National Air Emissions Monitoring Study
Overview & Summary
March 5, 2004

Executive Summary: This document provides an overview and summary of a research project designed to provide quality-assured air emission data from representative swine, egg layer, dairy and meat-bird (broiler and turkey) farms in the U.S. These benchmark data and accompanying analysis and interpretation will allow U.S. EPA and livestock and poultry producers to reasonably determine which farms are subject to the regulatory provisions of the Clean Air Act and reporting requirements of CERCLA and EPCRA. Following sound scientific principles and using accepted instrumentation and methods, this project will collect new data from a number of farms across the country and will also evaluate existing emissions data from other studies that may meet EPA quality assurance criteria. Together they will form a database to which additional studies of air emissions and effectiveness of control technologies can be compared.

EPA will review and approve (as described in the Consent Agreement) a comprehensive study design and plan, including a Quality Assurance Project Plan (QAPP) and budget for all aspects of the study. The QAPP will outline appropriate procedures to ensure acceptable accuracy, precision, representativeness, and comparability of the data, and will specify the use of properly maintained and reliable instrumentation, sampling schedules, ready supply of spare parts, approved analytical methodologies and standard operation procedures, description of routine QC checks, external validation of data, well-trained analysts, field blanks, electrical backups, audits, documentation and format of data submission, and other procedural requirements. Chain of custody documentation will be used for samples of particulate matter. Wetted materials for gas sampling will be Teflon, stainless steel or glass. All sampling flow rates will be calibrated.

The study Research Leader will be responsible for drafting the comprehensive study design and QAPP, and with the independent, third-party monitoring contractor described in the Consent Agreement -- the Federation of Animal Science Societies (FASS), will submit these to EPA for approval. FASS will provide a separation between industry representatives that fund the study (the nonprofit "entity" described in the Consent Agreement) and those scientists that conduct the monitoring program. FASS will have specific fiduciary, communications and technical responsibilities. FASS will oversee the process to ensure the money collected for the study is properly accounted for under the approved budget and federal check-off funding requirements and any applicable tax laws. FASS will report on the conduct of the study to EPA and the nonprofit entity. In addition, FASS will build a website specific for this study and regularly post updates for the public to follow the progress of the study. FASS will also be available for media interviews and to answer questions raised by producers and others about the study. In coordination with the study Research Leader and Project scientific consultant(s), FASS will oversee certain technical aspects of the study, will help interpret the progress of the study, and provide periodic reports to EPA and the nonprofit "entity."

The study Research Leader and his team will directly administer: (a) all subcontracts with the principal investigators (PIs) doing the data collection; (b) purchasing and inventory control of all equipment throughout the study, (c) construction and distribution of mobile laboratories, (d) direct supervision of the teams of PIs in the course of the study, (e) direct supervision of data acquisition, data management, data processing, data and equipment QA/QC, etc., and (f) other activities as detailed below. The Research Leader will interact with the business offices of the other universities to administer their respective PI's budgets. It is envisioned that these budgets will vary depending on the location of the farm(s), the number of barns and/or lagoons monitored, and local characteristics (e.g., distance PIs and technicians have to travel to visit the site(s), the climate extremes, etc.). The individual PIs will likely employ their existing technicians (generally already part of their teams) and their own university business offices will handle their team's payroll, travel reimbursements etc. as they would any other external contract or grant. The Research Leader's business office will monitor expenditures of each subcontracting university, approve transfer of funds to them according to approved budgets, review the financial statements of the business offices of the subcontracting universities, and report to FASS on a regular basis. The Research Leader will facilitate a process to select farms for monitoring, following the protocols developed by EPA and a volunteer team during several months in late 2003 and early 2004. The Research Leader will supervise the set up of those farms selected (e.g., advise the cooperating farmers on their responsibilities, verify utilities, arrange for high speed computer data transmission service, etc.) for conduct of the study and implement the quality assurance project plan for the study. The Research Leader will help solicit, select and then supervise principal investigators for the study.

The industry "entity" described in the Consent Agreement will be established as a nonprofit corporation and will operate like a company. Voting members will elect a board of directors that will meet regularly, run the "entity," approve the budget and the audits of expenditures. The entity will be responsible for holding and disbursing to FASS and the Research Leader the funds necessary to complete the study according to its approved schedule, protocol and budget.

On the following pages the swine, egg layer, meat bird (broiler and turkey) and dairy air emissions study components are summarized. These were developed over several months by a volunteer team of scientists, industry and other stakeholders. While the study scope varies from species to species in line with their data needs, available funding and industry characteristics, the technologies and measurement methodologies selected by the team are consistent across species.

1. Air Emission Research Plan for Swine

Introduction: Swine production phases include sows (breeding, gestation, and farrowing), nursery pigs, and finishing pigs. The buildings are either naturally-ventilated or mechanically-ventilated but many buildings have a combination of the two ventilation types. Manure treatment and/or storage generally consists of either basins (earthen, clay or synthetic lined earthen, concrete, glass lined steel) and deep underfloor pits that store manure collected from the barn, or clay/synthetic lined earthen anaerobic treatment lagoons that treat and store manure. Manure collection systems with external manure storage/treatment are generally scrape, flush or pull-plug.

Overall, the U.S. hog inventory is located in three general regions. The five top Midwest swine states (IA, MN, IL, MO, and IN) represent about 54% of the total inventory in the U.S. In the Southeast, NC, AR, VA, KY, and MS represent about 19% and in the West with OK, NE, KS, SD, and TX with 15%.

Farm selection for new measurements: Swine production farm types are identified by region, production phase, ventilation type, and manure storage/treatment in Table 1. Farms selected will be characterized by criteria such as facility age, size, design and management, local topography and meteorology, swine diet and genetics. The farm should be reasonably isolated from other potential air pollution sources. Producers/farm managers must be willing to: 1) attend a training session, 2) make changes as needed to accommodate the project, and 3) maintain and share certain production records to facilitate data analysis and interpretation.

Farms to be monitored will be further characterized using farm management data and samples collected for analysis of water, feed and manure. Farms will provide vital management information regarding ventilation controls/management and scheduling of barn activities such as manure management, animal load out, animal treatment, or feeding. Water, feed and manure samples will be collected and analyzed for total nitrogen and total sulfur content at minimum.

Table 1. Farm sites identified and proposed for monitoring. [G=gestation, F=farrowing, FI=finishing].

Production Phase	Ventilation type	Number of units measured	Location of measurements	
			Barns or rooms	Storage/lagoon treatment
Southeast				
Sow	MV	4	G & F	
		single or double		lagoon
Finisher	MV	4	FI	
		single or double		lagoon
Midwest				
Sow	MV	4	G & F	
		2		deep pit
Finisher	MV	4	FI	
		1		basin
West				
Sow	MV	4	G & F	
		single or double		lagoon
Finisher		single or double		lagoon

Methods: The mass balance technique will be used for measuring emissions from mechanically ventilated barns. Micrometeorological techniques will be used for manure storage/treatment systems located outside the barn. Table 2 summarizes the methods and emissions that will be measured from barns (5) and manure storage/treatment systems (6). A maximum of five farms will be selected for barn measurements and six farms for manure storage/treatment system measurements. If possible, at least one farm will have measurements conducted at both the barns and the manure storage/treatment system.

Table 2. Summary of emissions measurements and methodologies.

Source units	Methodology	Targeted emissions	Number of farms	Number of units to monitor
Barn	Mass balance	NH_3, PM_{10}, $PM_{2.5}$ VOC, H_2S, TSP, CO_2	5 (see Table 1)	20
Manure storage /treatment system	Micromet and Water 9	VOC, H_2S, NH_3	6 (see Table 1)	6

Barn Measurements: An on-farm instrumentation shelter will house the equipment for measuring pollutant concentrations at representative air inlets and outlets (primarily by air extraction for gases), barn airflows, operational processes and environmental variables. Sampling will be conducted for 24 months with data logged every 60 s. Data will be retrieved with network-connected PCs, formatted, validated, and delivered to EPA for subsequent calculations of emission factors. A multipoint air sampling system in the shelter will draw air sequentially from representative locations (including outdoor air) at the barns and deliver selected streams to a manifold from which on-line gas monitors draw their sub samples. Concentration of constituents of interest will be measured using the following methods:

- Ammonia will be measured using chemiluminescence or photoacoustic infrared.
- Hydrogen sulfide will be measured with pulsed fluorescence.
- Carbon dioxide will be measured using photoacoustic infrared.
- TSP will be measured using an isokinetic multipoint gravimetric method.
- $PM_{2.5}$ will be measured gravimetrically with a federal reference method for $PM_{2.5}$ at least for one month per site. It will be shared among sites.
- PM_{10} will be measured in real time using the tapered element oscillating microbalance (TEOM) at representative exhaust locations in the barn, and ambient air.
- An initial characterization study of barn volatile organic compounds (VOCs) will be conducted on one day during the first month at the first site (site 1). While total non-methane hydrocarbons (NMHC) are continuously monitored using a dual-channel FID analyzer (Method 25A) along with building airflow rate, VOCs will be sampled with replication at two barns using Silcosteel canisters, and all-glass impingers (EPA Method 26A). Each sample will be evaluated using concurrent gas chromatography – mass spectrometry (GC-MS) and GC/FID for TO 15 and other FID-responding compounds. VOC mass will be calculated as the sum of individual analytes. The 20 analytes making the greatest contribution to total mass will be identified during the initial characterization study. A sampling method that captures a significant fraction of the VOC mass will be chosen for the remainder of the study.
- The Method 26A sampling train is suitable for collecting samples for analysis of formaldehyde and acetaldehyde using NCASI 94.02, requiring only the addition of spectrophotometry for the detection of formaldehyde. These compounds will be

measured during the initial characterization study and, if not found, will not be analyzed during subsequent measurements.

- Total VOC mass may be estimated (scaled) by multiplying the total carbon as determined by Method 25A by the molecular weight/carbon weight ratio derived from GC-MS or GC-FID speciation. This should account for the VOCs that are not identified by GC methods due either to sampling bias or the analytical procedures used, although some error is anticipated due to the imprecise response of the Method 25A FID to oxygenated compounds. Acceptance of a scaling factor will depend on whether the Method 25A analyzer response is reasonable based on the manufacturer's stated response factors, bench-scale verification, or judgmental estimation of the mass of unaccounted for VOCs.
- By the middle of the second month, FASS will report results of the initial VOC characterization to EPA with recommendations on the appropriateness and validity of the selected methodologies.
- Quarterly VOC samples using the selected VOC sampling method will occur at all sites, along with continuous Method 25A monitoring at site 1 throughout the study.
- Method 25A measurements will be corrected from an "as carbon" basis to a total VOC mass basis by multiplying them by the mean molecular weight per carbon atom established by GC-MS evaluations during applicable intervals of time.

Mechanically ventilated barn airflows will be estimated by continuously measuring fan operational status and building static pressure to calculate fan airflow from field-tested fan performance curves and by directly measuring selected fan airflows using anemometers.

Specific processes that directly or indirectly influence barn emissions will be measured including pig activity, manure management/handling, feeding, and lighting. Environmental parameters including heating and cooling operation, floor and manure temperatures, inside and outside air temperatures and humidity, wind speed and direction, and solar radiation will be continuously monitored. Feed and water consumption, manure production and removal, swine mortalities, and animal production will also be monitored. As noted above, samples of feed, water, and manure will be collected and analyzed for total nitrogen and total sulfur. These data will enable the development and validation of process-based emission models in the future.

Table 1 identifies those types of farms where barn measurements will be taken to provide the needed data to complete the objectives of this study. A total of five farms will be selected as measurement sites. Two farms in the Southeast, representing the sow and finishing phases of production with lagoon manure treatment, will be selected. Two farms in the Midwest, representing a finishing farm using an in-ground manure storage basin and a sow farm with a deep pit gestation barn, will be selected. Finally, one farm in the West, representing a sow farm with lagoon treatment, will be selected. On each of the farms, four barns will have measurements taken simultaneously. Where applicable, the sow farms will have two farrowing rooms and two gestation barn emissions measured, and on finishing farms, up to four barns will have emission measurements.

Lagoons: Micrometeorological techniques will be used to estimate emissions of NH_3, H_2S, and a limited number of VOCs from lagoons. Fundamentally, this approach will use optical remote sensing (ORS) downwind and upwind of the lagoon coupled with 3-dimensional (3D) wind velocity measurements at heights of 2 and 12 m. The concentrations of NH_3 and the various hydrocarbons will be made using open path Fourier transform infrared spectroscopy (FTIR). Measurements of H_2S (and NH_3) will be made using collocated open path UV differential optical absorption spectroscopy (UV-DOAS) systems. A team of two persons with two scanning FTIR systems, two single-path UV-DOAS systems, and two 3D sonics with supplementary meteorological instruments will move sequentially from farm to farm.

Each of two ORS systems will be oriented parallel to the storage side and approximately 10 m from the lagoon edge. Each monostatic FTIR system will scan five retroreflectors; three mounted at 1m height equally dividing the length of the open path along the lagoon side and two mounted on a tower at heights of 6 and 12 m located at the corners down the adjacent sides of the lagoon, resulting in scan lines down each of the four sides of the lagoon. Two bistatic single-path UV-DOAS systems will be located at a nominal 2 m height within 2 m laterally of the FTIR scan lines on the two sides of the lagoon oriented most closely with prevailing winds.

Emissions will be determined from the difference in upwind and downwind concentration measurements using two different methods- an Eulerian Gaussian approach and a Lagrangian Stochastic approach. The Lagrangian approach is based on an inverse dispersion analysis using a backward Lagrangian stochastic method (bLS). This approach will be used to estimate NH_3 emissions from concentration measurements made using the FTIR and UV-DOAS systems and the H_2S emissions from concentration measurements made using the UV-DOAS systems. The emission rate for NH_3 will be the ensemble average of the estimated emissions for each of the five FTIR scans with a corresponding error of the emission estimate. The Eulerian approach is based on a computed tomography (CT) method using Eulerian Gaussian statistics and a fitted wind profile from the two- 3D sonics. Measurements of air and lagoon temperatures, wind speed and direction, humidity, atmospheric pressure, and solar radiation will be also be conducted.

The bLS and CT emission estimates will be quality assured using tests of instrument response, wind direction and wind speed, stability, turbulence intensity, differences between the lagoon and the surrounding surface temperatures, differences in the mean and turbulent wind components with height, and the temporal variability in emission. Emission estimates using the CT method will be qualified by the measured fraction of the estimated plume.

To estimate VOC emissions from lagoons, samples of the lagoon liquid will be collected and analyzed for VOCs, and the EPA model WATER9 will be used to estimate emissions based on measured VOC concentrations, pH, and other factors.

QAQC: Quality assurance/quality control (QA/QC) processes will be established before data collection commences. The QA/QC procedures will be based on EPA guidelines and will include the use of properly maintained and reliable instrumentation, ready supply of spare parts, approved analytical methodologies and standard operating procedures, external validation of data, well-trained analysts, field blanks, electrical backups, audits, and documentation. Calibration and maintenance logs will be maintained for each instrument.

2. Air Emission Monitoring Plan for Laying Hens

Purpose: The purpose of this research project is to provide quality-assured air emission data from representative laying farms in the U.S., to U.S. EPA, in the effort to determine which farms might fall under regulatory authority as defined in the consent agreement. Following sound scientific principles, this project will collect new data and aggregate existing emissions data from previous studies. These data will serve as the beginning of a database to which new data can be added as emissions and against which control technologies can be compared.

Objectives: New data will be collected and existing data will be aggregated to create tools (i.e. look up tables, charts, or models) to meet the following objectives.

- Determine whether individual egg laying farms are likely to emit particulate matter (both total suspended particulate [TSP], particles smaller than 10 and 2.5 microns [PM_{10} & $PM_{2.5}$]), and volatile organic compounds (VOC) in excess of applicable Clean Air Act (CAA) thresholds. Applicable federal emission thresholds for attainment areas are 250 tons per year for TSP and 100 tons per year for PM_{10} , $PM_{2.5}$, and VOC. Some State Clean Air Act thresholds vary.
- Determine whether individual egg laying farms are likely to emit ammonia (NH_3) and hydrogen sulfide (H_2S) in excess of applicable Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) reporting requirements. The applicable reporting requirement is 100 pounds per day for both ammonia and hydrogen sulfide.

Introduction: Most U.S. layer housing types and manure management schemes fall under one of four categories: 1) high-rise houses with manure stored in the lower level and removed every 1 to 2 yrs; 2) belt houses with quasi-continuous manure transfer to an external storage/treatment facility; 3) shallow-pit houses with regular manure removal by scraping and temporary storage in uncovered piles; and 4) liquid-manure houses with manure flushed daily into a lagoon. The locations for four sites with specific housing types were recommended for this study with consideration of these four housing categories along with the potential impact of climatic differences and the geographical density of egg production (Table 1). Final site selections will also depend on site-specific factors including: representativeness of facility age, size, design and management, and flock diet and genetics. The facility should be reasonably isolated from other air pollution sources and have potential for testing mitigation strategies. Producers/farm managers must be willing to: 1) attend a training session 2) make changes as needed to accommodate the project and 3) maintain and share certain production records to facilitate data analysis and interpretation.

Table 1. Recommended types and locations of laying hen houses to be monitored in this study.

Region/Location	House 1 – Type	House 2 – Type
Midwest	High-rise with inside manure storage (2)	Manure belt (2) with manure storage
West	Shallow pit with open manure storage	Manure belt with open manure storage
South	High-rise with inside manure storage	High-rise with inside manure storage
East	High-rise with inside manure storage	Flushing with anaerobic treatment lagoon

Methods: An on-farm instrument shelter (OFIS) will house the equipment for monitoring pollutant concentrations at representative air inlets and outlets (primarily by air extraction for gases), barn and manure shed airflows, and operational processes and environmental variables. Sampling will be conducted for 24 months with data logged every 60 s. Data will be retrieved with network-connected PCs, formatted, validated, and delivered to EPA for subsequent calculations of emission factors. A multipoint air sampling system in the OFIS will draw air sequentially from representative locations (including outdoor air) at the hen houses and manure sheds and deliver selected streams to a manifold from which gas analyzers draw their samples. Selected pollutants will be evaluated as follows:

- Ammonia will be measured using chemiluminescence or photoacoustic infrared.
- Hydrogen sulfide will be measured with pulsed fluorescence.
- Carbon dioxide will be measured using photoacoustic infrared or equivalent.
- TSP will be measured using an isokinetic multipoint gravimetric method.
- $PM_{2.5}$ will be measured gravimetrically with a federal reference method for $PM_{2.5}$ at least for one month per site. It will be shared among sites.
- PM_{10} will be measured in real time using the tapered element oscillating microbalance (TEOM) at representative exhaust locations in the barn, ambient air, and at manure storage exhaust (if manure is disturbed).
- An initial characterization study of barn volatile organic compounds (VOCs) will be conducted on one day during the first month at the first site (site 1). While total non-methane hydrocarbons (NMHC) are continuously monitored using a dual-channel FID analyzer (Method 25A) along with building airflow rate, VOCs will be sampled with replication at two barns using Silcosteel canisters, and all-glass impingers (EPA Method 26A). Each sample will be evaluated using concurrent gas chromatography – mass spectrometry (GC-MS) and GC/FID for TO 15 and other FID-responding compounds. VOC mass will be calculated as the sum of individual analytes. The 20 analytes making the greatest contribution to total mass will be identified during the initial characterization study. A sampling method that captures a significant fraction of the VOC mass will be chosen for the remainder of the study.
- The Method 26A sampling train is suitable for collecting samples for analysis of formaldehyde and acetaldehyde using NCASI 94.02, requiring only the addition of spectrophotometry for the detection of formaldehyde. These compounds will be measured during the initial characterization study and, if not found, will not be analyzed during subsequent measurements.
- Total VOC mass may be estimated (scaled) by multiplying the total carbon as determined by Method 25A by the molecular weight/carbon weight ratio derived from GC-MS or GC-FID speciation. This should account for the VOCs that are not identified by GC methods due either to sampling bias or the analytical procedures used, although some error is anticipated due to the imprecise response of the Method 25A FID to oxygenated compounds. Acceptance of a scaling factor will depend on whether the Method 25A analyzer response is reasonable based on the manufacturer's stated response factors, bench-scale verification, or judgmental estimation of the mass of unaccounted for VOCs.
- By the middle of the second month, FASS will report results of the initial VOC characterization to EPA with recommendations on the appropriateness and validity of the selected methodologies.
- Quarterly VOC samples using the selected VOC sampling method will occur at all sites, along with continuous Method 25A monitoring at site 1 throughout the study.
- Method 25A measurements will be corrected from an “as carbon” basis to a VOC mass basis by multiplying them by the mean molecular weight per carbon atom established by GC-MS evaluations during applicable intervals of time.

Mechanically ventilated barn airflows will be estimated by continuously measuring fan operational status and building static pressure to calculate fan airflow from field-tested fan performance curves and by directly measuring selected fan airflows using anemometers.

Specific processes that directly or indirectly influence air emissions will be measured including hen activity, feeding, and lighting. Measured environmental parameters include cooling system status, manure temperatures, inside and outside air temperatures and humidities, wind speed and direction, and solar radiation. Feed and water consumption, egg production, manure production and removal, and bird mortalities will also be monitored with producer assistance. Samples of feed, eggs, water, and manure will be collected and analyzed for total nitrogen and total sulfur. These data will enable the development and validation of process-based emission models in the future.

Quality assurance/quality control (QA/QC) processes will be established before data collection commences. The QA/QC procedures will be based on EPA guidelines and will include the use of properly maintained and reliable instrumentation, ready supply of spare parts, approved analytical methodologies and standard operating procedures, external validation of data, well-trained analysts, field blanks, electrical backups, audits, and documentation. Instrument calibration and maintenance logs will be maintained.

3. Air Emission Monitoring Plan for Meat Birds

Purpose: The purpose of this research project is to provide quality-assured air emission data from representative broiler and turkey farms in the U.S., to U.S. EPA, in the effort to determine which farms might fall under regulatory authority as defined in the consent agreement. Following sound scientific principles, this project will collect new data and aggregate existing emissions data from previous studies. These data will serve as the beginning of a database to which new data can be added as emissions and against which control technologies can be compared.

Objectives: New data will be collected and existing data will be aggregated to create tools (i.e. look up tables, charts, or models) to meet the following objectives.

- Determine whether individual broiler and turkey farms are likely to emit particulate matter (both total suspended particulate [TSP], particles smaller than 10 and 2.5 microns [PM_{10} & $PM_{2.5}$]), and volatile organic compounds (VOC) in excess of applicable Clean Air Act (CAA) thresholds. Applicable federal emission thresholds for attainment areas are 250 tons per year for TSP and 100 tons per year for PM_{10} , $PM_{2.5}$, and VOC. Some State Clean Air Act thresholds vary.
- Determine whether individual broiler and turkey farms are likely to emit ammonia (NH_3) and hydrogen sulfide (H_2S) in excess of applicable Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) reporting requirements. The applicable reporting requirement is 100 pounds per day for both ammonia and hydrogen sulfide.

Introduction: Meat birds include broilers and turkeys and are raised in confinement barns on dirt or concrete floors covered with litter. Broiler barns are typically mechanically ventilated (MV) and turkey barns are typically naturally ventilated (NV). The locations for four sites with specific housing types were recommended for this study with consideration of the potential impact of climatic differences and the geographical density of poultry meat production (Table 1). The final site selections will depend on site-specific emission generating factors including representativeness of facility age, size, design and management, and flock diet and genetics. The facility should be reasonably isolated from other air pollution sources and have potential for testing mitigation strategies. Producers/farm managers must be willing to: 1) attend a training session 2) make changes as needed to accommodate the project and 3) maintain and share certain production records to facilitate data analysis and interpretation.

Table 1. Recommended types and locations of meat bird houses to be monitored.

Region	Type	Ventilation type	Manure handling
Midwest	Turkey	Mechanical	Litter on floor
West Coast	Broiler	Mechanical	Litter on floor
Southeast	Broiler	Mechanical	Litter on floor

Methods: An on-farm instrument shelter (OFIS) will house the equipment for monitoring pollutant concentrations at representative air inlets and outlets (primarily by air extraction for gases), barn airflows, and operational processes and environmental variables. Sampling will be conducted for 24 months with data logged every 60 s. Data will be retrieved with network-connected PCs, formatted, validated, and delivered to EPA for subsequent calculations of emission factors. A multipoint air sampling system in the OFIS will draw air sequentially from representative locations (including outdoor air) at the barns and deliver selected streams to a manifold from which gas analyzers draw their sub samples. The pollutants targeted for measurement will be evaluated as follows:

- Ammonia will be measured using chemiluminescence or photoacoustic infrared.
- Hydrogen sulfide will be measured with pulsed fluorescence.
- Carbon dioxide will be measured using photoacoustic infrared or equivalent.
- TSP will be measured using an isokinetic multipoint gravimetric method.
- $PM_{2.5}$ will be measured gravimetrically with a federal reference method for $PM_{2.5}$ at least for one month per site. It will be shared among sites.
- PM_{10} will be measured in real time using the tapered element oscillating microbalance (TEOM) at representative exhaust locations in the barn, and ambient air.
- An initial characterization study of barn volatile organic compounds (VOCs) will be conducted on one day during the first month at the first site (site 1). While total non-methane hydrocarbons (NMHC) are continuously monitored using a dual-channel FID analyzer (Method 25A) along with building airflow rate, VOCs will be sampled with replication at two barns using Silcosteel canisters, and all-glass impingers (EPA Method 26A). Each sample will be evaluated using concurrent gas chromatography – mass spectrometry (GC-MS) and GC/FID for TO 15 and other FID-responding compounds. VOC mass will be calculated as the sum of individual analytes. The 20 analytes making the greatest contribution to total mass will be identified during the initial characterization study. A sampling method that captures a significant fraction of the VOC mass will be chosen for the remainder of the study.
- The Method 26A sampling train is suitable for collecting samples for analysis of formaldehyde and acetaldehyde using NCASI 94.02, requiring only the addition of spectrophotometry for the detection of formaldehyde. These compounds will be measured during the initial characterization study and, if not found, will not be analyzed during subsequent measurements.
- Total VOC mass may be estimated (scaled) by multiplying the total carbon as determined by Method 25A by the molecular weight/carbon weight ratio derived from GC-MS or GC-FID speciation. This should account for the VOCs that are not identified by GC methods due either to sampling bias or the analytical procedures used, although some error is anticipated due to the imprecise response of the Method 25A FID to oxygenated compounds. Acceptance of a scaling factor will depend on whether the Method 25A analyzer response is reasonable based on the manufacturer's stated response factors, bench-scale verification, or judgmental estimation of the mass of unaccounted for VOCs.
- By the middle of the second month, FASS will report results of the initial VOC characterization to EPA with recommendations on the appropriateness and validity of the selected methodologies.
- Quarterly VOC samples using the selected VOC sampling method will occur at all sites, along with continuous Method 25A monitoring at site 1 throughout the study.
- Method 25A measurements will be corrected from an “as carbon” basis to a total VOC mass basis by multiplying them by the mean molecular weight per carbon atom established by GC-MS evaluations during applicable intervals of time.

Mechanically ventilated barn airflows will be estimated by continuously measuring fan operational status and building static pressure to calculate fan airflow from field-tested fan performance curves and by directly measuring selected fan airflows using anemometers.

Specific processes that directly or indirectly influence barn emissions will be measured including bird activity, manure handling, feeding, and lighting. Measured environmental parameters include heating and cooling operation, floor and manure temperatures, inside and outside air temperatures and humidity, wind speed and direction, and solar radiation. Feed and water consumption, manure production and removal, bird mortalities and bird production will also be monitored with producer assistance. Samples of feed, water, and manure will be collected and analyzed for total nitrogen and total sulfur. These data will enable the development and validation of process-based emission models in the future.

Quality assurance/quality control (QA/QC) processes will be established before data collection commences. The QA/QC procedures will be based on EPA guidelines and will include the use of properly maintained and reliable instrumentation, ready supply of spare parts, approved analytical methodologies and standard operating procedures, external validation of data, well-trained analysts, field blanks, electrical backups, audits, and documentation. Instrument calibration and maintenance logs will be maintained.

Open Manure Piles: Micrometeorological techniques will be used to estimate emissions of NH_3, H_2S, and a limited number of VOCs from open manure piles. Fundamentally, this approach will use optical remote sensing (ORS) downwind and upwind of the source coupled with 3-dimensional (3D) wind velocity measurements at heights of 2 and 12 m. The concentrations of NH_3 and the various hydrocarbons will be made using open path Fourier transform infrared spectroscopy (FTIR). Measurements of H_2S (and NH_3) will be made using collocated open path UV differential optical absorption spectroscopy (UV-DOAS) systems. A team of two persons with two scanning FTIR systems, two single-path UV-DOAS systems, and two 3D sonics with supplementary meteorological instruments will move sequentially from farm to farm.

Each of two ORS systems will be oriented parallel to the storage side and approximately 10 m from the storage edge. Each monostatic FTIR system will scan five retroreflectors; three mounted at 1m height equally dividing the length of the open path along the storage side and two mounted on a tower at heights of 6 and 12 m located at the corners down the adjacent sides of the source, resulting in scan lines down each of the four sides of the storage. Two bistatic single-path UV-DOAS systems will be located at a nominal 2 m height within 2 m laterally of the FTIR scan lines on the two sides of the manure storage area oriented most closely with prevailing winds.

Emissions will be determined from the difference in upwind and downwind concentration measurements using two different methods- an Eulerian Gaussian approach and a Lagrangian Stochastic approach. The Lagrangian approach is based on an inverse dispersion analysis using a backward Lagrangian stochastic method (bLS). This approach will be used to estimate NH_3 emissions from concentration measurements made using the FTIR and UV-DOAS systems and the H_2S emissions from concentration measurements made using the UV-DOAS systems. The emission rate for NH_3 will be the ensemble average of the estimated emissions for each of the five FTIR scans with a corresponding error of the emission estimate. The Eulerian approach is based on a computed tomography (CT) method using Eulerian Gaussian statistics and a fitted wind profile from the two- 3D sonics. Measurements of air and storage temperatures, wind speed and direction, humidity, atmospheric pressure, and solar radiation will be also be conducted.

The bLS and CT emission estimates will be quality assured using tests of instrument response, wind direction and wind speed, stability, turbulence intensity, differences between the storage and the surrounding surface temperatures, differences in the mean and turbulent wind components with height, and the temporal variability in emission. Emission estimates using the CT method will be qualified by the measured fraction of the estimated plume.

4. Air Emissions Research Plan for Dairy

Purpose: The purpose of this research project is to provide quality-assured air emission data from representative dairy farms in the U.S., to U.S. EPA, in the effort to determine which farms might fall under regulatory authority. Following sound scientific principles, this project will collect new data and aggregate existing emissions data from previous studies. These data will serve as the beginning of a database to which new data can be added as emissions and against which control technologies can be compared.

Objectives: New data will be collected to create tools (i.e. look up tables, charts, or models) to meet the following objectives.

- Determine whether individual dairy farms are likely to emit particulate matter (both total suspended particulate [TSP], particles smaller than 10 and 2.5 microns [PM_{10} & $PM_{2.5}$]), and volatile organic compounds (VOC) in excess of applicable Clean Air Act (CAA) thresholds.
- Determine whether individual dairy farms are likely to emit ammonia (NH_3) and hydrogen sulfide (H_2S) in excess of applicable Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) reporting requirements.

BACKGROUND

Dairy operations are naturally ventilated buildings with different manure handling systems. Measurement of the emission from these operations is to be conducted with a series of measurement systems that provide a concentration measurement along a path that would be representative of the emission plume from the building. In order to estimate the emission rate it is necessary to couple the concentration with a measurement of the wind flow through the building or facility.

Manure storage sites could be either liquid (lagoons or slurry store) or piles of solid materials. These sites represent a different source area for emissions than buildings and will have to be considered separately in the measurement scheme.

The protocols that are developed for these studies are based on the following assumptions.

1. The buildings are naturally ventilated and require a measurement method that captures the entire plume leaving the building. Mechanically ventilated facilities are beginning to enter the industry.
2. Manure storage is separate from the building and will have to be measured as a distinct entity as part of the farm emission factor.
3. The primary emission sources are the housing and feeding areas and manure storage.
4. There is a large diversity among dairy operations across the United States and although there are similar characteristics in general structure, the difference in

building design, management, and climate require measurements of facilities that represent these factors.

5. Measurements will be conducted at facilities which represent a diversity of systems in three general areas; California and southern US, Northeast US, and Upper Midwest.

SITE SELECTION

Milk production facilities include cattle (dry cows, lactating cows, and replacement heifers) and calves. The partially open barns range from those with windows and flaps to fully open free stalls. The buildings are most typically naturally ventilated except for some mechanically-ventilated freestall and tie stall houses. The naturally ventilated barns range from partially open barns with windows and flaps to fully-open free stalls. External manure storages generally consist of either earthen basins that store undiluted manure collected from the barn, or anaerobic treatment lagoons that treat manure that is diluted by a factor of about 5:1. Manure collection systems generally are either scrape or flush. Four dairy sites that consider climate, and types of ventilation, manure collection, and manure storage have been identified by the dairy industry for collecting the comprehensive air emission data required by this study (Table 1). Final site selections will also depend on site-specific factors including: representativeness of facility age, size, design and management, and cow diet and genetics. The facility should be isolated from other potential air pollution sources and have potential for testing mitigation strategies. Producers should be willing to make changes and keep extra records to facilitate a quality study.

Table 1. Recommended types and locations of dairy facilities to be monitored in this study.

Region	Site type	Ventilation	Manure collection	Manure storage
Midwest	Freestall	Natural	Flush	Lagoon
Northeast	Freestall	Natural	Scrape	Basin
West	Open* freestall	Natural	Flush	Lagoon
South	Open freestall	Natural	Scrape	Basin

Cattle are free to walk outside in open freestall barns.

MEASUREMENT PROTOCOLS

Naturally Ventilated Buildings

To achieve the most representative measurements of the emissions of the gases, it is recommended that a FTIR system be used to quantify the concentration of NH_3, CO_2, and, at levels above 50 ppb, H_2S in various paths through the atmosphere. A variation of the horizontal gradient method called radial plume mapping utilizing multiple paths through the airflow from the building measures the concentrations. The FTIR method is selected because of the extreme turbulence adjacent to the building and the lack of a defined plume in this area of the facility. A scanning system rotates among the paths to provide a serial measurement of the paths utilizing horizontally and vertically located retro-reflectors. A computer calculates the concentration gradients in real-time. FTIR measurements would be coupled to two sonic anemometers positioned at two locations along the length of the building. This will provide the wind flow measurements needed to estimate the flux from the measured concentrations.

Particulate load would be sampled using a series of particle samplers located with a sampling height of 5 m adjacent to one of the sonic anemometer towers. These units would be designed to collect 2.5 µm, 10 µm and TSP values

Volatile organic compounds (VOCs) would be sampled at the same position as the particulate samples for the building emissions. VOC emissions from the manure storage would be sampled with a system located both upwind and downwind of the manure storage system. These units would be positioned at a height of 2 m.

Mechanically Ventilated Buildings

Mechanically ventilated buildings have begun to be used in the dairy industry. If warranted by current or future use, a mechanically ventilated facility will be included in this project. An on-site instrument shelter (OSIS) will house the equipment for monitoring pollutant concentrations at representative air inlets and outlets (primarily by air extraction), barn airflows, and operational processes and environmental variables. Sampling will be conducted for 24 months with data logged every 60 s. Data will be retrieved with network-connected PCs, formatted, validated, and delivered to EPA as hourly averages for subsequent calculations of emission factors. A multipoint air sampling system in the OSIS will draw air sequentially from representative locations (including ambient) at the barns and deliver selected streams to a manifold from which on-line gas monitors draw their sub samples. The pollutants targeted for measurement will be evaluated as follows:

- Ammonia will be measured using chemiluminescence or photoacoustic infrared.
- Hydrogen sulfide will be measured with pulsed fluorescence.
- Carbon dioxide will be measured using photoacoustic infrared.
- TSP will be measured using an isokinetic multipoint gravimetric method.
- $PM_{2.5}$ will be measured gravimetrically with a federal reference method for $PM_{2.5}$ at least for one month per site. It will be shared among sites.
- PM_{10} concentrations will be measured in real time using the tapered element oscillating microbalance (TEOM) at representative exhaust locations in the barn and ambient air.
- An initial characterization study of barn volatile organic compounds (VOCs) will be conducted on one day during the first month at the first site (site 1). While total non-methane hydrocarbons (NMHC) are continuously monitored using a dual-channel FID analyzer (Method 25A) along with building airflow rate, VOCs will be sampled with replication at two barns using Silcosteel canisters, and all-glass impingers (EPA Method 26A). Each sample will be evaluated using concurrent gas chromatography – mass spectrometry (GC-MS) and GC/FID for TO 15 and other FID-responding compounds. VOC mass will be calculated as the sum of individual analytes. The 20 analytes making the greatest contribution to total mass will be identified during the initial characterization

study. A sampling method that captures a significant fraction of the VOC mass will be chosen for the remainder of the study.
- The Method 26A sampling train is suitable for collecting samples for analysis of formaldehyde and acetaldehyde using NCASI 94.02, requiring only the addition of spectrophotometry for the detection of formaldehyde. These compounds will be measured during the initial characterization study and, if not found, will not be analyzed during subsequent measurements.
- Total VOC mass may be estimated (scaled) by multiplying the total carbon as determined by Method 25A by the molecular weight/carbon weight ratio derived from GC-MS or GC-FID speciation. This should account for the VOCs that are not identified by GC methods due either to sampling bias or the analytical procedures used, although some error is anticipated due to the imprecise response of the Method 25A FID to oxygenated compounds. Acceptance of a scaling factor will depend on whether the Method 25A analyzer response is reasonable based on the manufacturer's stated response factors, bench-scale verification, or judgmental estimation of the mass of unaccounted for VOCs.
- By the middle of the second month, FASS will report results of the initial VOC characterization to EPA with recommendations on the appropriateness and validity of the selected methodologies.
- Quarterly VOC samples using the selected VOC sampling method will occur at all sites, along with continuous Method 25A monitoring at site 1 throughout the study.
- Method 25A measurements will be corrected from an "as carbon" basis to a total VOC mass basis by multiplying them by the mean molecular weight per carbon atom established by GC-MS evaluations during applicable intervals of time.

Manure Storage Systems

Micrometeorological techniques will be used to estimate emissions of NH_3, H_2S, and a limited number of VOCs from manure storage systems and storages. Fundamentally, this approach will use optical remote sensing (ORS) downwind and upwind of the storage coupled with 3-dimensional (3D) wind velocity measurements at heights of 2 and 12 m. The concentrations of NH_3 and the various hydrocarbons will be made using open path Fourier transform infrared spectroscopy (FTIR). Measurements of H_2S (and NH_3) will be made using collocated open path UV differential optical absorption spectroscopy (UV-DOAS) systems. A team of two persons with two scanning FTIR systems, two single-path UV-DOAS systems, and two 3D sonics with supplementary meteorological instruments will move sequentially from farm to farm.

Each of two ORS systems will be oriented parallel to the storage side and approximately 10 m from the storage edge. Each monostatic FTIR system will scan five retroreflectors; three mounted at 1m height equally dividing the length of the open path along the storage side and two mounted on a tower at heights of 6 and 12 m located at the corners down the adjacent sides of the storage, resulting in scan lines down each of the four sides of the storage. Two bistatic single-path UV-DOAS systems will be located at a nominal 2 m height within 2 m laterally of the FTIR scan lines on the two sides of the storage oriented most closely with prevailing winds.

Emissions will be determined from the difference in upwind and downwind concentration measurements using two different methods- an Eulerian Gaussian approach and a Lagrangian Stochastic approach. The Lagrangian approach is based on an inverse dispersion analysis using a backward Lagrangian stochastic method (bLS). This approach will be used to estimate NH_3 emissions from concentration measurements made using the FTIR and UV-DOAS systems and the H_2S emissions from concentration measurements made using the UV-DOAS systems. The emission rate for NH_3 will be the ensemble average of the estimated emissions for each of the five FTIR scans with a corresponding error of the emission estimate. The Eulerian approach is based on a computed tomography (CT) method using Eulerian Gaussian statistics and a fitted wind profile from the two- 3D sonics. Measurements of air and storage temperatures, wind speed and direction, humidity, atmospheric pressure, and solar radiation will be also be conducted.

The bLS and CT emission estimates will be quality assured using tests of instrument response, wind direction and wind speed, stability, turbulence intensity, differences between the storage and the surrounding surface temperatures, differences in the mean and turbulent wind components with height, and the temporal variability in emission. Emission estimates using the CT method will be qualified by the measured fraction of the estimated plume.

To estimate VOC emissions from lagoons, samples of the lagoon liquid will be collected and analyzed for VOCs, and the EPA model WATER9 will be used to estimate emissions based on measured VOC concentrations, pH, and other factors.

Alternate Techniques

1. For the circuit rider system, an instrumental system such as the DustTrak by TSI could be used for continuous particle data for $PM_{2.5}$ and PM_{10}. These systems provide optical light scattering measurements of the concentration in mg/m^3 and cost about $5000 per point including an environmental shelter.

2. A radial plume mapping approach could be applied to the manure storage systems using a TDL system that has been approved by EPA for use in the aluminum industry in a single path mode. 1 upwind and 3 downwind paths provide the same type of data as the FTIR except for a single compound. The single laser is scanned via fiberoptic cables to the individual paths with a complete scan taking 40 seconds. It provides a fast, direct measurement of the flux of ammonia from these manure systems. A single 4-channel system costs $68,000.

3. It is recommended that one short-term (2-week) measurement of each facility be made with a LIDAR system to measure and quantify the plume dynamics of particles, water vapor, and ammonia surrounding the facility. This recommendation is made because the short-term measurements will be made at different times throughout the year and will be placed at a series of heights based on experience. These associated data of the plume structure will provide evidence of representativeness of the micrometeorological measurements for the emission rates.

4. It is recommended that each building site be instrumented with temperature and associated sensors to provide a continuous measurement record of the microclimate within and adjacent to the building. These systems can be linked with sensors to measure and record animal activity and floor temperature. A similar system would be located to measure the microclimate of the manure storage system and would include air temperature, wind speed, wind direction, surface temperature, and relative humidity of the manure storage system. The continuous record from these manure storage units and buildings would provide a reference for the short-term measurements made with the FTIR systems.

APPENDIX

Typical factors in determining farm selection

Farm Characteristics

1	Did the producer sign up the consent agreement and pay EPA?	
2	Does the producer's farm fit the description of any of the farms listed in table 4 or 5 of the plan?	
3	Is there a P.I. Within three hours of the site?	
4	Are there housing accommodations available within one hour of the site?	
5	Does your site have mechanical or natural ventilation for barns? Do the fans blow out directly over the lagoon/ manure storage area?	
6	Is the producer/farm manager cooperative to attend a training session and provide needed production information?	
7	Is there internet access at the farm? Is 220 V power available?	
8	What is the general topography on the farm? Describe the surrounding terrain (rolling hills, flat, low lying, river bottom, etc..) specifically for areas near the barns and the manure storage/treatment system.	
9	Is the farm free from large disturbances such as trees and other buildings?	
10	What is the distance from a public road? Is it gravel?	
11	Are there other potential air pollutant sources nearby? Explain type (other farms, industrial site, grain elevator/feedmill), distance and direction.	
12	Are there other animal species housed on the site, or planned for housing on site?	
13	How many barns are located on the site? How many animals in each barn? Please characterize the barns	
14	How far are the land application fields from the lagoons and barns?	
15	How often is manure removed from the manure treatment/storage system and land applied?	
16	How often is manure removed from the buildings and sent to the outdoor treatment/storage system?	
17	Describe (in general terms) the rations fed to the animals.	

18	Are the animals hand-fed or is feed delivered through an automatic delivery system?
19	Is fat (vegetable or animal) added to the rations?
20	Are feed rations pelleted or ground?

	Production phase	Rate your barn cleanliness: 1-5 (1 being the cleanest)	Age of barns	Air exchange rate
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Influences on emissions

	Producer Provided	Collected By study
Climate		
air temperature		X
manure temperature		X
barn temperature		X
wind speed		X
solar radiation		X
rainfall		X
relative humidity		X
wind direction		X
Feed conversion/efficiency		X
feed analysis (N & P & S)		X
phases		X
feeding to recommendations	X	
Manure production volume		X
management cycle	X	
storage duration	X	
Stocking density (actual)		X
Lagoon design	X	X
Swine genetics	X	
Animal inventory	X	
feed usage	X	
water usage	X	
closeouts	X	
feed analysis		X
water analysis		X
manure analysis		X
animal/barn activity		X