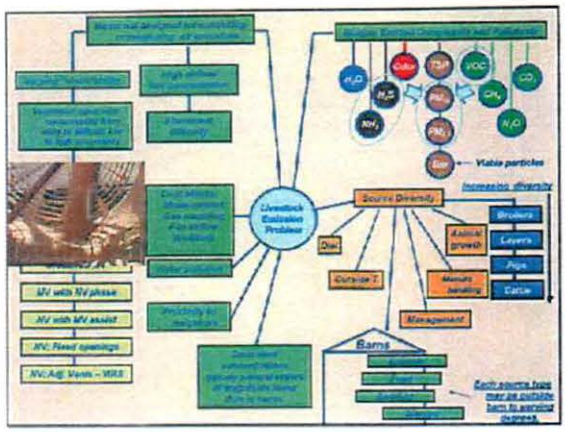
National Study of Livestock Air Quality in USA

ISHEAW, Chongqing, China, October 21, 2011

Al Heber, Purdue University
Jiqin Ni, Purdue University
Erin Cortus, South Dakota State University
Teng Lim, University of Missouri
Bill Bogan, Purdue University

Agricultural and Biological Engineering

Purdue University



Citizen's Odor Nuisance Suits

- Neighbors seek for:
  - Actual damages
  - Punitive damages
  - Injunction to close the operation
  - Court order for abatement of odour
- Ohio
  - Nuisance suit v Buckeye Egg Farm, 2001, $19.7M
- Missouri
  - 52 neighbors v. Continental Grain: $5.2M award
  - 50 nuisance suits against Premium Standard Farms, last 10 years

Sources: Miner, 1997; van Sickle, 2003; Lee, 2004

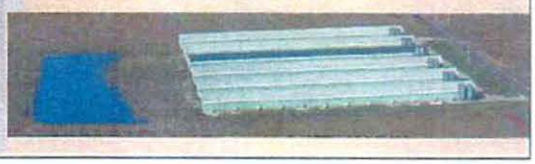
State Odor Regulations

- Indirect Regulations
  - Permits (odor management plans)
  - Setbacks (minimum buffer distances)
  - Operator training (certification)
  - Land application restrictions (inject)
- Direct Regulations
  - 10 states (Redwine and Lacey, 2000)
  - Property line limits
    - Field olfactometry readings (2-8 D/T)
    - Gas concentrations (H_2S and NH_3)
- Lawsuits and consent decrees



State Lawsuits

- Missouri v. Premium Standard Farms, 1999
  - $650,000 fine
  - $25M for "Next Generation" technologies
- Ohio v. Buckeye Egg Farms, 2001
  - $1,000,000 fine
  - Must convert deep pit barns to belt-batteries
  - Revoked operating permits, July, 2003
  - Closed down one facility, November, 2003



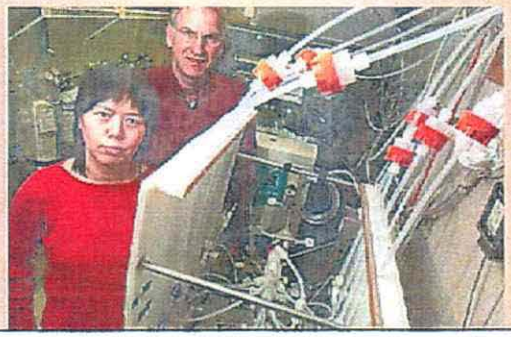
Federal Lawsuits (Authority: U.S. Clean Air Act of 1990)

- U.S. v. Premium Standard Farms, 2001
  - Air and water
  - $350,000 penalty
  - Lagoon emission monitoring
  - Barn monitoring tests, six (6) months long
  - Test soybean oil sprinkling in one (1) of the barns.
- U.S. v. Buckeye Egg Farms, 2004
  - Air issues
  - $860,000 penalty
  - Barn emissions monitoring and controls
  - Test dust and ammonia abatement
  - Brief summer tests showed 700 tpy > 250 tpy limit!
  - Owners moved back to Germany

Federal Regulations

- EPCRA (Community Right to Know Laws)
  - Covers NH_3 and H_2S among others
  - Must report if emissions ≥ 100 lbs/d (45.5 kg/day)
- Clean Air Act
  - "Substances of concern" (PM, VOC, etc.)
  - National Ambient Air Quality Standards
  - Defines "Major Source" thresholds
    - Requires annual permit fee for major sources

Gov't agencies needed reliable data. Livestock producers needed more time.



"Air Consent Agreement" (Jan. '05)

- Between U.S. EPA and livestock industries
  - Producers voluntarily paid a "penalty" based on farm size
  - EPA "forgave" producers for past violations of U.S. air laws
  - Producers participated in the NAEMS to get emissions data
  - EPA develop and applies data-based emission estimations or "Emission Estimation Methodologies" (EEM)
- National Air Emissions Monitoring Study (NAEMS)
  - Required by Air Consent Agreement (ACA)
  - Study approach finalized at meeting in Beltsville, MD (11/03)
  - Overseen by U.S. EPA
  - Funded by American Egg Board, Nat'l Pork Board, Nat'l Milk Producers Federation, and Nat'l Chicken Council via the Agricultural Air Research Council (John Thorne, Exec. V-P)
  - Turkeys, ducks and beef cattle groups did not participate.

2003 "Beltsville Meeting" to Design the Study

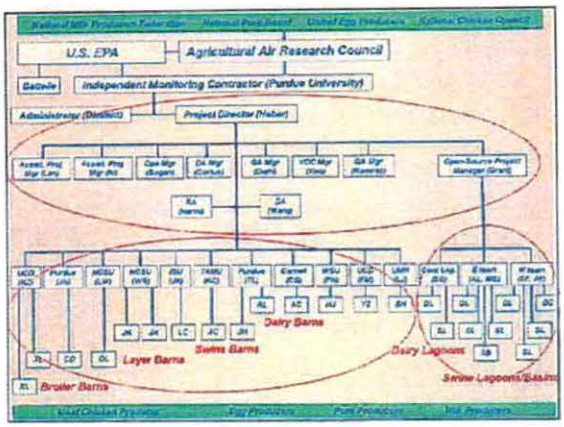
- Intensive vs. extensive tests
- Farm selection
- Organizational structure
- Whole farm vs. component tests
- Supporting data
- Public vs. private contractor

General Timeline of the NAEMS

2004	Protocol Development and Farm Selection Criteria
2005	PI Selection, Staffing, Budgeting, Educating Producers
2006	Site Selection, Quality Assurance Project Plan
2007	Setup of Barn and Open Source Emission Monitoring
2008	Data Collection, Analysis and Reporting, Audits
2009	Data Collection, Analysis and Reporting, External Audits
2010	Prepare and Submit Final Report for EPA, Further Analysis
2011	EPA Develops EEMs, Further Analysis, Journal Articles
2012	EPA Publishes EEMs, PI's Continue Publishing

NAEMS Principal Investigators

Poultry		
CA1B, CA2B	Ruihong Zhang	University of California - Davis
IN3B, IN3R	Jiqin Ni	Purdue University
NC2B	Lingjuan Wang	North Carolina State University
Swine		
IN3B	Teng Lim	Purdue University
NC3B, NC4B	Wayne Roberge	North Carolina State University
IA4B	J. Koziel, S. Hoff	Iowa State University
OK4B	Ken Casey	Texas Agricultural Experiment Station
Open Sources	Rich Grant	Purdue University
Dairy		
CA5B	Frank Mitloehner	University of California - Davis
IN5B	Teng Lim	Purdue University
NY5B	Curt Gooch	Cornell University
WA5B	Pius Ndegwa	Washington State University - Pullman
WI5B	Larry Jacobson	University of Minnesota
Open Sources	Rich Grant	Purdue University



Was industry-funded NAEMS "tainted" or "biased"? No!

- Tests required by consent decrees or agreements are typically funded by firms.
- AARC addressed budget and deadlines.
- EPA addressed data quality issues.
- NAEMS followed protocols of past studies and improved methods where possible.
- PI's maintained independence/neutrality as "Independent Monitoring Contractor."

Objectives of the NAEMS

- Quantify air emissions from livestock production.
- Provide reliable data for developing and validating barn and lagoon emission models.
- Develop national consensus on methods of measuring, calculating, & reporting emissions.



NAEMS Scope

- Baseline study
- Continuous high frequency QA'd barn data for two years using mobile labs
- Pollutants ($PM_{2.5}$, PM_{10}, TSP, NH_3, H_2S, CO_2, CH_4, VOC)
- Swine, egg, broiler, and dairy houses
- Collected as much "metadata" as possible (animal activity, wind, etc.)
- 35 livestock & poultry barns tested with similar protocols
- 2300 sensors and 2.45 billion data points
- Quality assurance/quality control
  - Oversight of U.S. EPA Office of Air Quality
  - Quality Assurance Project Plan (Category 1)
    - 78 standard operating procedures (SOPs)
    - 15 barn site monitoring plans (SMPs)
    - 10 open source site SMPs
  - On-site audits
- Allowed add-on studies of odor, N_2O, CH_4, pathogens, and mitigation.

NAEMS Methods

- Comprehensive real -time barn emission data
  - Ammonia (photoacoustic, chemiluminescence, TDLAS)
  - Hydrogen sulfide (pulsed flourescence)
  - Carbon dioxide (photoacoustic)
  - PM (tapered element oscillating microbalance)
  - Airflow (fan voltage, vibration, pressure, velocity, & flow)
  - Wind and air velocity (ultrasonic anemometers)
- Integrated sampling
  - Volatile organic compounds: GC-MS and canisters (24-h)
  - Seven 24-hour VOC samples from barn outlets (GC-MS analysis)
  - Odor samples: Tedlar bags and sorbent tubes
- Novel methods
  - NV barn airflows measured with 3-D sonic anemometers.
  - Fan operation measured with vibration sensors.
  - Custom designed data acquisition & processing systems

Slightly negative concentrations were "left alone"

- Gas analyzers have noise – random up and down variation, even when measuring zero.
- Slightly negative gas concentrations occur with zero or very low concentrations. Negative gas concentrations in the NAEMS were slight.
- Similar but unnoticed noise occurs at high gas levels.
- EPA advised Purdue not to delete noise-related negatives for the emission calculations.
- Slight to large negative PM concentrations can occur at short time scales (minute, hour) due to moisture, but disappear at longer time scales (day, month, year)
  - Negative PM2.5 more frequent than PM10 and TSP.

Barn inlet air was not community's ambient air.

- Inlet air often called "ambient air" in reports.
- Inlet air sampled in building wall or few feet away from the barn(s).
- Inlet air is close to source and surrounded by other sources, thus has elevated levels.
- Inlet air far from the property line.
- Inlet air concentrations should not be compared with National Ambient Air Quality Standards (NAAQS) or other thresholds intended to protect the community.

Exhaust concentrations do not always indicate exposure

- Fans downstream of animal/worker area
  - High-rise houses
  - Drying tunnels at IN2B
  - Broiler houses during brooding
  - Pit fan exhausts of deep pit swine barns
- Empty barns and ventilation shut downs
- Exhaust > average concentrations
  - Belted barns
  - Tunnel ventilated barns

NAEMS Emission Calculations

- Measured gas/PM at barn inlets and outlets
- "Subtracted inlets" - $E = Q\ (C_{out} - C_{in})$
  - Occasionally results in a short term "negative emission" especially when actual emissions are very low or with outside interferences
  - Negative emission data were not invalidated.
- We did not
  - Measure inlet concentrations with VOC canisters
  - Measure neighbor exposure
  - Measure worker/animal exposure
  - Remove/adjust negative concentrations
  - Remove/adjust negative emissions

Short term negative emissions were not removed or adjusted

- Emission calculations are "noisy" due to:
  - Analyzer noise
  - Wind caused variations in inlet concentrations.
  - Localized activities (mowing, manure hauling, gravel roads, etc.)
  - Location-shared and nonsimultaneous sequential sampling
- Subtracting inlet introduces some negative emissions when inlet concentration > outlet concentrations
  - Low emissions
  - Imperfect representation of inlet air (e.g. 1200 ft of eave inlet).
  - Interpolation of inlet air readings coupled with interpolation of outlet.
- Also introduces unnoticed high biases of emissions.
- Actual negative emissions could result from:
  - Dry scrubbing.
  - PM settling in barn.
  - Ammonia wet deposition and adsorption

Net emissions (outlet-inlet) does not underestimate emissions.

- Widely accepted approach in journal papers.
- Exhaust air reentry means pollutants counted multiple times if inlet is not subtracted.
- Pollutants from external sources would be credited to the barn if inlet not subtracted.
- Inlet NH3, H2S and PM10 were 2 to 6% of outlet at broiler site.
- "Gross" emissions overestimate emissions.

Greater resolution (1 min vs. 1 hr vs. 1 d) may not give better information

- Interpolated sequential gas data.
- Moisture interference of TEOM
- Analyzers have internal averaging methods.
- AirDac sampling frequency
- Depends on number of sampling points.
  - TEOM 1 point
  - Gases 3-18 points.

Barn Site Monitoring Plans

Site ID	Title	Site ID	Title
CA1B	Broiler Ranch in California	NC4B	Sow Farm in North Carolina
CA2B	Layer Site in California	OK4D	Sow Farm in Oklahoma
IN2B	Layer Site in Indiana – Manure Belts	CA5D	Dairy Farm in California
IN2H	Layer Site in Indiana – High-Rise	IN5H	Dairy Farm in Indiana
NC2B	Layer Site in North Carolina	NY5H	Dairy Farm in New York State
IN3B	Finisher Swine Farm in Indiana	WA5H	Dairy Farm in Washington State
NC3B	Finisher Swine Farm in North Carolina	WI5H	Dairy Farm in Wisconsin

These SMP's provided the roadmap for setting up each site.



Gas Sampling and Data Acquisition Systems



Gas sampling system with gas tubing and filters, for automated, multiple location sampling

Bank of data acquisition hardware



Equipment/DAC/Cylinders Installation



Raceway Installation



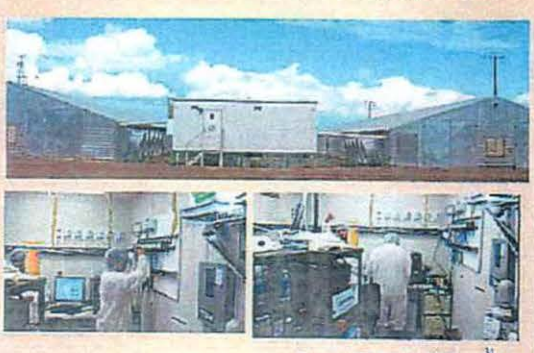


Bundled tubing and heat-tape

Insulated, temperature controlled bundle

Raceway is ready

Emission Measurement Equipment



Source: X.-J. Lin, UCD

Weather Station Installation



Rooftop weather station

Crank-up weather tower



Gas and PM measurement



Source: X.-J. Lin, UCD

Ventilation Measurement

(a) Fan Speed sensor
(b) Static pressure at three locations
(c) Fan anemometer



(a) Fan speed sensor (b) Static sensors (c) Fan anemometer

Source: X.-J. Lin, UCD

Site Setup and Monitoring Periods

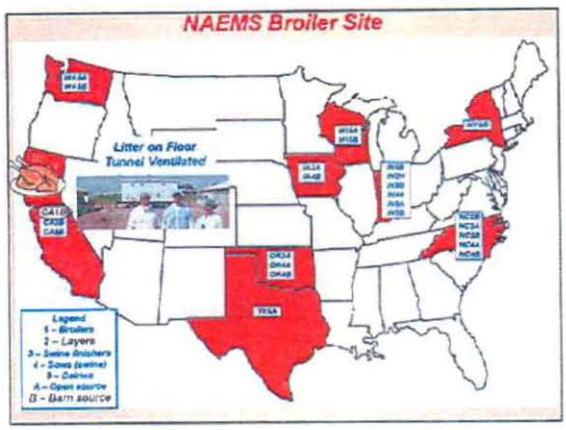
	Site	Day 1	Days to start	Monitoring Period
Broilers	CA1B	9/27/07	121	755
Layers	CA2B	10/17/07	114	745
	IN2B	1/1/08	235	730
	IN2H	8/1/07	41	730
	NC2B	9/25/07	125	736
Swine	IN3B	7/14/07	127	741
	NC3B	12/4/07	102	771
	NC4B	12/15/07	135	731
	IA4B	7/19/07	73	776
	OK4B	7/19/07	50	731
Dairy	CA5B	9/25/07	118	859
	IN5B	9/12/07	125	731
	NY5B	10/23/07	145	731
	WA5B	9/28/07	105	730
	WI5B	9/12/07	119	760
	Average	9/21/07	116	752
	Minimum	8/1/07	41	730
	Maximum	1/1/08	235	859

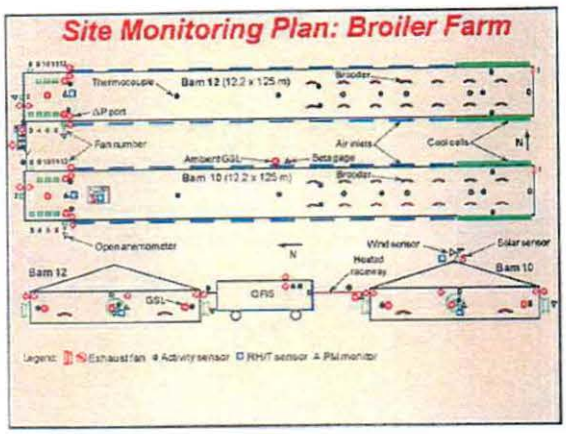
NAEMS Constraints and Limitations

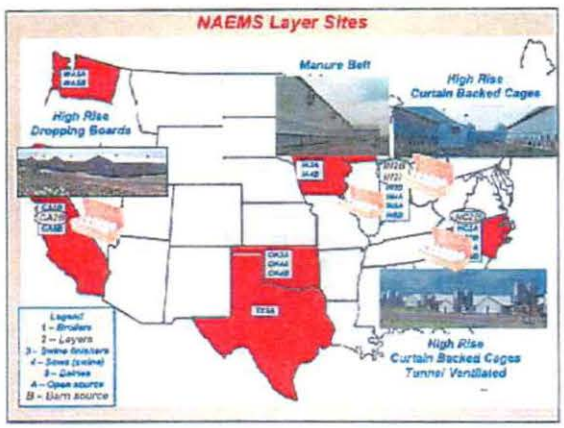
- Budget
- Producer participation in ACA
- Producer collaboration
- Proximity to university
- Long set-up time
- Ventilation method
- Data complexity
- Real-time VOC

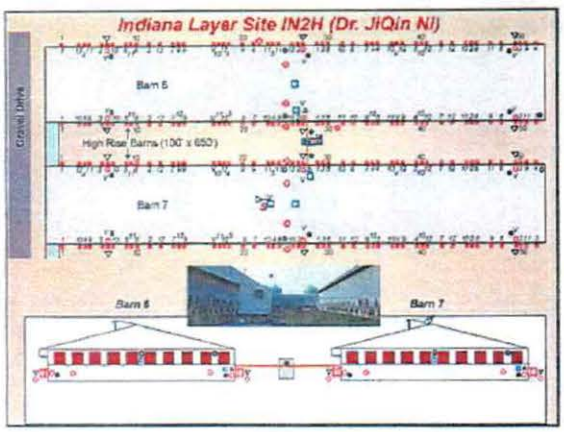
Monitored Barn Sizes

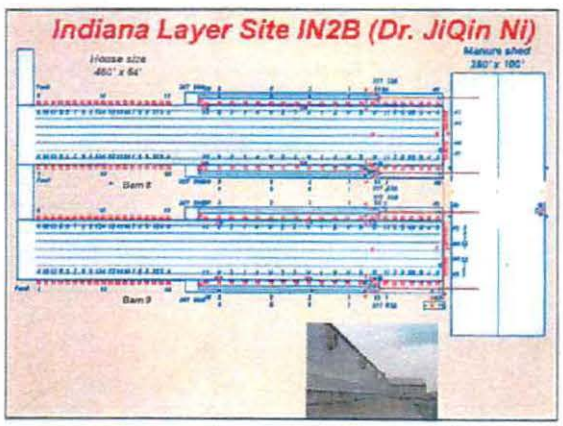
- Freestall barns (9): 275-800 cows
- Layer houses (8): 38K-250K hens
- Finishing barns (7): 880 - 1000 hogs
- Sow farms (3): 2000 - 2800 sows
- Broiler houses (2): 21,000 chickens

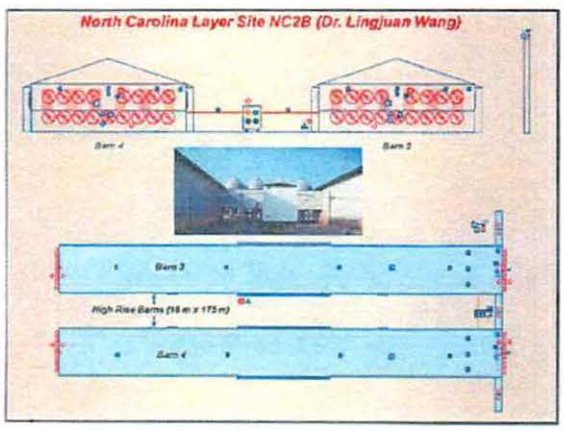

NAEMS Broiler Site
Litter on Floor
Tunnel Ventilated

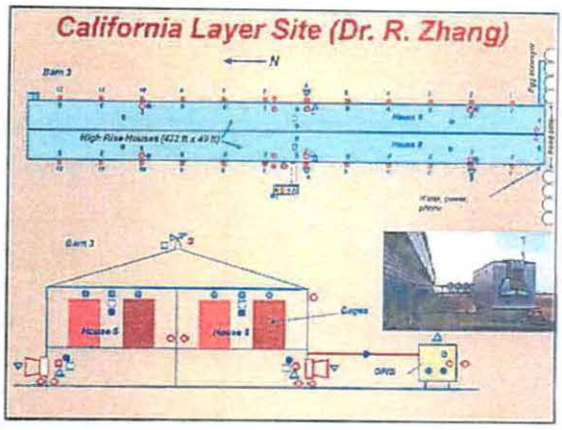

Site Monitoring Plan: Broiler Farm
Thermocouple
Barn 12 (12.2 x 125 m)
Brooder
ΔP port
Fan number
Air inlets
Cool cells
Ambient GSL
Beta gage
Barn 10 (12.2 x 125 m)
Open anemometer
Wind sensor
Solar sensor
Heated raceway
Barn 12
Barn 10
GSL
GRS

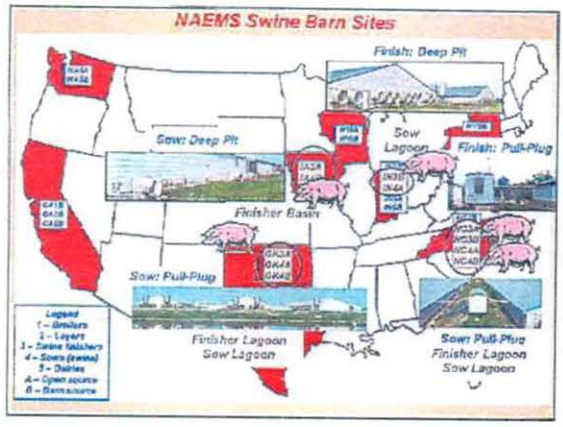

NAEMS Layer Sites
Manure Belt
High Rise
Curtain Backed Cages
High Rise
Dropping Boards
High Rise
Curtain Backed Cages
Tunnel Ventilated


Indiana Layer Site IN2H (Dr. JiQin Ni)
Gravel Drive
Barn 6
High Rise Barns (100 x 650)
Barn 7
Barn 6
Barn 7

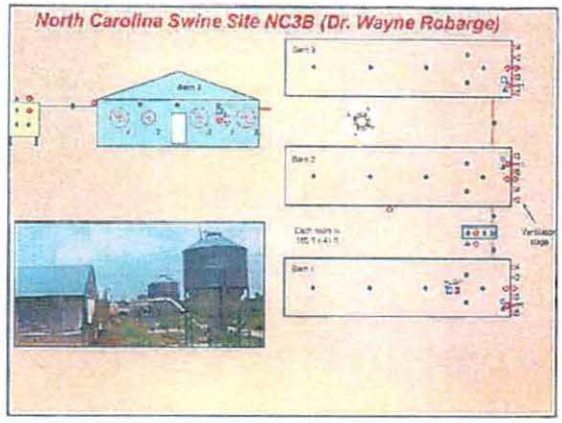

Indiana Layer Site IN2B (Dr. JiQin Ni)
House size
460' x 64'
Manure shed
380' x 100'
Barn 8
Barn 9

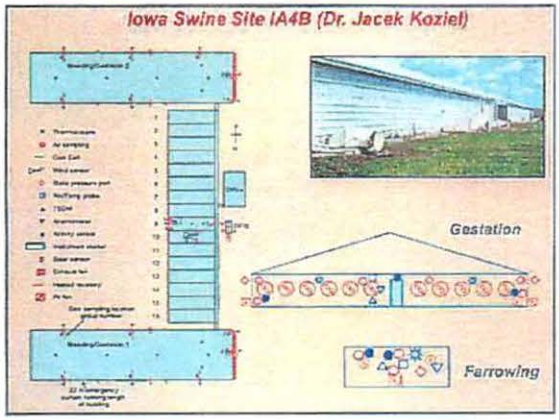

North Carolina Layer Site NC2B (Dr. Lingjuan Wang)
Barn 4
Barn 2
Barn 3
High Rise Barns (16 m x 175 m)
Barn 4

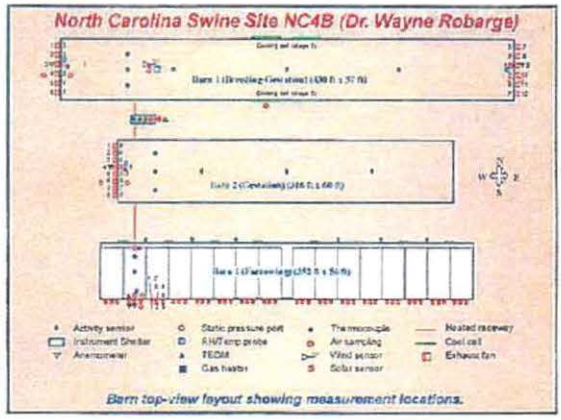

California Layer Site (Dr. R. Zhang)
N
Barn 3
High Rise Houses (432 ft x 49 ft)
House 6
House 5
Cages
Barn 3

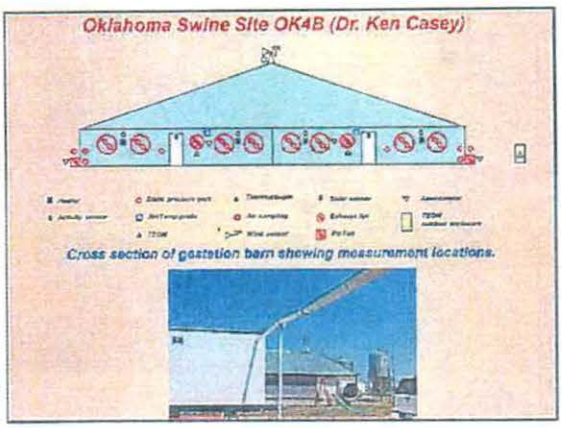

NAEMS Swine Barn Sites
Finish: Deep Pit
Sow: Deep Pit
Sow Lagoon
Finish: Pull-Plug
Finisher Basin
Sow: Pull-Plug
Finisher Lagoon
Sow Lagoon
Sow: Pull-Plug
Finisher Lagoon
Sow Lagoon

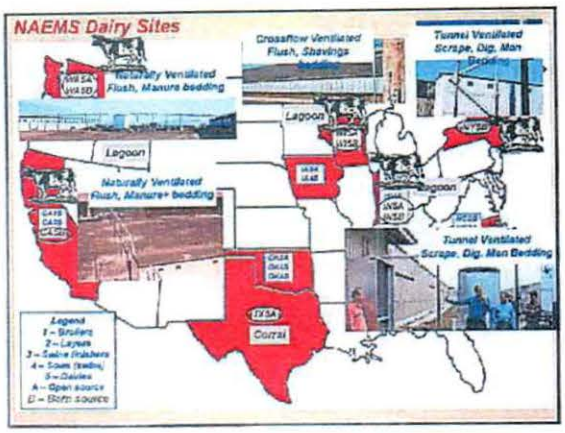

Shop
Barn 1
Barn 2
N
Swine Finisher
IN3B site (Dr.
Teng Lim)

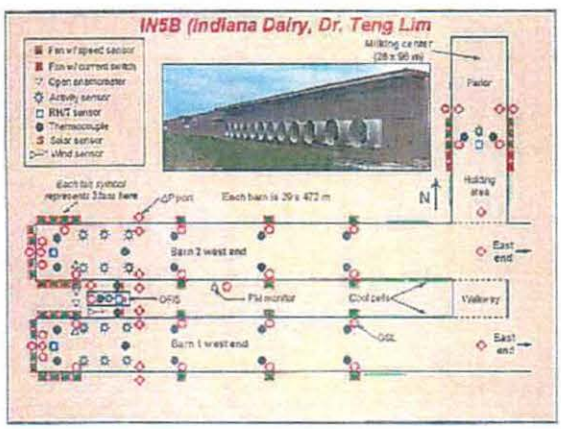

North Carolina Swine Site NC3B (Dr. Wayne Robarge)

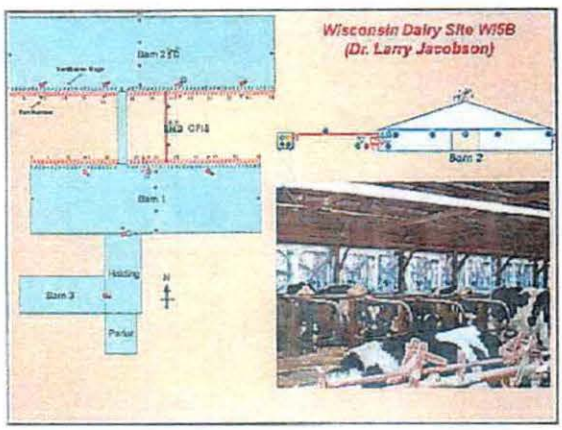

Iowa Swine Site IA4B (Dr. Jacek Koziel)
Gestation
Farrowing

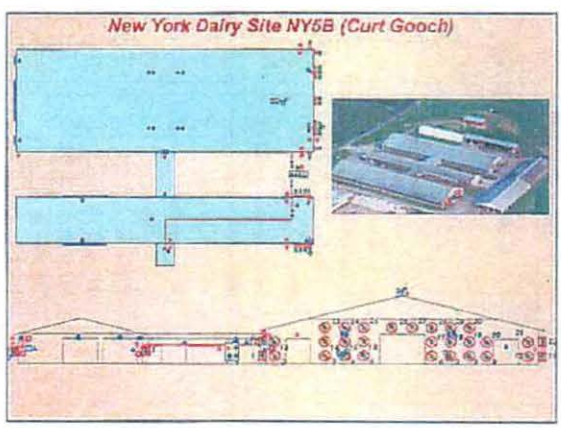

North Carolina Swine Site NC4B (Dr. Wayne Robarge)
Activity sensor
Instrument Shelter
Anemometer
Static pressure port
RH/Temp probe
TEOM
Gas heater
Thermocouple
Air sampling
Wind sensor
Solar sensor
Heated raceway
Cool cell
Exhaust fan
Barn top-view layout showing measurement locations.

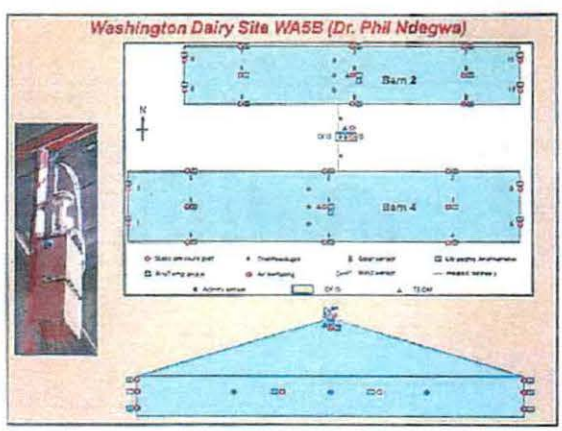

Oklahoma Swine Site OK4B (Dr. Ken Casey)
Cross section of gestation barn shewing measurement locations.


NAEMS Dairy Sites
Crossflow Ventilated Flush, Shavings
Tunnel Ventilated Scrape, Dig. Man
Naturally Ventilated Flush, Manure bedding
Lagoon
Naturally Ventilated Flush, Manure+ bedding
Tunnel Ventilated Scrape, Dig. Man Bedding
Corral
Legend
1 – Broilers
2 – Layers
3 – Swine (nurs
4 – Cows (lactac
5 – Calves
A – Open source
B – Storm source


IN5B (Indiana Dairy, Dr. Teng Lim
Fan w/ speed sensor
Fan w/ current switch
Open anemometer
Activity sensor
RH/T sensor
Thermocouple
Solar sensor
Wind sensor
Milking center (28 x 96 ft)
Parlor
Holding area
Each barn is 29 x 472 m
Barn 2 west end
Barn 1 west end
East end
Walkway
Cold pens
Flat monitor


Wisconsin Dairy Site WI5B (Dr. Larry Jacobson)
Barn 2
Barn 1
Barn 3
Holding
Parlor

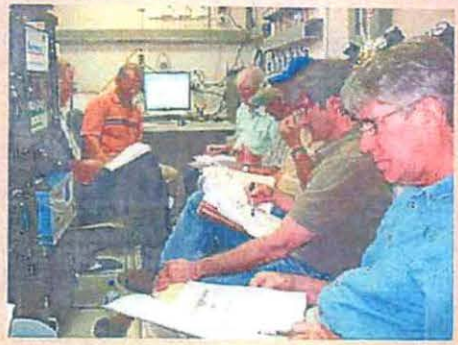

New York Dairy Site NY5B (Curt Gooch)


Washington Dairy Site WA5B (Dr. Phil Ndegwa)
Barn 2
Barn 4

Challenges "Along the Way"

Failures of OFIS HVAC, PC, analyzers	Mice damage to cables
Failures of TEOM Temp sensors, batteries	Faulty DIY TEOM cables
Storms: power outage, lightning, snow, etc.	Voltage fluctuations and electronic noise
Farm vehicle damaged equipment	Changes in farm management
Barn evacuations due to disease	Failure of fans and ventilation system
Changes in fan control strategy by farm	Fan maintenance affecting airflows
Overflowing pits	Wildfire smoke

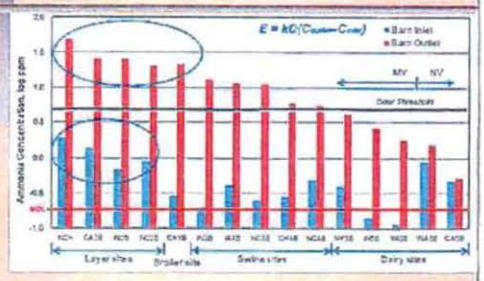
Ensuring Site Maintenance and EPA Audits



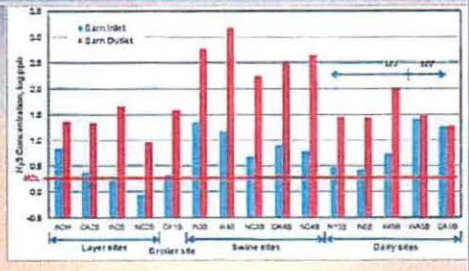
Data Completeness

Site	NH_3	H_2S	PM10	PM2.5	TSP
CA1B	457	591	364	48	38
IN2B	626	639	353	28	34
IN2H	518	363	407	13	19
NC2B	613	638	447	27	53
CA2B	593	623	489	41	34
IN3B	347	462	275	26	28
NC3B	496	498	440	42	53
IA4B	447	474	367	42	44
OK4B	588	595	454	32	76
NC4B	424	462	251	18	32
IN5B	428	480	358	29	72
WI5B	543	577	381	49	79
NY5B	403	573	450	55	58
WA5B	111	110	432	37	45
CA5B	207	241	486	51	65
Average	454	488	397	36	49
Target	548	548	456	21	66
100%	730	730	611	28	91

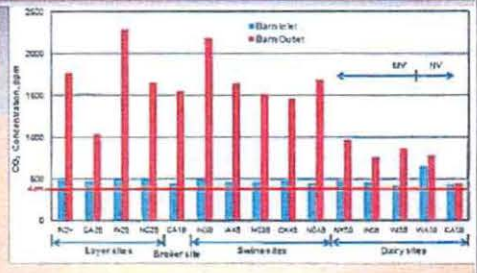
Mean Ammonia Concentrations Inlets vs. Outlets



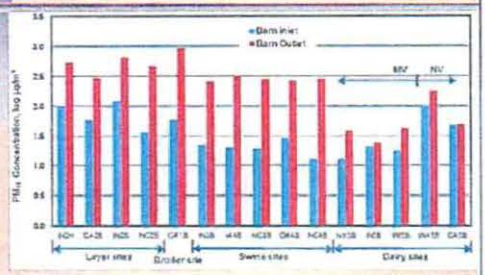
Mean H_2S Concentrations Inlets vs. Outlets



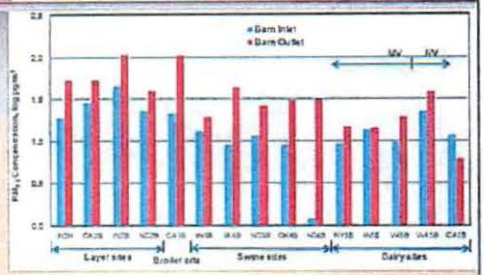
Mean CO_2 Concentrations Inlets vs. Outlets



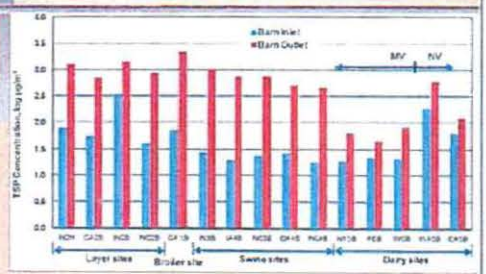
Mean PM_{10} Concentrations Inlets vs. Outlets



Mean $PM_{2.5}$ Concentrations Inlets vs. Outlets



Mean TSP Concentrations Inlets vs. Outlets



Do MV barns represent NV barns?

- Many important factors are the same in both:
  - Number, weight and age of animals
  - Feed type and schedule
  - Bedding type
  - Manure production
  - Manure collection and handling system
  - Temperature control setpoints.
- Some factors may be different but are accounted for in the NAEMS:
  - Manure and litter characteristics
  - Barn temperature and humidity
- Some factors may be different but can be predicted using computer models:
  - Air velocity across the emitting surfaces.
  - Ventilation airflow rate.

NAEMS' Unique Features

- Largest number of measured pollutants
- Longest monitoring period ever.
- Largest number of monitoring sites.
- Careful selection representative farms.
- Highest level of quality assurance/quality control.
- Most controversial air quality study ever.
- Most thoroughly planned air quality study.
- Benefited greatly from prior European research.
- Will hopefully benefit research in other countries.

Acknowledgements

- Funding
  - Agricultural Air Research Council
  - National Chicken Council, American Egg Board, National Milk Board, National Pork Board
- Cooperation and Support
  - Participating farms
  - Site PI's and Engineers
  - Data Analysts


Questions?