

Title: "Air Emissions from Swine Production Facilities: Assessment of Science and Market-Based Solutions" - **NPB # 02-222**

Investigator: Ms. Rhonda Kranz

Institution: The Ecological Society of America

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Abstract: Increased demand for dietary protein from animal sources has resulted in substantial growth and operational shifts in large-scale livestock production systems. But economically successful intensification of animal agriculture has also resulted in new and emerging environmental challenges that require improved understanding of scientific, technical, economic, and policy issues. In particular, concerns about air quality impacts from livestock production, associated in part with concentrated swine feeding operations, are gaining attention within both the regulatory and research communities.

In order to address these concerns effectively, it is important to consider current scientific and technical knowledge regarding air emissions from swine operations in the context of the entire pork production process, as well as both technical and policy mechanisms by which to achieve market-based solutions. A major key to success in coping with air-quality regulatory concerns is to stop thinking about animal manures as unpleasant waste materials that must be disposed of by least-cost methods and to start thinking of manure and other animal processing residues as valuable natural resources from which additional value-added products can be produced and sold at a profit.

Special attention is given in this report to atmospheric emissions of ammonia (NH₃), hydrogen sulfide (H₂S), methane (CH₄), and particulate matter (PM_{2.5-10}). New approaches to recovery of value-added products from livestock production systems are identified, as are various market mechanisms, pollutant trading regimes, and renewable energy possibilities. Of special importance in formulating viable technical, economic, and policy alternatives for science- and market-based environmental management is understanding and improvement of air quality monitoring, measuring, and modeling capabilities. These considerations are discussed specifically with regard to ammonia and particulate matter emissions.

In this report we recognize technical advancements that have occurred for livestock production and waste management primarily from a technical and pollution prevention approach. But we also point out important market-based opportunities and note potential improvements in monitoring and measuring emissions sources. The report ends with an outline of critical information gaps in which the swine industry and other stakeholders can make a significant contribution by guiding future research efforts.

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For more information contact:

National Pork Board, P.O. Box 9114, Des Moines, Iowa USA

800-456-7675, Fax: 515-223-2646, E-Mail: porkboard@porkboard.org, Web: <http://www.porkboard.org/>

Introduction: Livestock production systems in the United States and around the world have evolved to accommodate increased demand for higher protein diets and affordable food supplies. Many benefits are associated with this evolution in the industry. But some negative environmental externalities associated with large-scale production pose new challenges in environmental management. Some of these recognized environmental impacts have been subject to scientific study and assessment. As the science has evolved so has awareness of new concerns, particularly related to air quality. Over the past decade many agricultural industries, and the pork industry in particular, began evaluating air emissions concerns.

Research and funding efforts notoriously have focused on identifying technical and best management practices readily adaptable to current farming regimes. Combinations of existing waste management technologies from within the livestock industry and from other industries have been evaluated. Often the process has entailed bench-scale evaluations leading to varying scales of field demonstrations.

Many research efforts to date have focused on minimizing sources of odor, reducing pollutant discharges (primarily nitrogen and phosphorus compounds) into surface water and/or groundwater, and improving land application procedures. Greater attention is now being given to air emissions – particularly of ammonia and methane, but also of hydrogen sulfide. Management of these compounds could become influenced by new regulatory requirements.

In recent years the policy community and industries alike have begun to recognize the importance of market-driven alternatives to complement regulations as a means to stimulate improvements in environmental management. The scientific community also sees the need for multi-disciplinary and multi-media assessments that incorporate economic, policy, ecological, and social concerns along with technological evaluations aimed at specific pollution problems.

In this final report, we provide a brief summary and assessment of the current state of the science, with particular emphasis on air quality concerns and the relevance of existing information to the development of science-based and market-based environmental management systems within the industry. This information is intended to assist in identification of policy development needs and opportunities as well as economic and market considerations available to producers.

Objectives: The objectives of this research are to assess current and future air quality concerns facing the swine industry. The project will emphasize ammonia, methane, and hydrogen sulfide emissions. In addition, the goal of the assessment is to identify both technical (science-based) and economic (market-based) policy alternatives for improving management of air emissions from swine facilities in an economically viable way.

Specific Project Objectives: The National Pork Board asked that special attention be given to ammonia, methane and hydrogen sulfide emissions concerns. We identified five management considerations worthy of review for this project including:

- 1) The potential for capturing and concentrating the volatile ammonia generated in animal rearing facilities for sale and use as either chemical feedstocks or reagents in chemical formulation, industrial processes, and fertilizer manufacturing.

- 2) Converting the carbon compounds in animal wastes into energy in the form of methane, diesel fuel, or electricity for direct on-farm purposes or for sale through co-generation contracts with public utilities.
- 3) Exploring means by which to adapt the successful “Cap and Trade” systems currently being used and/or considered by the USEPA and determining the advantages and limitation of other “tradable permit” systems that could be adapted by the livestock industry.
- 4) Comparing and recommending more precise measurement methods and mathematical modeling tools for use in improving ammonia emissions inventories for local, state, regional, and national environmental assessments and planning purposes.
- 5) Developing improved estimates of the contributions of swine rearing facilities to particulate matter dispersal and accumulation in various swine-rearing local, state, and regional locations.

The following provides a concise account of the current information and documented research addressing these objectives, and ideas as to how the industry can help fill in important gaps for the purposes of informed decision-making among stakeholder groups.

Project Findings:

- 1) The potential for capturing and concentrating the volatile ammonia generated in animal rearing facilities for sale and use as either chemical feedstocks or reagents in chemical formulation, industrial processes, and fertilizer manufacturing.

A substantial body of knowledge and experience in decreasing emissions of pollutants by converting the pollutant waste streams into saleable products exists in other industries such as metal smelting, pulp and paper, and chemical manufacturing. Many of the by-products generated in livestock production are potential sources of reactive nitrogen, carbon, phosphorus and other nutrients that could be converted to a wide range of saleable by-products.

Leaders in the pork industry have long recognized the potential for capturing the nutrients contained in swine waste, especially nitrogen and phosphorus to be used as fertilizer materials and methane (or biogas containing methane) for use as a source of energy including generation of electricity for on-farm purposes or even for sale through cogeneration contracts with public utilities.

Until recently, limited if any attention has been given to the idea of capturing and concentrating the volatile NH_3 produced by animal feeding operations for sale as chemical feedstocks or reagents for industrial purposes. This is in part due to the assumption that few places exist in swine rearing or waste treatment facilities where the NH_3 concentrations are high enough to be captured efficiently for reuse.

Recently two patents issued to Dr. Israel Wachs of Lehigh University for catalytic conversion of (similarly dilute) methanol and mercaptan in waste stripper gasses from Kraft paper mills into saleable formaldehyde (Wachs 1999a, 1999b; Choi and Wachs, 2002; Burgess et al., 2002; Jacoby, 2002) suggest it may be possible to use a combination of thermal swing adsorption and catalytic-conversion technologies to increase NH_3 concentrations sufficiently to meet some commercial market needs. It

may also be possible to use existing NH_3 cracking technology to produce valuable hydrogen from the NH_3 produced in swine rearing facilities.

As excreted by pigs, about 75% of the reactive nitrogen (Nr) is contained in the urine and only about 25% in the feces. Thus, for efforts to capture ammonia as a chemical feedstock or reagent, swine urine appears to be the best physical source. Even so, the urine excreted from swine is considered a fairly dilute solution, only containing about 0.6-1.0% urea (van Kempen, 2002).

A possible approach to the development of an ammonia capture and purification/conversion process would start by separating swine urine from feces using existing slanted belt conveyor technology followed by maximizing the conversion of soluble urea in the urine, producing volatile NH_3 in an isolated gas stream with approximately 1% ammonia concentration. Thermal swing adsorption/desorption technology then could be used to concentrate and purify the NH_3 to commercially viable concentrations (20-60% NH_3). The captured NH_3 could then be further utilized to produce NH_3 -based fertilizer materials, in selective catalytic reduction of NO_x in power plant plumes, or by cracking the NH_3 to produce valuable H_2 for use as a fuel source to other processes. Harmless N_2 would be a by-product of this process.

To better understand the process, further research requirements include:

- Urease enzyme studies to optimize the conversion of urea in the liquid urine phase to NH_3 in the gas phase;
- Testing various thermal swing adsorption processes to further increase the NH_3 concentration in the gas stream and remove impurities;
- Catalyst-development studies to optimize decomposition of NH_3 to form H_2 and N_2 ;
- Use of ZnO sorbent technology to capture trace amounts of S-compounds and residual NH_3 that may poison the Pt/Ru-catalyst in hydrogen fuel cells.

Currently scientists at North Carolina State University have developed two somewhat different slanted belt conveyor systems, one aimed primarily at gasification of swine solids to provide energy and the other aimed primarily at dewatering and stabilizing the solids for use as fertilizer materials for crop production. So far, neither group has worked extensively with the liquid stream. Thus, a significant need exists for research to make comparative evaluations of the chemical characteristics of these two different liquid effluent streams, and to experiment with various physical, chemical, temperature, and enzymatic treatment methods capable of maximizing the concentration of NH_3 in gas streams derived from these two liquid streams.

More detailed suggestions for exploratory research would include efforts to:

- Compare and contrast the chemical composition, biochemical stability, and physical characteristics of the liquid streams derived from the experimental slanted conveyor belt systems.
- Compare the numbers of bacterial cells present in each stream, the concentrations of urea present, the endogenous urease activity of the two streams, the rapidity with which urea is converted to ammonia, the concentrations of H_2S present, and the nature and concentrations of other volatile substances present in the gas streams derived from the two liquid streams that might interfere with the ammonia adsorption/desorption or subsequent purification processes.

- Compare the effects of ambient temperatures and pressures, and various pH, enzyme, and other physical and/or chemical treatments that could be applied to the two liquid streams in order to maximize the NH₃ concentration in the gaseous headspace of the treatment vessel. Of particular interest in this connection would be the quantitative partition between the concentration of gaseous NH₃ present in the headspace and the concentration of dissolved NH₄OH present in the liquid within the treatment vessel. Such research could be guided by the earlier investigations of Zhang et al. (1994) who studied these partitioning phenomena and developed a computer model for predicting ammonia release rates from swine urine and feces. The objective of such experiments would be discover treatment conditions that maximize the concentration of gaseous NH₃ present in the headspace so that the starting air concentration of NH₃ will be as high as possible before using thermal swing adsorption systems to further increase the NH₃ concentration to meet commercial use specifications.

Potential markets for NH₃ recovered from swine wastes include a very wide range of value-added end uses. Most familiar, but likely the lowest value-added end-use, is NH₃-based fertilizers for crop or timber production. An intermediate value-added commercial use is reagents for catalytic reduction of nitrogen oxides in the flue gas streams of power plants. A very high-value end-use would involve cracking the recovered NH₃ to produce gaseous hydrogen for use in fuel cells for generation of electricity. There exists a wider range of value-added end products between and among these three examples.

Continued research and dialogue amongst professionals dedicated to finding economic solutions to environmental problems associated with livestock husbandry has resulted in identification of a suite of value-added products potentially derived from swine production by-products. Examples include:

- a) Ammonia and urea captured from confined animal feeding operations for sale as commercial feed stocks or reagents for the chemical, fertilizer, electric utility, and other industries;
- b) Energy in the form of methane, biogas, or electricity for direct on-farm purposes;
- c) Electricity for sale through co-generation contracts with public utilities;
- d) Synthetic growth media and fertilizer materials for use in green-house production of high-value floral crops and ornamental plants; as soil amendments for residential or commercial landscaping purposes; and as nutrient sources for direct application to crops such as corn, cotton, sweet potatoes; as a nitrogen source for fast-growing pine or hardwood plantations;
- e) Feed materials, nutritional supplements and/or protein products for veterinary applications for enhanced feed conversion efficiency in fish, poultry, and livestock production (supplements could include dehydrated duckweed, high-protein fish meal, and amino acid and vitamins); medicinal uses in aquaculture, poultry and livestock industries including nutritional enzymes, edible vaccines and anti-viral proteins such as interferon;
- f) Pet supplies such as chewable proteins and processed foods;
- g) Protein products for industrial applications including industrial antibodies and enzymes used in detergents, recycling, and in processing of pulp, paper, textile, and chemical products;

- h) High-value protein-based biomaterials including adhesives, fibers such as silk, optically active films, other biopolymers, and plastics.

Similarly to ammonia and methane, hydrogen sulfide (H₂S) is a gaseous compound that is emitted as a waste by-product from pork production systems and can cause or contribute to various health and environmental problems. In contrast to ammonia and methane, research efforts on hydrogen sulfide have focused on abatement of emissions but not on development of marketable sulfur-containing products. H₂S concentrations inside swine confinement facilities and in the vicinity of manure storage areas during manure handling events historically have been the focus of concern because of the potential for toxicity of H₂S to farm workers and animals. Because the odor threshold for H₂S is very low—0.5 ppb to 30 ppb—the compound has a large nuisance value. H₂S can attach to particles and therefore be transported well beyond the property line of a concentrated animal feeding operation (CAFO).

There currently are no national ambient air quality standards for air emissions of H₂S or NH₃ from animal operations, but they are limited as toxic substances under the Comprehensive Environmental Response, Compensation, and Liability Act. Any further regulation has been at a state level. Increased public attention on the potential influence of increasingly large animal operations on surrounding air quality, as well as longer-standing concern about water quality, has increased the potential for other federal regulations to be promulgated. A recent study recommended that standards be put in place that would require H₂S not to exceed 70 ppb for a 1-hour time-weighted average period at the CAFO property line (Iowa State University and The University of Iowa Study Group, 2002). Concentrations at a public use area or residence should not exceed 15 ppb. Exceedances would be allowed for 7 days per year.

Accurate determination of emission rates of H₂S or NH₃ from swine farms is difficult; animal buildings are point sources, while manure storage and treatment units and cropland fertilized with manure are regarded as area sources. In contrast to the contribution of agriculture to the atmospheric nitrogen inventory, agriculture is not considered to be a significant contributor to the atmospheric sulfur inventory, compared to SO₂ from fossil fuel burning. H₂S concentrations monitored continuously near both animal housing and manure storage was reported to show a diurnal pattern that was negatively correlated with temperature and positively correlated with relative humidity (Bicudo et al., 2002).

Zahn et al. (2001) categorized strategies to abate the emission rate of gases from swine waste management systems into two general categories, continuous or discontinuous, based on where in the system the emission is controlled. In continuous approaches, efforts are made to decrease the concentration of a specific compound in the anaerobic effluent and thereby reduce emissions from the liquid. Examples of continuous treatment systems are: anaerobic digestion, aerobic digestion, biological catalysis, pH adjustment, ferrous ion amendments, and addition of photosynthetic bacteria. In discontinuous approaches, the treatment process is decoupled from the anaerobic effluent and gaseous emissions are treated. Biofiltration is an example of a discontinuous treatment system.

Efforts have been made to alter the formulation of swine diets, such as reducing crude protein and adding synthetic amino acids, in an attempt to decrease odor in general and H₂S in particular, in manure. Mixed results for H₂S have been reported, from no effect on emissions to a decrease of up to 30%.

Some current waste management methods or technologies that show promise for H₂S emission mitigation are:

- manure composting systems integrated into swine houses
- biomass filter for solid/liquid separation, with filter/manure composting
- addition of hydrogen peroxide to finishing barn pits during agitation and pumping
- maintenance of smooth cleanable surfaces along with frequent and complete scraping and/or frequent flushing of feeding floor in slatted floor housing units
- biofilters used in housing ventilation air
- two-stage anaerobic sequencing batch reactor systems
- soybean oil misting in swine confinement areas

If an outside manure storage system is used, the most effective means to decrease emissions of H₂S is to cover the entire surface, either with an impermeable cover, which is often expensive, or with a permeable cover such as crop residue or other organic material. Laboratory tests of a peat bed cover, along with the addition of FeCl₃ and plants, separately and in combination, on an anaerobic pond showed very large (up to 95%) decreases in H₂S emissions (Picot et al., 2001). Research is ongoing to evaluate the efficiency of permeable lagoon covers in field situations.

There are some technologies that may provide opportunities for conversion of H₂S in animal waste into value-added products, but would require additional research and development. One such technology is extraction of the hydrogen from hydrogen sulfide for use as a fuel. Although the end product is valuable, some of the constraints are the cost of the process and the relatively dilute concentrations found in swine waste. Another potential end product, which would utilize both H₂S and NH₃, is conversion to ammonium sulfate for use as a fertilizer. The technological process has been developed by a firm in Denmark but is used currently in industrial refinery applications (www.haldortopsoe.dk).

Accurate determination of rates of emission of H₂S, NH₃, and other gaseous compounds of environmental concern is an issue of considerable importance, especially given the potential regulatory consequences. Zahn et al. (2000) developed a classification scheme for swine waste management systems based on effluent concentrations of S and P and emission rates of CH₄, NH₃, H₂S, and VOC. They found that H₂S emissions were independent of the waste management system, and may be explained by the determination that SO₄ excretions in urine provide a large part of the S-containing precursors of H₂S, whose production is driven by SO₄ reduction processes common in all management systems. This provides justification for the use of process-based and mass balance approaches to estimate emissions from CAFOs, as recommended in the NRC (2002 and 2003) report and discussed elsewhere in this report.

Policy Considerations: Additional biological and chemical/physical studies, as well as field demonstrations, are required to bring many of the potential value-added products described above to large-scale production. In most cases, it also would be beneficial and necessary to explore further the market potentials of a specific value-added product, as well as other possible end uses. Such economic and market-based studies should include potential prices, locations, and the magnitude of markets as well as the physical characteristics, chemical specifications, and environmental and marketing permits that would be required to meet the needs of both new and existing markets for

value-added NH_3 -enriched or hydrogen-based end products produced from swine waste. Assessment of economic feasibility is an important component of the evaluation process being utilized in the development of environmentally superior technologies for swine waste management as part of the agreement between the North Carolina Attorney General and several North Carolina pork production companies (Williams, 2002). A continued policy emphasis on hydrogen-based fuels increases the potential for the development of new markets and expansion of existing markets for hydrogen products from animal waste.

- 2) Converting the carbon compounds in animal wastes into energy in the form of methane, diesel fuel, or electricity for direct on-farm purposes or for sale through co-generation contracts with public utilities.

Due to increasing interest in alternative fuels and green energy source development, funding for research and technical innovation in this area has grown noticeably in recent years. Methane recovery technologies are being evaluated, utilized, and improved upon by several industries including the solid waste management sector. Isolated examples exist where green power pricing programs have created incentives to local utilities and governments to purchase power from green sources such as methane recovery systems. There are also examples of agricultural “closed-loop” systems deployed in regions with high concentrations of livestock and energy pricing schemes conducive to energy recovery and production on-farm. Many of the most recent projects involve dairy operations.

Anaerobic digesters and methane generation technology have been available in the marketplace for over 30 years, yet the application of such technologies on farms has been slow to evolve. To date it is estimated approximately 30 digesters are in operation on commercial livestock facilities. There are several factors impacting the use of digestion techniques and methane generators to manage livestock wastes, particularly the liquid content of the waste and local energy market influences.

Much research has been published discussing the specific influences on methane generation, in part due to recognition by the Intergovernmental Panel on Climate Change (IPCC) of methane as the most rapidly increasing greenhouse gas (GHG) impacting climate change. Researchers have compared different effects of environmental conditions and management practices on CH_4 emissions from anaerobic lagoons, revealing strong correlations to various surface processes and temperature variations encountered with lagoon storage systems (Sharpe et al., 2002; Sommer et al., 2000). They also identified the importance of waste solids composition and chemistry of solution factors such as total organic carbon, volatile solids, and pH. These types of influences have been the subject of substantial research. Though science has addressed these concerns fairly well, the link to more cost-effective recovery techniques appears limited.

An increasing demand for mitigating negative environmental impacts and discovering cleaner, secure sources of energy has spawned interests in waste-to-bioenergy conversion. Recently, the University of California-Davis intensified research into the use of a newer two-phase, closed-loop anaerobic digestion process for agricultural waste processing. So far the researchers have demonstrated an ability to create a medium-Btu gas containing approximately 60% methane, however the system has been found to be more cost-effective for wastes from stables due to desirable moisture characteristics. At this time a private enterprise is deploying the technology at a horseracing facility in California, where economic assessments demonstrate the

approach to be viable. The digester capital cost to the track was reportedly \$20 million with an estimated annual energy savings returned to the facility of \$2.1 million (assuming an 11¢/Kwh price). In addition the state supplements the facility 1.5¢/Kwh and savings accrued for both reduced equipment damage associated with power outages and elimination of tipping fees for stable waste disposal.

In California, Senate Bill 5X provides an incentive to the dairy industry to employ methane generation and recovery processes, placing \$10M into the California Energy Council funds for dairy power production programs. In Oregon the Portland General Electric utility has partnered with dairy operations to power residential subdivisions from digester-generated methane. The Oregon State Office of Energy gives PGE a 35% tax credit over five years for their investment in such power generation systems. More resources are expected to flow through the Integrated Biomass Programs as part of the year 2000 Biomass Research and Development Act. As a part of this policy effort, the established Advisory Committee set a goal to triple the production of bio-based power, products and fuels by 2020. In January 2002 the Biomass Research and Development Initiative Technical Advisory Committee released funding recommendations for Biomass Programs (Appendix A). The program enjoys joint participation by the Secretary of Energy and the Secretary of Agriculture in directing its focus and innovative efforts.

Throughout the past decade, the federal government has supported research and program development efforts targeting biofuel production and has created policies encouraging more focus on alternatives to fossil-fuel-based energy. Examples include the Renewable Energy Incentives Act (S.1566) set to modify and expand credits for electricity produced from renewable resources, the Energy Policy Act (1992), the Energy and Water Development Appropriations Act of 2002, and others. Some states have derived localized programs driving research and/or market activities associated with alternative energy resources.

Technology development for biodiesel processing and utilization continues to advance, with the biggest challenge perhaps being engine design adaptations required by equipment and vehicle manufacturing companies. Soybean-based biodiesel production continues to demonstrate progress in the marketplace, important to the agriculture industry at large. For the swine industry it may be that incentives and market returns can be gained from the waste-to-crop-to-fuel potential within their region or independent system.

Funding sources for innovative research exists within some foundations and non-profits dedicated to climate change and environmental protection concerns, community development, and specifically to energy. Several federal agencies continue to fund research and educational projects aimed at increasing the capabilities of energy generation in green, efficient, and secure ways. The National Industrial Competitiveness through Energy, Environment, and Economics is an exemplary program funding the demonstration of energy-efficiency and clean production in industrial systems. Information sources for continual updates concerning bioconversion activities can be found on the Internet at www.bioproducts-bioenergy.gov and www.oit.doe.gov. In addition to government sources, many private enterprises are embarking on partnerships to research and evaluate markets for alternative energy and market participation (such as various trading regimes). For example, the John Deere Corporation has been collaborating with soybean growers in the enhancement of soy-based biodiesel products and Pioneer teamed up with Carbon Energy Technology, Inc. (Ames, IA) to conduct research concerning carbon conversion processes. Such

partnerships are extremely important to the creation of economic and environmental solutions in agriculture.

Summary comments: Current research and information sources support the technical viability of generating methane effectively for recovery on livestock farms, however the efficiency of generation requires better understanding of waste inflow characteristics and interactions within the waste handling system. Economic data is weak, and thus far case studies available demonstrate pricing structures and existing energy policies tend to favor on-farm closed-loop utilization as opposed to off-farm sale of energy. This is certainly location-specific and subject to change as states push for more alternative sources of energy and as they develop Renewable Energy Portfolios, Green Power Pricing programs, net-metering services, and other policy incentives.

The agriculture industry also has an opportunity to evaluate combining incentive and market mechanisms as a means to affordably transition to more environmentally benign production practices. For example, there is strong momentum behind carbon sequestration as a means to mitigate CO₂ emissions impacts on climate change. Agriculture operations have an opportunity to evaluate how to utilize landscapes where wastes may be recycled to grow vegetation for sequestration purposes. This could be done in tandem with participation in conservation and wetland restoration programs as supported by the 2002 Farm Bill. Grasslands can serve multiple purposes in today's marketplace, providing habitat, surface water protection, sequestration, and biomass production for biofuels. Noel Uri (2000) with the USGS discusses similar observations in his evaluation of carbon cycle dynamics, GHG concerns and the implications of the new Farm Bill.

- 3) Exploring means by which to adapt the successful "Cap and Trade" systems currently being used and/or considered by the USEPA and determining the advantages and limitation of other "tradable permit" systems that could be adapted by the livestock industry.

Pollutant trading mechanisms, taxation schemes, and permit structures have been evaluated for several different types of pollutants of concern within different industries facing compliance challenges. Though there is currently a limited amount of research addressing the use of these market incentives in agricultural, there are a number of policy evaluations and models applicable to the livestock industry. It is interesting to note much of this work has occurred in Canada and Europe, particularly where different tax mechanisms have been evaluated for Greenhouse Gas (GHG) exchanges or trades.

Some beneficial work has been completed here in the U.S. evaluating monitoring and measurement requirements necessary for establishment of market-based trades by agriculture operations, particularly if the pollutant trading business should continue to grow. These assessments also consider similar requirements for improving cost-benefit evaluations of area (geographic)-specific pollutant mitigation alternatives.

The "cap and trade" system for mitigation of nitrous oxide and sulfur dioxide pollution from utilities and power generation sources has been in place for a long enough time in the U.S. to provide data concerning the effectiveness of these programs. Within many research reports and publications, whether scientific, policy or economic in nature, professionals involved in evaluation of air emissions trading activities comment on the lack of complete, accurate and timely data. This is thought to be the case for cost data, emissions source and composition data, and health exposure data. Regardless of the

market mechanism chosen, there are continual challenges associated with obtaining the appropriate science with such integral components as geographic influences, source areas, atmospheric chemistry and effective monitoring/measuring capabilities.

The two most common types of trading mechanisms used to date for managing air emissions are the Emission Reduction Credits (ERC) and Cap and Trade (C&T). In the U.S. the utility industry began to seek alternatives as Title V requirements forced evaluations of NO_x budgets and SO_x reductions from primarily point sources (facility stacks). One reason C&T has been so successful in this industrial market is the ability to monitor and verify emissions trends. Comparing C&T approaches to ERC, the use of C&T mitigates some of these difficulties by setting limits on total emissions and increasing source area coverage, however monitoring remains a challenge. Monitors have been developed and deployed at the source of the contaminant so effectively that trades and reductions are actually verified and known. This is a challenge for many other types of pollutants and sources of pollutants in terms of data support to market driven transactions. This remains particularly true for CO₂ and NH₃ emissions, each derived from various sources and quickly impacted by air chemistry and geological conditions.

In general Emissions Trading Potentials are influenced by:

- The need to set caps that are attainable, measurable, timelines that are workable
- Phasing of reductions (allows for and creates incentives for technological adaptation)
- Assure emissions sources are not subjected to 'dictated' compliance means but flexibility in how reductions are achieved
- Strict guidelines and rules are required for "proving" and "quantifying" reductions or emissions impacts
- Policing of trades needed – for both allowances and off-sets
- Workable financing (i.e., valuation of assets [reductions, allowances, trades, etc.]

Policy Issues and Considerations: There are a number of tools to be considered by the agriculture sector in evaluating the application of trading regimes and incentives for improved management of pollutant emissions. A Clean Air Markets Group currently exists comprised of representatives from source generators, trade associations, brokers, and others affiliated with industries dealing with NO_x and SO_x reduction demands. A similar group could be developed within the agriculture sector for pollutant trading activities.

The concept of embedding Economic Incentive Programs (EIPs) into State Implementation Plans (SIPs) has potential to drive environmental improvements. The EIP would address emissions trading as an emissions limiting activity; create market-response programs looking to tax or surcharges on pollution production practices; and bolster education activities about market mechanisms. Many states already are using green tax incentives, waste fees, streamlined permitting incentives, and renewable energy portfolios.

Some general policy considerations include:

- A cap and trade program must be an overlay to a mandatory, risk-based standard (such as NAAQS) and would become a tool complementary to state-specific SIPs.
- Market incentives for emissions reductions have a tendency to be more environmentally beneficial when an industry is broadly targeted (as opposed to singling out facilities or “hot spots” within airsheds.)
- Well designed trading regimes, particularly if used in tandem with other types of incentives, can motivate enterprises to control emissions beyond caps or regulatory limits in an effort to “bank” credits. Thus it is important for regions and industries within those regions understand market potentials.
- Both the public and government institutions need to be informed, educated, and helped to comprehend the value or benefits of using market-based approaches in tandem with regulations and standards.
- Development of programs and policies utilizing a consistent documentation and tracking system will increase credibility and likelihood of participation. There are examples of how registries and trading zones can be used to manage trading programs.

In the near term, it appears climate change implications of air pollution will be the primary driver of regulatory and market-based management, with newly implemented caps on NO_x and Hg facing the industrial sector (particularly utilities). The Federal government intends to drive further decreases in NO_x and SO_x as a means to get at risk-based concerns about particulate matter. Both 8-hour ozone and PM_{2.5} concerns are big issues due to scientific discoveries of their health implications. This is very important to the livestock industry, recognizing that ammonia and Nr both impact formation of small particulates and can thus indirectly impact other air quality concerns.

Researchers have begun to evaluate the effectiveness of trading regimes as compared to other types of policies or regulatory measures. Particular attention has been given to comparisons of specified percentage reductions from point or source areas versus overall reductions gained using trades. Nobel et al. (2002) looked at this issue while addressing the probable impacts of trading zones, the effects of pollutant (herein NO_x) spatial distributions, and the application of “impact indices”. They also evaluated models assessing ozone indices as related to trading or point-specific concentration reductions as correlated to population densities and exposure risks. The type of research conducted in Texas by Nobel lays a foundation for evaluating policy tools as applied to other air quality concerns such as CO₂ and NH₃.

- 4) Comparing and recommending more precise measurement methods and mathematical modeling tools for use in improving ammonia emissions inventories for local, state, regional, and national environmental assessments and planning purposes.

An increasing amount of scientific material concerning measurement methods and modeling systems has become available during the past two years. The attention drawn to global climate change initiatives and research on a national and international scale has resulted in the development of improved modeling and measurement tools for a wide range of airborne chemicals. With greater emphasis on fine particulate matter, it appears more work will be done to develop better assessment methods for PM_{2.5}, however this too will result in a greater demand to improve both particle size and

chemical composition measurement capacity. A number of federal agencies and international organizations are developing improved monitoring and measurement methods. This is necessary not only to help improve the science of air quality assessments and improve understanding of climate change concerns, but to facilitate emissions trading regimes at various geographic scales.

General Measurement and Modeling Issues: At the request of Congress and the National Academy of Science, the National Oceanic and Atmospheric Administration (NOAA) is expanding capabilities in modeling and forecasting air quality using an integration of photochemical, meteorological, and emissions models (Stockwell et al., 2002). The new forecasting capabilities, projected to be in place by 2004, will require inputs of real-time air quality monitoring and meteorological data, coupled with improved emissions inventories. The system utilizes deterministic models for simulating regional and national air quality conditions. Photochemical deterministic models contain modules describing meteorology, deposition, and atmospheric chemistry across a range of pollutant concerns including VOCs, NO_x, SO_x, NH₃, and PM. NOAA's Office of Oceanic and Atmospheric Research is continuing an aggressive program toward the development of new, more accurate assessment methods. Their focus is not only on emissions inventories and meteorological and chemical processes, but also on field-testing models for quality assurance.

In addition to NOAA's work, Section 165 of the Clean Air Act (CAA) requires EPA to establish and revisit Air Quality Model Guidelines, in particular analytical methods important to the New Source Review program (Hoffnagle, 2003). These guidelines are intended to assure greater consistency and equality in consideration of pollutant sources as models are implemented. Whenever changes are proposed to measurement and modeling methods under the CAA, a public and legal review process must be used that is very different from many other types of EPA guideline procedures. Most recently, EPA has determined it appropriate to recommend, based on two-decades of improving "state-of-the-practice" regulatory dispersion modeling, the AERMOD and CALPUFF models. These models utilize a multi-dimensional approach and therefore can integrate more parameters simultaneously, which is expected to increase the utility of output information. These models will require greater computational and computer skills for use, however. For more detailed information, visit EPA's Support Center for Regulatory Air Models (SCRAM) at www.epa.gov/ttn/scram.

In addition to the ongoing efforts of NOAA and EPA, other research has been conducted to assess the effectiveness of emissions inventory estimation techniques, particularly as states face stiffer Consolidating Emissions Reporting rules. Other federal agencies conducted research in earlier times to assess the magnitude and rate of fluxes of ammonia in terrestrial ecosystems (CENR, 2000; Langford et al, 1992). Majeed (2001) evaluated the implications of the Emissions Inventory Improvement Program (EIIP), with particular emphasis on estimating emissions in different time periods under different mitigation strategies.

Measurement and Modeling Issues Specific to Livestock Emissions: McCubbin et al. (2002) evaluated the relationship of livestock ammonia emissions on formation of particulates and the associated health-related risks, pointing out that there exists a need for better data on fine particles and animal-specific ammonia emission factors. It is noted there have been attempts to estimate emissions contributions across livestock operations from grazing, housing, manure storage, and land application practices, however such estimates contain a great deal of uncertainty because of inherent

assumptions, such as that confined versus unconfined livestock populations are proportional by livestock type and region.

McCubbin's work attempted to develop models to inform policy analysis and subsequently attempted to apply a nitrogen mass balance approach. They relied on the Climatological Regional Dispersion Model developed by E. H. Pechan and Associates as their baseline model. This model utilizes a source-receptor matrix with inputs from emission source inventories collected throughout 48 states and model outputs are county-level averages for PM₁₀ and PM_{2.5}, sulfate, ammonia and nitrate. As a result of this study, it was recommended that more precise source and less aggregate data be developed along with an improved means of linking emissions management scenarios to health risks.

Research completed by Anderson et al. (2002) points out that the majority of current models use chemical species inputs from meteorological and emissions inventory data sources that does not effectively account for particulate mass and associated chemistries (such as ammonia). Often inventories are reported as a rate within a region (mass per unit of time or unit of specified activity). Most of these models estimate livestock emission factors as the ammonia emitted in mass/animal/unit of time multiplied by the total number of animals in the defined area. And, despite recognizing volatilization rates of ammonia are influenced by many factors, such parameters are often not effectively equated into model calculations. For that matter, much of the ammonia data is generated as an annual value and thus does not accurately encompass the parameters impacting emissions and volatilization rates. The spatial resolution of data is also an important consideration, so presently county data appears to best serve modeling needs.

An alternative approach is application of a method comparable to a waste life-cycle analysis. Such an approach could effectively address the various phases of activity in animal production and associated variables in emissions due to changing parameters. As in previous research reports, Anderson et al. (2002) identified important research gaps in their conclusions, including: the need for improved emissions inventory data on particulate matter and atmospheric chemicals including ammonia; experimentation with waste life cycle impacts on emissions; an improved understanding of animal activity patterns that could influence temporal and spatial emissions measurements; and ammonia-chemistry/waste/environmental-conditions interactions.

The recently completed National Research Council study (NRC, 2003) of air emissions from animal feeding operations addresses the role of atmospheric modeling and associated complexities. In this report it was concluded that making direct measurements at an individual farm level is less practical than some other optional research settings. Existing measurement complexities are a result of variations in the types of air emissions that occur (chemical composition, photochemical reactions and mixtures of atmospheric compounds), temporal influences (season, day period), and geographic location, each of which impacts air dispersion and atmospheric reactions. Continued research into the application of advanced three-dimensional modeling techniques, such as ongoing work by NOAA, EPA and others, offers potential tools capable of improving emissions estimates from livestock operations. These emerging multi-parameter models better account for variations in terrain and air interactions, temperature and time effects, and other location-specific factors.

The NRC report resulted in several recommendations, including the need for EPA to develop and carry out more field research evaluating the extent to which ambient atmospheric concentrations of various compounds (including ammonia) and pollutants

are consistent with estimated emissions, and to improve understanding of how transport and atmospheric chemistry influences local and regional distribution of these various compounds. Also, EPA previously issued a recommendation to develop process-based mathematical emissions estimate models (as opposed to average emissions per animal by feeding operation type multiplied by total number of animals). This approach would be similar to that proposed by Anderson et al. (2002)

- 5) Developing improved estimates of the contributions of swine rearing facilities to particulate matter dispersal and accumulation in various swine-rearing local, state, and regional locations.

Various information sources, including the NRC report, recognize particulate matter (PM) from animal feeding operations tends to contain a significant fraction of mechanically generated material such as soil, dried manure, bedding materials and so forth. These particles are generally referred to as “coarse particulate matter” (material that is typically larger than 10 μm in aerodynamic diameter). In addition, research has revealed in rural, agricultural areas there may be significant contributions to fine particulate matter resulting from the reaction of gaseous ammonia with other chemical compounds such as nitric acid.

There is also speculation that organic particulate materials generated in rural areas contain bioaerosols such as toxins, allergens, viruses, bacteria, and fungi. To date, there are limited studies of bioaerosols in swine barns. This may be due in part to the lack of currently accepted standard methods for bioaerosol measurement and because no sampler has yet been fully characterized for bioaerosol collection efficiency. With this in mind, it is clear that there may be aerosol chemistry occurring in the rural atmosphere however, this chemistry is likely to be less complex than that occurring in the urban atmosphere especially with regard to organic particulate matter. Regardless, concerns about human health impacts and effects on other pollutant activity in the air due to increased development of particulate matter will continue to demand more scientific assessments in rural and urban environments.

Some of the work recently completed in the Netherlands can inform PM measurement issues and associated policy development. Opperhuizen et al. (2003) discussed the difficulty associated with using daily standards, recognizing that, even with planned abatement strategies already in place, exceedances are often frequent and/or numerous. There also are several critical aspects of PM risk assessments to be considered in model development, including questions such as:

- Does reliance on PM_{10} as pollutant description encompass risk evaluations in a way that can consistently assist in making management decisions? Perhaps other means of describing PM (such as fine, ultra-fine, source related), each more specific to certain forms of risk and mitigation activities, should be required inputs into various model applications.
- What are the averaging times (having exposure and transport implications) to be used and how much validity is attached to those temporal issues?
- What, if any, are the cost-benefit factors applied?

As PM assessments become more necessary and are utilized in developing guidelines, care must be taken in determining what types of measurements to use as input into models, and how to consistently obtain such measures. For example, it was discovered that the U.S. National Morbidity, Mortality and Air Pollution Study contained scientific and statistical flaws, particularly related to estimation of the maximum

likelihood values related to effects on health. EPA had originally proposed guidelines of $15 \mu\text{g}/\text{m}^3/\text{yr}$ and $65 \mu\text{g}/\text{m}^3/\text{day}$ for $\text{PM}_{2.5}$, each level of which could be exceeded on a regular basis. The agency also is planning to require states to provide at least three years of data for eventual use in establishment of attainment/non-attainment programs for particulate matter in the atmosphere. It is suggested that perhaps model inputs need to be chosen as follows:

- by size, realizing the $\text{PM}_{0.1}$ (ultra fines) are the dominant particles in terms of number in ambient air while particles $\text{PM}_{2.5}$ to PM_{10} constitute most of aerosol mass
- by source, with PM primary components emitted directly by sources (traffic, industry) or indirectly (wind-blown, sea spray)
- as the secondary components, formed in atmosphere by chemical reactions of gases (most notably SO_2 , NO_x , NH_3 and VOCs).

As new air quality models are developed for PM, it is important to recognize that inputs from existing meteorology models are available. These models are capable of evaluating both longer-term and shorter-term meteorological predictions and conditions, important to all types of air quality analyses.

Scientists recognize that decreases in concentrations of $\text{PM}_{2.5}$ can best be accomplished with decreases in primary and secondary sources, the latter of which includes gaseous precursors such as sulfate, nitrate, ammonium, and airborne organic compounds. These secondary sources often comprise a large percent of the $\text{PM}_{2.5}$ occurring in air zones beyond primary source influences and therefore contribute to geographic variability and associated monitoring challenges (Pun et al., 2002). Pun et al. (2002) looked at expanding the modeling capabilities of the Models-3/Community Multiscale Air Quality model in their research efforts evaluating biogenic sources of particulate matter in the Eastern U.S. The modifications made to the model included improvements to understanding and integrating secondary organic aerosol chemistry information into the applications. They also utilized the ACCESS database (application of seasonal and temporal factors to county level emissions data) to bolster the output capabilities of their modeling efforts. This research demonstrates the capabilities available in modeling PM by combining different methods thought to be the current state-of-the-science.

Similarly, Hughes et al. (2002) assessed the effectiveness of alternative sampling and analysis methods in the Los Angeles area, seeking to evaluate nitrogen species across air trajectories in the region. They tested the implications of air monitoring station placement and aerosol sampling techniques. As more of these types of research projects are completed and results assessed improved methods of measuring and modeling particulate matter from various sources are expected to emerge.

Summary Comments: As can be seen in the information discussed in items four and five, there is currently much attention being given to the development of multi-dimensional air quality models capable of outputting data and predictions useful for both policy formulation and inspiring further research. Though there is room for improvements in sampling and measuring techniques, measuring capabilities have been recently improved. The issue appears to be more one of cost and effectiveness of measurements in model applications. Temporal and spatial considerations for monitoring and measuring air quality parameters require greater attention and understanding.

There are multiple benefits associated with understanding atmospheric chemistry and photochemical reactions, particularly as impacted by climate variables and source management alternatives. The importance of emerging scientific discoveries in these areas will be noticeable to the livestock industry. Investing in improved monitoring and measuring capabilities can lead to more cost-effective mitigation strategies; protection of human, animal, and ecological health; and informed opportunities in pollution trading activities.

The livestock industry can benefit from collaboration with agencies involved in model development as well as learning from other industries facing multiple pollutant mitigation challenges. As the concerns with ammonia, atmospheric nitrogen, and particulate matter grow in terms of GHG's, climate change, and health, the demand for better measurement technologies and methods will be coupled with the emergence of real-time multi-parameter models capable of informing more cost-effective mitigation controls and policy guidelines.

Closing Remarks: This report has focused on assessments pertaining to current and future air quality concerns facing the swine industry. However, we would be remiss if we did not state that assessment of air quality issues from the pork industry should only be done in the context of the entire cycle of pork production. There are two major reasons. First, it is important that any action taken to reduce air emissions should not result in an increase in reactive nitrogen in the liquid or solid waste streams. The second is related to the first, and provides a mechanism for a systems approach – the assessment of any losses (e.g., N) from pork operations needs to be performed in the context of the entire system, including: inputs; internal recycling; losses to air, water, and soil; and tracking of products.

As proposed in NRC (2003) and illustrated in Figure 1, inputs include any and all materials used in support of animal production that enter the pork production operation. Consider the following – feed sources occur as an input from either a primary feed (e.g., corn produced for animal feed) or secondary feed (e.g., a waste product from a different type of agro-ecosystem). Water inputs can contain sulfur as dissolved sulfate salts and waste products contain the nitrogen, carbon, sulfur and phosphorus compounds from manure and mortalities. Recycling or reuse of waste by-products at the generating facility, at a different agriculture operation, or as a feedstock for another process becomes an incremental component of the system. Numerous products of the complete cycle have been identified including the basic outputs of meat, milk, eggs, live animals, and harvested crops. All of these components must be included in a systems analysis and design approach to ensure that chemical losses to the environment are minimized, while the pork production process is enhanced.

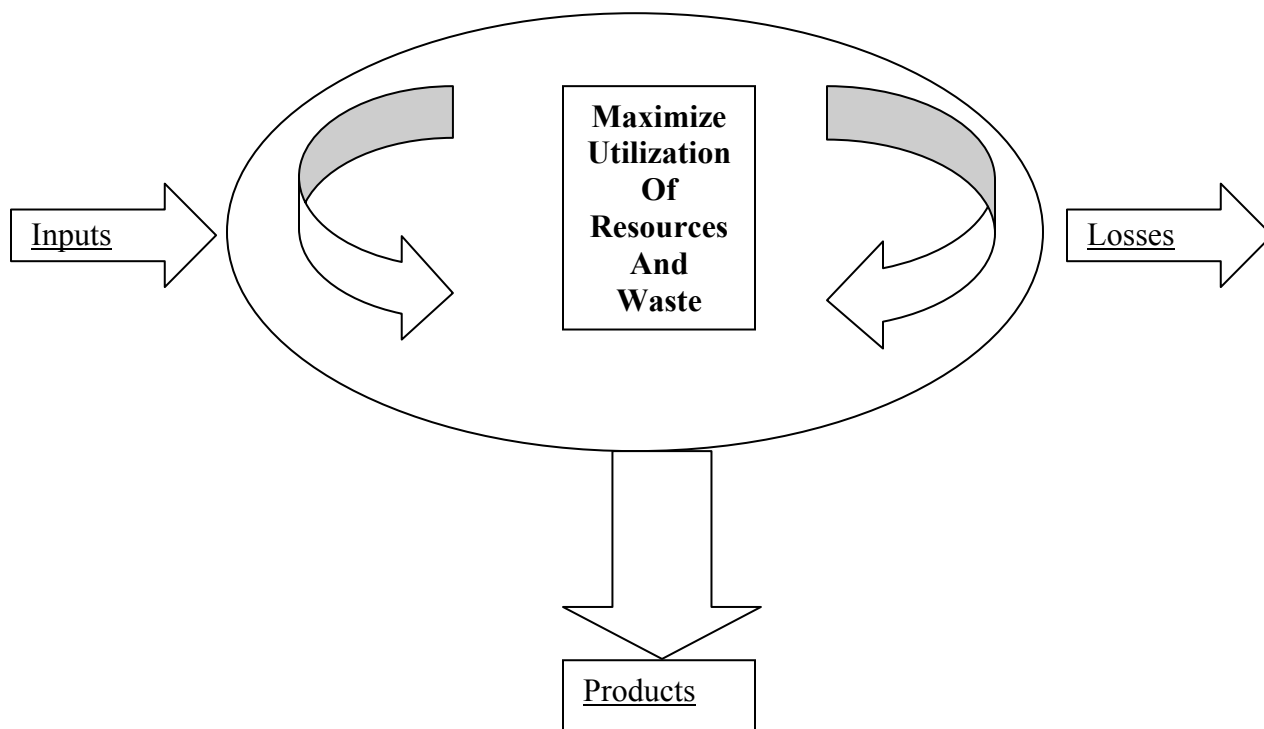


Figure 1. Animal feeding operations system (animals plus associated cropland).

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Future Considerations: The increased attention to environmental management concerns associated with livestock production, in particular air quality impacts from swine in concentrated feeding operations, has resulted in investment of resources toward an improved understanding of the issues at hand. The gains in scientific knowledge about production inputs, facility designs, both waste and pollutant characteristics, and market opportunities are notable. As the industry looks to the future there remain some areas where information gaps are critical to informed decision-making across stakeholder groups. In summary these include:

- More precise measurement methods and tools for specific types and mixtures of atmospheric pollutants, sources within production and waste cycles, and exposure risks.
- Increased understanding of waste stream characteristics and technologies for selective extraction of compounds having higher market values within and outside of the agriculture industry. The latter would involve further evaluations of alternative markets for captured ammonia, the hydrogen or sulfur potentially extracted from hydrogen sulfide, and clean energy resources.
- More complete economic assessments of the costs and benefits associated with environmental mitigation strategies and production life-cycle implications.
- Evaluations of alternative policy scenarios for decreasing negative externalities associated with waste generation resulting in pollutant emissions incorporating

regionally specific economic and market data, risk criteria, and science-based technical performance information.

There are a number of possibilities for collaboration and funding projects to address these research gaps, many from sources not traditionally sought out by the livestock industry. We envision this report will serve the National Pork Board in identifying such opportunities and pursuing efforts that will help the industry make informed and confident decisions as future challenges arise.

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APPENDIX A. Feature article from Bioproducts-bioenergy March 2002 newsletter.

Biomass Research and Development Technical Advisory Committee Recommendations to the Secretaries of Energy and Agriculture

Introduction

In January 2002, the Biomass Research and Development Technical Advisory Committee [Advisory Committee] submitted their recommendations on funding Biomass Programs for FY2002 to the Secretaries of Energy and Agriculture. The Biomass Research and Development Act of June 2000 authorized an Advisory Committee for the purpose of advising the Secretaries of Energy and Agriculture on the technical focus and future direction of programs that are funded through the Integrated Biomass Programs. The Advisory Committee is made up of twenty-five members from trade associations, environmental organizations, academia, private industry and government. Committee members bring diverse expertise in the fields of biobased products and bioenergy. The ultimate goal of the Advisory Committee is to create recommendations that will serve to triple the production of power, products and fuels from biomass sources by 2020.

During four public meetings in 2001, the Advisory Committee developed recommendations for increasing the availability and use of biobased power, products, and fuels. This first of a five-year term was used to provide a preliminary overview of the potential of biomass research and development activities (R&D).

The Recommendations

To address each of the unique technical issues involved in biomass R&D, the Advisory Committee provided both research and development and non-R&D recommendations in three key areas: biofuels, biopower, and biobased products. A crosscutting section was added to highlight recommendations that apply to more than one area.

Biofuel

With a growing market in place for alternative fuels, the Advisory Committee indicated that the goal to triple biofuel production can be reached as early as 2010.

To enhance increases in the use of biofuels, the Advisory Committee recommended an emphasis on R&D in the following areas:

- Lignocellulosic Materials
- Pretreatment
- Catalytic and Chemical Processing
- Utilization and Systems Management

In their recommendations, the Advisory Committee identified the need to reduce the cost and amount of financial risk involved with initial investment in biofuel technology. Recommendations also included measures to assist rural communities with economic development and increase the value of agricultural and forestry products. This could be achieved through increased federal government effort to create fleet standards, fuel standards, oxidation standards and tax incentives that encourage the use of biofuels.

Biopower

The Advisory Committee also indicated that sufficient resources exist to triple biopower production by 2010. The three main challenges to achieving this goal were cost, policy and efficiency of biopower technology. In order to meet this goal and overcome the challenges, the Advisory Committee recommended increasing R&D in:

- Thermochemical Conversion
- Direct Combustion
- Thermal Gasification
- Development of Modular Systems

In addition, non-R&D recommendations made by the Committee included improvement of systems management and encouraging the use of distributed generation technology. The Advisory Committee recognized that increased efficiency and development of advanced biopower technologies would provide employment and other economic benefits to rural communities.

Biobased Products

For biobased products, the Advisory Committee identified goals for 2010 and 2020: by 2010, the biobased products industry will triple the consumption of biobased products, improve the health of rural economies, and reduce the environmental impacts associated with the production and use of industrial biobased products; by 2020, the biobased products industry will replace 10% of the petroleum-based product market with biobased products. To achieve these goals, the Advisory Committee recommends increasing R&D in the following areas:

- Fractionation and Separation
- Biomass Fermentation and Hydrolysis
- Biobased Processing

Non-R&D areas identified as priorities to support reaching these goals are increased education and outreach activities. In addition, new product standards need to incorporate the use of new bio materials from various product categories.

Crosscutting

The Advisory Committee identified a number of crosscutting R&D opportunities that will benefit biofuels, biopower, and biobased products. In order to achieve the full potential of these technologies, the Advisory Committee recommended increasing R&D in the following areas:

- Industrially Useful Crops
- Biomass Fragmentation
- Product Recovery and Storage
- Genetically Enhanced Microbes

Non-R&D recommendations include the development of an infrastructure that will improve the recovery, transportation, and processing of biomass, while retaining its quality, so that it becomes a valued product in the market.

DOE Integration

The Office of Energy Efficiency and Renewable Energy [EERE] will incorporate the ideas outlined in the Advisory Committee's recommendations into their biomass R&D program for FY2002 and beyond. Areas from the Advisory Committee's recommendations that the Department of Energy has identified as priorities for the future of biomass R&D include: Gasification, Processing and Conversion, and Fuels and Chemicals.

The Department of Energy and the Advisory Committee are looking forward to working together over the next four years to improve the focus of federally funded biomass R&D. The Advisory Committee's work for 2002 will include a recommendations report to the Secretaries of Energy and Agriculture as well as a report to Congress that will showcase the significant work of the Advisory Committee Meetings of the Advisory Committee are open to the public and are advertised in the Federal Register. All interested parties are invited to attend.

The Advisory Committee recommendations paper is available at this link: <http://www.bioproducts-bioenergy.gov/pdfs/AdvisoryCommitteeRDRRecommendations.pdf>

Research Team

This Final Report summarizes the work completed to date. It is intended to inform members of the National Pork Board and other interested stakeholder groups as deemed appropriate by the Board. The research team contributing to this effort includes:

Ellis B. Cowling, Ph.D., College of Natural Resources, North Carolina State University, Raleigh, NC

Anita R. Bahe, Ph.D., The Lynx Group International, Cary, NC

Cari S. Furiness, M.S., College of Natural Resources, North Carolina State University, Raleigh, NC

James N. Galloway, Ph.D., Department of Environmental Sciences, University of Virginia, Charlottesville, VA

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