agric. & Life Sci., on file with C.M. Williams, 1998).

71. *See* J.M. SWEETEN ET AL., ODOR MITIGATION FOR CONCENTRATED ANIMAL FEEDING OPERATIONS: WHITE PAPER AND RECOMMENDATIONS, *available at* National Center for Manure & Animal Waste Management, United States Department of Agriculture, Fund for Rural America Grant (2002), http://www.cals.ncsu.edu/waste_mgt/natlcenter/center.htm.

72. *See* S.S. Schiffman et al., *Potential Health Effects of Odor from Animal Operations, Waste Water Treatment, and Recycling of By-Products.* 7 J. AGROMEDICINE 7-81 (2000).

near CAFOs.[73] A white paper prepared for the National Center for Manure and Animal Waste Management addresses the current state of knowledge about health effects of odor and odorants from animal operations.[74] An overview of much of the information contained in the white paper was also recently published.[75]

Technologies to address odor control are discussed in the white paper by Sweeten et al.; however, one non-technology approach involves adequate separation distances from the odor producing source(s) and impacted neighbors.[76] Sweeten reported that odor control may be achieved through odor dispersion based on separation distances required for maintaining a crop utilization nutrient balance for nitrogen and P as a function of the size and type of manure management system.[77] The results were based on odor data collected from two types of commercial manure and wastewater management systems, one was a flush / two-stage lagoon / spray irrigation system and the other was a scraper / external storage tank and pit / soil injection method.[78] Sweeten concluded that for the systems studied, distances required for adequate odor control may be greater than the minimum indicated for nitrogen balance, but less than the calculated values for phosphorus balance.[79] He noted, however, that this study included only 2 farm sites and additional field data on odor concentration measurements, and comparison with actual conditions should be collected for a larger number of farms, including different size swine farms with replication and different manure management systems.[80] A study commissioned by the Minnesota State Legislature through the Minnesota Department of Agriculture developed a methodology to estimate separation distances required for establishing varying levels of odor-annoyance-free frequencies.[81] The procedure accounts for site-specific variables

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73. *See* S. WING & S. WOLF, INTENSIVE LIVESTOCK OPERATIONS AND QUALITY OF LIFE AMONG EASTERN NORTH CAROLINA RESIDENTS (Report to the N. C. Dept. of Health and Human Services, 1999).

74. *See* S.S. Schiffman et al., *Health Effects of Aerial Emissions from Animal Production Waste Management Systems*, *in* PROCEEDINGS OF INT'L SYMPOSIUM—ADDRESSING ANIMAL PROD. & ENVTL. ISSUES (Session 2: Animal Production and Animal Health, G.B. Havenstein ed., Oct. 3-5, 2001).

75. *Id.*

76. *See* J.M. Sweeten, *Separation Distances for Swine Manure Odor Control in Relation to Manure Nutrient Balances*, 14(5) APPLIED ENG'G AGRIC. 543-49 (1998).

77. *Id.*

78. *Id.*

79. *Id.*

80. *Id.*

81. *See* L.D. Jacobson et al., *Odor Rating Systems: Odor from Feedlot— Setback Estimation Tool (OFFSET)*, *in* FOOD ANIMAL PROD. SYS. ISSUES & CHALLENGES (Proceedings of 2000 NCR Extension Specialist Triennial Workshop (MWPS-TRI1), E. Lansing, Mich., May 10-12, 2000).

including the type of animal housing, manure management system, and odor control technology.[82] A noteworthy component of the procedure is that it assigns an "odor control factor" regarding the efficacy of odor control technologies such as biofilters, permeable and impermeable manure covers, and oil sprinkling (to control dust and odor emissions).[83]

The referenced work by Sweeten and Jacobson et al.[84] are logical and relatively simple approaches for considering site location issues associated with odor emissions from CAFOs. However, as noted in both reports, odor concentration proximate to a livestock facility is dependent upon many variables including climate and type of manure management system and/or manure treatment technology.[85] As such, caution must be exercised when extrapolating data from these studies for CAFOs differing in geographic location and manure management systems.

F. Pathogen Emissions

Livestock feces can contain high concentrations of human pathogens.[86] These pathogens include viruses such as swine hepatitis E virus, bacteria such as Salmonella species, and parasites such as Cryptosporidium parvum.[87] Some of these pathogens are endemic and are difficult to eradicate from both the animals and their production facilities. Because these pathogens can be widely prevalent in livestock manure, they pose a potential risk to human and animal health, both on and off CAFOs. The subject area of pathogens in animal waste is addressed in detail in a white paper prepared for the National Center for Manure and Animal Waste Management.[88] An overview of the information in the white paper was recently presented.[89]

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82. *Id.*
83. *Id.*
84. *See supra* notes 76-80 and accompanying text.
85. *Id.*
86. *See* D.J. Cole et al., *Health, Safety, and Environmental Concerns of Farm Animal Waste*, 14(2) OCCUPATIONAL MED.: ST. OF THE ART REVS. 423-48 (1999); V.R. Hill & M.D. Sobsey, *Microbial Indicator Reductions in Alternative Treatment Systems for Swine Wastewater*, 38 WATER SCI. TECH. 119-122 (1998); V.R. Hill & M.D. Sobsey, *Removal of Salmonella and Microbial Indicators in Constructed Wetlands Treating Swine Wastewater*, 44 WATER SCI. TECH. 215-12 (2002).
87. *Id.*
88. *See* Sobsey et al., *Pathogens in Animal Wastes and the Impacts of Waste Management Practices on Their Survival, Transport and Fate*, *in* PROCEEDINGS OF INT'L SYMPOSIUM—ADDRESSING ANIMAL PROD. & ENVTL. ISSUES (Session 15: Animal Production and Animal Health, G.B. Havenstein ed., Oct. 3-5, 2001), *available at* National Center for Manure & Animal Waste Management, United States Department of Agriculture, Fund for Rural America Grant, http://www.cals.ncsu.edu/waste_mgt/natlcenter/center.htm (2002).
89. *Id.*

As noted previously, dust emissions from animal facilities can also contain bacteria. Studies have shown that the concentration of total bacteria in the air of swine buildings can average 3 X 10^2 colony-forming units (CFUs) per cubic meter and are variable dependent upon the type of building and geographic location.[90] Emissions from animal housing units have also been shown to include bacterial products such as endotoxins and exotoxins.[91] Spray irrigation systems for animal manure also are a concern for bioaerosol transmission; it has been reported that enteric indicator microorganisms were isolated from bacterial aerosols collected at distances up to approximately 400 feet.[92]

IV. Efforts to Develop New Animal Waste Treatment Technology

The attention that is directed to the development of new animal waste treatment technology involves academic institutions and the private sector, including the animal production industry. In some areas of the United States and the world, there has been greater focus on dairy and poultry production concerns, whereas other areas have focused on swine. Most regions that have considerable CAFOs are looking at several key issues, in particular: systems integration, atmospheric emissions research, performance of alternative manure handling technologies, policy implications, and utilization of by-products[93]

A. The Global Race for Animal Waste Treatment Technology

On a global scale, there are several countries besides the United States that have been very active in researching animal manure management related issues. In particular, Canada, Australia, the Netherlands, Denmark, Taiwan, China, and Israel are engaged in such research. Internationally, research projects have covered a variety of concerns with most technological research occurring on a bench scale with very limited commercial or pilot scale evaluations complete or in

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90. *See* S. Clark et al., *Airborne Bacteria, Endotoxin and Fungi in Dust in Poultry and Swine Confinement Buildings*, 44 AM. INDUS. HYGIENE ASSOC. J. 537-41 (1983); Y. Cormier et al., *Airborne Microbial Contents in Two Types of Swine Confinement Buildings in Quebec*, 51 AM. INDUS. HYGIENE ASSOC. J. 304-09 (1990).

91. *See* A. Marquis. & P. Marchal, *Atmospheric Quality Around Animal Buildings*, 7(5) CAHIERS AGRICS. 377-385 (1998).

92. *See* H.T. Bausum et al., *Comparison of Coliphage and Bacterial Aerosols at a Wastewater Spray Irrigation Site*, 43(1) APPLIED ENVTL. MICROBIOLOGY 28-38 (1982); P. Boutin et al., *Atmospheric Bacterial Contamination from Landspreading of Animal Wastes: Evaluation of the Respiratory Risk for People Nearby*, 39 J. AGRIC. ENG'G RES. 149-160 (1988).

93. *See* FRAMEWORK FOR THE CONVERSION OF ANAEROBIC LAGOONS AND SPRAYFIELDS—TECHNOLOGY PANEL FINAL REPORT (N. C. Dep't of Env't & Natural Res., on file with Dennis Ramsey, 2000).

place. Some countries are involved in efforts to cross over industries with technology applications such as the effectiveness of municipal or manufacturing techniques on livestock farms.

Several countries are looking at ways to recover nutrients and value-added organic products in an effort to improve overall agricultural efficiency within their respective region. Some countries, such as Canada, are developing a global inventory of manure-related technologies in collaboration with government agriculture divisions and commodity groups. Others are researching policy implications intently, especially the Dutch research community. There is very little consistent economic data being generated worldwide, however, especially concerning the environmental impacts associated with livestock production and manure management alternatives. Another observation relates to the emphasis on nitrogen and nitrogen compounds as the limiting, primary pollutant and nutrient of concern, noting that research is severely lacking with regard to P, other chemical elements, and pathogens.

Until recently, research has arguably been more intensive in Western Europe because of limited land area resulting in more urban pressure on animal agriculture. In 1997, fifteen experienced researchers from eleven countries, mostly in Western Europe, published a book entitled MANURE MANAGEMENT, TREATMENT STRATEGIES FOR SUSTAINABLE AGRICULTURE.[94] This book basically defined the "state of the art" of animal manure management and concluded that a range of treatments are already available that can address many of the identified environmental issues.[95] Available treatments included aeration, anaerobic digestion including lagoons, solids separation, and composting.[96] New processes that were identified as potentially effective included thermal treatments, purification by soil, use of chemical additives, and membrane processes.[97] However, it was noted that if the use of manure is to be other than direct land application as a source of plant nutrients, there are economic challenges to developing commercially competitive organo-fertilizers or other alternative co-products.[98]

Similar conclusions were recently noted in the state of North Carolina.[99] The North Carolina study also noted that progress had been

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94. *See* MANURE MANAGEMENT—TREATMENT STRATEGIES FOR SUSTAINABLE AGRICULTURE (C.H. Burton ed., 1997).

95. *Id.* at 163.

96. *Id.*

97. *Id.*

98. *Id.* at 114.

99. *See* NORTH CAROLINA DEPARTMENT OF ENVIRONMENT AND NATURAL

negatively impacted in the development of viable alternative technologies due to:

> Lack of comprehensive standards against which the parties developing new technologies can evaluate their systems.[100] The uncertainty of future requirements or limitations (such as atmospheric emissions, agronomic loading rates for P, pathogens) significantly complicates the process of development.
>
> Lack of urgency to develop new and improved technologies.[101] The current anaerobic lagoons and sprayfields were approved under state regulations and statutes for existing facilities. Major investments have already been made in this technology.
>
> Lack of incentive in states where moratoriums on new and expanded swine facilities using anaerobic lagoons and sprayfields have been imposed.[102] While this could have been a major driving force for the development of new technologies to meet exceptions of the moratoria, that did not materialize due to a combination of factors including low pork prices and limited processing space.
>
> Lack of developed markets for stabilized manure end products.[103]
>
> Lack of a commercial electrical pricing structure or incentives that encourages the production and use of biogases for fuel and electricity generated during the treatment of the manure by some proven anaerobic digester technologies.[104]
>
> The operating costs and complexities of many of the proposed technologies.[105]

B. *Perception vs. Reality*

Many stakeholders involved in animal waste treatment issues

RESOURCES, FRAMEWORK FOR THE CONVERSION OF ANAEROBIC LAGOONS AND SPRAYFIELDS—TECHNOLOGY PANEL FINAL REPORT (N. C. Dep't of Env't & Natural Res., on file with Dennis Ramsey, 2000).

100. *Id.* at 2.

101. *Id.*

102. *Id.*

103. *Id.* at 3.

104. NORTH CAROLINA DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES, FRAMEWORK FOR THE CONVERSION OF ANAEROBIC LAGOONS AND SPRAYFIELDS—TECHNOLOGY PANEL FINAL REPORT (N. C. Dep't of Env't & Natural Res., on file with Dennis Ramsey, 2000).

105. *Id.*

assume that there are readily available alternative management technologies that have been adequately developed and verified to the point that they can replace existing systems. This assumption, however, is not supported by field experience or objective data. While there are a number of different technologies and management systems available, the practicality of applying many of these alternative technologies is largely unproven at the present time. For example, many promising alternative technologies generate solids but only limited viable markets have been identified or established for the end products; this limitation significantly impacts the economic feasibility of the technology. In addition, some candidate replacement systems have not performed well under performance verification testing or are cost-prohibitive. Other potential replacement technologies are still in field trials and need further evaluation before any definitive conclusions can be reached. The present level of research, development, and demonstration efforts, however, provides optimism that alternatives equal to or superior to the anaerobic lagoon–sprayfield system may be developed and proven practical in the future. Efforts initiated by agreements between Smithfield Foods and Premium Standard Farms through the Attorneys General in North Carolina and Missouri are providing significant resources for the development of such technologies. These efforts are discussed in some detail below.

V. "Environmentally Superior Technologies"—The North Carolina Attorney General—Smithfield Foods & Premium Standard Farms Agreements

On July 25, 2000, an agreement was made between the Attorney General of North Carolina and Smithfield Foods, Inc. and its subsidiaries.[106] This Agreement, in part, provides $15 million in financial resources to North Carolina State University (NCSU) for the development of "Environmentally Superior Technologies" that may serve as alternatives to traditional lagoon and sprayfield technology.[107] A similar agreement providing $2.1 million was reached in September 2000 between the North Carolina Attorney General and Premium Standard Farms.[108]

106. *See* AGREEMENT BETWEEN ATTORNEY GENERAL OF NORTH CAROLINA AND SMITHFIELD FOODS (North Carolina Department of Justice, on file with Ryke Longest, 2000).

107. *Id.*

108. *See* AGREEMENT BETWEEN ATTORNEY GENERAL OF NORTH CAROLINA AND PREMIUM STANDARD FARMS (North Carolina Department of Justice, on file with Ryke Longest, 2000).

A. *Definition of Environmentally Superior Technologies*

The agreements define "Environmentally Superior Technologies" as:

> any technology, or combination of technology that (1) is permittable by the appropriate governmental authority; (2) is determined to be technically, operationally, and economically feasible for an identified category or categories of farms and (3) meets the following performance standards:
>
>> Eliminate the discharge of animal waste to surface waters and groundwater through direct discharge, seepage, or runoff
>>
>> Substantially eliminate atmospheric emissions of ammonia;
>>
>> Substantially eliminate the emission of odor that is detectable beyond the boundaries of the parcel or tract of land on which the swine farm is located;
>>
>> Substantially eliminate the release of disease-transmitting vectors and airborne pathogens; and
>>
>> Substantially eliminate nutrient and heavy metal contamination of soil and groundwater.[109]

B. *Challenges that the Agreements Share*

The elements of Environmentally Superior Technologies (items 1-5), while comprehensive, are open to broad interpretation and present numerous challenges. The most challenging task may well be the interpretation of "substantially eliminate." No two stakeholders impacted by CAFOs are likely to have the same definition of "substantially eliminate" for each of the environmental variables referenced.

A second concern is valid measurement for some of the environmental variables noted. Performance verification and subsequent monitoring for compliance purposes of odor emissions, ammonia emissions, and disease-transmitting vectors and airborne pathogens present unique challenges. There is currently much scientific debate regarding protocols and methodology for making these measurements. Further, the methodologies utilized for each can be expensive and often

109. *Id.*

represent single-point-in-time determinations. This is an issue for aerial emissions in particular because it is well established that such emissions can be highly variable within a given day dependent upon many environmental conditions, such as wind, humidity, temperature, precipitation, etc., at a CAFO site.

C. Developing Technology for CAFO Pollution Abatement

While these issues are indeed challenging, it is essential that they be addressed. To help meet these challenges, it is critically important for the animal production industry, university researchers, government regulators, and other impacted stakeholders to maintain close communication and engage in professional debate on this subject as new technologies and verification methods are developed, evaluated, and demonstrated. These agreement initiatives involve an advisory review panel composed of experienced researchers in the areas of animal waste management and environmental science and public health, state and federal regulators, environmental and community interest, business management, and agribusiness.

Technologies currently under consideration and planned for performance verification include:

> In-ground ambient temperature anaerobic digester / energy recovery / greenhouse vegetable production system,
>
> High temperature thermophilic anaerobic digester (TAnD) energy recovery system,
>
> Solids separation / constructed wetlands system,
>
> Sequencing batch reactor (SBR) system,
>
> Upflow biofiltration system,
>
> Solids separation / nitrification-denitrification / soluble phosphorus removal / solids processing system,
>
> Belt manure removal and gasification system to thermally convert dry manure to a combustible gas stream for liquid fuel recovery,
>
> Ultrasonic plasma resonator system,
>
> Manure solids conversion to insect biomass (black soldier fly larvae) for value-added processing into animal feed protein meal and oil

system,

Solids separation / reciprocating water technology system,

Micro-turbine co-generation system for energy recovery,

Belt system for manure removal,

High-rate second generation totally enclosed Bion system for manure slurry treatment and biosolids recovery,

Combined in-ground ambient digester with permeable cover / aerobic blanket—BioKinetic aeration process for nitrification-denitrification / in-ground mesophilic anaerobic digester system,

Dewatering / drying / desalinization system,

Solids separation / gasification for energy and ash recovery centralized system,

High solids, high temperature anaerobic digester system, and a

Mesophilic digester, membrane filtration system.[110]

VI. The Missouri Attorney General / Premium Standard Farms Consent Decree

In July 1999, Premium Standard Farms (PSF) entered into a Consent Decree with the State of Missouri.[111] In brief, this Decree involves up to a $25 million investment by PSF to develop and install on an operation-wide basis "Next Generation Technology" on their Missouri swine production operations over a time period of 5 years.[112] "Next Generation Technology" is described, in part, as an improved waste-handling and storage system designed to reduce or eliminate the release or threatened release, discharge, or emission of contaminants, odor, and pollutants from all of its Missouri operations to the fullest extent

110. Descriptions and progress reports for this initiative are available at North Carolina State University Animal & Poultry Waste Management Center, *Waste Management Programs at* http://www.cals.ncsu.edu/waste_mgt.

111. *See* CONSENT AGREEMENT BETWEEN ATTORNEY GENERAL OF MISSOURI AND PREMIUM STANDARD FARMS (Missouri Department of Justice, on file with William J. Bryan, 1999).

112. *Id.*

possible.[113] Technology applications under consideration and evaluation involve:

> Manure source reduction and release prevention (dietary phytase, dietary defibered / degermed corn, slat pH adjustment, essential oil misting, oil sprinkling for dust reduction, land application function and equipment analysis, and agronomic optimization of land resources for manure application).[114]
>
> Improved manure treatment (permeable covers, aeration basins, and nutrient reduction cells).[115]
>
> Beneficial manure reuse (Internal Recirculation System, Crystal Peak Farms Process, and Changing World Technologies Process).[116]
>
> Water Reuse Processes (use of traditional and proven wastewater and water treatment technologies to allow reuse via direct consumption by the hogs, and activated sludge biological treatment system with a microfiltration membrane system).[117]

At this time, objective performance verification data for most of these technologies is limited, but will be procured over the next few years per the terms of the Consent Decree. Descriptions and progress for this initiative are described in the Premium Standard Farms Environmental Work Plan—Year 3.[118]

VII. Conclusion

Animal production agriculture is facing serious scientific, social, and political challenges regarding environmental impacts and health effects attributed to CAFOs. The information herein provides an overview of salient issues impacting CAFO sustainability. Some efforts, including technology development, to address those issues are noted. In brief, evidence is available that indicates CAFOs can impact the environment and human health under certain conditions. Scientific documentation of the extent of those impacts is very limited. Technologies that range from simple to complex are under development and may significantly address the environmental impacts and health effects attributed to CAFOs. Such technologies, however, are currently

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113. *Id.*
114. *See* PREMIUM STANDARD FARMS, ENVIRONMENTAL WORK PLAN YEAR 3 (Premium Standard Farms, Kansas City, Mo., on file with Gerard Schulte, 2001).
115. *Id.*
116. *Id.*
117. *Id.*
118. *Id.*

not widely employed on CAFOs and the technical, operational, economic, social, and political feasibility for these technologies is yet to be determined. Although some noteworthy initiatives are underway, a long term coordinated and comprehensive effort involving research, environmental, regulatory, industry, and citizen representation will be required to adequately address the issues and challenges noted.

Appendix

Table 1. Manure excretion characteristics for swine.

Parameter	**Excretion concentration based on published data**[a]	**Excretion factor (calculated)**	**Excretion inventory (calculated)**[b]
Total Kjeldahl nitrogen	.52 kg/1000 kg live animal mass/day (ASAE 2001)	.08 lb excreted /150 lb live animal mass/d	29.2 lb excreted/animal finishing space/yr
Ammonia nitrogen (NH_3-N)	.29 kg/1000 kg live animal mass/day (ASAE 2001)	.044 lb excreted /150 lb live animal mass/d	16.1 lb excreted/animal finishing space/yr
Sulfur (S)	.076 kg/1000 kg live animal mass/day (ASAE 2001)	.011 lb excreted /150 lb live animal mass/d	4.0 lb excreted/animal finishing space/yr

Excretion concentration: mass of a parameter per unit volume of air.

Excretion factor: ratio of excretion rates and appropriate process descriptor (e.g. lbs/steady state live weight unit/day).

Excretion inventory: combination of a source and/or group category or excretion in terms of mass per year.

[a] Values represent fresh (as excreted) feces and urine. The reported values are developed by the Engineering Practices Subcommittee of the American Society of Agricultural Engineers (ASAE) Agricultural Sanitation and Waste Management committee and approved by the Structures and Environmental Division Standards Committee. The values are derived "from a wide base of published and unpublished information on livestock manure production and characterization" and "actual values vary due to differences in animal diet, age, usage, productivity and management."

[b] Calculations based on steady state live weight assumption of 150 lbs.

Table 2. Ammonia emission characteristics reported for swine.

Source	Emission rate [a]	Emission inventory [b]
Type 1 site [c] Type 2 site [d] Type 3 site [e] Type 4 site [f] Finish FSF [g] Farrow SF [i] Nursery SF Weaner PSF [j] Grow/Finish PSF HLSC [k] HLSC L [l] HSLC HSLC (summer) L L	101.7 kg/d (Zahn et al., 2001). 141.7 kg/d (Zahn et al., 2001). 232.8 kg/d (Zahn et al., 2001). 369.2 kg/d (Zahn et al., 2001). 2.71-6.13 g/h-AU [h] (Heber et al., 2000).	4.9 kg/pig place/yr (Gastel et al., 1995). 0.2 kg/pig place/yr (Gastel et al., 1995). 0.85 g/d/pig (Aanink et al., 1996). 6.10 g/d/pig (Aanink et al., 1996). 4.41 kg/pig /yr (Asman & van Jaarsveld, 1992). 7.58 kg/pig /yr (Battye et al. 1994). 1.0 kg/pig /yr (ECETOC, 1994). 3.18 kg/pig /yr (Dragosits et al., 1998). 4.88-9.52 kg/pig /yr (McCulloch et al., 1998). 2.2 kg/pig/yr (Aneja et al., 2000). 1.3 kg/pig/yr (Harper et al., 2000).

[a]Emission rate: mass of parameter released per unit of time

[b]Emission inventory: combination of a source and/or group category emission in terms of mass per day or year

[c]Feeder to finish, 13,680 animals/yr, deep pit manure management system

[d]Farrow to finish, 8,200 animals/yr, outdoor concrete lined basin—pull plus manure management system

[e]Feeder to finish, 14,170 animals/yr, lagoon—continuous pit flush manure management system

[f]Farrow to feeder, 18,500 animals/yr, phototrophic lagoon—continuous pit flush manure management system

[g]Fully slatted floor

[h]AU = animal unit (500 kg live weight)

[i]Slatted floor

[j]Partly slatted floor

[k]Includes emissions from lagoons, animal houses, and surrounding crops

[l]Includes emissions from lagoons only

Table 3. Hydrogen sulfide, VOCs, priority pollutants, particulate matter and odor emission characteristics for swine.

Parameter	Emission rate[a]	Emission inventory[b]
Hydrogen sulfide	0.6 kg/site [c]/d (Zahn et al., 2001). 0.9 kg/site [d]/d (Zahn et al., 2001). 0.7 kg/site [e]/d (Zahn et al., 2001). kg/site [f]/d (Zahn et al., 2001). 0.9 g/d-AU [g], winter (Heber et al., 1997). 8.26 g/d-AU , summer (Ni et al., 2001).	
Volatile organic compounds (as total non-methane VOCs)	9.3 ug/L slurry/h, (Zahn et al., 1997).[h] 8.6 kg/site [c]/d (Zahn et al., 2001). 23.2 kg/site [d]/d (Zahn et al., 2001). 3.4 kg/site [e]/d (Zahn et al., 2001). 0.9 kg/site [f]/d (Zahn et al., 2001).	
USEPA priority pollutants hydrogen sulfide, cresols, phenol, and acetophenones	1.6 kg/site [c]/d (Zahn et al., 2001). 2.1 kg/site [d]/d (Zahn et al., 2001). 1.2 kg/site [e]/d (Zahn et al., 2001). 1.2 kg/site [f]/d (Zahn et al., 2001).	
Particulate matter		9.0 lb/yr-finish pig, U.S. summer data (Heber et al., 1998). 0.7 lb/yr-finish pig, U.S. winter data (Heber et al., 1998). 3.1 lb/yr-finish pig, U.S. winter data (Keener et al., 2000). 2.4 lb/yr-finish pig,

		U.K. (Takai et al., 1998). 1.1 lb/yr-finish pig, Netherlands (Takai et al., 1998). 2.3 lb/yr-finish pig, Denmark (Takai et al., 1998). 1.4 lb/yr-finish pig, Germany (Takai et al., 1998). 1.8 lb/yr-finish pig, U.K./pellet feed (Heber et al., 1991).
Odor	34 OU/s-AU (Lim et al., 2001). [I] 19 OU/s-AU (Heber et al., 2001).[j] 29 OU/s-AU (Heber et al., 2001).[k] 36 OU/s-AU (Heber et al., 1998).[l] 1.5-2.0 $OU/s\text{-}m^2$ (Heber & Ni, 2001).[m] 128-160 OU $s\text{-}m^2$ (Pain et al., 1988, 1990).[n]	

[a]Emission rate: mass of parameter released per unit of time

[b]Emission inventory: combination of a source and/or group category emission in terms of mass per day or year

[c]Feeder to finish, 13,680 animals/yr, deep pit manure management system

[d]Farrow to finish, 8,200 animals/yr, outdoor concrete lined basin – pull plus manure management system

[e]Feeder to finish, 14,170 animals/yr, lagoon – continuous pit flush manure management system

[f]Farrow to feeder, 18,500 animals/yr, phototrophic lagoon - continuous pit flush manure management system

[g]AU = animal unit (500 kg live weight)

[h]Feeder to finish, 3550 animals/yr, single slurry basin constructed of concrete receiving waste from slotted floor scrapper system, emissions monitored at basin surface during July, Midwest U.S. site

[i]Nursery pigs, deep pit manure management system located in

Indiana

[j]Finishing pigs, daily flush manure management system located in Indiana

[k]Finishing pigs, pull-plug manure management system located in Indiana

[l]Finishing pigs, deep pit manure management system located in Illinois

[m]Surface aerated stratified facultative lagoon

[n]Measurements after land application of manure