ILLINOIS COUNCIL ON FOOD AND AGRICULTURAL RESEARCH

STRATEGIC RESEARCH INITIATIVE

SWINE ODOR AND WASTE MANAGEMENT

FINAL REPORT C OCTOBER 2003

EXECUTIVE SUMMARY

This is the Final Report of the Strategic Research Initiative on Swine Odor and Waste Management funded 1998 through 2003 by the Illinois Council on Food and Agricultural Research (C-FAR). Individual projects combined to focus variously on the Initiative's specific objective: To support continued development of an environmentally sustainable, socially acceptable, economically viable U.S. swine industry through a broad, integrated research program addressing issues of swine odor and manure management.

A total of 29 projects, ranging in duration from 1 to 5 y, were conducted by scientists from 11 Illinois units, institutions, and agencies in the areas of odor measurement, control, and management; system design and management; nutrition; manure processing and handling; and community considerations and legal issues.

The Initiative's 19 primary goals included new approaches to minimizing impacts of swine production; proper methods of volatile organic compounds (VOC)-, odor-, dust-, and gas-sampling-characterization, and -identification; models on nutrient flow, production systems, and environmental determinants of odor emissions; models to improve facility siting and manure application; develop dedusters, wet scrubbers, and catalytic converters to reduce dust and gaseous emissions; center for testing and evaluating devices and processes in a simulated industry production setting; various viable nutritional approaches to reducing excretion of phosphorus and other materials contributing to manure mass and formation of VOC; various viable manure-processing technologies to reduce manure volume, enhance odor control, reduce soil, ground, and water pollution, and develop a variable-rate slurry applicator; database on swine manure and odor; understand public reactions to large-scale swine operations; analyze and create a database of federal and state laws and court decisions governing swine odor and manure issues; and communication of up-to-date information and recommendations to various stakeholder clusters.

Work under the C-FAR Initiative resulted in invention or development of numerous processes, devices, and recommendations for practical application. These are presented in the Report as well as being highlighted later in this Summary. Many other products have evolved, only some of which also have been discussed in the Report. Some have been less tangible than but just as important as others, including establishment or formalization of enduring interdisciplinary and even interinstitutional scientific teams, $10 million in additional funding leveraged by existence and results of C-FAR projects and research teams, establishment of continuing facilities and staffing for sample collection and analysis and device and process evaluation and testing.

In Area 1, *Odor Measurement, Control, and Management*, in one project a reliable method for sampling swine-house air for dust, gases, and other VOC of interest was developed and modified after attempts to employ cotton-swatch adsorption were abandoned. Ultimately, the Tekmar-Dohrmann #6 trap at appropriate flow rate was used. Methods and instruments for chemically identifying VOC in swine-facility air and dust were established and refined. These included high-resolution gas chromatography (GC) and GC-mass spectrometry. Results led to improving odor-control technologies in other C-FAR projects. Methods and instruments were refined so precise sampling and testing protocols for organoleptic VOC analysis via dynamic olfactrometry (DO) could be developed. Correlation between DO-determined odor offensiveness and total VOC concentration was low; correlations between DO offensiveness descriptors and concentrations of individual VOC were higher. DO tests were used as adjuncts in several Initiative projects.

A basic model having simple nutrient flows that performed reasonably was developed. A statewide nutrient flow model was designed to study implications of swine facilities at the state level. A system dynamics model of pig growth was developed to evaluate economic feasibilites of 3 approaches to pig-feeding system as related to nutrient

excretion. A successful multiuniversity workshop on odor-control techologies was held. The UITERM program was established to provide producers faced with pollution or nuisance complaints with consultation by UIUC staff.

The Illinois Swine Odor Control Proving Center was established. It completed evaluation of frequent facility cleaning on odor and dust emissions; a new wet air scrubber; contributions of pig manure to ammonia generation; refinement of the manure-lagoon cover; effect of ozonation on pig-house air quality and pig performance.

A dispersion model based on source strengths from published and archived meteorologic data was built for use as a prediction aid in facility-siting decisions. The “Nanonose” instrument was invented and tested as a means of real-time quantitative measurement of specific VOC aerosols via size-change under specific conditions surrounding aerosol particles as small as 20 nanometers. An approximately linear relationship exists between size change of an aerosol distribution and odor dilution.

Three prototype air dedusters were built. The laboratory prototype removed ~80% of airborne particles and ~55% of ammonia. The 5000-cfm vertical prototype performed almost as well in simulated production settings. With a new wet scrubber, ~50% of dust was removed from the exhaust of an 18” fan. A sequential development process showed that catalytic methods hold promise of being cost-effective ways to reduce exhaust gases from swine houses.

In Area 2, *System Design and Management*, results of Initiative research projects and information from other sources were communicated to various stakeholder groups by several methods: accumulating an international database on swine manure and odor (>3000 citations on RefManager); website and CD-ROM systems potentiating easy, rapid future updating; newsletter; several trade-show exhibits; numerous speaking engagements; 2 workshops for scientists; and 2 field days for stakeholders. Illinois TRAILL is developing a website that will allow stakeholders to subscribe to an electronic newsletter, provide a searchable database of articles, and allow editors to upload their own content to the site.

In Area 3, *Nutrition*, recommendations were developed for adding phytase to wheat middlings- and corn-soy-based pig diets while eliminating the need for supplementation with inorganic phosphorus and reducing excretion of phosphorus and calcium. Reduced dietary nitrogen and sulfur concentrations supported normal performance but decreased concentrations of odor-causing components in pig manure. Efficacy of a new *Escherichia coli*-based phytase product for dietary inclusion in improving phosphorus utilization efficiency and reducing excretion was demonstrated. A series of nutrition experiments led to several recommendations on nutritional approaches to increasing dietary phosphorus utilization in and decreasing phosphorus excretion by pigs and chicks.

In Area 4, *Manure Processing and Handling*, it was determined that any model of nutrient balance and flow in a swine-production system will need to be site-specific. Each facility will need to frequently monitor its manure system for guidance in management and regulatory compliance. It was demonstrated that composting manure according to specific recipes of manure plus a carbon source (leaves, corn stalks, and so on) is a practical, economical, environmentally safe way for pork producers with small-, medium-, and large-scale operations alike to co-exist with continuing urban sprawl. Compost can be used on-farm as a soil amendment or sold off-farm as a value-added product. The anaerobic sequencing batch reactor was found to be an effective way to remove and recover phosphorus from manure flows, and hence reduce chances of environmental pollution. Three prototype systems for aerobic thermophilic microbic treatment of manure were demonstrated as effective means of using and thus removing manure from a swine-production site. Due to the value of several co-products this technology appears to be practically feasible. A high-temperature, high-pressure thermochemical means of converting pig manure into odor-free oil and char-like substance was developed as yet another means of removing manure from a swine farm. Covers were demonstrated to be effective in reducing odor emissions from manure lagoons. A variable-rate slurry applicator linked to a global positioning system was invented and successfully developed as a means of controlling nutrient levels in crop-field soil. Experiments were conducted to determine optimum design, manure specifications, and operating requirements for a successful, practical gravity liquid/solids settling tank.

In Area 5, *Community Considerations and Legal Issues*, a random survey of Illinois newspapers revealed local arguments pro and con large-scale swine facilities (LSSF)—pro: farm/industry structure, economics, moral stance, minimizing environmental risks; con: environmental concerns, health risks, farm/industry structure, ethics of rural life. A book, working title *Pigs in Print*, is a product of this survey. Two more books are being written resulting from many interviews with various stakeholders in the Illinois pork-production industry; working titles are *A History of the Hog in Illinois (1950-1980)* and *Citizen Reactions to Large-scale Swine Facility Sitings*. A database available to all was developed to identify and analyze laws and court decisions related to swine odor and manure issues. A guide to

important state and federal laws relevant to livestock facilities in Illinois–*How Environmental Regulation Affects Livestock and Poultry Production*–was produced.

The results of this initiative can be characterized as discovery and development, broad and deep, practical and theoretical. They have been described and disseminated to all stakeholder groups. They have thus fulfilled the mission of the Illinois Council on Food and Agricultural Research. Many of the findings will be immediately applicable, others will serve as important links in the chain of scientific study destined to further come to grips with the real problems and opportunities associated with swine odor and manure management in the Land of Lincoln as well as around the world. Outcomes include less tangible matters such as the formation of interdisciplinary research terms and analytical and testing capabilities that promise to long survive the Initiative per se. Illinois scientists' focus on swine odor and manure management has been permanently enhanced.

SPECIFIC OBJECTIVE

To support continued development of environmentally sustainable, socially acceptable, economically viable U.S. swine industry through a broad, integrated research program addressing issues of swine odor and manure management.

PRIMARY GOALS

1. New approaches to minimizing environmental impacts of swine production that will contribute toward its social acceptability and future prosperity
2. Proper dust- and gas-sampling methods and characterization of aerial dust and gas fractions at swine farms
3. Identify odorous compounds in swine facility air and dust
4. Odor offensiveness: Identify and quantify volatile odorous compounds at swine facilities
5. Dispersion models for improving facility siting and manure application
6. Modify aerodynamic deduster for reducing odor and dust in swine barns
7. Modify wet scrubber for removing odorous dust and gases from exhaust
8. Cost-effective catalytic converter to reduce malodorous gaseous emissions from swine barns
9. Odor and manure database summarizing existing information and allowing information to be easily accessed
10. Identify contributors to odor emissions and integrate findings into models on nutrient flow, production systems, and environmental determinants of odor emissions
11. Research center to evaluate odor- and manure-management practices in a simulated production setting
12. Ways to improve use of dietary nutrients so as to reduce phosphorus and nitrogen release into the environment
13. Dietary factors affecting formation and reduction of compounds responsible for odor
14. Role of dietary protein level on formation of compounds responsible for formation of odors as well as nitrogen levels in swine excrement
15. Ways to improve phosphorus use so as to reduce its excretion
16. Investigate potentially viable processing technologies to reduce volume of manure produced; enhance odor control; reduce contaminants in soil, ground, and surface water; develop a variable-rate slurry applicator
17. Understanding public reactions relating to risks and benefits associated with large-scale swine operations
18. Analysis of federal and state laws and court decisions that govern swine odor and manure issues
19. Database of legal information relevant to Illinois swine producers and citizens

PRINCIPAL INVESTIGATORS IN THE SRI

Area 1. Odor Measurement, Control, and Management

Brewer, M.S., Food Science and Human Nutrition, UIUC
Cadwallader, K.R., Food Science and Human Nutrition, UIUC
Masel, R.I., Chemical and Biomolecular Engineering, UIUC
Perkins, E.G., Food Science and Human Nutrition, UIUC
Riskowski, G.L., Agricultural and Biological Engineering, UIUC
Williams, A.L., Illinois State Water Survey
Zhang, Y., Agricultural and Biological Engineering, UIUC

Area 2. Systems Design and Management

Ellis, M., Animal Sciences, UIUC
Funk, T.L., Agricultural and Biological Engineering, UIUC
Hutjens, M.F., Animal Sciences, UIUC
Gabert, V.M., Animal Sciences, UIUC
Miller, G.Y., Veterinary Pathobiology, UIUC

Area 3. Nutrition

Apgar, G.A., Animal Science, Food and Nutrition, SIU-Carbondale
Baker, D.H., Animal Sciences, UIUC
Gabert, V.M., Animal Sciences, UIUC
Lambert, R.J., Crop Sciences, UIUC

Area 4. Waste Processing and Handling

Blackburn, J.W., Mechanical Engineering and Energy Processes, SIU-Carbondale
Funk, T.L., Agricultural and Biological Engineering, UIUC
Raskin, L., Civil and Environmental Engineering, UIUC
Walker, P.M., Agriculture, ISU
Zhang, Y., Agricultural and Biological Engineering, UIUC

Area 5. Community Considerations and Legal Issues

Grossman, M.R., Agricultural and Consumer Economics, UIUC
Reisner, A.E., Human and Community Development, UIUC

SUMMARY OF SRI OUTCOMES AND IMPACTS

Area 1. Odor Measurement, Control, and Management

1.1 Sampling odorous dust and gas; characterizing aerial dust and gas in swine facilities (2 years; FY99, FY00)

Principal Investigator G.L. Riskowski

Objective: To develop appropriate protocols for sampling and characterizing of aerial dust and odor in and around swine houses and methods essential to valid, repeatable results throughout the SRI.

Summary:

C *Collection of samples for chemical analysis.* Initially, several trap styles and analysis methods were tested. Concerns regarding storage of traps, moisture effects, method reliability were investigated. A Tekman-Dohrmann #8 trap, which does not trap moisture but adsorbs a broad spectrum of odorous compounds, was used for further method development. Several trap styles and sampling and analysis parameters were investigated. All tests used traps sampling either nonodorous air or air from a swine house. A flow rate of 20 ml/min was known (and confirmed) to be adequate to reduce breakthrough. First tests determined that 4 traps sampling same exhaust fan at 20 ml/min for 50 min provided acceptable reproducibility (low coefficient of variability).

C A single trap was analyzed consecutively to determine desorption thoroughness. Results showed that thermal desorption parameters used ensured complete desorption. Traps stored >1 d showed a slight increase in FID peak number and peak area; sulfur detector values decreased. These results showed that traps should be analyzed within 24 h of sampling.

C Tests showed the sampling method to be reliable allowing gas chromatography/mass spectrometry (GC/MS) work at UIUC. Another GC was set up with a nonpolar column, which improved detection of the important malodorous compounds, indole and skatole. With addition of the second GC, duplicate trap samples could be analyzed, providing more complete odor profiles.

C *Collection of samples for odor panel evaluation.* Initial strategy was to develop a cotton-swatch method to sample dust and odorous gas, which differs from the standard method which collects only odorous gas. An odor panel trained for various qualities would then rate swatches. Several attempts were made to develop a suitable swatch method. Problems encountered included determining the proper moisture content for good adsorption,

precleaning to remove cotton-processing chemicals, odor adsorption capacity, proper storage pre- and post-sampling, and variability of odor panels. This strategy ultimately was discarded in favor of collecting samples of air in Tedlar bags, a method that determines the dilution where odor is detected. Bag samples initially were sent to Purdue University for olfactometry analysis. An olfactometry laboratory was subsequently set up at the University of Illinois, where this analytical approach was improved and expanded by employing the trained odor panel developed by Dr. Brewer (Project 1.3).

Outcome: Illinois now has capabilities to collect and analyze samples pertinent to swine odor and manure management issues.

1.2 Chemical identification of odorous compounds in swine facility air and dust (5 years; FY99 - FY03)

Principal Investigator E.G. Perkins (deceased); K.R. Cadwallader

Objective: To identify and characterize important odorous compounds in air in and around swine houses. To assist other SRI projects with chemical identification.

Summary:

C Swine odor comes from a complex mixture of organic compounds with widely varying volatilities and chemical properties. This project served a service and support function as it evaluated the efficacy of experimental odor-control and -abatement strategies and tactics by measuring aerial odorants by use of modern analytical instrumentation such as high-resolution GC and GC-MS. Data were correlated with odor-panel results (dynamic olfactometry, DO) by application of headspace GC-olfactometry (GC-O), GC-MS, and DO on the same swine-facility samples. Results improved understanding of swine odor chemistry, which ultimately led to improved odor-control technologies.

C Work was also carried out to further characterize and analyze odors of swine-production waste streams, e.g., manure, dust. This supported ongoing efforts in SRI projects studying effects of diet and methods to remove dust from air streams. Identification of key odor components of dust was done so as to better understand the role of dust in swine odor.

Outcome: Instrumental analyses to characterize and measure chemicals involved in swine odor and waste management is now possible in Illinois.

1.3 Odor offensiveness: qualitative and quantitative identification of odor-significant volatiles at swine facilities (5 years; FY99 - FY03)

Principal Investigator M.S. Brewer

Objective: Correlate results of project 1.2 (identification of chemical components of) odor offensiveness of the air in and around swine houses as determined by a panel (subjective assessment). Establish an odor evaluation panel based on dilution olfactometry.

Summary:

C This project was closely linked with 1.1 (development of sampling methodology) and 1.2 (chemical characterization of odor). In addition, this project provided an analytical service for many other projects in the SRI, carrying out odor analysis to test the efficiency of various odor reduction strategies.

C Initial focus was on odor evaluation of samples form the sampling methods development project (1.1).

C At the outset, cotton swatches were used to adsorb odor and these were presented to panelists for evaluation. Research showed that the results of this approach were subject to the environmental conditions, particularly humidity levels, and values obtained were not very repeatable. Consequently, a direct dilution olfactometer was acquired and used for all subsequent odor evaluations in the SRI.

C Relationship between chemical and sensory odor evaluation. Odorous volatile materials were analyzed using dynamic headspace GC. Effluent air adsorbed onto cotton gauze was desorbed onto a high-resolution GC column for separation and quantitative analysis. Initial analyses attempted to relate total volatiles (total detector response) to qualitive results obtained from the sensory panel. Correlation coefficients were not high.

C Detection thresholds for significant odor compounds. GC-grade organic compounds were diluted with distilled water to obtain various concentrations of odor compounds, mixed, dispensed into gauze squares into sniffing apparatus flasks, and allowed to equilibrate 2 h at 22°C prior to presentation to panelists who described aroma of suprathreshold concentrations of compounds, then trained in use of threshold score card, and recognition of odors based on group-selected descriptors. Panelists were presented with 3 samples (two were the same, one different)

and asked to identify the different one. Panelists received 5 concentrations in ascending order of each compound a total of 5 times once the general range was established. Detectable odor threshold (DOT) was calculated. Concentration at which 50% of panelists detected a difference compared to control was considered DOT. Judges were asked to rate the "offensiveness" at concentration 10 × DOT. Correlation coefficients for individual volatiles with various sensory descriptors and with odor offensiveness and tolerability were lower than with total volatiles.

C A trained panel was developed that evaluated up to 8 samples per day, three days per week. During the lifetime of the SRI, approximately 700 odor samples per year were evaluated by the dilution olfactometry panel.

Outcome: Methods, equipment, and human resources for human evaluation of odor offensiveness and strength are now available in Illinois.

1.4 Facility siting and site modification for better odor dispersion (5 years; FY99 - FY03)

Principal Investigator A.L. Williams

Objective:

C Develop dispersion models for odorous gases, volatiles, and dust-borne compounds around swine houses under different weather and management conditions as a basis for facility siting decisions. Develop a device for the objective measurement of hog odor.

Summary: *Dispersion Modeling.*

C The modeling portion involved use of a modified version of EPA's Industrial Source Complex (ISC) model to produce simulations of odor transport in the atmosphere. Using correlations from simulations over multiple years and at different sites, relations between the distance odor travels and its strength and frequency of occurrence were developed. Based on such results a general-use computer program called "Setback" was developed to compute distance from source that odor is expected to be above a specified level both 5% and 1% of the time.

C A model study of diurnal variation of odor dispersion was conducted based on meteorological observations over 8 years. A striking aspect was the wide diurnal variation of odor-transport distances. Results indicated that beyond immediate vicinity of source, odor levels exceeding detection threshold occurred predominately at night when the atmosphere is more stable. The study showed that for the odor source considered, 94% of threshold exceedances occurring were more than 500 meters from source do so during nighttime. To minimize impact of odor emission, swine management activities that temporarily increase odor emissions should be conducted during periods of atmospheric instability, i.e., in the daytime. In some cases increased odor control may be attained by identifying upcoming periods of favorable wind and instability conditions to carry out activities that cause increased odor emissions.

C Using source strengths from published literature and archived meteorologic data as model inputs, a preliminary assessment was made of the odor impact from the three University of Illinois hog confinement facilities. Results were reported in terms of spatial contours, showing frequency that odor emissions from lagoons and buildings exceed odor threshold for average summertime conditions. Reductions in odor levels for building emissions from an elevated source were computed. Finally, dispersion modeling results for a single confinement facility over a range of source strengths were combined to compute setback distances, characterizing how far a swine facility should be removed from areas where high odor levels are problematic. It was shown that offset distances can be quantitatively derived from the model results in terms of frequency of exceeding specified odor intensity levels. According to present calculations, current Illinois setback distances correspond to an intensity of <1 (i.e., threshold value close to 2) occurring at frequency of 1% of the time. Resulting setback distances are very sensitive to distinctions between subjective sensory levels, such as whether "faint" or "just perceptible" odor intensity is the governing criterion.

C A derivation was developed to specify room concentration of different odorous species as a function of ventilation rate for confinement buildings based on mass-transport theory. A mechanism was introduced showing that under humid conditions odorous acids may be scavenged by ambient aerosols, thus lowering odor concentration at a rate comparable to dispersion.

C *Objective Measurement of Odor.* This aspect focused on interaction of aerosols and organic acids in hog odor, with the goal of more precise description of removal processes and routine real-time measurement of hog odor. Initial experiments focused on propionic acid rather than the more complex odor mixture, which includes about 6 major organic acids that together compose about 85% by mass of odorous compounds in hog odor . The base material used was sodium hydroxide (NaOH). When exposed to propionic acid vapor, aerosols generated from dilute NaOH solution reacted to form an aerosol of the acid salt. Because of this chemical reaction the particles grow by a

measurable amount. Thus, most odorous material in hog odor can be removed from vapor and stabilized in aerosolized particles that would not substantially re-volatilize. The process has potential application for the removal of hog odor by a droplet-scavenging technique that could be used in a scrubber or similar approach. An approach was based on the process, where it was postulated that the organic acids can be removed from the layer of air above a manure pit by introducing spray from mist humidifiers. Further discussion addressed how the process of acid/base aerosol interaction can be used as an instrument to measure amount of organic acid in an air sample. Dependant on how hog odor correlates with the odor of its constituent organic acids, the technique might be useful as a tool to measure odor level of hog odor.

C The focus of the experimental portion of this work was to develop an instrument to measure hog odor. The basic approach is to generate precisely sized alkaline aerosol particles, subject them to odor vapor, and observe a change in size due to an acid base reaction between the alkaline particles and the organic acid vapor contained in the hog odor. Results were obtained from a series of measurements of hog odor at different dilutions from the same source. An approximate linear relationship was shown to exist between the response, which is a measure of the size change of the aerosol distribution and the odor dilution. Efforts were concentrated at improving the method of injection of odor into the system to improve sensitivity and to reduce carryover effects between samples.

C With the technology used, alkaline particles as small as 20 nanometers (nm) in diameter can be employed, and size changes as small as a few nm can be detected. This research has established that odor vapors do react with alkaline particles and change their size to a measurable degree. Considerable enhancement of the experimental capability has been accomplished, especially concerning temperature and flow control in the reaction section of the instrument, and improvement in the method of odor injection into the system. With these improvements and the technical support now available it appears feasible that the instrument can be adequately calibrated by comparison with subjective odor panel assessments using dilution olfactometry. When adequate calibration has been accomplished, the instrument can be employed in a series of laboratory and field measurements. An alternate goal of the effort is to install the instrument in a research trailer, move it adjacent to a hog facility, and monitor the diurnal variation of odor concentration.

Outcome: Models yielding information important to facility siting decisions were built and proved functional. A novel approach to measuring quantities of aerosolized malodorants in air has been invented and partly developed and refined.

1.5 Development and evaluation of dedusters for dust and odor reduction (5 years; FY99 - FY03)
Principal Investigator Y. Zhang

Objective: To further develop dedusters for removal of dust and odor from swine barns.

Summary:

C We developed three prototype uniflow aerodynamic dedusters to separate odorous dust particles from air in swine buildings: (1) 300-cfm uniflow laboratory unit, (2) 5,000-cfm horizontal concentric unit, and (3) 5000-cfm vertical unit. A prototype uniflow aerodynamic deduster to separate odorous dust particles from air within swine buildings was developed. The deduster utilized aerodynamic principles to separate particles from an air stream without making physical contact with filtration media that would occur with a fiber filter, thus avoiding the need for frequent cleaning or replacement of the filters. Laboratory tests showed that the prototype removed 80% of the particulates with very low energy requirements.

C A large capacity horizontal concentric multi-annular deduster (horizontal model) was designed and fabricated. An automatic dust cleaning mechanism was developed for the dust bunker. Unlike the first prototype, the multi-annular concentric deduster was installed on exhaust fans instead of for recirculation cleaning of room air in the building. Preliminary results showed that longer retention time was required to remove gases from exhausted air.

C A bench-scale prototype was designed by attaching the aerodynamic deduster to a wet scrubber. Tests showed that 85% of particulates could be removed by this prototype with low energy consumption, and 57% of the ammonia was removed when the inlet ammonia concentration was ~10 ppm. However, ammonia removal efficiency did not increase much at higher inlet ammonia concentrations of 30 or 50 ppm.

C The vertical system contained 4 parts: exhaust fan, separation section, coagulation section, and connecting section. Polluted air enters the coagulation zone. Three nozzles were used to generate mist. Gas molecules and very small particles diffuse to liquid mists, and small particles coagulate (attach to) each other to form larger particles or droplets. Particles or droplets are separated from air when the mixture enters the separation zone, the critical part

of the system.

C Both the horizontal (#1) and vertical (#2) prototypes were evaluated in field. Mass removal efficiency of dust of prototypes #1 and #2 was about 90 % and 80 %, respectively, and ammonia removal efficiency was 25% and 35%, respectively. Dust removal efficiency of either pilot scale prototype varied slightly with residence time, which was determined by fan power level. However, residence time did significantly influence gas removal efficiency; the longer residence time, the higher the removal efficiency. The difference in performances between these two pilot-scale prototypes was due to design differences. Prototype #2 contains fewer concentric multi-annual dedusters, which decreased slightly the dust removal efficiency. On the other hand, the gas removal efficiency was increased significantly higher for #2 due to the longer residence time for gas removal. What is more, the vertical system is simple in structure and costs less in manufacture and operate. Therefore, the overall performance of prototype #2 was better than #1.

C The design of next generation deduster system was based on the field evaluations of these two pilot scale prototypes. A vertical setup is being used because of long residence time, limited space requirement, and higher exhaust level for faster emission dilution. In addition, more water nozzles at the lower stage and a longer separation section are recommended. The next generation, prototype #3, is expected to have higher efficiency for both dust and gaseous pollutants without increasing cost to any great extent.

Outcome: A series of air deduster designs culminated in a practical model for retrofitting hog houses.

1.6 Wet scrubber and biofilter for removing odorous dust and gases* (5 years; FY99 - FY03)

(*Project completed FY 99/Combined with 1.5 in FY 00)

Principal Investigator G.L. Riskowski

Objective: To field-test a prototype wet scrubber and a biofilter to remove odorous compounds from swine house exhaust air.

Summary:

C A new wet scrubber design minimally affected fan performance with a 1.5 % decrease efficiency compared to fan with discharge cone. Despite some difficulties with sampling, wet scrubbers have been tested at a finishing house for dust and odor removal. Approximately 52% (SD 8%) of dust was removed by the wet scrubber for an 18" exhaust fan. This removal rate was lower than expected because the room was only 30% full of pigs so it had low dust concentration (0.3 mg/m^3). Performance should improve when the dust concentration rises to the typical values (~8 mg/m^3) characteristic of a fully operational facility. Preliminary odor evaluation results showed a 35% reduction in odor. These results were difficult to interpret due to high variability (COV 31-82%) of odor panel response. Protocol improvements in characterization of odor by an odor panel reduced the variability by half.

C For the biofilter, testing of airflow characteristics of wet and dry media were completed. Wood chips had relatively high pressure drops and are considered to be unacceptable. Corn cobs and pine bark nuggets exhibit lower pressure drop than materials typically used. If these materials absorb adequate amounts of odor, then this should reduce operation costs considerably. Corn cobs will be tested in future research since it has good airflow characteristics and is readily available at low cost in Illinois.

Outcome: Prototype wet scrubbers and biofilters offered promise for practical application in removing aerial malodorants from hog-house exhaust air.

1.7 Cost-effective catalytic methods to reduce gaseous emissions from swine facilities (2 years; FY99, FY00)

Principal Investigator R.I. Masel

Objective: To develop catalytic converters for retrofitting swine house ventilation outlets to reduce odor emissions.

Summary:

C The approach was to find cost-effective methods to reduce emissions of odorous gases from swine buildings. Laboratory studies demonstrated that one of the key components in swine odors, acetic acid, was easily removed by an inexpensive copper catalyst. The conversion of the acetic acid was easier and more complete than expected, and the catalyst was inexpensive. These laboratory studies demonstrated that catalytic methods were feasible for odor reduction of exhaust air.

C Subsequent laboratory studies demonstrated for the first time that odorous molecules in simulated swine odor were rapidly adsorbed on a copper/magnesia catalyst and were then easily converted to carbon dioxide and water

upon heating the catalyst. These studies also showed that there were no new toxic or odorous molecules produced were the catalysts.

C Initial studies at the UIUC swine farms using a very inexpensive catalyst, demonstrated odors removed from barn exhaust air. The designs had too large of a flow restriction to be used practically, but there are standard approaches to overcome these difficulties.

C Results of these initial studies showed that catalytic methods held promise of being cost-effective ways to treat exhaust gases from swine facilities. The catalyst system also has the advantage that the odorous molecules are converted to CO2 and water which are odorous and non-toxic. Most odor cleanup systems produce a waste product containing the odorous molecules.

C Unfortunately, the lightoff temperature (i.e., the temperature required to burn off the adsorbed odorous compounds) was higher than anticipated and the flow restrictions were much higher than desired. With development, these issues can be addressed and catalytic odor control methods in swine facilities could be feasible and cost-effective.

Outcome: Catalytic converters proved to be effective in reducing concentrations of volatile odorous compounds in swine house exhaust air. Early attempts in practical application proved promising.

Area 2. Systems Design and Management

2.1 Information systems, industry communications, and information delivery (5 years; FY99 - FY03)

Principal Investigator M.F. Hutjens

Objective: To deliver results of SOWM SRI research projects and information from other sources to stakeholders using websites and other delivery systems.

Summary:

C A search of the worldwide literature relating to swine odor and waste management was completed. All available sources of information relevant to the control and management of waste and odor were reviewed, appropriate papers and relevant material were collected, and the information was coded into a computerized reference database (RefManager). The literature searched included scientific journals, conference proceedings, research reports, trade magazines, popular press articles, and commercial sources. Over 3,000 references were collected and entered into the database, and abstracts and summaries from these were added. The database was made available via the SRI website (http://sowm.outreach.uiuc.edu).

C Materials for presentations and displays highlighting SRI activities and results were prepared and used at a wide range of meetings and to a number of groups within the state, including Illinois Pork Expo, Board of the Illinois Pork Producers Association, various legislative groups, and a range of producer groups.

C A workshop was carried out at the UIUC to address the issue of "Swine Odor Sampling and Measurement Methods". At the outset of the SRI one of the major challenges was to develop methods for collecting and analyzing odor that would produce quantitative, repeatable results. A number of SRI scientists had proposed approaches to address this challenge and four experts were brought in for a 2-day workshop. The scientists were Susan Schifman (Duke University), Larry Jacobson (University of Minnesota), Al Heber (Purdue University), Al Sutton (Purdue University). These experts shared their philosophies and approaches to odor sampling and measurement as well as results of their research. They also reviewed approaches being proposed for use within the SRI and made suggestions for modifications and improvements. This workshop was extremely valuable to all involved in creating a forum within which ideas could be shared with leaders in the field and results could be used to improve the focus of the research within the SRI.

C The SOWM web site was designed for effective information delivery. Progress reports and updates were regularly posted to the website.

C A newsletter was mailed to interested parties and archived on the SOWM web site for easy retrieval.

C Information and materials on composting were developed in conjunction with Paul Walker were presented with photos and video taken at various locations in Illinois, including composting sites at Illinois State University.

C While the current website has been maintained, Illinois TRAILL has developed a site that when complete will allow users to subscribe to an electronic newsletter, provide a searchable database of articles, and allow for editors to upload their own content to the site. The system will allow for new material to be added at low technical support level. The old website will be archived and will be able to be accessed via the new website.

Outcome: A variety of media and personnel supported successful dissemination of Initiative results as well as

pertinent information from around the globe.

2.2 Systems Design and Management Modeling (5 years; FY99 - FY03)
Principal Investigator G. Miller
Objective: Conduct primary research related to swine manure and odor management integrate and field test results from other components of this SRI.
Summary:
C *Land Application Considerations in Managing Swine Manure:* Geographic concentration of swine production seems increasingly at odds with the fundamental expectation that swine manure will be land-applied, safely and according to sound agronomic principles.
C Since land-applying animal manure is required, a given swine production facility implies a predictable landscape footprint – i.e., the minimum amount of land required to safely absorb and recycle nutrients in the operation's waste stream. The objective of this effort was to further develop the landscape footprint concept and use it as a framework to discuss aspects of swine manure management, including regulatory guidelines, agronomic recommendations for crop nutrients, economic considerations, geographic concentration of operations, and policy concerns. Results of a manure management planning exercise suggested that the value of fully using nutrients in swine manure can significantly exceed the cost of application and full use of the nutrients requires a much larger footprint than a cost-minimizing disposal strategy typical of many current operations. Implications of these results are the needs for greater dispersal of production facilities and to re-integrate swine production with crop production.
C *On-Farm Surveys:* The overall objective of this on-farm survey study was to examine air-quality differences between deep-pit and shallow-pit finish buildings, accounting for various practices and building characteristics controlled by management. Additionally, to identify any need for sampling at both inlet and exhaust locations on each building. Air samples were collected at inlets and exhaust fans at 26 finishing houses in early summer 2000 and evaluated by both sensory (using dilution olfactometry) and chemical analysis. Barn conditions and management data were also collected. Deep pit systems had higher odor concentrations in air emitted even after accounting for pig inventory, dustiness, barn cleanliness, problems with dunging, and temperature. Combining results with costs of strategies to improve dustiness, cleanliness, and dunging patterns will establish a relative value of these strategies to control odor. Also, air inlet odor concentration measured by dilution olfactometry depended on farm, building within farm, and panelist, so inlet sampling is important if the objective is to characterize the building as a potential source of odor emissions. Correlations between olfactometry and chemical results were very low with very clean/low odor samples but higher for more odorous samples.
C *Modeling Projects:* Manure management encompasses more than merely how to handle swine manure generated as a part of production. A more holistic approach requires integration of nutrient management with manure management that also incorporates environmental considerations. Thus, the modeling component developed a nutrient and manure management model to assess pig growth and implied economic impacts while simultaneously manipulating the diet and tracking nutrient flow of N, P, and K. The model currently includes pig growth, nutrition, excretion, and economic components to evaluate economic feasibility of nutritional strategies at herd level.
C An integrated nutrient flow, manure management, and economic model was developed to be used to study inputs and outputs of the swine farm environment. A basic model with simple nutrient flows (tracking N, P, and K) was established. It allows high-end users to put in different diet formulations (7 different ingredients), daily feed intake, and start and end dates for each stage. Evaporation rate (depends on wind, precipitation, area of lagoon surface, temperature), seasonal pumping, and dilution of lagoon water components are variables in the model. Model performance was reasonable on the nutrient-flow side up to the point of manure production.
C A statewide nutrient (N, P, and K) flow model was developed to investigate implications of swine production facilities at the state level. It included all animal species and crops in agricultural production as well as people. The model was run for 27 years and showed the nutrient balance of the state of Illinois. It also investigated the possible contribution of swine production to nutrient excretion using cross-sectional data. Finally, agriculture census data at county level were used to investigate the spatiality of the problem. The analysis was presented by watersheds in Illinois.
C A system dynamics model of pig growth and associated farm-level economic impact was developed to evaluate the economic feasibility of three nutritional approaches (phase feeding, avoiding over-formulation, and more accurate estimate of nutrient requirements) to reduce nutrient excretion. The strategies were evaluated in terms of ARC

elasticity of nutrient excretion (either N or P) with respect to profit. ARC elasticities ranged from -0.6 to -2.4 indicating a decrease in nutrient excretion of 0.6% to 2.4% while still having an increase in profits of 1%. All three nutritional approaches decreased nutrient output and improved profitability. We found that more accurate nutrient requirement estimation may be the most profitable way in terms of nutritional approaches to reduce nutrient excretion.

C *Odor Emission and Control Technologies Workshop:* This 2-d workshop was attended by 42 individuals with several institutions bringing additional laboratory staff and students. Participants included faculty from the University of Illinois, Illinois State University, Illinois EPA, North Carolina State University, Texas A&M, Purdue University, University of Minnesota, Iowa State University and University of Kentucky. Discussions and questions were open and probing.

C The workshop included discussion on the contributions of livestock facilities to greenhouse gas emissions and climate changes. Some research reports confirm that livestock units do contribute substantially. This topic was interesting to the attendees because of the influence on choice of sampled gases from swine facilities. Mass balance data collection and data management software were also discussed. Researchers from the 6 collaborating universities agreed on the nutrients or gases to be analyzed, manure and feed sampling strategies, and the time table for sampling. The workshop ended with a technical discussion on the use of sampling instruments.

C *UITERM:* A UITERM program has been established which is designed to assist swine producers faced with environmental pollution or nuisance complaints. At the request of a producer, a team of people visited the farm and proposed strategies and solutions. While solving the farm's immediate pollution problem was a primary goal, a team was selected to address other areas of concern to the producer, for example, facility engineering, animal health, nutrition, or economics. A confidential follow-up report was sent to the producer after each visit. The program was designed to provide producers with consultation by U of I staff and simultaneously to give the team knowledge of the details of pork production issues in the state. The overall goal of the response team was to identify factors that put a producer "at risk" of environmental complaints. The first priority for UITERM was swine producers who were facing a pollution complaint.

Outcome: A variety of models were built to enlighten scientists as to critical gaps in our knowledge of swine odor and manure management. New information about factors in hog houses affecting odor emissions was generated. A UIUC-based consultation service for farmers was established.

2.3 Illinois Swine Odor Control Proving Center (I-SOC-PC) (5 years; FY99 - FY03)

Principal Investigator Y. Zhang

Objective: To establish a research center for swine odor and waste management with the capacity and flexibility to alter pertinent practices and evaluate prototype processes and technologies.

Summary:

C Studies carried out include: Effects of frequent cleaning on odor and dust emission reduction efficiency. Effects of washing and pit-flushing methods and scheduling were also investigated. Daily room washing reduced ammonia concentration, odor intensity, and sulfur volatile organic compound (VOC) concentration. However, dust and total VOC concentrations were not influenced by room washing. Furthermore, growth performances of pigs were negatively affected by room washing. Daily and careful washing may lower odor emissions in swine facilities, but further research is needed to evaluate other washing methods that will not negatively affect pig performance.

C A new wet scrubber was constructed and tested under field conditions. Compared with the old wet scrubber, the new model provided more contact time between water and odorous air. It also uses a momentum-change mechanism and wet surface to capture more particles, gases, and odor. Initial field test runs conducted did not indicate significant reduction in odor concentration for odor levels between 100 and 300 odor units. However, preliminary laboratory results showed a removal efficiency of >30% for ammonia; increasing water pressure from 30 to 60 psi did not significantly improve the ammonia removal efficiency.

C A nutrient-balance study using dynamic airflow chambers showed that reducing crude protein of diets affected pig performance, as the 18% and 16% diets had higher ADG, ADFI, and G/F ratios than did the 12% diet. However, reduction of crude protein had a detrimental effect on total volatile organic compounds and odor levels. Overall, reducing crude protein levels of diets reduced slurry pH and ammonia concentration, but reduced pig performance and increased odors.

C A cover installed over one a lagoons at UIUC Moorman Farm was tested for gas and odor emissions. Results indicate that the lagoon cover was able to reduce NH_3 emissions. Measured average NH_3 emission rates of 5.4 g/d

and of odor emissions of 116 OU/s, were lower than values for uncovered lagoons found in other studies.

- The effect of ozonation on odor, air quality, and pig growth performance was studied in a finishing building consisting of two identical rooms. One room was untreated (control) and the other had ozone applied at 0.1 ppm (the maximum level allowed by OSHA); the ozone treatment was switched between rooms during the study. Ozone application in a swine barn at the maximum concentration of 0.1 ppm did not affect dust mass, ammonia concentration, sulfur compound concentration, or bacteria count. In addition, ozone administration had no effect on dust distribution, hydrogen sulfide, or odor intensity but adversely effected the growth of the pigs.

Outcomes: A proving center was founded at UIUC. Several processes and practices aimed at reducing swine odor and enhancing manure management were evaluated.

Area 3. Nutrition

Objective: A series of nutrition studies were carried out with the primary objective of reducing nutrient output in swine manure, particularly phosphorus, but also nitrogen and sulphur. These were as follows.

3.1 Phytase Addition to Wheat Middling Diets (2 years; FY99, FY00)

Principal Investigator G.A. Apgar

Summary:

- Phytase added to diets containing wheat middlings enabled grow-finish pigs to have performance comparable to that of diets containing wheat middlings and inorganic phosphorus. Phytase released calcium and phosphorus from diets containing wheat middlings, improving digestibility of these nutrients and decreasing fecal concentrations.

3.2. Dietary P removal with and without phytase addition for growing-finishing pigs (2 years; FY99, FY00)

Principal Investigator G.A. Apgar

Summary:

- Removing supplemental inorganic P from late finishing diets reduced ADG and ADFI, but addition of phytase to the diets restored pig performance.

3.3 Effect of elevated and reduced dietary nitrogen (N) and sulfur (S) concentration upon concentration of odor causing components in waste of finishing pigs (2 years; FY99, FY00)

Principal Investigator D.H. Baker

Summary:

- Crossbred finishing pigs (BW 82 kg) were used to evaluate effects of elevated or reduced dietary N and S concentrations on growth performance and odor components of waste. Reduction of nitrogen and sulfur in swine finishing diets did not affect growth performance but did alter the concentration of components implicated in the odorous qualities of swine manure.

3.4 Improving Dietary Phosphorus Utilization and Decreasing Phosphorus Excretion by Swine (2 years; FY99, FY00)

Principal Investigator D.H. Baker

Summary:

Results of a series of studies showed that:

- When microbial phytase was added to the diet at the rate of 227 phytase units/lb (FTU/lb) of complete feed, roughly 9 lb dicalcium phosphate could be removed from 1 ton of feed. This lowered the total amount of P in the diet by ~0.08% unit and reduced P excretion by 20 to 30% without affecting animal performance.
- Feeding 400-500 FTU/kg (225 FTU/lb) of EcoPhos™ (Phytex LLC, Portland, ME)), an *E. coli*-based phytase, allowed a minimum of 0.10% unit reduction of supplemental inorganic P.
- Feeding 5,000 and 10,000 FTU/kg (2,275 and 5,575 FTU/lb) of EcoPhos™ effectively released almost 100% phytate-derived P from corn and soybean meal in chick diets. These excessive levels of EcoPhos are both efficacious and apparently safe for pigs, but are unlikely to be economical.
- At all dose levels, including excess levels (5,000 to 10,000 FTU/kg), efficacy advantage of *E. coli*-derived phytase over commercially available fungal phytases is greater in chicks than in pigs.
- Phytase in feed works best in diets with nearly equal calcium:available phosphorus ratios. Research shows pig

performance and bone strength improve when the ratio is between 1.2:1 and 1:1 (calcium :phosphorus).
C With proper phytase supplementation during the last 50 d of finishing, supplemental P, Zn, Cu, and Mn can be reduced or eliminated without deleteriously affecting growth or carcass characteristics.

3.5 Phytase and Phosphorus Availability (2 years; FY99, FY00)
Principal Investigator D.H. Baker
Summary:
C Effects of microbial phytase on protein and phosphorus utilization in corn: evaluation of nutritionally enhanced corn hybrids and coproducts Formulating early/late (180-260 lb) finish pig diets using genetically enhanced (low-phytate) corn containing reduced amounts of indigestible phytate (P) and greater amounts of inorganic P can reduce P excretion by up to 50%.
C Phytase and Organic Acids Implementation of citrate in nonruminant diets may not be practical due to its expensive and widespread use in the human sector. Formic acid improved utilization of phytate-P, and may offer a more economical alternative for producers wishing to incorporate organic acids into swine and poultry diets. Efficacy of citrate or formate for improving protein and amino-acid utilization, however, has not been thoroughly investigated.
Outcome: A variety of approaches generated much information on reducing phosphorus excretion in pigs. Recommendations were made to producers on inorganic phosphorus in – and phytase addition to – diets.

Area 4. Waste (Manure) Processing and Handling

4.1 Manure materials and Nutrient Balance Survey (2 years; FY99, FY00)
Principal Investigator R. Steffen
Objective: To quantify the flow of manure material and nutrients through selected pork-production systems.
Summary:
C Subtle differences among and even within facilities (e.g., between 2 halves of a barn) can result in variation in manure analysis. In one case, whether the sampling area was covered with floating solids (suggesting a difference in analysis could occur) the results depended on whether the ventilation fans were on or off at or just prior to sampling. Some seasonal differences are suggested by the data.
C Implications of these findings are significant. Objectives were to develop a nutrient and materials balance and a data set to guide producers. But differences among and within facilities suggest that the modeling of a facility is site-specific. Any model developed will need to be tailored to an individual facility. Also, the need for each producer to thoroughly sample his own facilities may be a very important procedure in the future. Each swine facility may indeed need to monitor and regularly analyze its manure for purposes of management and environmental compliance.
Outcome: Clearly, each swine facility is unique and models of nutrient flow must therefore be site-specific.

4.2 Composting (5 years; FY99 - FY03)
Principal Investigator P.M. Walker
Objective: To develop composting procedures for use on Illinois farms.
Summary:
C Composting manure is a practical, economical, environmentally safe way for pork producers to co-exist with increasing urban sprawl.
C Composting is an age-old practice of manure management whereby organic components of various waste streams are biologically decomposed under controlled conditions to form a stabilized state in which they can be safely handled, stored, or applied to land as a soil amendment.
C Composting can occur in the presence of oxygen (aerobic composting) or its absence (anaerobic). Small-, medium-, and large-scale producers should find the results of these studies useful.
C A variety of carbon sources can be utilized for composting either solid or liquid manure.
C A brand-name compost has been developed that can be used by Illinois producers for value-added marketing of compost.
C Several cooperator compost sites have been developed for use as demonstration sites in designated locales to advance the concept of composting.
C An in-depth compost market analysis has been conducted for Illinois and is available to producers interested in developing a compost operation and marketing compost as a value-added product.

C Corn and soybeans grown on soils amended with compost yield similarly to crops grown with inorganic fertilization.
C Composting reduces volume of manure that must be land-applied.
C Composting can inactivate pathogenic microbes.
C Cost to compost depends on several factor; cost of production can range between $10 and $32 per ton.
C On average 1 lb manure must be mixed with 1 lb carbon source, but mixture can range between 0.54:1 and 3.5:1 (manure:carbon source) depending on types of manure and carbon source.
C On average 2 lb raw material (manure + carbon source) yields 1 lb cured compost.
C Compost can be used on-farm as soil amendment or sold off-farm as value-added product.
C Prices for compost range between $10/ton and $200/ton depending on quality.

Outcome: Practical and economical applications of composting technologies are now available to farmers in Illinois as a result of this work.

4.3 Anaerobic Sequencing Batch Reactor: On-site removal and recovery of phosphorus from manure (3 years; FY99, FY00, FY01)

Principal Investigator L. Raskin

Objective: Evaluate the potential of an Anaerobic Sequencing Batch Reactor (ASBR) for swine waste treatment.

Summary:

C Laboratory-scale studies were performed to evaluate strategies to reduce capital and operating costs of swine waste digestion (ASBR). The startup period to achieve stable operating conditions at an organic loading rate of 4 g volatile solids/liter/d was considerably shorter when ASBR was inoculated with sludge from an anaerobic lagoon used for swine waste treatment compared to that from an anaerobic digester used for municipal biosolids treatment. Farmers should inoculate ASBR systems with sludge from a swine waste system. In addition, methane production and reactor stability were better for ASBR with the lowest mixing level, allowing operation with less powerful, hence less expensive, mixers. Mixing in ASBRs should be kept to a minimum. Some mixing is necessary to prevent formation of scum. On the other hand, the area of nutrient recovery from ASBR effluent needs further study before implementation at full-scale level may be warranted.

C Although several research groups have studied ASBR treatment of swine waste, sufficient data on methane yields were lacking. Some controversy existed on the high methane yield that was found for a full-scale ASBR system in Nevada, Iowa. With our controlled laboratory studies we were able to verify this very high methane yield, as the quality and quantity of swine waste fed into our laboratory-scale ASBRs was maintained constant over extended periods.

Outcome: Means of removing and recovering phosphorus from manure streams are practical and doable.

4.4 Aerobic treatment for energy from waste (5 years; FY99 - FY03)

Principal Investigator J.W. Blackburn

Objective: To develop a model for testing the technical and economic feasibility's of aerobic thermophilic microbic treatment of swine manure for various sizes of operations.

Summary:

C Aerobic thermophilic (A-T) treatment is a technique for animal wastes that has received little attention. Developments in this work show that the process can be utilized at low capital cost, and that energy for space heating or aquaculture applications can be produced. It has no resemblance to thermophilic anaerobic digestion processes attempted in the past.

C Three experimental systems were constructed and operated to test and validate process efficacy. These were 1) 2-L Laboratory Biocalorimeter, 2) 1000-gal Batch Pilot Plant System, and 3) 1000-gal Semi-continuous Pilot Plant System.

C Heat production from aerobic thermophilic process was measured in the lab system and verified in both pilot systems. Biological heat production is related to COD removal.

C Air recycle used to increase amount of recoverable heat from the system was shown not to negatively affect heat production.

C Odor removal was noticed at lab scale and verified by olfactometry and GC-MS analysis at Batch Pilot Plant Scale. It is reasonable to expect 80% odor removal from a full-scale semi-continuous system after system startup.

C Nitrogen in the system is converted to ammonia. The most current system configuration includes a scrubber system to eventually convert the ammonia to nitrogen gas.
C Both types of pilot runs indicate P is removed from the liquid reactor product. The most likely hypothesis is that P is converted to an insoluble inorganic compound which may collect at the bottom of the reactor with apparent removal. The fate of this type of P upon land application was not conclusively determined.
C The process effectively lowers the levels of zoonotic pathogens. *Enterococcus* and *Clostridium perfringens* survived reactor conditions but at greatly reduced levels.
C The antibiotic Tylosin was also removed. Resulting reactor solids failed to inhibit growth of a sensitive bacterial strain, suggesting no antibiotic activity. This may factor into current discussion that pork farms using antibiotics may cause increased levels of antibiotic-resistant pathogens in the environment. Results from chlortetracycline and oxytetracycline are pending.
C A dry value-added product may be made with reactor heat and reactor product, leading to an economical year-round process. Evaluation of this product as a vegetable fertilizer is underway.
C Including components to manufacture and sell the value-added dry product, this technology is expected to pay off its initial investment in 5 years or less.
C Detailed designs for a full-scale system to be built on an Illinois farm are in preparation.
C Technically and economically, this odor-removal technology has the potential to compete with other manure-management technologies and should be given strong consideration. However, full-scale application, evaluation, and validation on commercial operations is required before it could be recommended for widespread adoption.
Outcome: A new technology for manure processing involving an aerobic thermophilic bacterial approach has been developed to the farm-test phase.

4.5 Kinetics of thermochemical conversion of liquid manure (4 years; FY00 - FY03)
Principal Investigator Y. Zhang
Objective: To optimize operating conditions for a process that treats liquid manure at high pressure and high temperature to produce oil and a char-like solid, both low-odor products.
Summary:
C In the first stage research, a batch thermochemical (TCC) reactor was developed and a systematic investigation of process parameters conducted. TCC process parameters include operating temperature, type and initial pressure of process gases, retention time, total solids content, and pH level of feedstock. The process was evaluated in terms of oil-production efficiency and waste-reduction efficiency. The oil product was analyzed for its benzene solubility, elemental composition, and heating values. Necessary retention time to achieve an oil product largely depended on operating temperature. At 295°C to 305°C, retention time was 15 to 30 min. Based on an average of 135 different treatments, 62% of volatile solids (or 54% of total solids) was converted to oil product. Waste strength was reduced by 60 to 70%. Highest oil-production efficiency was 80% of volatile solids (or 70% of total solids). Average carbon and hydrogen contents were as high as 72% and 9%, respectively. Heating values for 80% of oil products ranged from 32,000 to 36,700 kJ/kg. Average conversion rate of volatile solids to oil can be as high as 70%. Based on this, the lifetime manure from one finishing pig can yield 20 gal crude oil, or a farm producing 10,000 market hogs per year can produce 4,760 barrels of crude oil per year. Based on a crude oil price of $30/barrel, oil production from manure could amount to $15/pig value added. We have also further processed TCC crude oil and obtained refined oil. TCC oil may also be used for alternative applications such as making plastics and inks.
C Based on results obtained from the batch reactor study, we have a much better understanding of key variables involved in the TCC process. A continuous TCC (CTCC) process appears more practical.
C A draft of the design for a semi-continuous thermochemical conversion reaction system (CTCC) has been developed. Before being pumped into the high-pressure reactor, feedstock will have to be processed into a homogeneous slurry using a high-performance processor so as to prevent pressure leakage across the slurry check valves. The high-pressure feeder can be either a diaphragm or a plunger pump. The high-pressure reactor will be the batch type reactor used in the first stage research, but with some modifications. Ancillary parts include control modules, feed inlet and liquid products outlet, gas products outlet that runs through a reflux condenser, and mass flow controllers. The liquid products will be withdrawn to a pressure vessel equipped with a cooling jacket to lower liquid products temperature and simultaneously reduce pressure. Gas products will be collected in a gas cylinder. Reflux condensers are added to prevent condensable gases from escaping the reactor.

C Swine manure will have to be pre-processed (by gravitational settling and grinding) to the desirable solids content and consistency, before being fed to the CTCC feed hopper. Based on the preliminary study using the batch reactor, the following operating conditions are recommended for use in the continuous TCC processor.

- Operating temperature 295 to 305C
- Operating pressure 90 to 110 bar
- Retention time 15 to 30 min
- Total solids content of feedstock (by weight) 20 to 25%
- Feedstock pH not controlled

C The following factors and analytical parameters are recommended for evaluation of technical feasibility, economical viability, and environmental soundness of the proposed continuous TCC process.

- Oil production efficiency of process
- Elemental or chemical composition of process products
- Energy content of oil product
- Physical properties of oil product, including thermal heat loss and viscosity
- COD reduction rate of feedstock

Outcome: It is now practically possible to produce useful oil and a char-like substance from pig manure.

4.6 Inflatable cover for earthen lagoons (3 years; FY99, FY00, FY01)

Principal Investigator Y. Zhang

Objective: To design, manufacture, and evaluate a relatively permanent plastic cover for manure lagoons to reduce gaseous emissions.

Summary:

C Two plastic covers were designed, fitted to a swine lagoon on one of UIUC swine farms, and tested.

C A positive pressure cover, which is an inflated cover over the lagoon, was effective at reducing emissions, but was difficult to construct and maintain. This design was rejected.

C A negative pressure cover, which is kept in contact with the slurry surface by drawing a continuous low volume of air from beneath the cover, was both effective at reducing emissions from the lagoon and structurally sound.

Outcome: Design standards and validation of efficacy of plastic lagoon covers have been established.

4.7 Variable rate slurry applicator (5 years; FY99 - FY03)

Principal Investigator T.L. Funk

Objective: To develop an economical, accurate swine manure application technique having a variable application rate linked to global positioning system technology to control nutrient levels in soil.

Summary:

C Based on this C-FAR-supported laboratory and field research, we can recommend the following system development steps to commercial slurry-tank manufacturers and to producers who wish to convert an existing tank to variable-rate control.

C Set reasonable goals for slurry application-rate accuracy. This affects selection and operation of variable-rate equipment. Our research on the nutrient management process indicates that accuracy on the order of about +/-15% from the application-rate setpoint is as much control as can be justified.

C Fit vacuum-loaded slurry tanks with control systems that can regulate flow from the tank to 25% to 100% of full flow. Systems should be able to maintain a constant flow rate and provide verification of the setpoint in the tractor cab.

C The pneumatic control valve (pinch valve) proved to be a robust, reliable, and relatively inexpensive component for controlling flow of slurry from a manure tank.

C Pneumatic systems incorporate on-board air compressors and easy-to-maintain components that are familiar to farm mechanics. Using the system design proposed here, electronic pressure sensors are inherently separated from contact with manure slurry.

C Calibration is equipment-specific and should be performed as part of system installation and check-out.

C Migrate the control system through three phases of automation to accomplish all desired goals of slurry application: (1) set and hold a slurry flow rate (gal/ min) based on calculated ground speed; (2) combine sensed vehicle ground speed to set and hold a constant application rate (gal/A); (3) combine GPS-based nutrient needs and

setback “no-fly zones” with sensed vehicle position and ground speed so as to vary slurry application rate and also completely shut off the applicator when entering setback areas.
Outcome: A new approach to fine-tuning flow rate of manure-slurry application has been developed and proved feasible and economical.

4.8 Gravity solid-liquid separation tank (2 years; FY01, FY02)

Principal Investigator T.L. Funk

Objective: Develop a low-cost gravity solid-liquid separator.

Summary:

C Experiments were conducted that showed the optimum floor slope for solids removal, and the performance of the settling tank with various percent solids manure and different retention times.

C The optimum slope of the tank bottom was shown to be 35 degrees from horizontal. The amount of solids leaving the tank could be removed by almost half, using gravity and the continuous solids removal, with no further treatment. The retention time of 30 minutes was optimal for the tank configuration tested. Lower initial solids content (1% vs. 3 or 5%) improved the separation efficiency and nutrient recovery.

C We verified that use of gravity settling tanks for high solids manure streams (e.g., gravity pull-plug pit configuration without supplemental flushing water) is not particularly efficient. A lagoon-water flush system on the other hand would be suited to gravity liquid-solid separation and continuous removal system could feed a secondary separation system such as a belt press. The two liquid-solid separation systems working in tandem could greatly reduce the size requirement for the more expensive secondary unit.

Recommendations:

C For gravity liquid solid separation tanks built with pumps, augers or other devices for continuous removal of solids from the tank bottom, the 30 to 35 degree angle of repose of manure solids defines the most efficient slope of the tank bottom.

C Systems designed with a separation tank in the manure stream to intercept solids should have at least a 30-minute hydraulic detention time in the tank, to optimize solids settling.

C Gravity liquid-solid separation tanks work best with very dilute manure, not as-excreted. Therefore a system with a tank works best in underslat flush systems; next best, in pit recharge systems that add considerable amounts of fresh or recycled water before or during the additions of manure to the pit; and least successfully in pit systems that add very little dilution water to the manure (greater than 5% solids content).

C Gravity tanks with coagulants, flocculants or precipitants added to the incoming manure stream could form an excellent system component for primary liquid-solid separation treatment prior to a belt press or other mechanical separator.

Outcome: Design standards for a gravity-settling system of liquid solids separation were established.

Area 5 - Legal Issues and Community Consideration

5.1 Community Issues (5 years; FY99 - FY03)

Principal Investigator A.E. Reisner

Objective: Understand the debate relating to risks and benefits associated with large-scale pork-production operations. Understand the development of the Illinois Swine Industry since the introduction of confinement farming in the 1950s.

Summary:

C Illinois counties were separated into those that did or did not have a large-scale swine facility (>1000 head) sited or proposed as of January 1998. Twenty-two daily newspapers were selected from 70 with circulation 3,500 to 700,000. Relevant articles were collected from each newspaper from June 1995 through December 1998. Each article was content analyzed using EthnographTM version 5. Each article was coded for arguments, sources of arguments, and evidence to support arguments. The 22 newspapers yielded 1741 articles concerning large scale swine facilities, one newspaper had 200 articles, 6 other newspapers had >100 articles each, another newspaper only 2, and 6 other newspapers had <50 each. There were 9 major argument themes in the newspaper articles.

C Arguments that support swine facilities tend to focus on: farm/industry structure, economics – growth for survival and inheritance, moral stance, and minimizing environmental risk.

C The opposition arguments tend to group around: environmental quality concerns, most commonly those regarding

water and air, health risks, farm/industry structure – desire and concern for small-scale farms, and ethics of rural community life.

C *History of Illinois Swine Production since the 1950's.* Interviews were carried out with 30 key individuals that were/are involved in the development of swine production in Illinois over the last 50 years. The most significant results were: Development of the large-scale swine industry in Illinois was a mutually intertwined cooperation between science and industry. The initial breakthrough was development of dietary formula that supply pigs adequate nutrition year-round.

C Knowledge developed from this move -- through interactions between science and the pig --enabled farmers to house pigs year-round. But confinement led to a cascading series of problem-solution-problem dilemmas that increased the scientists' understanding of the needs and outer limits of the pig's ability to adapt to confinement.

C The spread, and to some degree the building, of this knowledge, however, was at the least greatly facilitated by a horizontal communications network among industry, farmers, and animal scientists, a three-way collaboration that left out, virtually completely, nearby communities.

C In the last 20 years, horizontal communication networks have been greatly weakened by changes in promotion and tenure requirements in the university, weakening of extension, and hiring scientists from non-agricultural backgrounds who lack affinity with the agricultural industry. At the same time, communities and national organizations began to demand a place at the table in terms of environmental or zoning regulations on agricultural industry, possibly as a direct effect of being left out of earlier communication transfers. This resistance is the most negative note on a history of a triumph of technological development over natural constraints, but it is an important one that might overshadow the last 50 y of history.

C The expected output for this project will be two books and a dissertation rather than journal articles. A History of the Hog in Illinois (1950-1980). This book will concentrate on the changes in swine production from 1950 to the 1990s, with some coverage of periods prior and subsequent to that time.

C Citizen Reaction to Large-Scale Swine Facility *Sitings*. This book will examine how newspapers in smaller communities covered a major structural change in agriculture. The findings are based on an examination of 3 y of news coverage (1828 articles) from 22 newspapers in Illinois (ranging from 3,000 to 60,000 circulation).

C *Fact sheets:* A set of fact sheets was designed with the following topics:

- C Do LSSFs hurt community solidarity?
- C What are the different kinds of contract arrangements?
- C What are the health risks from large-scale livestock facilities?
- C Large-scale livestock facilities and lagoon leaks: What is their track record in Illinois?
- C Farmers' options: Expanding.
- C Farmers' options: Running a small-scale operation.
- C Historical evolution of large-scale livestock facilities.
- C Antibiotics: What consumers need to know. What farmers need to know.
- C Large-scale livestock facilities: Economic boon for surrounding communities?
- C Large-scale livestock facilities: Economic bust for surrounding communities?
- C Do LSSFs harm small farmers?
- C What is it like to live next to a LSSF: What can you expect if one locates nearby?
- C What are the current laws regarding LSSFs?
- C What can communities do to prevent LSSFs from locating nearby?
- C Environmental comparison of LSSFs and other hog production systems.

These fact sheets are still being completed.

C *Survey of major stakeholders (farmers, zoning officials, residents and activists).* NEED DETAILS

We had an extremely high response rate of 72% overall from surveyed persons.

C In addition to a report, there were an additional 5 executive summaries were prepared, one for each major stakeholder group (farmers, residents, activists, zoning board officials, and journalists).

Outcome: A survey was carried out of farmers, nearby residents, zoning officials, and journalists involved in the processes of siting and building of large-scale swine facilities to balance the objections raised in newspapers about potential problems with actual experiences. Summary of Illinois newspapers and interviews of various stakeholders were used to characterize public reaction to large-scale swine facilities.

5.2 Legal issues of swine odor and waste management (5 years; FY99 - FY03)

Principal Investigator M.R. Grossman

Objective: To identify and analyze federal and state laws and court decisions related to swine odor and waste issues. A database was developed and made available to all interested parties.

Summary:

C Initial work focused on identification and analysis of federal and Illinois laws that govern swine odor and manure. A document was completed that makes information about laws available to the general public and this material was prepared for eventual publication in scholarly legal publications. Comprehensive results were prepared and published at the SRI website.

C An article was drafted on state regulation of odor and air pollution from livestock facilities. Comparison with some European laws that regulate livestock wastes was carried out.

C New regulations were analyzed, and the website was updated to incorporate these.

C A guide to many of the federal and state laws relevant to livestock facilities in Illinois was produced. The guide, *How Environmental Regulation Affects Livestock and Poultry Production*, was posted to the SRI website (http://sowm.outreach.uiuc.edu). Work involved analysis of numerous state and federal statutes and regulations. The website was revised to reflect numerous changes, especially in Illinois regulations that were implemented as part of the Livestock Management Facilities Act.

C The legal materials assembled for this analysis, plus other resources, are the basis for further research on state regulation of livestock odor. A draft of an article on state regulation of odor and air pollution from livestock facilities.

C Related research has resulted in publication of "Nitrates from Agriculture in Europe: The EC Nitrates Directive and Its Implementation in England", 27/4 Boston College Environmental Affairs Law Review 567-629.

C Frequent amendments of laws and regulations suggest that work related to this project will continue. For example, new federal regulations for Concentrated Animal Feeding Operations (CAFO) became effective in 2003. These will result in new state regulations, as well. Grossman has been authorized to continue work through 2004, under a no-cost extension, to complete research in progress.

Outcome: Laws, regulations, and court decisions governing odor and manure management at livestock operations in Illinois and around the nation and the world were analyzed and databased.

PRODUCTS

A range of products have been derived either directly or indirectly as a result of the Initiative:

C Various computer-based models to aid producers and others in decisions regarding siting of facilities and odor and manure management (odor dispersion, nutrient flow, state-wide manure considerations, manure application).

C A wide range of fact sheets and recommendations for use by producers in planning manure and odor management strategies.

C A comprehensive web-based compilation of published information relating to all aspects of manure and odor issues and management.

C A number of odor and manure management technologies that have been developed to commercial application as a direct result of C-FAR Initiative research.

C Development of a group of researchers and extension workers with expertise in all aspects of managing manure and odor that provide a resource to continue into the future to help address issues within the state.

C Comprehensive facilities and equipment that will form the basis of future research and development efforts.

C Two branded value-added compost products were developed; one specifically for use by Alan Dale Farms (Rare Earth) and one for use by any farm producing compost (Sweet Earth).

C Development of a phytase product, evaluated in part with C-FAR funding, that is being marketed commercially.

C An extensive range of publications, including papers and articles in scientific journals, meeting proceedings, and popular press (See Appendix I).

INITIAL OBJECTIVES

C All of the initial objectives and goals were accomplished to a greater or lesser degree. One area where progress was much slower than initially anticipated and which limited progress in other projects was that of odor sampling and measurement. This is an extremely complex area that still today somewhat limits effective research aimed at odor-reduction strategies.

C Initial efforts to develop reliable, repeatable methods for odor sampling and analysis, which were based on the state of knowledge at the outset of Initiative, quite frankly failed. Reliable techniques and approaches were eventually developed based on human assessment of odor, which of itself involves procedures that are both slow and expensive.

C In all other areas, substantial progress was made toward developing technologies and approaches to addressing the issues. Initiative results are already being applied commercially, and a number of technologies have been taken to initial commercial testing and application.

OUTREACH ACTIVITIES

This C-FAR Initiative was heavily focused on outreach activities and providing information to stakeholders in a timely manner. Outreach efforts were closely co-ordinated with those of the Extension Service of the University of Illinois. In particular, two leaders within the state, Dr. Ted Funk (Agricultural Engineering) and Dr. Gilbert Hollis (Animal Sciences) were key members of the Initiative team who were closely involved in both the planning and the execution of a number of research projects.

Results of the research conducted and information produced in the Initiative have been delivered to stakeholders via a number of mechanisms. Producer and industry meetings and seminars carried out within the state included:

C Certified Livestock Manager Training workshops, a state-mandated certification program for livestock producers with a potential audience of several thousand.

C Regular meetings with producers and producer groups within Illinois, including the Boards of Directors of Illinois Pork Producers Association as well as Illinois Pork Council and Pork Illinois.

C Meetings with staff at the Illinois Attorney General's Office

C Workshops on Odor Emissions and on Control Strategies, 2-day events held at the University of Illinois.

C Compost/Manure Management Workshops/Field Days were held at various farms by Illinois State University.

C Displays at Manure Management Field Days, organized by the UI Extension Service

C Two Swine Field Days, jointly organized with the Illinois Pork Producers Association in August 2001 and July 2002. A third such event is planned for 2004.

C Displays at the Illinois Pork Expo, the major trade and industry show in the state that attracts hundreds of producers and key industry people (a major display of Initiative results was presented for the past 4 years with plans to continue in the future)

C Various websites: details of SRI, including results from specific projects, have been posted on the SRI home page (http://sowm.outreach.uiuc.edu) as well as the web pages of departments and individuals involved in the SRI.

C Press releases: numerous articles in newspapers, major agricultural newspapers and trade magazines, and radio and TV bulletins have been released about the SRI in general as well as about specific projects

C Publications, including articles in the popular press and the University of Illinois Swine Research Reports and papers presented at scientific and producer meetings or published in the scientific literature (a list of publications that have arisen from SRI efforts is appended to this report as well as several books on public reaction to large-scale swine farms).

Future Outreach Activities include:

C University of Illinois Pork Industry Conference on Swine Odor and Manure Management, a 2-day event to be held in December 2003.

C Display at 2004 Illinois Pork Expo February 2004

C Display at UI Extension Swine Seminar January 2004

SRI COMPONENTS CONTINUING (NON-C-FAR FUNDING)

Many of the projects initiated under the SRI will continue with other funding, including:

C *Nutritional approaches to reducing phosphorus excretion:*

Drs. Apgar and Baker continue efforts to optimize the use of phytase and other approaches to minimize phosphorus excretion.

C *Catalytic conversion of odors:*

Dr. Masel has funding from a number of non-agricultural sources to continue the development of catalytic methods of odor reduction. Spinoff from this research will be further development of this approach for application to swine.

C *Dedusters and air scrubbers:*

Dr. Zhang is continuing efforts to develop prototype equipment for commercial application.

C *Liquid-solid separation and composting:*

Dr. Walker's work continues to refine approaches to manure handling and composting.

C *Integrated Crop/Livestock Research:*

Drs. Ellis and Zhang are collaborating with crop scientists and USDA ARS laboratories on an integrated research aimed at improving the fertilizer value of swine manure.

C *Commercial Evaluation of Odor Reduction Technologies:*

A number of SRI researchers (Curtis, Ellis, Funk, Hollis, Williams, and Zhang) are working on several projects aimed at on-farm evaluation of various approaches and technologies for odor reduction.

SRI COMPONENTS CONTINUING (WITH C-FAR FUNDING)

Two existing projects are being continued beyond the lifetime of the SRI to allow completion (with no-cost extensions) as follows:

C 2.3. Illinois Swine Odor Control Proving Center

C 5.2. Legal Issues of Swine Odor and Waste Management

One new project related to work carried out under the Initiative has been funded by C-FAR:
Thermochemical conversion of miscanthus grass
Investigator: Dr. Yuanhui Zhang, Department of Agricultural and Biological Engineering, UIUC
Funding source: C-FAR SRI on Biomass Energy Crops

LEVERAGED FUNDING

Principal Investigator	Awarding Organization	Amount ($)
Apgar, G.A.	DPI (In-Kind)	4,000
Blackburn, J.W.	USEPA and Illinois EPA	240,000
	Illinois Department of Agriculture	31,762
	DCEO/DOE	80,000
	Illinois Attorney General's Office	251,000
Ellis, M. and Zhang, Y.	ARS/USDA Grant	2.35 million
Ellis, M. et al.	Illinois Attorney General's Office	497,640
	Alpha-Omega Environmental, Inc.	58,500
Grossman, M.R.	Fulbright Leave	8,500
Masel, R.L.	Microbchemical Systems	2 million
	Formic Acid Fuel Cells	3 million
Miller, G.Y.	Producer collaborators (In-Kind)	30,000
Raskin, L.	NSF Supplemental Grant	75,000
Reisner, A.E.	Rural Sociological Society	12,000
	UIUC Agricultural Research Office	5,000
	UIUC Agricultural Research/Extension Offices	16,000
Walker, P.M.	Illinois Department of Agriculture/Sustainable Agriculture BihlerTech (In-Kind)	109,446 25,000
	Illinois Soybean Program Oper.	12,500
	Illinois State University	32,000
Williams, A.	Illinois State Water Survey Grant	93,000
Zhang, Y.	John Deere	202, 475
	ASHRAE	105,870
	DOE/EPA	705,000
	USDA	26,265
	C-FAR SRI: Biomass energy crops for power and heat generation in Illinois	110,454
Zhang, Y. and Funk, T.	CPBR/DOE	20,000
	TOTAL	**9,898,937**

PUBLICATIONS APPENDIX

Published Articles: (including presentations at meetings, conferences, seminars, abstracts, and full peer-reviewed papers.)

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--Lori Vail, Channel 12 News, Cape Girardeu
--Ryan Bank, Channel 8 News
--WVXU, 91.7 Cincinnati, NPR, 3800 Victory Parkway, Cincinnati, OH 45207
--WRSD, Columbus, 4 interview segments
--KRFM, PO Box 16, 1815 Meadowlark Road, 20 min., Clay Center, Kansas 67432
--Tom Ash, WIUS, National Public Radio, Springfield, IL (in both Sept., 1999 and Sept. 2000)
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