Controlling Odor and Gaseous Emission Problems from Industrial Swine Facilities

A Handbook for All Interested Parties

Yale Environmental Protection Clinic

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Preface

In the late twentieth century, American cities offer their inhabitants jobs, shopping, and entertainment. On the down side, urban areas can be plagued by dirty air and water. In contrast, rural areas, while lacking some of the amenities of city life, have traditionally been able to claim fresh air, clean water, and the quality of life that these bring.

Unfortunately, fresh country air is no longer a given in some rural areas of the United States, including in Oklahoma, especially in areas adjacent to the new corporate mega-farms devoted to raising hogs. With the rapid spread of large confined animal feeding operations (known as CAFOs) into Oklahoma, rural citizens found themselves without solid information about such facilities, especially information about their odor and gas emissions.

CAFOs are controversial. The pros and cons of these facilities need to be addressed in a fair and open forum, and in order to address these issues intelligently, Oklahomans need current, unbiased information. After citizen groups expressed the need for such information, the Kerr Center for Sustainable Agriculture requested this study from the Yale Environmental Protection Clinic. The resulting report is a non-technical, readable introduction to the problem of odor from hog waste. It will give rural citizens and state leaders a quick, comprehensive overview of the issue.

The Yale Environmental Protection Clinic draws students from the Yale Law School and master's degree candidates from the School of Forestry and Environmental Studies. Each semester under the supervision of Clinic director Daniel Esty, teams of students research policy on behalf of various non-profit and governmental organizations.

To prepare this report, the Yale team searched the Internet for current information on swine facility odor and emissions, researched both U.S. and European statutory and case law on the subject, consulted scientific studies on the public health implications of odor and gaseous emissions and researched the latest odor and emission control technology. They collected information from the pork industry's On-farm Odor Assistance Satellite Broadcast. They also analyzed and compared current regulations, technology, and health-risk assessments. The report ends with recommendations for reform.

This study is being released by the Kerr Center's Sustainable Rural Development and Public Policy Program. Headed by Michelle Stephens, the program monitors agricultural policy issues and studies the sustainability of various rural development strategies.

The Kerr Center is a non-profit agricultural foundation headquartered in Poteau. Our mission is to offer progressive leadership and educational programs to all those interested in making farming and ranching environmentally friendly, socially equitable, and economically viable over the long term. We offer competitive sustainable agriculture grants to Oklahoma producers, maintain the Stewardship Farm (a model sustainable farm/ranch), and produce and distribute educational materials, including a newsletter. An endowment from the estate of Oklahoma senator Robert S. Kerr funds the Center.

Because odor and gas emissions from industrial swine facilities can cause a quick, dramatic decline in the quality of life for people living nearby, we hope this study will provide the basis for a healthy dialogue on how to solve these problems and put the "fresh" back into country air.

To order the Handbook or for more information on Kerr Center programs contact

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EXECUTIVE SUMMARY

This paper addresses the complex odor issues associated with large-scale swine production in both Oklahoma and other states. It includes an overview of the nature and effects of these odors and gases, outlines the different odor-reduction technologies available to corporate swine producers, and describes existing odor and gas regulations in various states and countries and the laws that have expedited this regulatory process. Finally, this paper offers recommendations as to how neighboring communities and swine producers can move forward in the pursuit of regulating and alleviating the odor and gas problems associated with industrial swine production.

Regulating the gaseous and odor problems associated with swine production is difficult because of the elusive nature of the problem itself. Because it is uncertain as to which specific swine emission is contributing to adverse public health effects, creating health-based regulations would be a challenge at this time. The same is true for threshold-based odor regulations. Because there are neither indicator compounds within odor plumes nor electronic devices for measuring odor emissions, it is difficult to develop meaningful threshold value limits. Gases, on the other hand, can be measured; yet regulating gases will curb the odor problem only if the regulated gas is present in the odor plume. Furthermore, regulating swine emissions by mandating that best available technology be installed does not give any incentives for creating new and better pollution control technologies. Finally, a problem underlying any regulatory decision is determining which substances to regulate out of the hundreds of odor-causing gases and compounds emitted from swine facilities.

Reform of the swine production process must incorporate both regulatory and economic structural changes. Some degree of federal regulation may be needed to curb the current "race toward the bottom" of states lowering their standards to lure new industry. However, state and local controls are also necessary to tailor regulations to the needs of particular areas. In the interim between non-regulation and regulation, pork producers should focus on incorporating existing odor abatement technologies into their processes to reduce the number of odor complaints. In any case, pork producers and consumers should incorporate the costs of environmental protection. Pork products should pay for the harms — pollution and nuisance to neighbors — caused by industrial-scale swine production. Economic incentives, such as labeling measures, should be incorporated to give the public a voice in declaring the type of production methods it will and will not tolerate.

Focusing on community control of large-scale swine facility emissions is perhaps the most effective means of remedying the odor problem. In addition to empowering community members in the decision-making process, specific leaders in the community, such as county extension officers, could be directly involved in the odor abatement process. If the community is empowered in the decision-making process, they will have a sense of control

over the situation and will be able to contribute to improving both the air quality in their community and their future overall well being.

1.0 INTRODUCTION

Throughout the ages, industrialization has continually symbolized economic growth and increased social development in socioeconomically deprived locales. However, environmental degradation, increases in pollution-related health problems and destruction of indigenous community values oftentimes follow closely on the heels of industrialization. The situation is no different in the scenario of industrial swine production. The swine industry is continuing to move further away from traditional methods of hog farming, adopting assembly-line methods of corporate, large-scale production, where hog "farms" have metamorphosed into swine "factories". The number of hog farmers selling fewer than 1,000 hogs annually has declined 73 percent from 1969, while the number of producers selling more than 1,000 hogs has increased by 320 percent (Grimes, 1998).

In addition, newly imposed swine facility regulations in the eastern U.S have prompted a 'westward expansion' of these large-scale facilities, where the lax environmental regulations of states such as Oklahoma have acted as a magnet for corporate swine production (Stephens, 1997). It is debatable whether the introduction of these facilities have generated new jobs and economic development in the communities upon which they have descended; however, it is indisputable that the odors and gases emitted from these facilities have drastically altered the quality of life in neighboring communities. Odors and gases emanating from swine "factories" have yet to be regulated or controlled in Oklahoma; thus, residents living downwind from these facilities have no recourse for altering their malodorous living conditions.

This paper addresses the complex odor issues associated with large-scale swine production in both Oklahoma and other states. Section 2.0 provides an overview of the nature and effects of these odors and gases, while Section 3.0 outlines the different odor-reduction technologies available to corporate swine producers. Section 4.0 offers an account of both existing odor and gas regulations in various states and countries, and the laws that have expedited this regulatory process. Finally, Section 5.0 will present conclusions as to how neighboring communities and swine producers can move forward in the pursuit of regulating and alleviating the odor and gas problems associated with industrial swine production.

2.0 ODORS AND GASES: AN OVERVIEW

2.1 Distinction between Odors and Gases

Although many people refer to swine odors and gases interchangeably, there is a difference between these two terms, and there is no known correlation between swine odors and the specific gases emitted from swine facilities. The term "odor" refers to the complex mixture of gases, vapors and dust that result from the anaerobic decomposition of swine manure. The characteristic smell of ammonia and the familiar "rotten egg" odor of hydrogen sulfide gas are often associated with swine facility odor emissions. However, the anaerobic process of manure decomposition associated with industrial swine odor also gives rise to approximately sixty other volatile compounds. These substances include fatty acids, organic acids, alcohols, aldehydes, carbonyls, sulfides, esters, mercaptans, amines and nitrogenous compounds, which often contribute far more offensive odors than ammonia or hydrogen sulfide (Swine Odor Task Force [SOTF], 1995). Many of these odorous compounds are carried by swine dust and other airborne particulates, including swine dander, bedding dust and manure dust, which also contribute to an odor plume. In addition, these particles are capable of carrying bacteria and other microorganisms that may originate in a large swine facility. Thus, swine odors are quite complex, making it not only difficult to determine the specific substances that are contributing to the offensive smell, but also problematic in regulating these ambiguous mixtures.

On the other hand, the term "gases" refers solely to the specific gaseous compounds that are emitted from swine facilities. Some of these gases may be constituents of an odor plume; however, unlike odors, these compounds--in their pure forms--are neither combinations of compounds nor carriers of microorganisms and other particulates. Contrary to odors, many gases are also odorless and tasteless, making them seem benign since they are difficult to detect with the human nose. Ammonia (NH_3), hydrogen sulfide (H_2S), methane (CH_4) and carbon dioxide (CO_2) constitute the majority of gaseous emissions from swine facilities (Taraba and Piercy, undated). These gases are also the most important compounds generated because of both their hazardous properties and their potential for causing environmental damage.

It is important to recognize the distinction between odors and gases because they not only are measured and regulated separately, but also have different effects on human and environmental health. For example, odors are often a nuisance to nearby residents of swine facilities; however, many researchers argue that it is the specific gases of manure decomposition that contribute to severe adverse public health and environmental effects. Moreover, gaseous constituents of odors, which are targeted for regulation due to their offensive smell, are not necessarily the same gases that contribute to health and environmental problems (Thu, 1998). Thus, since 99 percent of the research efforts addressing swine emissions focus on the odor problem rather than the specific gas problems, many of the gaseous culprits of public health and environmental problems are bypassed in the research process.

Furthermore, it is also necessary to delineate the differences between the actual odor intensity of specific gases and their respective gas concentrations. Odor intensity is a measure of gas detection by the human nose, while gas concentration measurements denote the actual concentration of the gas in the atmosphere (Schmidt and Jacobson, 1995). The relationship between these two parameters varies among different gases. For instance, odor intensity and gas concentrations of ammonia are positively correlated, yet do not follow a 1:1 correlation ratio; thus, reductions in gas concentrations do not translate into the same reductions in odor intensity. This phenomenon was observed in a 1991 study where it was found that although ammonia gas concentrations were completely reduced when manure storage units were covered, odor intensity of ammonia was only reduced by 72 percent (Schmidt and Jacobson, 1995).

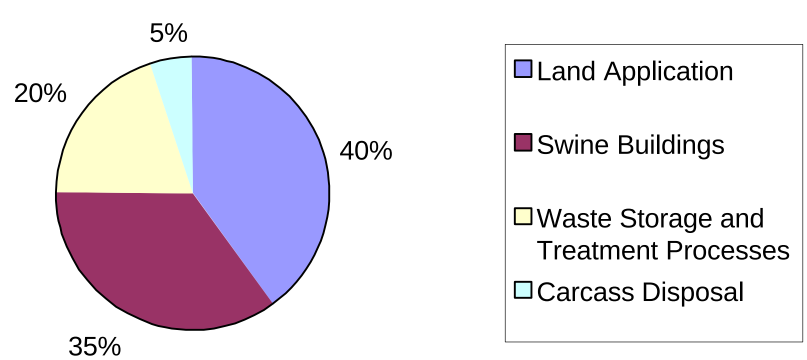
Although it is important to differentiate between odors and gases, both substances are contributing to the decreased quality of life that is experienced by neighbors and workers of large-scale swine facilities. Thus, this section addresses both odors and gases, including a discussion of the following sub-topics: sources, measurement techniques, public health implications and effects on ecosystems, local economics, and property values.

2.2 Odors

2.2.1 *Odor Sources*

Odors emanating from large-scale swine facilities originate from four main sources: swine buildings, waste storage and treatment processes, land application practices and carcass disposal areas (See Figure 1).

Figure 1: Sources of odor and gases



Swine Buildings

Swine buildings contribute approximately 35 percent of the odor emissions associated with commercial swine production (Jacobson, 1995). In comparison to traditional swine housing on smaller-scale farms, swine buildings utilized in industrial swine facilities are more enclosed and tightly constructed (www.inform.umd.edu). These facilities also house a higher density of animals, 24 hours a day from "semen to cellophane".

There are two main sources of odors within these buildings: the actual hogs, and the manure and urine, which is excreted at two to four times the daily rate of a 70-kilogram man. In the tight confines of these buildings, swine become soiled with manure, urine and feed dust, their body heat radiating the odor of the culmination of these substances. In most large-scale facilities, the manure and urine that do not collect on the swine pass through slatted floors into a holding area beneath the building, where they remain until the next removal date. These holding areas often generate a large portion of the odors associated with housing facilities, especially when ventilation devices are utilized, pumping the odorous by-products of decomposition outdoors. In addition, when dust from dander, feed and manure is neglected, coating walls and ventilation systems, nearly every surface of the facility releases odors, which may escape from swine buildings in a concentrated dose (SOTF, 1995).

Waste Storage and Treatment Processes

Waste storage facilities account for approximately 20 percent of industrial swine odors (Jacobson, 1995). In most cases, swine wastes are washed, pumped or scraped from beneath housing structures and stored in outdoor lagoons. During the start-up phase of a new lagoon, several offensive odors are produced until decomposition processes reach an equilibrium status. Mature, well-managed lagoons are capable of releasing minimal odors; however, if a mature lagoon is mismanaged, with excessive amounts of new raw waste being added too rapidly, a relatively severe odor problem may develop. Furthermore, when manure wastes are extracted from lagoons for land application, strong odors may ensue if the waste is extracted from the deeper, anaerobic layers of the lagoon. Thus, extraction from the uppermost, aerobic layer of the lagoon is the preferred technique in this process (SOTF, 1995).

Land Application

Due to the rich nutrients present in swine excreta, manure wastes are often utilized as fertilizers for pastures, crops and woodlands. In this process, liquid manure is drawn from the surface of lagoons and distributed across the area of destination. Yet this process is often performed during the summer months; thus, with heat and humidity promoting the release of odorous compounds, land application practices contribute approximately 40 percent of the swine odor problem (Jacobson, 1995). As stated above, liquid manure drawn from the surface of lagoons generally does not create a severe odor problem when used for land application. However, if the deeper anaerobic sludge of manure lagoons is spread across land, highly volatile compounds rapidly rise into the air, creating offensive odors for downwind bystanders. In addition, the odor problem associated with land application is oftentimes aggravated when the application process is poorly managed. For example, even if surface lagoon manure is spread across land, the odor can become severe if too much manure is spread on one occasion (a practice occurring when mature lagoons are reaching maximum capacity).

Carcass Disposal Areas

Due to disease, crowding, and other mass production techniques utilized by industrial swine facilities, thousands of pigs meet their demise each month before they are finished and ready for slaughter, introducing the problem of carcass disposal. According to the Swine Odor Task Force from North Carolina, a farrow-to-finish operation supporting 1,000 sows produces nearly 40,000 pounds of dead swine each year. In North Carolina, swine carcasses are disposed of in the following ways: landfills, mass on-farm burial sites, incineration or rendering for future use (SOTF, 1995). However, decomposing carcasses can emit nauseous odors in the storage and transport processes that precede these disposal methods. Furthermore, the risk of disease transmission is inherent if hogs that died from infections are not disposed of properly.

2.2.2 *Odor Measurement*

Due to the complex composition of odors, variable sources, environmental factors, and varying human perceptions of offensive smells, it is very difficult to measure swine odors and determine a reasonable, objective threshold limit for swine odor emissions from large-scale operations. However, odor measurement can provide a scientific basis for odor control policy, with regard to site selections, complaint resolutions, and nuisance litigation (Sweeten, undated). Therefore, it is imperative that odor measurement protocols be developed and utilized in assessing odors emitted from large-scale swine operations. Odor measurement standards also can be utilized to make comparisons between different facilities, such that facilities that do not meet the standards can learn from the odor management techniques implemented by facilities that do adhere to established standards.

A number of electronic devices have been developed and tested to measure odors. In Australia, scientists have experimented with an instrument that measures para-cresol, an agent that potentially could be an ‘indicator chemical’ in swine odor plumes. However, scientists in the United States and Western Europe contend that no reliable ‘indicator chemicals’ are present in odor plumes as complex as those produced by the decomposition of swine manure (SOTF, 1995). Thus, since no proven electronic device for odor measurement exists, the human nose is the best available detector. Several sensory methods involving the human nose have been developed and used on a widespread basis. The major methods are absorption media, olfactometry and scentometry (Sweeten, undated). Each of these techniques requires the following five steps: sample collection, sample dilution and presentation to panelists, indication of response, interpretation of response and presentation of results.

Absorption Media

The absorption media technique utilizes dry cotton swatches to capture odor samples from swine facilities at different observation sites. The sample swatches are then presented to a group of panelists, along with two control swatches, and the panelists are instructed to determine which swatch is different from the others. This technique is helpful in determining “the effectiveness of alternate manure handling methods and odor reduction practices in swine buildings, in terms of relative odor strengths and offensiveness" (Sweeten).

Olfactometry

The most popular olfactometry method involves the use of a dynamic olfactometer device, which samples and analyzes odors onsite, without the use of sample storage. This instrument takes in an odorous air sample along with a stream of non-odorous air (charcoal-filtered air or bottled breathing air), which is used to dilute the sample odor or provide relief-breathing to panelists (Sweeten, undated). Various dilutions of the odor sample are then smelled by a group of 4 to 16 panelists, who indicate the dilution at which odor is detected. A dilution-to-threshold value is then established using the dilution that was first detected by the majority of the panelists. This technique works well in comparing different odorous air samples; however, a drawback to dynamic olfactometry is that a standard design for dilution tools has not been established. Therefore, different researchers and labs produce dissimilar results for the same odor sample. In addition, olfactometers can cost between $15,000 and $40,000 and an odor panel must be trained and compensated for their work, making this method of odor assessment quite costly.

Scentometry

A scentometer, which is also used to determine a dilution-to-threshold for odors, is a hand-held device, which can be used for direct field measurements of threshold dilutions. The device consists of "a small plexiglass box, two glass nose pieces, two activated carbon filter chambers and a series of graduated intake orifices" (Huey, 1960). Varying ratios of odorous ambient air are drawn into the device, passed through the carbon filter and introduced to one panelist through nose pieces, which are designed to fit into the panelists' nostrils with an airtight seal (Sweeten, undated). The panelist then indicates which ratio of odorous air to filtered air is detectable and the identified ratio is reported as the dilution-to-threshold value. Unfortunately, this method of odor measurement requires the panelist to be present at the observation site; therefore, bias may be introduced if panelists unknowingly anticipate the odor or become immune to the odorous ambient air. In addition, scentometry involves only one panelist; thus, the results are difficult to verify (SOTF, 1995). Perhaps a future area of study in scentometry could entail the development of a multi-person scentometer. This would enable verification and averaging of results.

2.2.3 *The Development of Thresholds Outside of the United States*

Although odor measurement has proved to be complex and difficult, European countries still favor the use of odor thresholds and promote the development of a standardized protocol for odor measurement. In Germany, determined thresholds have even been effectively used in lawsuits against odor offenders. Furthermore, researchers in the

Netherlands have achieved some degree of measurement standardization with approximately ten labs applying the same procedures for measuring odors (SOTF, 1995). The Netherlands also has implemented an ecolabel system for swine production facilities that do not exceed threshold values for ammonia emissions. This system is based on the results of European studies, which contend that reducing levels of ammonia significantly reduces the severity of odors, even though ammonia is generally not the most offensive compound within the odor plume. Perhaps this practice may be the most effective method of odor control, because it bypasses the complexities of establishing odor thresholds, relying instead on gas thresholds, which are more easily measured and more reliable.

2.2.4 *Bioaerosols in Odor Plumes*

Other elements of odor that are also difficult to measure are bioaerosols present in an odor plume. Bioaerosols are defined as biological particulates "with biological action indicated by viability, infectivity, allergenicity, toxicity, or pharmacological activity" (Cox and Wathes, 1995, in Homes, 1995). They are generated from the fragmentation and subsequent aerosolization of biological materials including dander, feed, excreta and bedding. Bioaerosols are likely to be a constituent in odor plumes emitted from large-scale swine facilities.

The pressing issue associated with bioaerosols is that evidence suggests that microbial pathogens of swine can be carried and spread by dust or nuclei present in the aerosols. Moreover, these organisms could be transmitted downwind via different air patterns, depositing on a final destination, several hundred meters away from the source. Thus, there is concern among pork producers and neighbors that bioaerosols present in odor plumes may have occupational, swine, and human health implications (Homes, 1995).

2.2.5 *Public Health Implications of Swine Odor*

Odor and Human Health in General

Minimal data is available concerning the public health effects of odor because most odor studies investigate the impact of specific gases on human health rather than the responses or outcomes elicited from the presence of malodorous air in general. Moreover, odor researchers have not been able to demonstrate whether odor triggers a psychological or physiological response. For example, odors have been found to affect cognitive performance, heart rate and electroencephalogram (EEG) patterns (Schiffman, 1995). However, these responses could be the result of a person merely being distraught or angered because of the offensive smell. Conversely, these symptoms could have emerged from a physiological basis, in which olfactory ciliary receptors in the nose bonded to the odorous compounds, eliciting some sort of signal transduction, which was transmitted to the brain via olfactory neurons.

However, if one uses the World Health Organization's definition of health--"A state of complete physical, mental and social well being and not merely an absence of disease or infirmity"—it does not matter whether the odor psychologically or physiologically induces a response. The point remains that an elicited response can occur in the presence of an offensive odor, altering a person's overall state of well being, which is integral to good health.

Effects on Neighbors

Thus far, two scientific studies have been conducted in the United States addressing the effects of industrial swine facilities on the health of nearby neighbors. The first study, "The Effect of Environmental Odors Emanating From Commercial Swine Operations on the Mood of Nearby Residents," was conducted by Susan Schiffman et al. (Department of Psychiatry, Duke University Medical Center). This study used the Profile of Mood States (POMS) to assess the effects of swine odors on mood. Forty-four persons living near large hog operations and 44 controls participated in the study by filling out the POMS questionnaire. The results indicated that people who live near hog operations and experience the odor plumes reported significantly more tension, depression, anger, fatigue and confusion than the control subjects. In addition, the experimental group reported an overall feeling of less vigor (Schiffman, 1995). The mood states of people exposed to malodors is important because mood has been found to play a role in the immune status of an individual, contributing to subsequent disease outcomes (Schiffman, 1995).

The second study, conducted by Kendall Thu, Kelly Donham et al., assessed both the physical and the mental health of residents living near a large-scale swine operation. Physical and mental health information was collected through personal interviews with 18 residents living within a 2-mile radius of a 4,000 sow facility, and 18 demographically comparable rural residents living near minimal animal production facilities. The results indicated that neighbors of large-scale swine facilities reported higher rates of respiratory problems; nausea; headaches; plugged ears; and irritated eyes, nose and throat (symptoms that also have been well-documented among swine-confinement workers) (Thu, 1997). Yet no environmental data was gathered in this study; thus, it is difficult to establish a causal relationship between the swine odors and the adverse physiological health effects. The nearby residents could have been experiencing 'environmental stress syndrome,' a newly coined term for a condition similar to sick building syndrome, where psychological or psychosocial symptoms have triggered a physiological outcome (Donham, 1998). Similar situations eliciting environmental stress syndrome may have occurred at Love Canal in New York and Three-Mile Island in Pennsylvania, where symptoms were reported, yet levels of toxicant that could have contributed to these symptoms were difficult to detect (Donham, 1998).

On the other hand, this study showed no evidence that neighbors of large-scale swine facilities experience higher rates of psychological problems. However, these results could have been due to the relatively small sample size included in the study. Donham hypothesizes that there is a complex interplay between physiological and psychological symptoms, where stressed or over- worked people may feel susceptible and sickly even from hearsay regarding toxicants in the ambient air (Donham, 1998).

Another study entitled, “Viability of Bioaerosols from a Swine Facility,” sought to determine concentrations of bioaerosols at different distances from gestation buildings (Homes, 1995). The original intent of this study was to determine the distance at which a nursery building would be safe from pathogenic bioaerosols that could infect newborn piglets. However, the data from the study can also be useful in determining safe distances for neighbors and human activities. Bioaerosol measurements were taken at a 500 sow farrow-to-finish operation in areas located at the intersection of circles and radials (spaced every thirty degrees) surrounding the gestation building. Five circles, ranging from 5 to 300 meters away from the building, were sampled for the following bacterial species: *Streptococcus suis, Hemphillus parasuis, Bacillus and E. coli* (Homes, 1995). Results of this study confirmed that airborne microorganisms are still viable after traveling considerable distances. For instance, some of the bacteria were detected nearly 200 meters away from the gestation building. However, the day that this study was conducted was “not conducive to bacterial viability because it was very dry and sunny” (Homes, 1995). Therefore, these results may be conservative and cannot be generalized to cloudy, humid days, where higher levels of bioaerosols and greater viability are expected.

Future Research

There are many other avenues of research that merit investigation with regard to the effects of swine odor on the health of swine facility neighbors. For example, during the summer of 1998, Kendall Thu will be initiating a larger study that will examine the levels of hydrogen sulfide, dust and symptomatologies associated with different types of large-scale swine facilities (Thu, 1998). This study also will examine the social relationships between neighbors of large-scale facilities. Moreover, this study will assess whether the clusters of symptoms in neighbors are analogous to the symptoms appearing in swine workers, who spend intense periods of time within swine buildings.

In addition, a study assessing both the ambient air quality of individual residential areas and the symptoms reported by respective residents should be conducted in order to provide insight into whether any correlation exists between these two variables. More investigations are also necessary to accurately determine the dispersion and viability of bioaerosals emitted from swine facilities under a variety of different conditions (Homes, undated). These investigations could be helpful in the development of odor control policies based on separation distances between swine facilities and neighbors. Furthermore, a comparative study between a facility that has implemented odor control technologies and a facility that has not attempted to control odors should be conducted. This type of study could provide insight into what specific technologies are useful in reducing not only swine odors but also the possible health problems triggered by these odors. Moreover, systematic data on different forms of large-scale swine production need to be collected to determine what kind of producers are more likely to be “good neighbors,” controlling odorous emissions from their facilities (Thu, 1998). The use of Geographical Information Systems (GIS) in future studies would also shed light on wind flow patterns that transport odors across different landscapes, providing insights into where odor problems are likely or unlikely to exist (Hatfield, 1997).

Effects on Workers

In contrast to the possible effects that swine facility odors may have on neighbors, the effects of these odors on workers have been well studied and documented. Studies describing the adverse respiratory effects on swine production workers have been published in the United States, Sweden, Canada, the Netherlands and Denmark (Reynolds, 1996). Results of these studies concur that approximately 50 percent of these workers experience one or more of the following health outcomes: bronchitis, toxic organic dust syndrome (TODS), hyper-reactive airway disease, chronic mucous membrane irritation, occupational asthma and hydrogen sulfide intoxication (Reynolds, 1996).

In addition, results from a study conducted by the University of Iowa (Reynolds, 1996), which assessed chronic swine worker exposures, indicated a dose-response relationship between increased "doses" of industrial swine environments and decreased Forced Expiratory Volume (FEV1) a measure of overall pulmonary function. Additional studies reveal that this dose-response relationship, indicated by changes in pulmonary function throughout the workday, is a predictor of eventual chronic loss in pulmonary function (Donham, 1998). Another study, conducted by the National Institute for Working Life in Solna, Sweden (Muller-Suur, 1997), confirmed that an acute exposure (3 hours) to airborne swine dust induces intense alveolar inflammation in the lower airways of healthy subjects. This inflammation is due to the recruitment of neutrophils, alveolar macrophages and lymphocytes in the lungs (Muller-Suur, 1997). However, further studies are necessary in order both to determine the specific proinflammatory agents of swine dust and to aid in the development of methods and equipment that reduce worker exposures to these constituents.

2.2.6 *Effects of Odor on Local Economies, Property Values, and Community Dynamics*

Odors emanating from large-scale swine facilities not only affect human health but also influence local economies, property values and community dynamics. For instance, in North Carolina, travel and tourism—an industry boasting more than nine billion dollars in annual sales—has suffered immeasurable losses due to national media sources highlighting North Carolina's tainted air quality (Hatfield, 1997). Foul air can also sway consumers away from local businesses, such as grocery stores or other small establishments that are located downwind from a swine facility. Furthermore, the actual swine facilities that are emitting offensive odors also have a direct impact on local economics. Results from a study conducted by Labao reveal that corporate agricultural facilities tend to provoke population declines, lower mean incomes, fewer community services, less retail trade, more unemployment, less participation in democratic processes and "an emerging rigid class structure" (Center for Rural Affairs, 1994). Thus, an increase in corporate hog production in previously uncharted areas, such as western Oklahoma, "can only be expected to accelerate the past trends toward declining rural employment and rural economic decay" (Ikerd, undated).

More specifically, property values also have been adversely affected due to the release of offensive odors from large swine facilities. A study conducted by Abeles-Allison and Conner assessed house sales surrounding eight large hog operations in Michigan. The results revealed "that house values decreased by 43 cents for each additional hog within a 5-mile radius," of the house (Abeles-Allison and Conner, 1990). These results also indicated that the magnitude of adverse effects on property values can vary with respect to both the size of a nearby hog operation and the distance between the facility and a private residence (Palmquist, 1997). Unfortunately, the data for this study were only collected around swine facilities that had received numerous complaints; therefore, the results cannot be generalized. Abeles-Allison and Conner note that it is "reasonable to believe that those farms may have been managed poorly, hence creating a larger nuisance for the surrounding home-owners compared to possible effects on neighbors of well-managed operations" (Abeles-Allison and Conner, 1990). Regardless of these limitations, the results of this study suggest that swine odors have a tangible effect on property values.

An additional study, entitled "Hog Operations, Environmental Effects, and Residential Property Values" (Palmquist et al, 1997) also sought to determine whether swine operations have a significant effect on property values. The scope of the study area included nine counties located in southeastern North Carolina. Results revealed that reductions in the prices of houses within close proximity to swine operations were statistically significant, with prices having a maximum decline of nine percent, depending on the distance and size of the facility (Palmquist, 1990). However, this study did not provide additional data on the particular hog facilities in question. For example, data regarding the specific type of facility, distances between properties and facilities, and wind patterns in the area were not gathered. Thus, future studies investigating these aspects of the odor situation would be helpful in determining a more realistic view of the monetary impacts of swine odor (Palmquist, 1990).

In addition to the adverse impacts on property values, swine odor has woven itself into the social structure of rural communities, creating glitches in existing community dynamics. Swine odor has created social and class demarcations (Thu, 1997), fostering intense conflicts between neighboring landowners. Furthermore, many residents believe that the "construction and presence of the [swine] facility violate core rural values of being a good 'neighbor'" (Thu, 1997).
"Rural 'neighborliness' embodies central cultural principles of egalitarian relationships, reciprocal exchange such as helping…in times of need, mutual respect and being kept informed. The facility's construction and continuing presence [is] viewed as eroding these cornerstones of agrarian life" (Thu, 1997).

Therefore, there are many issues—other than physiological and psychological health—that are embodied in the dilemma associated with swine odor, making it difficult to implement an all-encompassing policy. However, including members of the community in the actual policy-making process may be the best way to prevent the omission of less-evident issues, such as social and interpersonal health. Moreover, a policy concerning swine odor will be more successful if the community is empowered in the decision-making process; instead of having no control over the situation, they will be able to contribute to improving both the air quality in their community and their future overall well-being.

2.3 Gases

2.3.1 *Gases of Major Concern*

Although severe swine odors can create numerous problems in surrounding communities, the specific gases that either constitute the odor plumes or escape on their own from large-scale swine facilities can also pose serious threats to human, environmental and community health. For example, in Iowa, many incidents of people being "overcome by deadly manure gases" are reported each year (Lorimor, 1994). These incidents include several deaths, among a multitude of minor and severe illnesses. As mentioned above, the four main gases of concern are hydrogen sulfide (H_2S), carbon dioxide (CO_2), ammonia (NH_3) and methane (CH_4). These gases are emitted from the same sources that emit swine odors: swine buildings, waste storage and treatment processes, land application practices and carcass disposal areas. Exposure to elevated levels of these gases, even over a short period of time, can produce symptoms ranging from mild irritation to death in both animals and humans (Taraba and Piercy, undated).

Hydrogen Sulfide (H_2S)

Hydrogen sulfide, produced by both the anaerobic decomposition of protein in swine manure and the bacterial reduction of natural sulfates, is the most toxic gas emanating from swine excreta (Taraba and Piercy, undated). It is heavier than air and soluble in water; thus, it will accumulate in underground pits and other low-lying unventilated areas (Lorimor, 1994). Its distinct odor of rotten eggs can be detected at levels less than 1 part per million (ppm). However, at 100 ppm, hydrogen sulfide deadens the sense of smell and no odor will be detected.

According to the National Institute for Occupational Safety and Health, "hydrogen sulfide is a leading cause of death in the workplace," (NIOSH, 1977 in Thornton, 1996). Moreover, it is accountable for most manure-related deaths in both humans and animals (Lorimor, 1994). The threshold limit value (TLV) or maximum allowable concentration for humans is 10 ppm. Concentrations from 20 - 150 ppm can "severely irritate the eyes after 6 to 8 minutes and the respiratory tract after one hour" (Taraba and Piercy, undated). In addition, levels between 500 ppm and 1,000 ppm induce acute intoxication associated with the following symptoms: sudden fatigue, headaches, anxiety, loss of olfactory senses, nausea, sudden loss of consciousness, optic nerve dysfunction, hypertension, pulmonary edema, coma, seizures and severe respiratory distress, often followed by cardiac arrest and death (Thornton, 1996). Moreover, one to two breaths of 1,000 ppm of hydrogen sulfide causes instantaneous unconsciousness and death through complete respiratory paralysis, unless artificial means of respiration are performed (Taraba and Piercy, undated).

Elevated levels of hydrogen sulfide also can have negative impacts on swine health. Swine living under conditions of 20 ppm can develop fear of light, loss of appetite and nervousness. Concentrations of 50 - 200 ppm can give rise to nausea, vomiting and diarrhea, while levels above 400 ppm can cause death (Taraba and Piercy, undated). (See Appendix A, Table 1, for complete list of the effects of hydrogen sulfide on humans and swine).

Carbon Dioxide (CO_2)

Carbon dioxide, a traditionally non-polluting gas present in the ambient air at a concentration of 350 ppm (0.035 percent) under normal conditions, is a natural respiratory product of both humans and animals. It is also the product of the anaerobic decomposition of organic acids and carbohydrates found in swine manure ($C_6H_{12}O_6 \Rightarrow 3CH_4 + CO_2$) and is generally the most abundant gas generated from manure lagoons during anaerobic decomposition. Carbon dioxide is a colorless, odorless gas that is denser than air and soluble in water (Taraba and Piercy, undated). Although it is prone to disperse within liquid manure due to its density, vigorous agitation often results in the release of significant amounts of carbon dioxide into the ambient air.

At elevated levels, carbon dioxide can cause respiratory problems, eye irritations and headaches. It is not a highly toxic gas; however, it can cause asphyxiation since it dilutes the oxygen content of inspired air. The threshold limit value (TLV) of carbon dioxide is 5,000 (0.5 percent) and acute exposures to air with 100,000 ppm can induce violent gasping and panting (Taraba and Piercy, undated). Average concentrations in swine buildings can range from 1,000 ppm during well-ventilated periods to 10,000 ppm during the winter months when ventilation is minimal. Furthermore, carbon dioxide can act as a narcotic (even when present with adequate amounts of oxygen), and exposure to atmospheric conditions of 250,000 ppm can kill humans and animals within a few hours (Tarabe and Piercy, undated). (See Appendix A, Table 2 for a complete list of the effects of carbon dioxide on both humans and swine).

Ammonia (NH4)

Protein from animal feed is the primary source of swine manure nitrogen, which exists in two predominant forms within manure: ammonia and organic nitrogen (Fulhage, undated). In fresh swine manure, approximately 56 percent of the total nitrogen is present in the form of ammonia (American Society of Agricultural Engineers, 1994). However, the organic nitrogen can be converted to ammonia by bacteria present in the manure; therefore, all nitrogen products expelled by swine can potentially be emitted into the atmosphere through ammonia volatilization (Fulhage, undated). The Environmental Defense Fund (EDF) estimates that over eighty percent of the nitrogen in hog manure is vaporized as ammonia (EDF, 1997). Using this value, the EDF also calculated that ammonia nitrogen emissions--from hog farms in Eastern North Carolina alone--translate to approximately 135 million pounds of nitrogen deposition per year (EDF, 1997).

Ammonia in its pure form is irritating to the eyes at concentrations between 20 and 25 ppm. At levels of 1,500 ppm, exposed persons will cough and froth at the mouth, while at a concentration of 5,000 ppm, the ambient air is deadly (Lorimor, 1994). Fortunately, ammonia has a very sharp, pungent and distinct smell, detectable at levels as low as 5 ppm (Lorimor, 1994). The recommended TLV or maximum acceptable dose is 25 ppm, a level which is debated among safety experts since this concentration can produce burning sensations in the eyes (Lorimor, 1994). (See Appendix A, Table 3, for a complete list of the effects of ammonia on both humans and swine).

Methane (CH_4)

Methane production by swine occurs in both the digestive tract and the manure decomposition process. Gastrointestinal production of methane occurs in varying degrees in all animals; however, it is most prominent in ruminants (Fulhage, undated). Approximately "95 percent of animal methane emissions are from ruminants, and ruminants typically belch 6 to 8 percent of gross dietary energy to the atmosphere in the form of methane" (Van Horn, 1995). The remainder of swine methane emissions predominantly comes from solid manure. In swine, twenty percent of total dietary energy is excreted as volatile solids in urine and feces (Fulhage, undated). All of this energy can potentially be converted to methane in the anaerobic decomposition process that occurs in lagoons ($C_6H_{12}O_6 \Rightarrow 3CH_4 + 3CO_2$) (Van Horn, 1995). The resulting methane is subsequently volatilized into the ambient air. The rate of conversion from manure solids to methane is dependent on a number of environmental factors including temperature, pH, humidity and the presence of bacterial nutrients (factors that should be considered in any manure management program).

Once methane is emitted into the atmosphere it is highly combustible, making it very dangerous, especially in high temperature conditions. At levels of 50,000 ppm (5.0 percent of ambient air), methane can spontaneously explode (Lorimor, 1994). Methane is also dangerous because it is colorless, odorless, and tasteless, making it very difficult to detect. The TLV for methane is 1,000 ppm (1.0 percent of ambient air) and, since methane is lighter than air, it can potentially reach this concentration at the top of unventilated areas such as closed manure pits (Lorimor, 1994). However, manure pits are not known to emit significant levels of methane. (See Appendix A, Table 4, for a complete list of the effects of methane on both humans and swine).

2.3.2 *Measuring Swine Gases*

Measuring swine gases is a relatively straight-forward procedure, unlike the complex and problematic processes involved in measuring swine odors. A hydrogen sulfide analyzer is utilized to measure concentrations of hydrogen sulfide, while an infra-red analyzer can be used to measure both carbon dioxide and methane. A chemiluminescent NO_x analyzer is often used to analyze the levels of ammonia in ambient air; although traditional methods, such as gas chromatography and mass spectrometry, are also utilized (Sweeten, undated).

Unfortunately, since most of the research concerning swine facility airborne emissions has focused on the odor issue, there have been few studies that provide any information on the levels of gases present in communities surrounding large-scale swine facilities. However, one study, concerning the measurement of hydrogen sulfide emitted from swine facilities, has revealed useful results.

In the summer of 1994, in Renville County, Minnesota, there was concern among some residents that two manure holding ponds of a nearby hog operation were emitting dangerous levels of hydrogen sulfide, which induced fits of vomiting, nausea and blackout periods in both adults and children (DeVore, 1997). In response to this concern, the Minnesota Department of Health (MDH), along with the help of local citizens, conducted a study testing for airborne hydrogen sulfide at a number of different sites, including beef, dairy, poultry and swine operations, and a beet processing plant (MDH and MPCA, 1996). Continuous monitoring, with the use of a Jerome Hydrogen Sulfide Analyzer, was performed over half-hour or full-hour monitoring periods (MDH, MPCA, 1996). Results indicated that the beet processing plant and the swine operations had the highest hydrogen sulfide emissions. Average swine emissions ranged from 0 to 47 parts per billion (ppb) during 30-minute sampling periods. However, hydrogen sulfide levels from 8 to 53 ppb were recorded near six swine operations. These tests laid the groundwork for the Minnesota Feedlot Hydrogen Sulfide Program discussed later in Section 4.1.7.

The results were helpful in revealing 'above normal' levels of hydrogen sulfide around swine operations. Yet, since emissions from these operations are unpredictable and uncontrolled, it is difficult to generalize these results to facilities that were not involved in the study. Thus, the MDH recommended that Renville County residents, who are concerned about hydrogen sulfide levels, should be provided with portable monitors, so that MDH can "better characterize the nature of emissions and enable the county to respond to complaints" (MDH and MPCA, 1996). Perhaps this method of "case-by-case" measuring of hydrogen sulfide is the best way for individual counties to control these emissions until a national ambient air quality standard (NAAQS) for hydrogen sulfide is established. However, future investigations concerning the swine emissions of hydrogen sulfide and other dangerous gases, such as ammonia, carbon dioxide and methane, should also be conducted. The results of these studies could enable standards for each of these gases to be developed if it is found that the gases reach levels that compromise public health.

2.3.3 *Effects of Swine Gases on the Environment*

Although it is important to measure gaseous swine emissions for the purposes of protecting public health, it is also important to measure these concentrations in order to determine whether swine gases are contributing to adverse effects on the environment. Recently, there has been concern that the abundance of ammonia emissions from swine facilities is contributing to the over-fertilization of nitrogen-sensitive prairies, "resulting in the proliferation of weedy species at the expense of native plants…" (Rudek, 1997). In addition, since the Midwest is a drainage basin for the Mississippi River system, it is thought that the excessive amounts of nitrogen deposition (by route of ammonia emissions) being delivered to the Gulf of Mexico—via the Mississippi River—are contributing to the recently discovered "dead zone" (Rudek, 1997). This phenomenon of nitrogen deposition in the hydrosphere (the waters of the earth) is believed to have taken place in North Carolina, where 135 million pounds of nitrogen emitted from swine facilities has potentially contributed to the decline in estuary health along the North Carolina coast. However, the scientific community is not in complete agreement concerning this issue because there is limited long-term data on atmospheric levels of swine ammonia (Fulhage, undated).

In addition to the potential environmental problems caused by ammonia emissions, methane and carbon dioxide emissions from large-scale swine facilities may be contributing to even greater environmental problems. Methane, a gas that has been implicated in the degradation of the earth's ozone layer, is also a greenhouse gas, capable of absorbing enormous amounts of radiation. Carbon dioxide is a greenhouse gas as well, although it is not nearly as damaging as methane, which "on an equal weight basis [absorbs] 70 times as much infrared radiation as carbon dioxide" (Fulhage, undated). This absorption of infrared radiation has been implicated in the controversial debate concerning the existence of global warming; thus, if it is proven that global warming truly is a reality, then the gaseous emissions of industrial swine facilities are also contributing to the warming of the planet.

2.3.4 *Summation*

Whether or not it is proven that swine odors and gases contribute to public health and environmental problems, the presence of these emissions still has a negative overall effect on the quality of life of workers and neighbors of large-scale swine operations. People have been psychologically affected, property values have been depressed, local economies are suffering and community dynamics have been interrupted and altered, to say the very least. Thus, if large-scale swine facilities intend to remain next-door-neighbors to rural America, it is imperative that the levels of odor and gas emissions be either reduced or controlled in both the indoor and outdoor environments of these facilities. The following section of this paper will introduce methods by which this effort can be successfully achieved.

3.0 METHODS OF ODOR CONTROL

Odorous compound formation is primarily due to the biodegradation of organic material such as manure. Therefore, inhibiting or controlling biological activity prevents the formation of odor. Since the primary cause of odor at a swine production facility is the lack of cleanliness, the best method of preventing this odor is to operate a well-managed, clean facility. However, cleanliness alone cannot rid a swine facility of odors. Odors, which can be generated during each stage of manure handling, from generation to disposal, will result no matter how clean a swine facility is kept.

Due to the increasing size of swine facilities, the proximity of these facilities to human populations and the pressure of imminent regulations, research and the development of waste-management and odor-control technologies has accelerated. Such research and technological development have produced numerous innovations that can substantially reduce the amount of odor emitted from swine facilities, especially when used in combination. Several technologies also produce by-products, such as fertilizer, fuel and flush water, that have other beneficial uses. These benefits can offset the additional cost of implementing and maintaining these technologies. The following sections describe current methods that have been used in the United States and Europe to minimize odors at swine production facilities.

3.1 Swine Buildings

Most swine buildings that have severe odor problems lack cleanliness. If not frequently cleaned and ventilated, swine houses generate odor, which can be intense during warm, humid weather. The swine themselves generate odor as they become dirty with feed dust, urine and manure, and the odor intensifies as the body heat of the swine rises. Keeping the floors and walls clean by flushing and scraping out manure regularly can substantially reduce odors. Clean floors and walls can also help keep the swine clean.

As well as being improperly managed, malodorous swine facilities may also be improperly designed. Older swine buildings may lack adequate ventilation or have solid floors preventing the separation of manure and urine from the swine. In order to minimize odor as much as possible, older swine buildings should be cleaned more often or modified, and new buildings should be designed to include odor-abating features. Swine buildings should be equipped with slotted floors to allow manure to fall below into a collection pit, preventing the manure from accumulating near the swine. They should also contain smooth walls, raised floors, flushing gutters, concrete collection pits and basins; open pens, ventilation fans, and biofilters. In addition, surfaces that will have contact with manure on a daily basis, such as floors and walls, should be constructed out of a material that is smooth, nonporous and easy to clean (SOTF, 1995; Jacobson, 1994).

3.1.1 *Ventilation*

Swine buildings should have adequate ventilation to prevent the buildup of gases, moisture, heat and dust, which can intensify odors and be detrimental to human and swine health. When designed and managed properly, ventilation systems can significantly reduce odor both inside and outside the swine building. However, the improper design and mismanagement of these systems can intensify odors and cause a significant odor problem

(SOTF, 1995; Heber, undated). It should be noted that ventilation systems will not get rid of all odor-producing agents because manure, dust and dirt adhere and accumulate on the swine, bedding materials and building surfaces. Therefore, ventilation should not be a substitution for cleaning. Swine, bedding materials and building surfaces should be kept clean and dry to impede organic decomposition (SOTF, 1995; Jacobson, 1994; Heber, undated; Murphy, 1990).

Swine buildings should be properly constructed, minimizing any openings such as cracks and holes, which could cause drafts and interrupt the air flow within the swine building (Murphy, 1990). Pen partitions should be open rather than closed as not to interrupt airflow (Christianson, undated). Insulation should be used to reduce heat loss and condensation in cold weather; warm air can absorb and remove moisture as it flows through the swine building (Murphy, 1990).

Ventilation systems in swine buildings can be run either mechanically or naturally (Jacobson, 1994; Driggers, 1989). Due to the increasing size of swine buildings and severe climatic changes, mechanical ventilation systems are preferable for controlling temperature, moisture and odor, especially when used in conjunction with biofilters and air scrubbers.

Many swine buildings and some waste storage facilities have mechanical ventilation systems, which typically consist of exhaust fans, air circulation fans, distribution ducts, air inlets and air jets (SOTF, 1995; Heber, undated). There are three types of mechanical ventilation systems, which are characterized by pressure: positive, negative and neutral pressure systems. Positive pressure systems blow air into the swine building. Conversely, negative pressure systems exhaust air from the swine building. Neutral pressure systems are the result of an equal amount of air coming in and out of the swine building at any given time. It is essential that the proper pressure, and thus air direction, be maintained, especially for negative pressure systems. A reverse of airflow in a ventilation system that removed air from the collection pits, for example, would result in the flow of odorous air going back into the swine building (Murphy, 1990).

Fresh air should be uniformly distributed throughout the swine building. The use of air circulation fans and distribution ducts mixes indoor and outdoor air, which is particularly advantageous in colder weather for heat conservation. The speed of the air circulating in the swine building should be effective but as low as possible; as air speed increases, the amount of odorous gases, such as ammonia, emitted from manure also increases. The design, location and management of fans, ducts, inlets and jets can control air speed (Heber, undated).

The best method of ventilation entails the introduction of outside air into the building from the ceiling and then directing the air throughout the building, down to the floor. By the time the air reaches the floor, the speed of the air is quite low, reducing ammonia emissions (Heber, undated). This method is particularly useful in colder weather because adequate ventilation can be provided without losing much heat (Murphy, 1990).

Additionally, studies have found that the continuous inflow of air from ceiling inlets provided the most even distribution of air, whereas wall inlets produced the worst conditions (Heber, undated; Murphy, 1990). Because the direction of the air flow is toward the floor, this method allows most of the odor-causing compounds to accumulate at floor level where most of the odor from the swine and the manure is emitted. Therefore, air should be discharged from the swine building at this level, which would require the installation of exhaust fans at floor level. Studies have indicated that the use of fans that exhaust air directly from the collection pits and gutters reduce odor and the concentrations of gases from the entire swine building (Heber, undated).

Most mechanical ventilation systems are equipped with sensors and controls, providing easy management. These sensors and controls should be constructed to withstand moist, corrosive conditions. In order to manage properly a mechanical ventilation system, these sensors and controls should be placed at animal level to accurately assess ambient air quality, but they should be within reach of the operator, not the swine. Locations that are subject to abnormal conditions such as direct sunlight and drafts should be avoided (Murphy, 1990).

The major problem with ventilating swine buildings and waste storage facilities is that exhaust fans release into the environment the highest concentrations of odors measured at swine facilities. However, these odors can be reduced through the use of biofilters and air scrubbers, which have been shown to significantly reduce the concentrations of the biodegradable compounds that cause odor (SOTF, 1995; Nicolai, 1997; U.S. Department of Agriculture [USDA], undated).

3.1.2 *Biofilters and Air Scrubbers*

Biofiltration has been shown to effectively and efficiently remove low concentrations of biodegradable compounds from the air. It is a naturally occurring process in the soil that has been adapted for commercial use. Biofilters contain microorganisms that break down volatile organic compounds and oxidizable inorganic gases and vapors into non-malodorous compounds such as water and carbon dioxide. Biofilters have been constructed out of various materials including compost, straw, wood chips, peat, soil and other inexpensive, biologically active materials (SOTF, 1995; Nicolai, 1997; North Carolina State University [NCSU], 1997).

Research has found that biofilters have reduced odors in swine buildings by as much as 90 percent (SOTF, 1995; USDA, undated). Reductions in odor and contaminant concentrations, such as hydrogen sulfide and ammonia, appear to vary seasonally. This variation may be due to the lack of adequate moisture in the filter material; moisture is essential for the survival of the microorganisms. Therefore, some maintenance of the filters may be required (Nicolai and Janii, 1997).

Generally, biofilters are inexpensive, especially if they are constructed from materials that are readily available from the swine production facility (Nicolai and Janni, 1987; Arogo, undated). For example, one study estimated that the cost for the construction and operation of a biofilter to treat the ventilation exhaust from both the gestation and farrowing buildings of a 700-sow facility in 1996 would be 28 cents per piglet produced, assuming an equipment life of 10 years with the filter itself being replaced every 3 years (Nicolai and Janni, 1997).

Another method under development is the use of air scrubbers or bioscrubbers. Air is forced up through the shaft, while water flows down the shaft, trapping odorous gases and particulates (Heber, undated). Water-soluble components of these gases and particulates are transferred from a solid phase into a liquid phase. Bacteria subsequently oxidize these components, breaking them down (Arogo, undated). Studies using air scrubbers have found that more than 90 percent of odorous gases can be removed. Ammonia, for example, can be reduced by up to 40 percent. Scrubbers have also shown to be effective in removing significant amounts of carbon dioxide, dust and bacterial and fungal spores. Although studies indicate that the use of air scrubbers would be relatively inexpensive, air scrubbers are not in widespread use. Research involving the design and feasibility of air scrubbers is ongoing (Heber, undated; USDA, undated; NCSU, 1995).

3.1.3 *Dust Control*

Feed and dried manure are the primary sources of dust in a swine building (Barker, 1996). Other sources include bedding materials and the swine themselves. The amount of dust depends on the amount of animal activity, stocking density, feeding methods and the temperature, relative humidity and ventilation rate of the swine building (Nicolai, 1998). Dust is of serious concern, as it is believed to carry much of the odor from swine buildings to the outside (NCSU, 1997).

There are several methods that are currently being used or developed to control and capture dust. One of the best methods is to periodically clean ventilation systems, walls and floors (Barker, 1996a). Modifications to existing feed delivery systems such that feed is not agitated as much have also been effective in reducing dust. Methods in capturing dust include the use of ventilation systems that are equipped with biofilters and/or air scrubbers. Without such technology, ventilation systems are the primary vehicle in the dispersal of dust to the outside air. Research is currently addressing the feasibility and the odor and dust reduction potential of biofilters and air scrubbers (Heber, undated; USDA, undated; NCSU, 1995; NCSU, 1997). Additionally, several mechanical dust removal systems, which would probably be more expensive to purchase and operate, are also being developed (Bundy, undated). Ventilation systems, if properly designed, can also assist in dust removal by trapping particulates in the wastewater in the floor gutters or collection pits (SOTF, 1995).

3.2 Waste Handling Systems

The primary cause of odor generation in the removal of manure from swine buildings is the agitation and mixing of manure. Therefore, the method and frequency of removing manure from swine buildings is crucial in preventing the release of odors.

There are several methods used to remove manure from swine buildings: manual or mechanical scraping, periodic or continual flushing, and gravity draining (Meyer, 1990). In the United States, periodic flushing appears to be the preferred method of manure removal. Most swine production facilities flush the manure from the swine buildings with recycled lagoon effluent (Barker, 1996a; Barker, 1996b). Depending on the quality of the lagoon effluent, additional odors may be generated than if water were used. Gravity draining, which entails the use of gravity and little to no water to remove manure from open-floor gutters into storage units, has been used in areas where minimal waste volume is desired (Meyer, 1990).

A flush system collects the manure wastes from under-floor pits and open-floor gutters and discharges the waste into manure storage and/or treatment facilities, such as tanks, basins and lagoons. Although the floors of swine buildings housing gestational swine cannot be flushed, the open-floor gutter systems of these buildings can be flushed (Barker, 1996a; Barker, 1996b).

Recommended design specifications for the floor of a swine building include a 24-inch distance between the slotted floors and the collection pits or gutter floor below. The slope of the gutter floors should be between 1 and 2 percent, while the collection pit floors should be level if water is to be left at the bottom of the floor to prevent the adherence of manure. Wide collection pits should be divided into 4- to 5-foot channels. Studies have indicated that a minimum flow velocity of 3 feet per second and a discharge duration of 10 seconds is adequate for flushing most swine buildings. The volume of water used is dependent on manure viscosity, solids carrying capacity of the flush water, manure production or animal density/weight, and channel slope (Barker, 1996a; Barker, 1996b).

Water used for flushing is usually stored in flush tanks, which should have at least 1.5 gallons per 100 pounds of live animal weight per flush. Recycle pumps, which are low pressure, self-priming centrifugal or submersible pumps, are used to pump lagoon effluent into flush tanks. These pumps are equipped with an intake that has a screen to prevent solids from entering the flush system (Barker, 1996a). Periodic cleaning or equipment replacement may be required to prevent the buildup of a greyish-white crystalline salt primarily composed of magnesium ammonium phosphate (Barker, 1996b).

Several different types of flush tanks have been used, but valved or gated discharge tanks that are covered are recommended. These tanks, which are typically constructed from concrete or concrete reinforced with steel, can be situated at ground level adjacent to the swine building. The tanks can be flushed either manually or with a gate mechanism. These mechanisms include a water-weight valve, which can open multiple valves simultaneously at varying valve diameters without the need for electromechanical activation (Barker, 1996b). The diameter of the valves and associated piping is dependent on the width of the channels being flushed, the slope of the floors and the volume of water discharged (Barker, 1996a; Barker, 1996b). It should be noted that high-volume pumping systems are also used, especially for swine buildings that have pit floors of a slope less than 0.5 percent. These systems, however, require the use of much more water (Barker, 1996b).

When the waste is flushed, it flows toward a drain in the collection pit, which empties into an exterior collection box. Liquid wastes from the collection box flow into a smooth-walled drainpipe, which empties into the manure storage and/or treatment facility (Barker, 1996a; Barker, 1996b). If the waste is to be stored in a lagoon, it is recommended that a turndown collar be used at the end of the drainpipe so that the waste can be discharged below the liquid surface (Barker, 1996b).

In order to reduce odors, the flush tank and collection boxes should be covered. If sumps or storage basins are used in the flushing system, the sump tanks and basins should also be covered. Valves releasing lagoon effluent into the channels and the flush tanks should be fitted with anti-siphon vents. In the collection pit channels, the valve dispersing flush water should be extended near to the bottom of the channels to minimize the agitation of the lagoon effluent (SOTF, 1995).

As well as using a well-designed manure removal system, the system has to be properly ventilated. Ventilation systems not only prevent the accumulation of odorous gases, but they also remove excess moisture and assist in the regulation of temperature, thereby inhibiting biodegredation (SOTF, 1995; Barker, 1996b). (See sections 3.1.1 and 3.1.2).

3.3 Manure Liquid/Solid Separation

Once retrieved from swine buildings, liquid and solid manure should be separated so that their maximum usable potential can be achieved. Recovered solids can be used in composts for eventual use as fertilizer, while liquids can be used in flushing systems. The primary benefit to manure separation is that the life span of a lagoon is extended. Not as much solid matter flows into the lagoon, reducing the amount of sludge buildup on the bottom. Therefore, manure separation has been recommended in most states, including Oklahoma (Natural Resources Conservation Services [NRCS], 1995). The removal of solids can reduce odors by lessening organic loading in lagoons; however, the separation of liquid and solid manure can also produce odors if mismanaged (Barker, 1996c; Safley, 1993).

Currently, both mechanical and gravity methods are used to separate manure at swine facilities. It is recommended that vibrating-screen, stationary sloping screen or pressure-roller mechanical separators be used so that a relatively dry solid by-product can be recovered (Barker, 1996c; Safley, 1993; Agpro, Inc., undated). A pump at the bottom of the settling basin mixes the manure waste into a slurry, which is then pumped across the separator. Mechanical separation removes up to 30 percent of the total solids and 25 percent of the “oxygen-demanding” solids (Barker, 1996c). Mechanical separation involves the cost of maintenance and management as well as the initial expense of purchasing the equipment (Safley, 1993).

Gravity separation, which is less costly than mechanical separation, occurs within the settling basin or tank. Solids settle in a 2- to 6-foot deep basin. A porous dam or a perforated/screened pipe outlet is used to filter solids as the liquid passes through to either a tank or lagoon. Gravity separation removes in excess of 50 percent of the solids from the manure waste. Solids are subsequently removed from the basin by a front-end loader (Barker, 1996c; Safley, 1993).

Other methods of manure liquid/solid separation are under development. These methods include the use of aerobic biofilters and chemical additives that bind with solids to facilitate settling (Kantardjieff, undated; NCSU, 1997a; NCSU, 1997b).

3.4 Waste Storage Systems

Traditionally, manure was directly applied to the land after collection. Due to increasing amounts of manure and the complexities of land application, manure storage systems are used prior to land application or disposal. These systems include lagoons and waste storage facilities, such as tanks, basins and pits.

Waste storage facilities are used temporarily to store undiluted raw manure waste (NRCS, 1996). Stored manure is removed as needed for treatment in units such as lagoons or composters. Earthen pits, which are typically unlined and uncovered, have been a source of significant odors as well as groundwater and surface water pollution. In addition, several human fatalities have resulted from the lack of proper security (Taraba and Piercy, undated). Therefore, it is recommended that tanks and basins be used; they can be covered and are typically constructed of concrete, which prevents water pollution (SOTF, 1995).

Lagoons, once thought of as being the “total disposal system,” are used to promote digestion and stabilization of the manure solids (Barker, 1996a). Water is used to dilute the manure, promoting microbiological digestion and reducing ammonia concentrations that can impede digestion. Thus, dilution minimizes odors and greatly reduces the concentration of solids in the lagoon. Typical dilution rates are 6 to 10 parts of water for each part of manure, which provides a pH balance of 7 to 8 (Barker, 1996d; Lorimor, 1995). Acidic lagoon effluent, a result of inadequate dilution, will result in an increase in odor (Barker, 1996d).

Solids that settle at the bottom of the lagoon are digested anaerobically, while aerobic bacteria breakdown solid matter floating at the surface. Consequently, the concentration of solids in lagoon effluent can be as low as 0.5 percent, depending on the temperature and type of lagoon used (Lorimor, 1995). In addition to considering the amount of manure that will be loaded into a lagoon system, design specifications should consider additional volume resulting from the accumulation of sludge, precipitation and surface water runoff (Safley, 1993; Koelsch, 1996).

Lagoons used in the swine production industry are anaerobic (bacteria requiring the lack of oxygen for digestion), aerobic (bacteria requiring oxygen for digestion) or facultative (a combination of aerobic and anaerobic) (Safley, 1993). Anaerobic lagoon systems, which are most commonly used at swine production facilities, treat more organic matter per volume than aerobic lagoons, thereby producing less inert sludge. However, anaerobic digestion produces malodorous compounds. The intensity of the odors resulting from anaerobic digestion can be significantly reduced if anaerobic lagoon systems are managed properly (Safley, 1993; Barker, 1996d).

To manage a lagoon system properly, the long-term rate of adding manure should not exceed the rate at which stabilization can occur. Loading rates, defined as the amount of manure that will be added per volume of lagoon per day, must be pre-determined (Safley, 1993; Barker, 1996d). Typically, loading rates for Oklahoma vary between 5 to 6 pounds of volatile solids per 1,000 cubic feet per day (Miner, 1988).

Design specifications should also take into consideration seasonal changes; loading rates vary seasonally due to the change in temperature. Generally, as the temperature increases, the loading rate will increase as the bacteria become active and digest more manure waste (Safley, 1993; Koelsch, 1996). In winter, anaerobic digestion is greatly reduced so that in the spring, anaerobic bacteria must be allowed time to digest solids that accumulated during the winter as well as any newly added solids. If the lagoon has more solids than the amount the bacteria can digest, pungent odors will result. Thus, it has been recommended that loading rates should be lower in winter and early spring (Safley, 1993). Although loading rates should be varied depending on climate conditions, manure should be added regularly. Infrequent loading can “shock” the system, causing significant increases in odor and a fluctuation in effluent nutrient content (Barker, 1996d).

Anaerobic decay occurs in three stages, the first of which involves fermentative bacteria that decompose long chains of complex carbohydrates, proteins and lipids into shorter ones. In the second stage, acid producing bacteria convert the intermediates into acetic acid, hydrogen and carbon dioxide. Acid-producing bacteria create an anaerobic condition essential for methane producing bacteria by using up the oxygen in the manure. These bacteria also reduce low molecular weight compounds into alcohols, organic acids, amino acids, hydrogen sulfide and methane. In the third stage, methanogenic bacteria, which are very sensitive to environmental changes, decompose acids into methane and carbon dioxide (IASAT, 1996).

Anaerobic lagoon systems can either be designed to encompass a single “stage” or multiple “stages.” The number of stages used is dependent on the amount of precipitation, the designated use(s) for the lagoon effluent and the amount and frequency of lagoon effluent removal. Multistage lagoon systems may be beneficial for odor control. The first stage consists of the primary treatment unit, in which organic material is allowed to stabilize. The second and any subsequent stages contain relatively clean water, which can easily be pumped for use in flush systems or to be applied to cropland. Sludge and effluent removal is easier in a multistage system (Safley, 1993).

Aerobic lagoons are either equipped with mechanical aerators or encompass a large surface area so that there is enough free oxygen to sustain aerobic bacteria. Due to such requirements, aerobic lagoons are more costly than anaerobic ones. However, aerobic digestion is more complete than anaerobic digestion resulting in almost odorless end products (Safley, 1993; Barker, 1996d). Biological/biochemical oxygen (BOD_{50}) demand varies depending on climate, ranging from 40 to 50 pounds per acre per day in Oklahoma (NRCS, 1995a). Lagoon design should also take into consideration the chemical oxygen demand (COD). Complete aerobic digestion can occur if the aerobic lagoon system has provided sufficient oxygen to satisfy 50 percent of the daily COD inflow. For mechanically aerated lagoons, it is important to use aerators that provide sufficient turbulence so that sufficient oxygen is produced to promote aerobic digestion, thus minimizing odors (Safley, 1993; NRCS, 1995a).

3.5 Lagoon and Pit Additives

Although odor control products or additives are widely available, there is little scientific data supporting the effectiveness of these products. In general, no products have been proven both reliable and effective either in the United States or Europe (SOTF, 1995; Nicolai, 1998; (Safley, 1993; University of Minnesota (UMN), undated[a]).

Odor control products include masking agents, counteractants, digestive and chemical deodorants, and absorbants. Some products, such as masking agents, have a stronger odor than the original odor and can be just as offensive to neighbors due to their odor intensity. Most of these products can only be used intermittently and often do not correct the source of the odor problem. Additionally, a single odor control product cannot typically inhibit or reduce all of the odor causing compounds found in swine manure. Some of these products are composed of organic compounds that can be broken down by bacteria, or a combination of these products may worsen the odor or kill beneficial bacteria (SOTF, 1995). The cost of these products varies widely, but can be quite expensive. Thus, the use of odor control chemicals is not typically recommended (Safley, 1993; UMN, undated[a]).

3.6 Biofilters and Covers for Waste Storage Facilities and Lagoons

Research and development appears promising for the development of covers and biofilters for waste storage facilities and lagoons, which prevent the escape of odorous gases. Currently, these technologies are under development. Several studies are being conducted to determine the feasibility of using covers and biofilters that can withstand various weather conditions and the corrosivity of odorous gases at swine production facilities. Similar to those being developed for ventilation systems in swine buildings, experimental biofilters for lagoons and waste storage facilities are composed of inexpensive, biologically active material. Various materials are being studied for use as cover materials including oil, straw, industrial fabrics and flotation devices (NCSU, 1995; NCSU, 1997; Safley, 1993; UMN, undated[a]; UMN, undated[b]). Researchers who are developing biogas generation technologies (see Section 3.7) are also studying the feasibility of lagoon covers, which are necessary for the collection of methane, the primary component of biogas (Safley, 1993; Miner, 1988; Jones, 1980; U.S. DOE, undated; IASAT, 1996).

3.7 Biogas Generation

Biogas generation, which is the result of the decomposition of organic matter by anaerobic bacteria, occurs in the absence of oxygen and produces a waste product known as "biogas". Presently, biogas generation using swine manure is still under development and not widely used worldwide. In the United States, this technology is rarely used except on dairy farms where simple systems capture methane under lagoon covers and at on-farm alcohol production plants (SOTF, 1995; Jones, 1980). The primary hindrance in the development of biogas generation technology is the high relative cost compared to petroleum energy. However, as a result of the oil crisis in the 1970s, this technology achieved viability in countries such as Denmark and Switzerland (Jones, 1980; ETSU, undated). While petroleum energy costs were high, these biogas generation facilities were profitable; however, these facilities are currently supported primarily with government subsidies (Jones, 1980).

Biogas generated from this process consists primarily of methane (50 to 80 percent), carbon dioxide (20 to 50 percent) and trace levels of organic gases (1 to 5 percent), such as hydrogen, carbon monoxide, nitrogen, oxygen and hydrogen sulfide (Jones, 1980; U.S. Department of Energy [DOE], undated; Information and Advisory Service on Appropriate Technology [IASAT], 1996). The amount of each gas produced is dependent on the type of feed material used and the management quality of the biogas generation process itself. Methane, which is the major component of natural gas (95 to 98 percent), is used to produce energy. According to the U.S. Department of Energy, when burned, a cubic foot or 0.028 meters of biogas yields approximately 10 British Thermal Units (BTU) or 2.52 kcal of heat energy per percentage of methane composition (U.S. DOE, undated). The by-product, digested waste, has significantly less odor than non-digested waste. However, there is not a significant reduction in the amount of manure after biogas generation. Although digested waste has slightly less value as a fertilizer, the composition of digested waste has been converted such that the waste is in a more useful form for crops (Jones, 1980). Prior to land application, the digested waste should be sampled to determine its nutritional content so that it can be applied to farmland in conjunction with specific crop nutrient requirements. Also, the digested waste can be used as a feed additive when dried, providing that it does not contain any toxic substances, such as heavy metals or pesticides (U.S. DOE, undated).

Many different forms of anaerobic digesters have been constructed using various building materials. Digesters have been constructed out of concrete, steel, brick or plastic; designed looking like silos, troughs, basins or ponds such as lagoons; and constructed above or under ground. The primary components of anaerobic digesters are a pre-mixing area or tank and a digester vessel(s). Systems for storing and using methane and storing and spreading the digested waste are also necessary.

There are two types of anaerobic digesters. In a batch anaerobic digester, one "batch" of manure is digested at a time, emptied from the digester and spread. In a continuous anaerobic digester, which can be either a vertical tank, horizontal tank or plug-flow or municipal tank system, manure is regularly loaded into the digester. Continuous digesters are better suited for large-scale operations because biogas is generated continuously without interruption for the emptying and reloading of manure. A continuous, constant supply of biogas can be produced if the system is well designed and properly operated and maintained (U.S. DOE, undated; IASAT, 1996).

The rate of biogas generation is dependent on the rate of anaerobic digestion. Environmental factors affecting the rate of anaerobic digestion include temperature, pH, carbon to nitrogen and water to solid ratios, particle size, retention time and the quality of manure agitation. Temperature is the most important factor in promoting bacterial growth. Biogas generation can be achieved with digestion occurring in two temperature ranges: mesophilic (90 – 110^{o}F) and thermophilic (120 – 140^{o}F). Decompostion and biogas generation occur more rapidly in the thermophilic range. Also within this temperature range, more pathogenic bacteria are killed. However, the anaerobic digestion process within the thermophilic temperature range is very sensitive to climatic changes which have the potential of significantly altering the temperature of the digester. More energy is required to achieve high temperatures, requiring well-insulated digesters (U.S. DOE, undated; IASAT, 1996).

While operating a biogas generation facility, one has to keep in mind the "tradeoffs in maintaining optimum digester temperatures to maximize gas production while minimizing expenses" (U.S. DOE, undated). In areas such as the northern and central portions of the United States where temperatures are normally below freezing, it has been found that the net biogas production can occur in digesters maintained at temperatures as low as 72^{o}F (22.2^{o}C), below the mesophilic temperature range; however, biogas generation is quite slow (Jones, 1980; U.S. DOE, undated).

Optimally, manure should be maintained at a uniform consistency with a carbon to nitrogen ratio of 20:1 (Jones, 1980; U.S. DOE, undated). If nitrogen levels are too high, bulking material such as crop residues should be added (Jones, et al, 1980). The pH usually does not need to be adjusted, being naturally neutral to slightly alkaline (basic) (IASAT, 1996). Urine should be segregated from the manure; ammonia concentrations exceeding 1,500 ppm will inhibit methane production, in which case, water should be added (Jones, 1980). Other toxic substances that inhibit methane production are detergents, heavy metals and antibiotics in animal feed, such as bacitracin, flavomycin, lasalocid, monensin, spiramycin, and rumensin. Mixing of the manure is recommended to provide bacteria population density and temperature uniformity, remove gas metabolites and prevent the formation of scum and dead spaces (Jones, 1980; U.S. DOE, undated; IASAT, 1996).

Several disadvantages of biogas generation have been documented. Starting up the digestive process can be difficult and may require several weeks as methane producing bacteria are relatively slow-growing. The anaerobic digester requires constant management so that environmental changes will not slow down or impede biological digestion which may require months to correct. Methane storage can be difficult at normal temperatures without additional equipment to liquefy methane gas. Methane gas can also be compressed for storage, but is dangerous to handle as it is highly explosive when mixed with air (Jones, 1980). It has been estimated that the cost-effective production of electricity using biogas requires "manure from more than 150 large animals," which is not a problem in commercial swine operations. However, biogas generation cannot be used in operations where antibiotics are added to feed (U.S. DOE, undated). Thus, biogas generation is not generally feasible for industrial swine production, which requires the use of numerous antibiotics due to crowded, unnatural living conditions that promote the rapid spread of disease.

In areas where electricity and animal waste disposal are expensive, biogas generation can reduce overall operation costs while providing by-products of economic value. To date, such an economic climate does not exist in the United States because petroleum fuel is inexpensive and abundant. However, biogas generation may become more viable in the future, especially since biogas generation can treat wastes in a manner that reduces overall odor (U.S. DOE, undated; Center for the Analysis and Dissemination of Demonstrated Energy Technologies [CADDET], 1997).

3.8 Land Application

Depending on the method used, the application of manure wastes to land can be a major source of odor at swine production facilities. The most offensive odors are generated by the spreading and the spraying of untreated manure with high trajectory guns on the land. Spraying produces small droplets which can volatilize and migrate great distances from the fields. Generally, odors from the spreading of manure are the most pungent within a few hours of application. Intense odors can be released for up to 48 hours. Odor intensity, which can last up to two weeks depending on whether conditions, is reduced exponentially over time but is subject to daily fluctuations. Coupled with higher temperatures and solar radiation occurring from midday to late afternoon, odors may intensify due to the increased release of ammonia as the manure dries (SOTF, 1995; Nicolai, 1996). The drying of manure also prevents the absorption of nutrients by the soil; manure that has been either sprayed or spread on to the land can lose about half of its total nitrogen content (Schmitt and Reuhm, 1998).

In order to minimize odors and the potential for water quality degradation due to surface water runoff, the injection or incorporation of manure into the soil has been recommended. Of these two options, the injection of manure has been found to be the most effective in reducing the intensity of odors (SOTF, 1995; Nicolai, 1996). One study found that the odor intensity from the surface application of manure at approximately

1,300 feet (400 meters) downwind of the application site was perceived to be equal to that from injection at only approximately 164 feet (50 meters). If manure is to be incorporated into the soil, it has been recommended that manure wastes should be incorporated as quickly as possible within 12 hours of application to ensure minimal odors and the maximum nitrogen efficiency.

Studies have found that the removal of solids from untreated manure prior to land application can reduce odors. The solids can then be treated aerobically and subsequently applied to the land (Nicolai, 1996). Optimally, manure should be treated aerobically or anaerobically prior to application (SOTF, 1995). Such treatment can be achieved via composting, biogas generation or biodegradation in lagoons and/or tanks.

For planning purposes, it has been recommended that farmers consider the crop nutrient removal of the crop(s) slated for planting on the land where manure is to be applied. Such planning should be conducted during the planning of crop rotations, which are done on three- to five-year schedules. There should be enough land area included in the plan to prevent nutrient buildup in the soil beyond recommended agronomic levels. If not enough land is available, then the plan should include options for the disposal of excess manure. Several states, such as Minnesota and Ohio, have formulated computer software for farmers to use for the development of "environmentally sound and economically viable manure application plans" (Schmitt and Rehm, 1998; BMP, 1995; UMN, undated[c]).

Prior to each land application of manure, the soil and the manure should be sampled to determine the nutrient requirements of a particular crop and the nutrient content of the manure itself. Excess nutrients may result in crop damage, soil contamination and contaminated surface water runoff, which may pollute nearby surface water bodies, causing ecological damage and human health problems (Schmitt and Rehm, 1998; Johnson, 1995; BMP, 1995). The manure sample should also be tested for moisture content. Likewise, the moisture capacity of the soil should also be determined.

The application of manure should be conducted such that the moisture of the manure does not exceed the moisture capacity of the soil, thereby avoiding surface water runoff. Manure should not be applied to frozen or compacted soils, nor should it be injected into soil in locations prone to flooding or in close proximity to surface water bodies, property lines and shallow groundwater tables (Schmitt and Rehm, 1998; Johnson, 1995; NRCS, 1995b). Researchers and soil conservation experts recommend that manure be injected or incorporated below the surface of the soil on cloudy, cool days when the wind direction is blowing away from nearby residences. If possible, manure should be applied on weekdays, when most nearby residents are not at home (SOTF, 1995; Nicolai, 1996).

Manure has been traditionally injected into the soil with equipment that have "injection knives" spaced 30 to 60 inches apart. These knives inject manure into the soil in a concentrated vertical band measuring approximately 6 to 8 inches below the soil surface. Newer equipment such as sweep and disc injectors can spread manure horizontally under the soil surface, allowing for the faster breakdown of the manure and is more optimal for plant uptake (Schmitt and Rehm, 1998). Whichever equipment is used should be calibrated to ensure the desired application rate (Schmitt and Rehm, 1998; Johnson, 1995; Jacobson and Schmidt, 1998).

The primary disadvantage of injecting manure into the soil is the potential for soil erosion. Injection loosens the surface soil and crop residue which then can be more easily washed away during rainfall events. Crop residue is one of the most cost-effective soil erosion practices. Hence, in the United States, crop residue management is the primary erosion control practice outlined in conservation plans, which specify that 30 to 65 percent of crop residue must remain for adequate erosion control. Researchers from the University of Nebraska are currently investigating how much crop residue is lost due to the injection of manure into the soil and identifying the best methods and equipment for the injection of manure such that minimal soil erosion will result (Shelton, 1997).

Initial costs of converting to a manure injection system may be high due to the purchase of specialized equipment. Producers may experience additional costs if they are not already sampling the manure and soil.

3.9 Carcass Disposal

In the United States, farmers have traditionally disposed of carcasses by rendering, burial, composting and incineration (The Ohio Environmental Protection Agency [EPA], 1996). Prior to the Food and Drug Administration (FDA)'s ban on ruminant-to-ruminant feeding due to Bovine Spongiform Enteropathy (BSE), commonly known as "mad cow's disease," anaerobic fermentation was an emerging method of dead animal disposal (Vansickle, 1998). This biological process, once popular in Europe, preserved carcasses at the swine production facility for recycling into feed by grinding them into particles of one inch or less, mixing the particles with a fermentable carbohydrate and an acid-forming bacteria. This process produced a semi-liquid "silage" that was used as an ingredient in animal feed (SOTF, 1995). Due to the lack of oxygen diffusion, this process also produced highly odorous compounds such as hydrogen sulfide and organic acids (American Bio Catalysts [ABC], Inc., undated).

Traditional carcass disposal methods have many disadvantages. Due to the FDA's ban, the number of rendering facilities has dropped. Additionally, renderers tend to prefer cattle carcasses as they can get much higher returns per carcass. Swine producers are concerned that rendering trucks may spread infectious diseases. Due to cost, incineration is not a viable method of disposal for most swine producers. In some states, carcass burial is an option; however, many of those states require carcasses to be buried at least 3 feet below ground surface which may not be possible in some areas due to a high groundwater table. The burial of dead animals may be a potential source of water pollution, and due to insufficient oxygen, burial is typically not a good method for decomposing carcasses. Additionally, a producer may not have a sufficient amount of land available (Vansickel, 1998).

The most effective method of disposing of swine carcasses is composting, an aerobic decay process facilitated by naturally occurring bacteria and fungi. Generally, composting swine carcasses requires the carcasses to be layered with sawdust or other bulking material, animal manure and water in a primary composter bin. Typically, after three months, the material in the primary composter bin is mixed and transferred to a secondary composter bin where the mixture is allowed to compost for an additional three months (ABC, Inc., undated; Fulhage, 1997).

The rate of composting and the by-products produced are dependent on the quality of the surrounding environment. Without proper management, decay may be slow or incomplete and produce foul odors and highly contaminated liquids. If managed properly, by-products from this process include carbon dioxide, water and heat. Maintaining proper moisture content is crucial. If the moisture content is less than 40 percent, decay slows as there is not sufficient water for bacteria to survive. However, if the moisture content exceeds 60 percent, anaerobic microorganisms will replace aerobic ones, producing noxious hydrogen sulfide and organic acids (ABC, Inc., undated).

The oxygen concentration within a compost pile should be at least 5 percent. If the oxygen concentration falls below 5 percent, the decaying process is slowed, and aerobic microorganisms may be replaced by anaerobic ones, producing malodorous by-products. In order to maintain the oxygen concentration above 5 percent, the compost should not be too moist; coarse composting material should be used; and mechanical aeration may be necessary (ABC, Inc., undated). By using a sufficient amount of compost material and moving the compost mixture from the primary composter bin to the secondary composter bin, there may be adequate oxygen needed for composting; however, to ensure successful composting in the briefest amount of time, the pile should be turned several times (Vansickle, 1998).

To maintain the porosity of the compost material, it has been recommended to use sawdust, wood chips, ground corncobs or peanut shells. Most importantly, these materials provide a carbon source, which is required to maintain the necessary carbon to nitrogen ratio, needed to facilitate bacterial processes. These materials contain little nitrogen, slowing the decaying process; therefore, manure needs to be added to lower the carbon to nitrogen ratio. The bulking material also allows oxygen to diffuse through the compost pile and gases, such as ammonia, which inhibits microbial activity, to escape. This material also absorbs excess moisture released during the decaying process and prevents leaching. It is recommended that each carcass be covered on all sides with a minimum of 1 foot of sawdust or 4 cubic yards per 1,000 pounds of carcass composted. When properly covered with sawdust or similar material, odors are "sufficiently absorbed such that they do not increase the general odor levels" emitted from a swine production facility (Fulhage, 1997).

The ideal temperature for composting is between 130 and 150^{o}F, which ensures the destruction of the majority of pathogens that may be produced and stimulates the rapid growth of thermophilic bacteria that promote rapid decay. Reportedly, there have been no disease outbreaks attributed to composting to date (The Ohio EPA, 1996; Fulhage, 1997). The temperature of each bin should be monitored daily to ensure that the conditions of the bins are optimal for composting (The Ohio EPA, 1996; Vansickle, 1998).

It has been recommended that each composter bin have at least 20 cubic feet of total bin capacity per pound of carcass composted daily (ABC, Inc., undated; Fulhage, 1997). Typical composter bins are designed as three-sided enclosures with the fourth side able to open wide enough for access by a front-end or skid-steer loader (Fulhage, 1997). Also recommended is that the walls of the composting bin be constructed of concrete or treated wood, and that the composter facility have a roof to protect the pile from precipitation that would increase the moisture content beyond the optimal range. Also strongly recommended are an asphalt or concrete floor underneath the compost bins and a dry storage area for the storage of co-composting materials such as sawdust (ABC, Inc., undated).

After six months, most of the animal carcasses would have decayed; however, the complete decay of bone may take longer. Bones from small carcasses should be soft and easily crumbled, but bones, especially skulls from large carcasses may jam land application equipment and attract scavengers. Thus, burial for such bones is recommended. A longer amount of time may be needed if the composter contains several large carcasses, or if ambient temperatures were low enough to sufficiently slow the composting process daily (ABC, Inc., undated; Fulhage, 1997).

As mentioned in Section 3.8, prior to application, the compost should be tested to determine its nutritional content so that it can be applied to farmland in conjunction with specific crop nutrient requirements. Typically, finished compost consists of 25 pounds of nitrogen, 13 pounds of phosphorous (P_2O_5) and 7 pounds of potassium (K_2O) per ton of manure (Fulhage, 1997). Compost can be spread with standard manure spreading equipment daily (ABC, Inc., undated; Fulhage, 1997).

3.10 Site Selection and Design for Future Swine Production Facilities

In the selection of a site for future swine facilities, odor considerations must be taken into account. A site that may be ideally suited for swine production with respect to transportation, accessibility, feed supply or property ownership may be inappropriate due to existing or proposed development in the area (Barker, 1996; Hamilton, undated). The following factors should be considered during site selection: distance from surface water bodies, soil type, depth to the seasonally high water table, depth to bedrock, presence of fractured bedrock, drainage patterns and the location and amount of cropland available for land application (Chastain and Jacobson, 1996). A swine facility should not be located in valleys or areas where wind primarily blows downwind toward nearby development. It has been recommended that swine facilities which house 1,000 or fewer swine should be at least 0.25 mile from nearby development, and for facilities with more swine, the facility should be at least 0.5 mile away. It has been recommended that the separation distances between uncovered, anaerobic lagoons and nearby development should be doubled (Hamilton, undated).

While designing and constructing new swine facilities, odor control principles must be kept in mind. If open lots are to be used, they should be well drained. Sites that receive the runoff should be as far away from nearby development as possible (Barker, 1996). Waste treatment facilities and fields receiving manure and lagoon effluent as fertilizer should be located as far away as possible from drainage ditches, streams, rivers, ponds, lakes and estuaries (Barker, 1996; Best Management Practice Team, 1995). Swine buildings should be built on elevated land so that surface water drainage will flow away from the buildings and the flushed manure can flow into tanks and lagoons naturally. If it can be avoided, swine production facilities should not be constructed in areas with a high water table to avoid groundwater contamination (Barker, 1996).

When designing anaerobic or facultative lagoon systems, loading rates and volumes of excess sludge and precipitation/surface water runoff should be calculated conservatively. The potential of the herd increasing in size should also be considered. If the herd size is to increase, then the lagoon capacity should also be increased (Safley, 1993).

In most areas, the local soil conservation or natural resources service or extension service can provide assistance in the selection of a site and the design of new facilities. Usually, a professional engineer would need to approve design specifications. Due to regional variations, it is recommended to contact the local soil or natural resources conservation service or extension service for assistance (Chastain and Jacobson, 1996). Above all, a swine producer should consider all available alternative waste treatment, storage and odor control technologies; decide which technologies are best; and then commit to the proper design, construction and management necessary to ensure their proper function. Above all, a clean, properly operated swine facility generates the image of a good quality product.

4.0 LAW AND REGULATION

The odor and air quality issues surrounding industrial swine operations have not received as much attention in the regulatory sphere as have the water pollution problems of these facilities. A few states have directly tackled air quality and odor, while most only address these problems (if at all) as a derivative of their water protection programs. For example, regulations regarding manure storage facilities, land application, and setback distances are often components of water protection laws, but these measures can also prevent some degree of air and odor pollution. Minnesota's feedlot hydrogen sulfide program is currently the most extensive livestock air pollution program in the United States A number of European countries, on the other hand, have taken direct measures to combat nitrogen emissions as well as odor problems. Because of the virtual absence of regulation in the United States, neighbors of these facilities must often resort to traditional common-law nuisance suits instead of relying on agency protection. However, "right-to-farm" laws can sometimes make nuisance actions difficult to win.

4.1 Regulatory Action

4.1.1 *The Oklahoma Effort: "an emergency is hereby declared to exist ..."*

On March 9, 1998, Oklahoma enacted House Joint Resolution No. 1093, imposing a moratorium on issuing authorizations for both swine feeding operations with over 5,000 hogs and expansions to existing swine feeding operations. The bill read, "to protect the health, safety, and welfare of the citizens of Oklahoma and natural resources of this state, it is imperative to stem the growth of some of the swine animal feeding operations while still protecting the family farm until a state policy can be developed for the management of some swine animal feeding operations in Oklahoma" (1997 OK H.J.R. 1093). This moratorium will be lifted if bills regulating the industry are passed before the session ends on May 29, 1998.

The moratorium follows a "tough new law" (Center, 1998) adopted on September 1, 1997. The Oklahoma Concentrated Animal Feeding Operations Act specifies nuisance and setback requirements for CAFOs and requires facilities with more than 5,000 hogs to obtain a permit for operation (Okla. Stat. Ann. tit. 2 § 9-210 (West 1997)). Although Oklahoma is beginning to regulate large swine facilities, there are still no specific requirements for gaseous emissions or odor control.

4.1.2 *No Federal Regulations...Yet*

Currently, there is no federal regulation of odor problems from agricultural facilities. The Clean Air Act does not apply to agricultural odors, though it does apply to certain gases. Earlier this year, however, California Representative George Miller introduced legislation to amend the Clean Water Act to strengthen regulation of industrial livestock operations. The proposal would phase out the use of open-air lagoons or ponds as principal methods of waste storage. Although it would be an amendment to the Clean *Water* Act, the bill also begins to address the problem of atmospheric pollution from feedlots (EDF, 1998).

Early in 1998, the EPA announced that in the next few years it would propose regulations dictating pollution-control measures for large livestock facilities. The regulations could potentially range from requiring equipment for capturing methane fumes, to changing the composition of animal feed. EPA may also promulgate regulations regarding manure application (Cushman, 1998). Another federal agency, the Occupational Safety and Health Administration (OSHA), is also considering regulating these operations. For example, OSHA may begin to apply permissible exposure limits (PELs) to agriculture, such as those currently applied to industrial and construction workers (SOTF, 1995).

4.1.3 *Federalism Concerns: State or Local Control?*

The war over swine facilities depends in large part on the arena in which it is waged. In a number of states, key decisions regarding the authorization and placement of industrial swine facilities depend on who is making the determination—state regulators or local authorities and citizens.

For example, the most recent controversy regarding corporate swine farms in Iowa relates to a county's ability to zone agriculture. A state law passed in 1946 prevents counties from zoning land or buildings used for agriculture (Center, 1998). In *Kuehl v. Cass County* (555 N.W.2d 686 (Iowa 1996)) the Iowa Supreme Court held that all agriculture is exempt from county zoning. The court went on to say that swine production, regardless of its size or the absence of crops, is primarily adapted for agricultural purposes and therefore cannot be zoned by county governments.

One month before the decision came down in the *Kuehl* case, Humboldt County, Iowa, adopted four ordinances governing "large livestock confinement feeding facilities." The four ordinances regarded permitting, financial assurance, groundwater protection, and toxic air emissions. The district court upheld all of the ordinances except Ordinance 25, the one addressing air pollution. It held that Ordinance 25 constituted zoning of land and buildings for agricultural purposes and thus violated state law. This holding was expanded even further on appeal when the state supreme court struck down all of the ordinances and held that counties cannot regulate in this area (*Goodell v. Humboldt County, Iowa* (1998 WL 92658 (Iowa))). The court reasoned that the state legislature had preempted the county's authority to enact these ordinances. The decision is frustrating to county governments in Iowa who find state law inadequate to prevent their counties from being overrun by swine confinement problems. In fact, several other counties had adopted the Humboldt County ordinances before the state supreme court invalidated them (Center, 1998).

Unlike Iowa, Kansas does allow its counties to decide their fate with regard to corporate farming, and on September 16, 1997, Seward County became the eighteenth county in the state to oppose new corporate hog operations. The county's residents voted 2 to 1 to block a proposed facility, and county commissioners promised to honor the referendum in their decisions. Virginia, too, gives broad discretion to its counties in this area, allowing them to write their own swine regulations, and in fact, some counties have chosen to do so (SOTF, 1995).

The importance of having different levels of regulation can be seen in the recent developments in Colorado. In 1997, the Colorado state legislature rejected a bill that would have imposed controls, such as setback distances, on operations with more than 2,500 hogs. However, some counties in the state have begun imposing their own regulations. Yuma County requires that swine operations hold public hearings, while Washington County is considering setback requirements and other restrictions (Center, 1998). Without this county authority, citizens in the state would have been left without recourse against incoming swine farms — until the next state elections, anyway. The ability to regulate at the county level also proved useful to citizens in Indiana when the state legislature was debating House Bill 1915. The legislature removed the 1-mile setback requirement from the bill (Center, 1998), but the decision will revert to local control. All but 16 counties in Indiana have the authority to zone agriculture (Vansickle, 1997).

Tensions regarding authority to regulate have been seen in Minnesota as well. Counties in Minnesota have agricultural zoning authority, in some cases even to the township level (Vansickle, 1997). Several counties have chosen to adopt moratoria on the expansion of large swine operations while they update their county zoning ordinances to deal with the issue (Center, 1998). The counties of Mower, McLeod, and Polk enacted these temporary moratoria, while Rice County passed a permanent moratorium limiting the growth and expansion of hog farms (Vansickle, 1997). However, there are limits to this county rule, as demonstrated by the decision of *Board of Supervisors of Crooks Township, Renville County v. Valadco* (504 N.W.2d 267 (Minn. Ct. App. 1993)). In this case, a township sought declaratory and injunctive relief based on a local ordinance to prohibit the construction of swine confinement facilities. The ordinance required anyone wanting to operate a feedlot or lagoon to obtain a permit from the township. Valadco did not apply for such a permit, though it did receive permission to build from the Minnesota Pollution Control Agency (MPCA). The court held that the local ordinance was not only preempted by state regulation of animal feedlots but also conflicted with state law. Even though there is county rule, it cannot conflict with statewide actions.

The relationship between state and local government in South Dakota is also interesting. Counties in South Dakota have the right to regulate the siting of agricultural operations (Duxbury-Berg, 1997), but the state has issued “model regulations” for the counties to reference. The South Dakota model contains the highest setback requirements of all states. The setbacks provide for two types of distances — those from schools, churches, and dwellings and those from populated areas. The distances required depend on the number of swine in the facility. However, the model allows producers to apply for variances and/or obtain waivers from neighbors (Heber, 1997).

Some state attorneys general have addressed the industrial swine problem in their states. On August 27, 1997, the attorney general of Nebraska issued a nonbinding opinion declaring that state lawmakers may impose a moratorium on the construction of large hog farms to protect the environment and public health. Regardless of state action, however, counties in Nebraska have the ability to zone agriculture. In fact, almost all counties under pressure from swine farms have begun to develop comprehensive plans and zoning ordinances. Also, the attorney general in Kentucky issued a non-binding opinion stating that counties have the authority to regulate large swine facilities as “industrial” rather than “agricultural” operations (Center, 1998).

In some instances, the swine operations themselves have taken action against attempts at local control, rather than relying on state laws to do so. One of the most severe instances of this resistance occurred recently in Missouri’s Lincoln Township. When the township passed an ordinance in 1994 imposing bonding requirements on swine facilities and requiring that new livestock operations be at least 1 mile from residences, Premium Standard Farms sued the township for $7.9 million. Although Premium Standard dropped the damages claim, they were successful in having the ordinance struck down (*Premium Standard Farms, Inc. v. Lincoln Township of Putnam County* (946 S.W.2d 234 (Mo. 1997))). Specifically, the court held that the township had exceeded its state-granted zoning authority when it regulated "farm buildings or structures."

4.1.4 *See You in Court: Citizen Suits against Swine Facilities*

The Lincoln Township incident was not the end of Missouri's battles with Premium Standard Farms. In October 1997, Missouri Attorney General Nixon notified Premium Standard that he intended to sue them under the Clean Air Act for violations of hydrogen sulfide and ammonia emissions standards. The attorney general also asked state regulators to revoke Premium's exemptions from state regulations of odor (Cushman, 1998). Two months later, Nixon petitioned the state Air Conservation Commission to repeal the regulation exempting large swine facilities from odor control. He stated that this exemption "'adversely affects the quality of life for neighbors and generally threatens the public health, safety, and welfare of the people of Missouri'" (Cushman, 1998). Another case against Premium Standard Farms is underway in Missouri. Citizens Legal Environmental Action Network (CLEAN), a group of about 60 family farmers in Northern Missouri, is suing Premium Standard for alleged violations of the Clean Air Act and the Clean Water Act. In addition, a group of 80 family farmers is suing Continental Grain Company, another major swine producer (Williams, 1998).

Citizens in Illinois took their frustrations to court as well and were successful. In the 1997 Illinois Pollution Control Board case of *Gott v. M'Orr Pork, Inc*. (1997 WL 85191 (Ill.Pol.Control.Bd.)), residents of Kinderhook, Illinois, filed a citizens' enforcement action under the Illinois Environmental Protection Act. They alleged that odors from a lagoon and swine building at a swine confinement facility both injured their health and unreasonably interfered with the enjoyment of their lives and property. The complainants testified of eye, nose, throat, and skin irritation; nausea; and respiratory problems including asthma. Several of them had sought medical attention for their ailments. The complainants also claimed to have been unable to garden, walk outside, have guests, or open their windows.

The Board held that there was insufficient proof that the odors had injured plaintiffs' health or that M'Orr had violated the state's siting and field application regulations. The Board did, however, hold that the odors had caused unreasonable interference with the complainants' enjoyment of their lives and property. Therefore, the odors constituted air pollution under state law, and M'Orr Pork was held to have violated the state Environmental Protection Act and Board regulations. The Board issued an interim order requiring M'Orr to prepare an evaluation of measures to diminish the odor from the swine confinement and lagoon. If M'Orr failed to comply within a few months, the Board would determine the damages to be assessed against M'Orr.

4.1.5 *General Agricultural Legislation*

Within the past few years, a number of states have enacted legislative packages addressing large livestock operations. Very few of these laws, however, mention odor and air pollution specifically. Most require training for facility operators and mandate development of waste management plans. Setback distance requirements are also a common feature of these laws. Some require notification of neighbors and local governments of a facility's construction or expansion, and a number address the role that counties will play in the regulation of large facilities. Several states have enacted moratoria on new or expanded confinement facilities until more research and policy design can be conducted in their respective states. In general, citizens have found the laws to be too lax on facilities. The following are brief descriptions of some of these state livestock laws.

Arkansas

After a 1990 moratorium on the construction of new swine facilities, Arkansas adopted "Regulation 5" in 1992. Although Regulation 5 mostly focuses on water pollution, some of its more general provisions may help abate odor nuisance. All managing owners and operators of a swine facility must certify that they have completed a training in waste management and odor control. Regulation 5 also requires a setback distance of 0.25 mile between a residence and an operation with more than 1,500 finishing hogs or 600 sows. In terms of direct odor control, the law requires permittees to adopt a "good neighbor policy" to use chemical or biological additives (even though research has shown these methods to be ineffective in controlling odor—see Section 3.5) or other best management practices. These relatively weak provisions have led Arkansas citizens to call for stronger odor controls (Center, 1998).

Illinois

In 1996, Illinois adopted the Livestock Management Facilities Act (510 Ill. Comp. Stat. 77/1 et.seq.). This law requires facilities to develop a waste management plan and provides for varying setback distances. For an operation with 125 to 2,500 finishing pigs, a setback of 0.25 mile from a non-farm residence and of 0.50 mile from a populated area is required. The distance increases by 220 and 440 feet, respectively, for every increase of 2,500 hogs, to a maximum setback of 0.50 mile and 1 mile (Heber, 1997). Again, citizens in the state find this regulation too weak and want greater control (Center, 1998).

Indiana

In 1997, the Indiana legislature passed House Bill 1915. The bill requires producers to gain approval for construction and to notify adjoining neighbors of expansion intentions (Vansickle, 1997). There are no provisions for odor control.

Iowa

Iowa's "manure law" was enacted in 1995. House File 519 requires a manure waste management plan to be submitted to the Department of Natural Resources (Center, 1998). The law also created a complex system of setback distances for lagoons and buildings, depending on the nature of the surrounding area (Heber, 1997). The owner must receive a site appraisal before development to verify the distance. There are also exemptions to these setback requirements, including a written waiver by neighbors that is recorded at the courthouse (Iowa, undated). A potential operation must also give notice of construction to the county. The Iowa Department of Natural Resources has proposed new regulations for swine producers. The proposed rules would require manure injection rather than spreading and would expand the number of operations that must obtain permits (Center, 1998).

Kansas

In March 1998, a Kansas legislative panel drafted a bill that would require swine producers to develop management plans to deal with waste disposal and odor (Greenwire, 1998). Prior to this, in 1994, the Kansas legislature established a setback requirement of 4,000 feet between a residence and an operation of more than 2,500 hogs (Center, 1998).

Kentucky

On September 18, 1997, Kentucky's governor, Paul Patton, declared a short moratorium to give state officials time to review and update environmental regulations regarding swine facilities (Center, 1998). Governor Patton also ordered the state to develop emergency swine waste regulations and to stop issuing permits for swine waste systems. The emergency regulations contained specific provisions that would provide a trade-off between the use of liquid manure injection and shorter setback distances. The regulations also contained requirements for documentation of the amounts and sites on which liquid manure is disposed (Taraba, 1998).

Maine

Though the general trend in the siting of corporate swine farms has been toward the west, Maine is also becoming a target of these operations. Currently, state Senator Judy Paradis is pushing for a state moratorium on the development of new large swine facilities until May 1, 1999. Her proposed law also establishes new permitting requirements for such facilities. For example, the bill would require Maine facilities to submit nutrient management plans to the state as a condition for development. Currently, there is virtually no regulation in Maine for large swine facilities, and some residents are getting nervous. In the town of Caribou, for example, 86 residents signed a petition asking the city council to enact a ban on swine operations (Chutchian, 1998).

Minnesota

On March 5, 1998, the Minnesota House approved a bill that would impose a 3-year moratorium on new or expanded large feedlots. The bill would also require the Minnesota Pollution Control Agency to create standards for hydrogen sulfide within 5,000 feet of both waste-storage sites and livestock confinement areas (Halvorsen, 1998). The MPCA already has an extensive hydrogen sulfide program that began in July 1997. An in-depth look at the program is found later in this report (Section 4.1.7).

Missouri

Missouri enacted a short moratorium on the granting of new permits. The moratorium was followed by a "mild piece of legislation" requiring, among other things, setback distances of 1000 feet between a residence and an operation with more than 2,500 hogs. An operation with more than 17,500 hogs must be 3000 feet from a residence (Center, 1998).

Virginia and Wisconsin

House Bill 1334 was introduced in Virginia on January 16, 1998. The bill calls for a moratorium on permitting, construction, and expansion of confined swine feeding operations with more than 750 hogs (SOTF, 1995). Wisconsin's state legislature is now considering a bill that would limit farms to 750 animals (Chutchian, 1998).

Wyoming

A 1997 Wyoming law requires operations to prepare manure management plans addressing both water quality and odor. The law also dictates setback distances of one mile between an operation and a residence, school, or town. The Wyoming Department of Environmental Quality is in the process of drafting regulations implementing the new law (Center, 1998).

North Carolina

Also in 1997, the North Carolina state legislature enacted House Bill 515, which includes a two-year moratorium on all new construction of operations with more than 200 swine, except those using "innovative" technology to handle manure (i.e. not anaerobic lagoons). The law gives counties the authority to zone and regulate hog facilities with approximately 4,000 or more swine. However, a county cannot exclude an operation from the zoned area. H.B. 515 also provides for setback distances between an operation and a home (1,500 feet), a public area (2,500 feet), and a property line (500 feet). Also, manure cannot be spread within 75 feet of a property line. If the setbacks are violated, citizens have the right to sue. In addition, operators must notify neighbors and county officials if they plan to build or expand a facility (Center, 1998).

4.1.6 *Some Unique State Provisions*

North Carolina

Part III of North Carolina's House Bill 515, "Control of Odor Emissions from Animal Operations," specifically addresses plans for odor control. The bill dictates that the Board of Governors of the University of North Carolina is to present its findings on economically feasible odor control before September 1, 1998. If the Board finds that such technologies are available, then the Environmental Management Commission (EMC) is to adopt a temporary rule regulating emissions of odors from animal facilities by March 1, 1999. The EMC is then expected to continue developing and adopting regulations for the emission of odors from animal waste management systems.

South Carolina

South Carolina also adopted laws that specifically address odor. In July 1996, the state adopted tougher new laws with regard to confined swine feeding operations with approximately 3,000 hogs or more (S.C. Code Ann. § 47-20-70 (Law. Co-op. 1996)). This law provides that producers may not emit "any substance or combination of substances in quantities that an undesirable level of odor is determined to result." The State Department of Health and Environmental Control has the authority to require certain abatement or control practices, such as best available control technology. Setback distances are also provided: lagoons must be 1000-1750 feet from property lines, and land application must take place at least 200 feet from residence property lines.

Other States

Kentucky has a specific odor regulation for agriculture as well (401 KAR 53:010). Specifically, odor must not be detected above a certain level at the property line using a Barnaby-Cheney scentometer (Taraba, "Laws"). Although Nebraska has a health-based hydrogen sulfide standard, feedlots are exempt. (Sullivan, 1998) Texas regulates its livestock operations with a particulate standard that measures the dust from feedlots (Sullivan, 1998).

Some states have decided to focus air quality regulations on worker health in swine facilities. North Carolina's occupational safety and health regulations limit the exposure of workers to some gases such as ammonia, but these regulations do not extend to protect neighbors from odor and gaseous emissions from hog farms (SOTF, 1995). Minnesota is considering regulating worker health inside hog facilities (Sullivan, 1998).

In 1990, Iowa became the first state to require mediation to resolve disputes involving livestock production contracts (Hamilton, 1995). Iowa Code sections 657.10 and 654B require a party to obtain a mediation release before initiating a nuisance claim against an entity that is covered by the statutes. This rule is further explicated in the decision of *Arends v. Iowa Select Farms, L.P.* (556 N.W.2d 812 (Iowa 1996)). In this case, neighbors of a swine finishing operation filed a nuisance action against the owners of the facility. The court held that the statute's requirement that a "farm resident" obtain a mediation release before suing another "person" for nuisance did apply to the neighboring farmers' action against the business entities that owned the hog operation. The court also held that a lawyer could satisfy the requirement that a party representative attend the meeting.

4.1.7 *Minnesota Feedlot Hydrogen Sulfide Program*

Currently, the most extensive agricultural air quality program in the country is the Feedlot Hydrogen Sulfide Program administered by the Minnesota Pollution Control Agency (Minn. Stat. §116.0713 (Supp. 1997)). This program requires the MPCA to "monitor and identify potential livestock facility violations of the state ambient air quality standards for hydrogen sulfide." There is a specific protocol established for responding to citizen complaints regarding feedlot odor which includes the use of portable monitoring equipment to follow plumes.

In the past, Minnesota left the issue of livestock odor to local zoning. However, when the late 1980s and early 1990s brought an increased number of large-scale swine operations to the state, the MPCA decided to take a more active role. The agency chose to focus on hydrogen sulfide in its efforts to address concerns of odor and gaseous emissions from these facilities. The 1994 Renville County hydrogen sulfide study mentioned in Section 2.3.2 above was key in the early stages of this effort. On July 1, 1997, the MPCA formally established the feedlot hydrogen sulfide team.

The hydrogen sulfide standard works in the following way: each gas sample represents an average value of the gas over a continuous 30-minute period. A violation occurs if the hydrogen sulfide ambient air quality level exceeds 30 and 50 ppb within certain time periods.

The MPCA investigations are primarily complaint-driven. Citizens are able to telephone the MPCA 24 hours a day to report a feedlot odor complaint. Complainants do not have to reveal their identities, but the MPCA finds the investigation and consequent recommendation process much easier if the complainant is involved. The MPCA also likes to meet with the complainant when possible to get a better sense of the problem, including the following aspects: 1) the effects of the emissions on the complainant's life, 2) the technical aspects of the incident, such as time and weather conditions, 3) any practices that might be ongoing when the incident occurs, and 4) the time when odor is most prevalent.

After the complaint, the MPCA notifies the facility operators that a feedlot odor complaint has been received and that their feedlot has been identified as a possible source of the emissions. The MPCA informs the operator that it will be conducting compliance screening to determine whether the facility complies with the ambient air quality standards for hydrogen sulfide. Then the MPCA conducts the compliance screening at or beyond the property boundary of the facility with a hand-held Jerome meter. Sampling data is recorded and logged and later analyzed. Interestingly, none of the facilities tested under the program in 1997 were found to be out of compliance with state standards.

If the screening reveals noncompliance, the MPCA requires the operator to begin implementing a compliance plan, which can include increased monitoring, evaluation of best management practices, and implementation of a community action plan (Minnesota, 1998). If an operator does not work toward a solution in a timely fashion, the MPCA may install a Continuous Ambient Monitor (CAM) — at the operator's expense. Each CAM costs about $50,000 to $120,0000 (Sullivan, 1998), which gives operators quite an incentive to cooperate with the MPCA's suggestions.

One major problem with the Minnesota program is that hydrogen sulfide levels are not always an adequate indication of an odor problem. There can be a severe odor without any hydrogen sulfide present (Sullivan, 1998). In spite of this, other states can learn much from the Minnesota effort. Not only has the state taken active measures toward controlling gaseous emissions (and consequently often controlling odor) from feedlots, but Minnesota has also tried to involve all interested parties in its actions. The MPCA ultimately wants the producers to develop and implement solutions, and it bases most of its actions on citizens' complaints. During the process of responding to these complaints and working with producers, the MPCA tries to facilitate constructive dialogue between the two groups. It stresses "maintaining open lines of communication with the regulated community and general public" (Minnesota, 1998). Also, because the program is so new, other states can learn from Minnesota's trials and errors and even work with the state to develop improved strategies for addressing this issue.

4.2 A Right to Farm?

Because most states do not have a program like Minnesota's, neighbors of commercial swine facilities often must rely on traditional common-law nuisance claims in seeking relief from odor problems. A nuisance occurs when someone uses her property in a way that unreasonably interferes with another person's ability to enjoy his own property. A nuisance can be either private (impairing an individual's property) or public (harming the public in general). One traditional defense to a nuisance claim is that the complainant has "come to the nuisance," which means that a person cannot claim that a nuisance exists if he has moved into the area of a pre-existing nuisance. If a person is found to have "come to the nuisance," he is generally unable to collect damages or prevent the nuisance from operating.

Over the past 25 years, states have codified this traditional defense by adopting "right-to-farm" laws. Today, every state has some form of a right-to-farm law (*Weinhold v. Wolff*. 555 N.W.2d 454, 462 (1996) [citing Neil D. Hamilton, A Livestock Producer's Legal Guide to: Nuisance, Land Use Control, and Environmental Law 21 (1992)]). Most of these laws are dedicated to preserving, protecting, and encouraging "the development and improvement of ... agricultural land for the production of food and other agricultural products" (740 Ill. Comp. Stat. Ann. 70/3-4.5 (West 1993)). Most right-to-farm laws provide that if a farm has been in operation for more than one year, no changed conditions in the surrounding area (such as expanding suburbanization) will make it a nuisance.

However, if a facility were operating in a negligent, improper, or illegal manner, the right-to-farm protection would be lost. While some states have more restrictions on facility behavior, this is the basic thrust of a right-to-farm law.[1]

In their article "The Emerging Legal Framework for Animal Agricultural Waste Management in Arkansas," Martha L. Noble and J.W. Looney provide a list of questions to consider when examining a state's right-to-farm law:

1. What agricultural practices are protected?
2. How long must the agricultural operation pre-date changes in the neighborhood?
3. Are changes in the use of surrounding land necessary?
4. What is the effect of expansion of the agricultural enterprise or changes in technology employed?
5. Is reasonable operation required?
6. Are all types of nuisance creating activities, such as water pollution or soil erosion, included?
7. What is the effect of local regulation?

[8]. Are generally accepted agricultural management practices required?
[9]. Are both private and public nuisances covered?
[10]. Are provisions for fee shifting included?

(Noble, 1994 (citing Neil D. Hamilton, A Livestock Producer's Guide to: nuisance, land use control, and environmental law (1992)). These questions can help both operators and citizens understand their legal options in a nuisance suit.

4.2.1 *Oklahoma's Right-to-Farm Law*

Oklahoma's right-to-farm provisions are found at Okla. Stat. Ann. tit. 50 §1.1 (West 1988) and in the 1997 Oklahoma Concentrated Animal Feeding Operations Act, Okla. Stat. Ann. tit. 2 §9-210 (West 1997). The Oklahoma right-to-farm law can be best understood by using the above list of questions.

1. The agricultural practices protected by the act include, but are not limited to, "the growing or raising of horticultural and viticultural crops, berries, poultry, livestock, grain, mint, hay and dairy products" (Okla. Stat. Ann. tit. 50 §1.1 (West 1988)).
2. The operation simply has to be "established prior to nearby nonagricultural activities."

[1] For a sampling of specific right-to-farm laws, see Ark. Code Ann. §2-4 (Michie 1981), Fla. Stat. Ann. §823.14 (West 1987), Ga. Code Ann. §41-1-7 (1980), Ind. Code Ann. § 34-1-52-4 (West 1983), Iowa Code Ann. §352.11 (West 1994), Kan. Stat. Ann. §2-3202 (1996), Ky. Rev. Stat. Ann. §413.072, La. Rev. Stat. Ann. §3:3601 (West 1987), N.Y. Agriculture & Markets Law § 308 (McKinney 1997), N.C. Gen. Stat. §106-701 (1979), 3 Pa. Cons. Stat. Ann. §954 (West 1995), Tenn. Code Ann. §43-26 (1982), Utah Code Ann. §78-38-7 (1995), and Va. Code Ann. §3.1-22.28 (Michie 1981).

3. The Oklahoma statute is unlike many others in that it does not require changes in the surrounding land for the right-to-farm defense to operate. This means that even if the surrounding area has not experienced a new growth of residences or suburbanization, the operation can still be protected from a nuisance suit (provided it meets the other requirements, of course). The lack of a "changed conditions" provision further removes the law from any sort of common law "coming to the nuisance" protection.
4. The statutes do not mention anything about expansion of the enterprise or changes in technology.
5. The Oklahoma statutes state what will be presumed reasonable and then say that these reasonable actions will not constitute a nuisance (with one exception — if it has a substantial adverse effect on the public health and safety). "Agricultural activities conducted on farm or ranch land, if consistent with good agricultural practices and established prior to nearby nonagricultural activities, are presumed to be reasonable."
6. The statutes do not specifically mention water pollution or soil erosion.
7. Abiding by local, state, and federal laws is a huge plus for a swine operation in an Oklahoma nuisance suit. If the activity is "undertaken in conformity with federal, state and local laws and regulations, it is presumed to be good agricultural practice and not adversely affecting the public health and safety." This is not a very strong restriction, because there are no strict laws by which to abide.
8. Generally accepted agricultural practices are required for the operation to be presumed reasonable.
9. Because the Oklahoma statute does not specify one way or the other, presumably both public and private nuisances are covered.
10. No provisions for fee shifting are included.

In sum, the Oklahoma right-to-farm law protects from nuisance suits swine farms that were established before nearby nonagricultural activities, are consistent with good agricultural practices, and abide by the law. The surrounding area does not even have to change for this protection to apply.

4.2.2 *Right-to-Farm Case Law*

There have been no right-to-farm cases brought in Oklahoma. To see how right-to-farm laws play out in the court system, it is helpful to see how other state courts have interpreted the laws. The right-to-farm defense has been successfully used only three times (Noble 1994), and two of those involved hog farms in Indiana. (*Laux v. Chopin Land Assocs., Inc.*, 550 N.E.2d 100 (Ind. Ct. App. 1990), and *Shatto v. McNulty*, 509 N.E.2d 897 (Ind. Ct. App. 1987)). The third, *Northville Township v. Coyne*, 429 N.W.2d 185 (Mich. Ct. App. 1988), was about a barn in Michigan.

In the *Laux* case, the Lauxes sold part of their land to Chopin Land Associates early in 1987. The previous summer, the Lauxes had purchased some hogs, but they did not begin construction of a facility until March 1987. Later in 1987, the Lauxes increased their herd size. Chopin sued to abate the operation as a nuisance. Because of the odor, Chopin had lost the chance to sell a portion of its land. The Court of Appeals of Indiana held that merely increasing the number of hogs and building a facility are not sufficient to be a "significant change in the type of operation" and therefore could not prevent the use of the right-to-farm defense. The court reversed the circuit court's grant of an injunction ceasing the hog operation and remanded the case for a new hearing (*Laux v. Chopin Land Assocs., Inc.*, 550 N.E.2d 100 (Ind. Ct. App. 1990)).

In *Shatto v. McNulty*, the other successful use of the right-to-farm defense by a hog operation, McNulty began his hog farm in 1956, and the Shattos did not move into the neighborhood until 1968. The court referred to the legislative intent behind the right-to-farm statute by stating, "People may not move to an established agricultural area and then maintain an action for nuisance against farmers because their senses are offended by the ordinary smells and activities which accompany agricultural pursuits" (509 N.E.2d at 900). The court concluded its analysis with the observation that "pork production generates odors which cannot be prevented, and so long as the human race consumes pork, someone must tolerate the smell."

While neither of these cases involved an industrial-sized hog confinement facility, the case of *Weinhold v. Wolff* (555 N.W.2d 454 (Iowa 1996)) did involve such an operation. In 1977, the Weinholds purchased land one-half mile from the Wolffs. After the Wolffs began their hog operation in 1990, the Weinholds began experiencing stomach sickness, sneezing, headaches, sore throats, coughing, tightness in their chests, and sleeping troubles. They even spent some nights in a camper at their son's home to avoid the odor. Visitors to their home would complain of burning eyes and phlegmonous irritation. The supreme court held that the right-to-farm defense did not apply, because the Wolffs' operation had been a nuisance without the protection of the "agricultural area" designation. The Wolffs started the operation about a year before their land was approved as an agricultural area, and because the court found the nuisance to be permanent, the damage was theoretically complete when the nuisance arose—at the time the operation commenced.

Similarly, in *Durham v. Britt* (117 N.C.App. 250 (N.C. Ct. App. 1994)), the court rejected the right-to-farm defense. The court held that a change from the operation of turkey houses to the operation of a hog production facility is a fundamental change in the agricultural use of the land. This fundamental change removed the operation from right-to-farm protection.[2]

4.3 European Trendsetters

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[2] For additional right-to-farm and agricultural nuisance cases, see *Pasco County v. Tampa Farm Service, Inc.*, 573 So.2d 909 (Fla. Dist. Ct. App. 1991), *Herrin v. Opatut*, 248 Ga. 140 (Ga. 1981), *Wendt v. Kerkhoff*, 594 N.E.2d 795 (Ind. Ct. App. 1992), *Yeager & Sullivan, Inc. v. O'Neill*, App. 324 N.E.2d 846 (Ind. App. 1975), *Michael v. Michael*, 461 N.W.2d 334 (Iowa 1990), *Valasek v. Baer*, 401 N.W.2d 33 (Iowa 1987), *Goeke v. National Farms, Inc.*, 512 N.W.2d 626 (Neb. 1994), and *Kopecky v. National Farms, Inc.*, 510 N.W.2d 41 (Neb. 1994).

Europe has been more active than the United States in addressing air quality and odor problems from large-scale swine facilities. Individual countries as well as the European union as a whole have enacted measures to curb the problem. The European Economic Community is currently moving toward a common standardized procedure for measuring odor (SOTF, 1995). In 1991, the European Union issued a Nitrate Directive to control manure applications in all "vulnerable areas." After the year 2000, those with manure surpluses will be required to pay a high tax (Gassman, 1995).

With regard to air quality, countries in Europe have focused on two primary areas of concern —nitrogen emissions and odor prevention. Specifically, countries have focused on ammonia (NH_4) and NO_x and are beginning to examine nitrogen oxide, a greenhouse gas. NO_x emissions are a concern because of their role in creating acid rain, which can disrupt estuaries and native plant populations (Ellingboe, 1998). Ammonia standards were also created because of acid rain and water quality problems, not because of odor (SOTF, 1995). The other major concern regarding air quality is odor. Setbacks have been the major method of addressing this problem, and each country calculates these distances differently (Ellingboe, 1998).

In general, European countries have used three basic approaches to controlling emissions from livestock operations: 1) stricter regulatory approach (production quotas, manure manifests, application standards, fees), 2) public and private investment in technological research, and 3) environmental education (Gassman, 1995).

4.3.1 *The Netherlands*

The Netherlands has the most extensive program in Europe for addressing issues of gaseous emissions and odor from large swine facilities. The government uses a variety of tools — from strict regulation/enforcement to market mechanisms — to prevent these problems. In 1984, the government instituted restrictions on farmers' increasing their herd sizes. In 1986, the National Manure Bank was formed to facilitate efficient redistribution of manure. The bank allows regions with a surplus of livestock manure to trade with areas that are able to use it on crops. "Surplus manure farmers" must pay a fee for the bank's services (Gassman, 1995). This is part of the Netherlands' system of manure production rights (MPR), an economic incentive and trading program (Derrikx, 1996).

Some of the stricter command-and-control measures implemented by the Netherlands include the enforcement of a manure spreading/incorporation law. During the first 24 hours after manure is spread, equipment must be constantly at work to incorporate the manure into the soil. Police and other inspectors patrol the sites and can issue a ticket or fine for each violation. Producers must also use a bookkeeping system to keep records of the nutrients produced in their animals' wastes and balance those with the nutrient requirements of the crops to which they will be applied. Violators of this law can be fined based on worst-case assumptions about their nutrient production and usage (SOTF, 1995). Also, manure application is banned from September 1 to October 1 and from

December 1 to January 31, based on vegetation and soil vulnerability to nitrate leaching (Gassman, 1995).

The Netherlands has “an extremely strict approach” to regulating nitrogen emissions (Ellingboe, 1998). By 2010, farmers must reduce their emissions by 70 percent of 1980 levels (SOTF, 1995). The government realized that the problem cannot be fixed overnight, and this phased approach gives farmers time to think and plan. A farmer will choose the method he thinks will be most efficient, but he must demonstrate its effectiveness (Ellingboe, 1998). The government has given incentives for certain improvements, however. Environmentally friendly housing for animals (that which does not exceed the threshold for ammonia emissions) is given a “green label” (SOTF, 1995), and farmers who build a green-label building do not have to make improvements to reduce emissions further within the first 15 years. However, new legislation would further reduce ammonia emissions by restricting new construction to low-emission housing, instead of this opt-in green label system (Derrikx, 1996). In 1994, all surface applications of manure were banned, and all manure storage facilities had to be capped (Gassman, 1995). Concrete, tent, and other roofs may be used to satisfy this requirement, as are some floating cover systems. Straw, however, has proven unable to meet the required reduction level. The law permits different methods of incorporation to be used for grasslands and arable lands (Derrikx, 1996).

Many of these methods for reducing ammonia emissions will have an impact on odor problems as well. In the Netherlands, it is generally assumed that a 10 percent reduction rate in ammonia emissions will result in a 7 percent reduction of odor. Currently, researchers are trying to quantify the reduction of odor from each green label system individually (Derrikx, 1996). As of now, 10 certified laboratories apply a standardized procedure for measuring odor (SOTF, 1995).

The approach of the Netherlands to nuisance suits is quite different from the American right-to-farm statutes. The Netherlands’ Nuisance Act defines the maximum number of animals allowed in a facility, given the distance between the operation and its neighbors (Derrikx, 1996). These setback distances were developed by public health inspectors in 1972 (Ellingboe, 1998). A producer may, however, increase his number of animals if the total ammonia and odor emission of the farm remains constant (by building green-label housing, for example). The producer must also have a permit from the local government to have livestock buildings at all (Derrikx, 1996). Finally, even if a farm abides by all these rules, neighbors can still bring legal action if there is a significant odor problem (Burton, 1996).

4.3.2 *Denmark*

Denmark has adopted measures for reducing both nitrogen emissions and odor problems. First, for example, there are regulations on the times manure may be applied to crops, depending on the type of manure (liquid or solid) and the type of crop (Sommer, 1996 and Gassman, 1995). Second, to reduce nitrogen emissions, manure must be applied directly to the ground and cannot be sprayed through the air during application. Third, swine farms are also required to store manure in concrete containers (Ellingboe, 1998). Liquid manure without a cover or a natural surface crust should be sealed with an ammonia-impermeable material, such as a floating plastic cover or floating burned clay granules. These simple and cost-effective techniques have already achieved large reductions in ammonia volatilization. Some have suggested that emissions could be reduced even more through further controls on land application, such as reducing the time between application and incorporation or increasing the use of combined application/incorporation techniques, such as injection (Sommer, 1996).

Odor laws were first established in Denmark during the period from 1950 to 1980. These laws required ventilation chimneys and setback distances from houses. By the end of the 1980s, it was clear that the general code of good agricultural practice had not reduced odor to acceptable levels. The Ministry of Environment then imposed restrictions on the construction and location of manure storage and swine buildings, as well as on the land application of manure. One such regulation specified that manure was not to be applied to the ground on Saturdays, Sundays, or public holidays on areas closer than 200 meters from residential areas. Also, liquid manure should be incorporated within 12 hours after application to bare soil, and solid manure should be incorporated immediately after application (Sommer, 1996). Citizen concerns may have to be addressed by a proposed facility (Ellingboe, 1998), and legal action can be brought against even a well-run farm if it poses a significant odor problem for its neighbors (Burton, 1996).

Denmark also employs the use of biogas plants, with subsidies from the government. The biogas plants return the sludge, which has little odor, to the farmers for application on their fields. There have been very few complaints from neighbors when this process is used (SOTF, 1995).

4.3.3 *Germany*

Germany focuses more on managing nutrients than on paying specific attention to ammonia emissions (Ellingboe, 1998). The Fertilizer Ordinance enacted on July 1, 1996, requires manure to be worked into nontilled soils immediately after application (Hahne, 1996). There are also prohibitions on spreading manure during certain times of the year, depending on crop and soil type (Hahne, 1996 and Gassman, 1995).

There are many regulations governing odor in particular. These regulations are based on a number of factors, ranging from zoning rules, to esthetics, to animal health. There are approximately twelve committees governing permit issuance, and the entire permitting process can take up to three or four years. Another odor-controlling regulation involves documentation. German producers must send records of both manure storage and cropland application to the government (Ellingboe, 1998). There are strict controls on lagoons as well — they must be lined, covered, and equipped with underground pipes for the detection of leaks. In addition, thresholds based on the use of olfactometers have withstood legal challenges (SOTF, 1995).

4.3.4 *Other European Approaches*

Economic Incentives

A few countries in Europe use economic incentives to combat odor and gaseous emissions problems. In addition to the Netherlands' Manure bank and green-label system, other countries are relying on taxes and incentives to encourage emissions and odor reductions. Belgium, for example, is considering installing sensors in livestock facilities to monitor ammonia emissions, with the ultimate purpose of taxing those that exceed a standard (Gassman, 1995).

France's incentives focus on nitrogen emissions. A tax proportional to the size of the farm and to the residual pollution level will be paid by farmers in the near future. The purpose of the tax is to assist and subsidize farmers in improving their situations. The tax is an application of France's belief in the "polluter pays principle" and "should motivate farmers to apply, accept and develop agricultural practices that minimize this residual pollution" (Martinez, 1996). Italy has also employed economic tools with regard to swine operations. In 1992, the government encouraged biogas recovery systems by offering incentives for self-production of electric energy from biogas. This could translate into a renewed interest in biogas systems for swine facilities (Piccinini, 1996).

Setback and Permit Requirements

Austria

In 1995, the Austrian Ministry of Environment issued a non-binding setback guideline that considers facility size, local topography, wind frequency, and the effects of building design/management and odor abatement techniques. The model first estimates the strength of the odor source and then estimates the dispersion of odor from that source (Heber, 1997). The Austrian recommendations attempted to improve upon guidelines from Germany, the Netherlands, and Switzerland, all of which are based on scientific odor measurements and neighbor surveys (Ellingboe, 1998).

Greece

Because of the large tourism industry, keeping odor under control in Greece is a major concern. Livestock farms can legally operate only when odors and pollution are kept to a minimum. The specific requirements depend on the production character and environmental sensitivity of the region. First, before land disposal, liquid wastes must be treated and managed to reduce the odor and organic load. Second, new farms must complete an extensive permitting process, and there are setback distances preventing one farm from encroaching upon another and thereby compounding an odor problem. These setback requirements are set forth in Public Works and Environment Ministry Order: 69269/5387/25-10-90 (Georgacakis, 1996).

United Kingdom

To alleviate problems of noise and smell in the U.K., the Town and Country Planning Act of 1990 requires a permit for a new or extended livestock building within 400 meters from the boundary of a residence (Bloxham, 1996). There is a laboratory-derived empirical equation to estimate setbacks, but the odor emission rate is required to use this model, thereby making it somewhat difficult to use (Heber, 1997). Spreading manure is banned during winter months, because the frozen ground keeps the manure lying on top of the ground, causing runoff, emissions, and odor problems. When manure is spread, the government recommends that it be incorporated within 24 hours. British laws also control methods of carcass disposal (Manitoba, 1995).

Others

In the Flanders region of Belgium, the law forbids any manure application from November 2 to February 15 (Gassman, 1995). In France, the spreading of pig slurry on fields is forbidden from November 15 to February 15. In addition, any activity that could have an impact on the environment needs a license (Martinez, 1996). The Irish EPA is in the process of introducing licensing for pig farms above a certain size. Some units may consider a processing option that would reduce the volume of slurry to facilitate transport and eliminate odor. (Carton, 1996)

Producers in Norway are recommended control ammonia emissions, though there are no strict regulations to date. However, the Ministry of Agriculture is giving this problem higher priority (Skjelhaugen, 1996). In Italy, the objective of reducing ammonia emissions by at least 60 percent is far from being reached. Sergio Piccinini of the Research Center for Animal Production stated: “The lack of regulations [in Italy] concerning the specific kind of emission means that the improvements necessary for protecting the environment are hard to achieve.” (Piccinini, 1996).

Nuisance

Part III of the United Kingdom’s Environmental Protection Act 1990 addresses “statutory nuisance and clean air.” Local Environmental Health Departments can inspect facilities for problems of smell, noise, and dust nuisances. If a nuisance is found, abatement notices and requirements to obviate the nuisance can be issued (Bloxham, 1996). The Statutory Codes of Good Agricultural Practice are not compulsory, but a breach may be considered in legal actions arising from pollution problems. If there is a significant odor problem for local people, legal action can be brought, even against a well-run farm (Burton, 1996).

4.3.5 *What does it all mean?*

The Swine Task Force of North Carolina State University summarized the economic impacts of the increased European regulation as follows:

Stringent regulations in several European countries have, in some cases, led to waste-management and odor-control systems more advanced and elaborate than those in the U.S. But in Europe, producers generally recoup the cost of those systems in the higher prices paid for pork. In some parts of the world, then, society has been willing to pay more for its food in order to ensure cleaner water and air (1995).

Essentially the regulations allow producers to internalize costs, meaning that those who use the product pay for the environmental protection. Society eats pork; society pays to keep itself clean and safe from the effects of producing this pork.

4.4 Summary of Law and Regulation

Finding regulatory methods to combat odor and gaseous emissions from industrial swine farms is an ongoing challenge in the United States. To date, no federal regulations address the issue, and state regulations are few and far between. Minnesota, however, has taken steps in this direction with its new Feedlot Hydrogen Sulfide Program. European countries have also implemented programs with a direct focus on air and odor problems from livestock facilities. Because citizens in the United States do not have numerous statutory remedies for seeking relief from odor and gaseous emissions, they must often rely on common law nuisance suits. This is not always a guaranteed victory; right-to-farm laws can sometimes provide swine operations a defense against nuisance claims. More action needs to be taken in the United States to ensure that citizens are not bearing a disproportionate amount of the negative side-effects of pork production.

5.0 CONCLUSIONS

Regulating the gaseous and odor problems associated with swine production is difficult because of the elusive nature of the problem itself. Because there are no conclusive correlations between swine emissions and adverse public health effects, creating health-based regulations would be challenging at this time. The same is true for threshold-based odor regulations. Since there are neither indicator compounds within odor plumes nor electronic devices for measuring odor emissions, it is difficult to develop meaningful threshold value limits for odors. Gases, on the other hand, can be measured; yet, regulating gases will curb the odor problem only if the regulated gas is present in the odor plume. The Netherlands has found, however, that regulating ammonia gases does decrease the intensity of offensive odors emitted from industrial swine facilities. Furthermore, regulating swine emissions by mandating that the best available technology be installed does not give any incentives for creating new and better technologies. Finally, a problem underlying any regulatory decision is determining which substances to regulate out of the hundreds of odor-causing gases and compounds emitted from swine facilities.

Reform of the swine production process must, however, incorporate both regulatory and economic structural changes. Some degree of federal regulation is necessary to curb the current "race toward the bottom" of states lowering their standards to lure new industry.

However, state and local controls are also necessary to tailor regulations to the needs of particular areas.

In the interim between non-regulation and regulation, pork producers should focus on incorporating existing odor abatement technologies into their processes to reduce the number of odor complaints. Generally, the best method to abate odor is to operate a well-managed, clean facility. A facility should be kept clean so that the biodegradation of organic material (the process that causes odor) can be controlled in treatment facilities specifically designed to facilitate this process. In turn, these facilities should be well designed and managed so that manure can be effectively treated, while producing the maximum quality of by-products and the minimal amount of odor.

Although many technologies designed to control and/or reduce odor are under development, there are several options currently available to swine producers. Older buildings should be cleaned more often and modified. The selection of new facilities should be carefully considered, and the facilities themselves should be properly designed and constructed. Ventilation systems should provide adequate air flow without enhancing the odor problem. Solid concrete floors should be modified to include slotted floors and collection boxes. Collection boxes and floor gutters should be flushed regularly with relatively clean lagoon effluent or water. Flush liquid should be dispersed using anti-siphon vents. Manure waste should be separated before being put into treatment lagoons. Lagoons, collection boxes, tanks and basins should all be covered. Dead animals and even solid manure waste should be disposed by means of composting, the remnants of which can be used as fertilizer for cropland. Likewise, inert sludge and treated wastewater from lagoon treatment can also be used for land application. Treated wastes should either be incorporated or injected into the soil, disturbing existing crop residue as little as possible.

Technologies that are still under development but hold promise are biofilters, air scrubbers, lagoon covers and biogas generation. Biofilters, air scrubbers and lagoon covers are perceived to be very effective in inhibiting and/or treating gases and particulates that cause odor and are relatively inexpensive, being primarily composed of inexpensive materials in ready supply.

Although biogas generation is not yet a viable alternative waste treatment process in the United States, there is increasing interest in the development of this technology in both the United States and Europe. Future technological developments, funding assistance and rising fuel costs are factors that could spur the utilization of this technology.

In general, a swine producer should consider all available alternative waste treatment, storage and odor control technologies, decide which technologies are best and then commit to the proper design, construction and management necessary to ensure their proper function. Above all, a clean, properly operated swine facility generates the image of a good quality product.

In any case, the costs of environmental protection need to be incorporated by pork producers and consumers; thus, those who consume the products of pork production should help pay for both the pollution and the nuisance to neighbors caused by this process. Economic incentives, such as labeling measures, should be incorporated to give the public a voice in declaring the type of production methods it will and will not tolerate. In 1996, only 8.8 percent of the wholesale value of U.S. pork production was exported (U.S Meat, 1997), meaning that Americans themselves are consuming the majority of pork products created by environmentally “unfriendly” means. Thus, a “green labeling” system for pork produced in environmentally responsible ways could be feasible in the United States. Moreover, according to the Federal Reserve Bank of Chicago, a recent national survey “indicates that over half of America’s consumers are willing to pay some premium for food produced in a socially and environmentally responsible manner” (Hudson, 1998). However, in order for such a labeling program to work, there must be an increase in public education about the current methods of pork production. Regulators should also examine European programs and consider “manure banks” or similar devices that encourage producers to find the most efficient means of reducing emissions.

These programs alone will not solve the odor problem; stronger regulations are definitely in order. Regulating bodies should look to the progressive initiatives of Minnesota and the Netherlands to see both the successes and shortcomings of their programs. In addition, for regulatory or other control programs to be effective, they should include both members of the community and directors of the swine operations in the actual policy-making process. As stated above, this would be the best way to address less-evident issues concerning the odor problem, such as social and interpersonal health. Moreover, a policy concerning swine odor will be more successful if the community is empowered in the decision-making process, where instead of having no control over the situation, they will be able to contribute to improving both the air quality in their community and their future overall well being.

Focusing on community control of large-scale swine facility emissions is perhaps the most effective means of remedying the odor problem. In addition to empowering community members in the decision-making process, specific leaders in the community, such as county extension officers, could be directly involved in the odor abatement process. For example, the county extension officer could develop programs that assist swine facility owners in managing odor emissions. The development of such programs could foster trust between county officials and facility owners, opening the lines of communication such that animosity between the county and facility owners is prevented.

Furthermore, odor control policy that focuses on setback distances would be most effective if the regulations were developed at the local level. Local policies could take into consideration local weather patterns, topography, and demographics, yielding a setback requirement that is tailor-made for the community, rather than a boilerplate regulation from a distant agency.

In sum, federal regulations should be issued to curb the westward expansion of swine facilities into states with lax regulations. State and local control should play a major role in formulating federal standards to address local conditions and concerns. In addition, producers should focus on incorporating odor abatement technologies into their production processes to reduce the number of odor complaints. Community involvement is key, and all interested parties should have a voice in the decision-making process. A variety of programs and initiatives should be explored, and cooperation among agricultural non-governmental organizations will facilitate the development and growth of programs that work. These suggestions should provide a good foundation for those interested in improving the air quality as well as the quality of life in their communities.

Tables

Table 1: Symptoms in humans and swine after exposure to hydrogen sulfide

Concentration (ppm)	Symptoms
	Humans
10	Red, irritated eyes
20	Eyes, upper respiratory irritation
50 to100	Headaches, nausea, vomiting, diarrhea
200	Fatigue, paralysis of sense of smell, dizziness
500	Unconciousness, nervousness, CNS malfunction
>600	Immediate death
	Swine
20	Fear of light, loss of appetite, nervousness
150 to 200	Pulmonary edema, shortness of breath, unconciousness, possible death

Table 2: Symptoms in humans and swine after exposure to ammonia gas

Concentration (ppm)	Symptoms
	Humans
5 to 20	Eyes, upper respiratory irritation
100	Continual irritation to eyes, respiratory tract and mucosal surfaces
500	Eyes, upper respiratory irritation
5,000	Rapid breathing, respiratory spasms, suffocation
>10,000	Rapid death
	Swine
50	Increased susceptibility to pneumonia and other respiratory problems
100	Loss of appetite, sneezing
>300	Mouth and snout irritation, shortness of breath

Table 3: Symptoms in humans and swine after exposure to carbon dioxide

Concentration (ppm)	Symptoms
	Humans
50,000	Headaches, fatigue
>100,000	Narcotic effect, unconsciousness, dizziness
>200,000	Rapid death
	Swine
50,000	Shortness of breath, rapid breathing
90,000	Uneasiness
>200,000	Untolerable after one hour

Table 4: Dangers to humans and swine after exposure to methane

Concentration (ppm)	Dangers
50,000 to 200,000	Explosive
>500,000	Asphyxiation

Note: Information for these tables was gathered from Barker et al., 1996, and Taraba, 1996

GLOSSARY

Aerobic – bacteria that require molecular oxygen as an electron receptor

Anaerobic – bacteria that can only function incomplete absence of molecular oxygen which can be quite toxic

Air Scrubbers - technique where air is forced up through a shaft while water flows down the shaft, trapping odorous gases and particles.

Biological Oxygen Demand (BOD) – the amount of oxygen required to decompose all of the biodegradable organic wastes in a given volume of water during a 5-day period

Chemical Oxygen Demand (COD) – the amount of oxygen required for the chemical conversion of organic waste matter

Biodegredation - the breakdown of organic matter by bacteria

Biofilters - filters constructed of biologically active materials, such as compost, straw, wood chips, peat or soil, that contain microorganisms that break down volatile organic compounds and oxidizable inorganic gases and vapors into non-malodorous compounds such as water and carbon dioxide

Biogas - gas generated by bacteria during the decomposition organic matter, the components of which include methane, carbon dioxide and trace levels of organic gases such as hydrogen carbon monoxide, nitrogen, oxygen and hydrogen sulfide

Facultative – bacteria that utilize free oxygen when it is available and use other substances as electron receptor (i.e. oxidants such as nitrate and sulfate ions)

Farrow – *(verb)* to give birth to a litter of pigs; *(noun)* a litter of pigs

Farrow-to-Finish - Swine operation encompassing from birth to slaughter/death

Gestational – pregnant

Geographical Information Systems (GIS) - airborne and satellite remote sensing of geographical areas used to create an integrated database that combines a computerized map product with layers of information about the manmade and natural features of the land; enables users to collect, analyze, manage and access all types of data related to the land

Mesophilic - temperature range of 90 - 110 ^{o}F

Methanogenic - bacteria that produce methane while breaking down organic matter

pH – a value used to express acidity and alkalinity (scale 1 to 14, with 1 being very acidic and 14 very being alkaline; water typically has an a pH value of 7)

Thermophilic - temperature range of 120 - 140^{o}F

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