What Does the NAEMS Data Results Mean for Dairy Producers?

Midwest Manure Summit
Radisson Hotel & Conference Center
Green Bay, Wisconsin
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Agricultural and Biological Engineering

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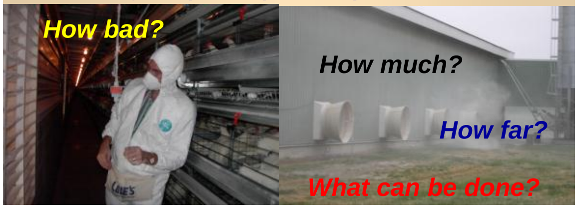
Outline

- Air Quality Conflicts/Regulations
- Air Consent Agreement
- Overview of NAEMS
- NAEMS Dairy Data
  - Comparison with literature
  - Implications for producers

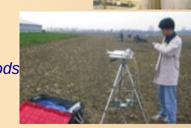
Air Emission Sources and Impacts

Air Emissions from Livestock

- Ammonia
- Hydrogen sulfide
- Volatile organic compounds (VOC)
- Particulate matter (TSP, PM_{10}, $PM_{2.5}$)
- Odor (as sensed by humans)
- Greenhouse gases (CO_2, CH_4, N_2O)
- Pathogens (viable particles)

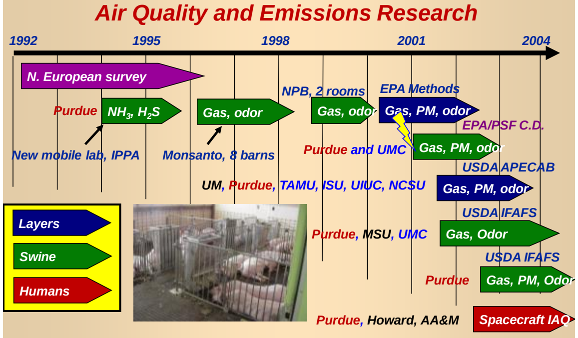


Increasing Knowledge about Emissions



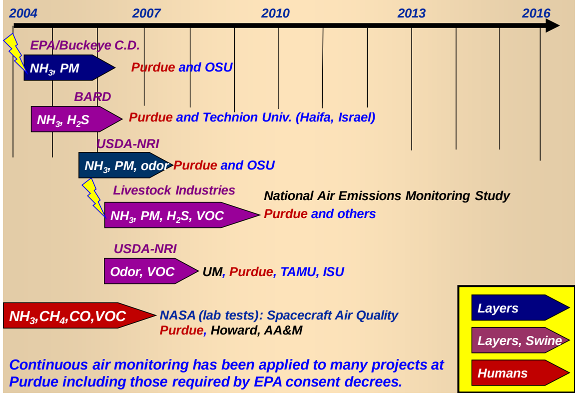
- Laboratory tests
  - Kinetics and process dynamics
  - Controlled tests of abatement ideas
- Field measurements
  - Baseline source emission rates
  - Emission characteristics
  - Demonstrations of abatement methods
  - Ambient downwind concentrations
- Scientific models
  - Process-based
  - Component emissions, e.g. barns, manure storage, etc.
  - System models (show tradeoffs and consequences)
- Regulatory models
  - Often shaped by untimely political and societal pressures
  - Marked by simplicity, unfairness, arbitrariness, and inaccuracy!
  - Can be influenced by scientific knowledge in a positive way.
- Multi-state and interdisciplinary research and education

Air Quality and Emissions Research



Our mobile lab approach began in 1994 after observing how it was done in Europe during a summer sabbatical to England in 1993.

Air Quality and Emissions Research



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

- Lawsuits and consent decrees
- 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
  - $880,000 penalty
  - Barn emissions monitoring and controls
  - Test dust and ammonia abatement
  - Brief summer tests showed 700 tpy > 250 tpy limit!

National Ambient Air Quality Standards (NAAQS)

Pollutant	Level, µg/m^3	Averaging time
PM_{10}	150 (primary and secondary)	24-h
$PM_{2.5}$	12 (primary) 15 (secondary)	Annual (3-yr average)
	35 (primary and secondary)	24-h (98th percentile, averaged over 3 yrs)

"Primary standards provide public health protection, including protecting the health of "sensitive" populations such as asthmatics, children, and the elderly. Secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings."

Source: http://epa.gov/air/criteria.html

Federal Regulations

- EPCRA (Community Right to Know Laws)
  - Must report if NH_3 or H_2S emissions ≥ 100 lbs/day
  - Failure to report may result in significant fines.
- Clean Air Act
  - National Ambient Air Quality Standards
  - "Substances of concern" (PM, NMVOC, etc.)
  - Defines "Major Source" thresholds (annual permits)
- CAFO = 700 dairy cows or 1000 calves
- U.S. EPA began regulating AFOs in 2000
- EPA lacked data to determine whether AFOs violated these regulations
- 2003: NRC panel recommended U.S. EPA improve its methods of estimating AFO emissions.

"Air Consent Agreement" (2005)

- 2005: U.S. EPA announced Air Consent Agreement: The Plan:
  - Producers fund national emissions study, and accept data.
  - EPA "lays off" enforcement until after study.
  - Over 6,000 farms voluntarily participated.
- Between U.S. EPA and livestock industries
  - Producers voluntarily paid a "penalty"
  - EPA "forgave" producers for past violations
  - Producers voluntarily participated in the NAEMS (see below)
  - EPA develops "Emission Estimation Methodologies"
  - Controversial
- National Air Emissions Monitoring Study (NAEMS)
  - Required by Air Consent Agreement
  - EPA oversight
  - Funded by egg, pork, dairy, chicken checkoff dollars.
  - Turkeys, ducks and beef groups declined participation

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.

Washington Dairy (Site WA5B)

NAEMS Approach

- Livestock barns (38) and manure storages (9) tested with same protocols to determine baseline emissions
  - Real-time barn emissions for two years – 2300 sensors, 2.5B data pts.
  - Subtracted inlet from outlet concentrations.
  - Manure storages for 2 weeks per season
- Quality assurance/quality control
  - Oversight of U.S. EPA Office of Air Quality
  - Quality Assurance Project Plan (Category 1)
  - On-site audits
- Pollutants: $PM_{2.5}$, PM_{10}, TSP, NH_3, H_2S, CO_2, CH_4, VOC
- Add-on studies measured N_20, odor and pathogens.
- Collected as much "metadata" as possible.
  - Weather: wind, temperature, humidity, barometric pressure, solar.
  - Environment: temperature, humidity
  - Process: worker and cow activity, flushing, fans
  - Biomaterials: manure, feed, bedding, milk, water

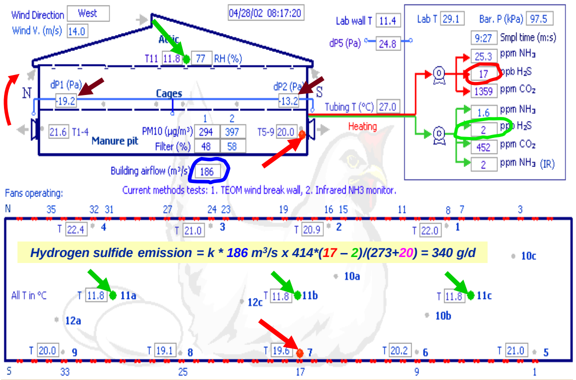
General Timeline of the NAEMS

2004	Protocol Development and Farm Selection Criteria
2005	PI Selection, Staffing, Budgeting, Producer Education
2006	Site Selection, Quality Assurance Project Plan
2007	Setup of Emission Monitoring at 20 Farms
2008	Data Collection, Analysis & Reporting, Audits
2009	Data Collection, Analysis & Reporting, Audits (1)
2010	Submit Final Report to EPA, Further Analysis (2)
2011	EPA Worked on EEMs, Further Analysis, Publish (3)
2012	SAP, EPA Worked on EEMs, Publish (14)
2013	SAP, EPA Publishes EEMs, Publish

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

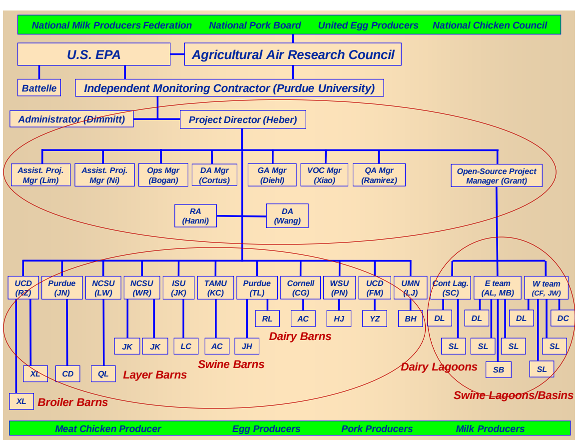
- Tests required by consent decrees or agreements typically funded by industry.
- AARC oversaw budgets and deadlines.
- EPA oversaw methods and data quality.
- NAEMS followed protocols of past studies and improved methods where possible.
- "Independent Monitoring Contractor" maintained independence/neutrality.

Measuring/Calculating Barn Emissions



The NAEMS did not:

- *Monitor downwind exposure*
  - *Monitored barn inlet air, not comparable to NAAQS*
- *Monitor worker/animal exposure*
  - *"Emission concentrations" were measured.*
- *Remove/adjust valid negative concentrations*
  - *Calibration zero offsets caused slight negative concentrations due to instrument noise.*
- *Remove/adjust valid negative emissions*
  - *Brief negative emissions were calculated when background > exhaust concentrations.*



Timeline Since Data Submission

7/31/10 Data reports (6,211 pages) submitted to EPA

Dairy: 1,420 pp (barns) + 616 pp (open) = 2,036 pages

9/27/10 AAQTF Air Emissions Standardization Workshop, NC

1/13/11 EPA posted data to "www.epa.gov/airquality/agmonitoring/data.html"

6/30/11 536 pages of data analysis submitted to National Pork Board

8/4/11 NAEMS-related ASABE papers (14) presented in Louisville

2/1/12 EPA announced new Science Advisory Board

Review EPA's Emissions Estimation Methodologies

First meeting March 15-17, 2012

Second meeting March 7-8, 2013

2/29/12 181 pages of data analysis submitted to United Egg Producers

7/24/12 379 pages of data analysis submitted to Dairy Research Institute\

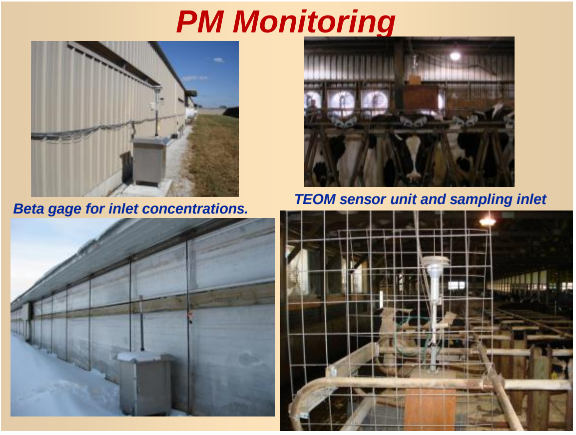
12/31/12 20th journal article: NAEMS methods, data and add-on studies.

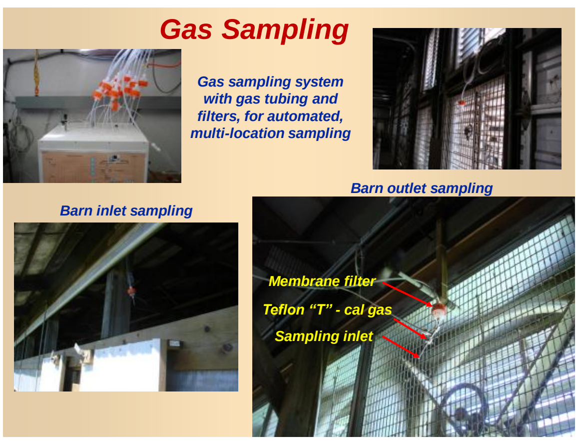
NAEMS Journal Articles (Published)

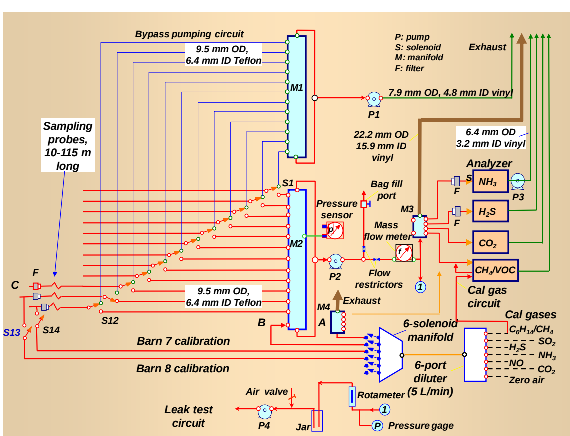
1. Joo ... '13. Particulate matter emissions from naturally-ventilated freestall dairy barns. Atm Env 69:182-190.
2. Akdeniz ... '12. Odor & chem. emissions: Pt. 2 – Odor emissions. T ASABE 55(6):2335-2345.
3. Akdeniz ... '12. Odor & chem. emissions: Pt 4 – Corr. between sens. & chem. emissions. T ASABE 55(6):2347-2356.
4. Bereznicki … '12. Odor & chem. emissions: Pt. 1 – Project overview, collection meth. & QC. T ASABE 55(6):2325-2334.
5. Chai ... '12. Ventilation rates at large commercial layer houses with 2-yr continuous mon. Brit. Poul. Sci. 53(1):19-31.
6. Jin ... '12. Emissions mon. at a deep-pit finishing facility: Res. methods & system perf. J AWMA 62(11):1264-1276.
7. Li ... '12. Field evaluation of PM measurements using TEOM in a layer house. J. AWMA 62(3):322-335.
8. Lim ... '12. Field evaluation of biofilters at a commercial pig finishing barn. Bio. Eng. 112(3): 192-201.
9. Lin ... '12. NH3, H2S, CO2 and PM emissions from commercial high-rise layer buildings. Atm. Env. 46:81-91.
10. Lin ... '12. Thermal environmental control of high-rise layer houses in California. T ASABE 55(5):1909-1920.
11. Lin ... '12. Air emissions from broiler buildings in California. T ASABE 55(5):1895-1908.
12. Ni ... '12. Assessment of NH3 emissions from swine farms: Application of knowledge from exp. Res. ES&P 22:25-35.
13. Ni ... '12. Volatile organic compounds at swine facilities: A critical review. Chemo. 89:769-788.
14. Ni ... '12. Charact. of NH3, H2S, CO2, PM conc. in high-rise and manure-belt layer houses. Atm. Env. 57:165-174.
15. Parker ... '12. Odor & chem. emissions: Pt. 6 – Odor activity. T ASABE 55(6):2357-2368.
16. Chen ... '11. Large scale appl. of vibration sensors for fan monitoring at layer houses. Sensors 10(12):11590-11604.
17. Lin ... '11. Ventilation monitoring of broiler houses in California. Trans. ASABE 54(3):1059-1068.
18. Ni, J. … '11. Imp. NH3 emission modeling & inv by data mining & intelligent interp. air quality data. Atm 2(2):110-128.
19. Chai ... '10. Assessment of long-term gas sampling design at 2 manure-belt layer barns. J. AWMA 60:702-710.
20. Ni ... '10. An on-site computer system for comprehensive AAQ research. Comp. & Elect. Ag. 71(1): 38-49.
21. Ni ... '09. AQ monitoring & on-site computer systems for livestock & poultry env. studies. T. ASABE 52(3):937-947.

NAEMS Journal Articles (Submitted)

1. Wang-Li, et al. (1/7/13). NAEMS – SE layer site: Pt I - site specifics & monitoring methodology. T ASABE.
2. Li, et al. (1/14/13). NAEMS – SE layer site: Pt II – particulate matter. T ASABE.
3. Wang-Li, et al. (1/24/13). NAEMS - Southeast layer site: Pt III – NH_3 concentrations & emissions. T ASABE.
4. Li, et al. (2/10/13). NAEMS - Southeast layer site: Pt IV -impacts of house management practices. T ASABE.
5. Zhang, et al. (1/24/12). Odor & chem. emissions animal bldgs: Pt 5 – Correlations. T ASABE.
6. Cai, et al. (1/17/12). Odor & odorous chem. emissions animal bldgs: Pt 3 – Chemical emissions. T ASABE.
7. Grant, et al. (1-30-13). Ammonia emissions from lagoons at sow & finishing farms in OK. Atm Env.


PM Monitoring
Beta gage for inlet concentrations.
TEOM sensor unit and sampling inlet

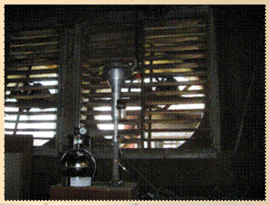

Gas Sampling
Gas sampling system with gas tubing and filters, for automated, multi-location sampling
Barn outlet sampling
Barn inlet sampling
Membrane filter
Teflon "T" - cal gas
Sampling inlet


Bypass pumping circuit
9.5 mm OD, 6.4 mm ID Teflon
P: pump
S: solenoid
M: manifold
F: filter
Exhaust
M1
7.9 mm OD, 4.8 mm ID vinyl
P1
Sampling probes, 10-115 m long
22.2 mm OD 15.9 mm ID vinyl
6.4 mm OD 3.2 mm ID vinyl
Analyzer
S1
Bag fill port
Pressure sensor
M3
NH_3
P3
H_2S
F
Mass flow meter
CO_2
M2
P2
CH_4/VOC
Flow restrictors
C
F
9.5 mm OD, 6.4 mm ID Teflon
Cal gas circuit
M4
Exhaust
Cal gases
S13
S14
S12
B
A
6-solenoid manifold
C_6H_{14}/CH_4
SO_2
H_2S
NH_3
NO
CO_2
Zero air
Barn 7 calibration
Barn 8 calibration
6-port diluter
Air valve
Rotameter (5 L/min)
Leak test circuit
P4
Jar
Pressure gage

VOC Sampling and Analysis

24-h sampling at barn outlets

Canisters

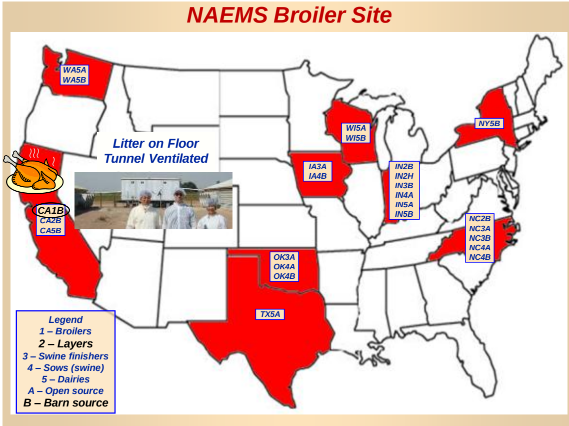


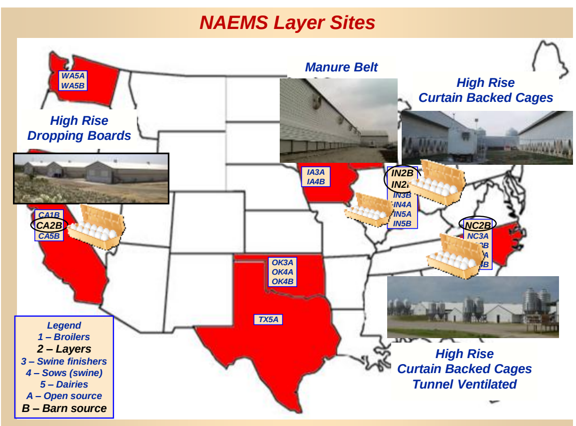
Summary of NAEMS Sites

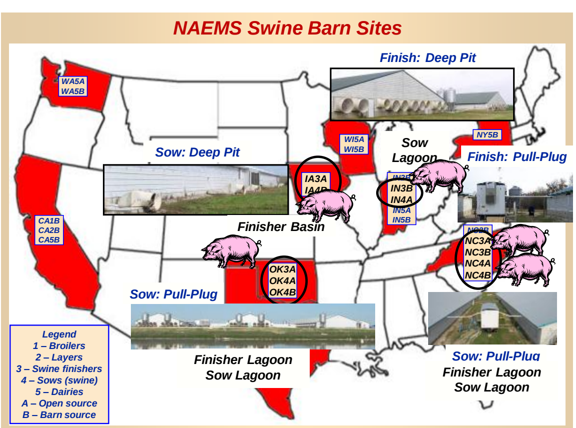
Species	Barns per Site			Total number		Number of Area Sites			
	2-b	3-b	4-b	Sites	Barns	Corrals	Lagoons	Basins	Total
Swine	0	4	1	5	16	0	5	1	6
Dairy	5	0	0	5	10	1	3	0	4
Layers	4	0	0	3	8	0	0	0	0
Broilers	1	0	0	1	2	0	0	0	0
Total	6	6	2	14	38	1	8	1	10

MV barns represent NV barns

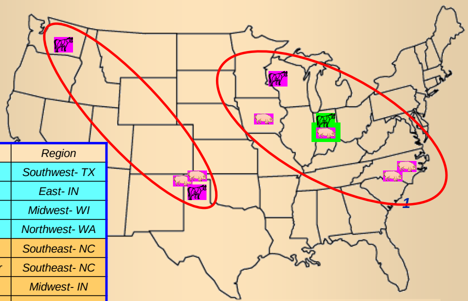
- *Many important factors are the same:*
  - *Cattle inventory, weight and age*
  - *Feed type and schedule*
  - *Bedding type*
  - *Manure production, collection and handling*
  - *Temperature control setpoints.*
- *Some factors were accounted for:*
  - *Manure and litter characteristics*
  - *Barn temperature and humidity*
- *Some factors can be predicted using models:*
  - *Air velocity across the emitting surfaces.*
  - *Ventilation airflow rate.*


NAEMS Broiler Site
WA5A
WA5B
WI5A
WI5B
NY5B
Litter on Floor
Tunnel Ventilated
IA3A
IA4B
IN2B
IN2H
IN3B
IN4A
IN5A
IN5B
CA1B
CA2B
CA5B
NC2B
NC3A
NC3B
NC4A
NC4B
OK3A
OK4A
OK4B
TX5A
Legend
1 – Broilers
2 – Layers
3 – Swine finishers
4 – Sows (swine)
5 – Dairies
A – Open source
B – Barn source


NAEMS Layer Sites
WA5A
WA5B
Manure Belt
High Rise
Curtain Backed Cages
High Rise
Dropping Boards
IA3A
IA4B
IN2B
CA1B
CA2B
CA5B
NC2B
NC3A
OK3A
OK4A
OK4B
TX5A
Legend
1 – Broilers
2 – Layers
3 – Swine finishers
4 – Sows (swine)
5 – Dairies
A – Open source
B – Barn source
High Rise
Curtain Backed Cages
Tunnel Ventilated


NAEMS Swine Barn Sites
Finish: Deep Pit
WA5A
WA5B
WI5A
WI5B
NY5B
Sow
Lagoon
Finish: Pull-Plug
Sow: Deep Pit
IA3A
IN3B
IN4A
IN5B
CA1B
CA2B
CA5B
Finisher Basin
NC3A
NC3B
NC4A
NC4B
OK3A
OK4A
OK4B
Sow: Pull-Plug
Legend
1 – Broilers
2 – Layers
3 – Swine finishers
4 – Sows (swine)
5 – Dairies
A – Open source
B – Barn source
Finisher Lagoon
Sow Lagoon
Sow: Pull-Plug
Finisher Lagoon
Sow Lagoon

Open Source Measurement Sites (Dr. Rich Grant)



Type	Region
Dairy	Southwest- TX
Dairy	East- IN
Dairy	Midwest- WI
Dairy	Northwest- WA
Pork-sow	Southeast- NC
Pork-finisher	Southeast- NC
Pork-sow	Midwest- IN
Pork-finisher	Midwest- IA
Pork-sow	West- OK
Pork-finisher	West- OK

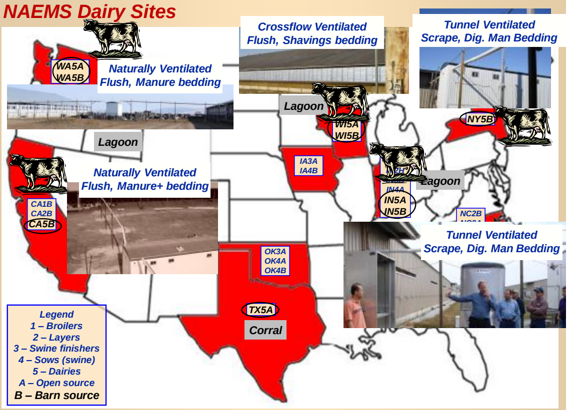
Roving teams visited each area source once each quarter

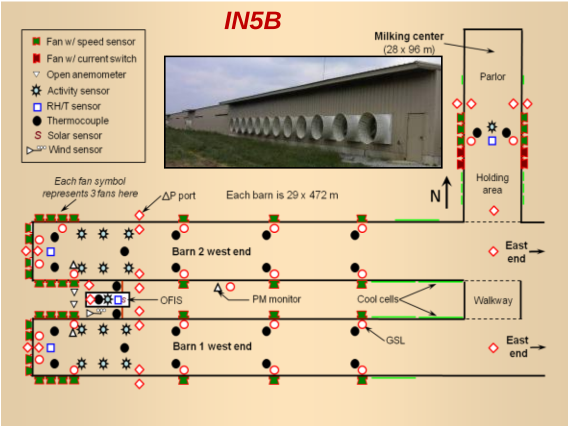
Source: Dr. Rich Grant, Purdue University, April, 2008

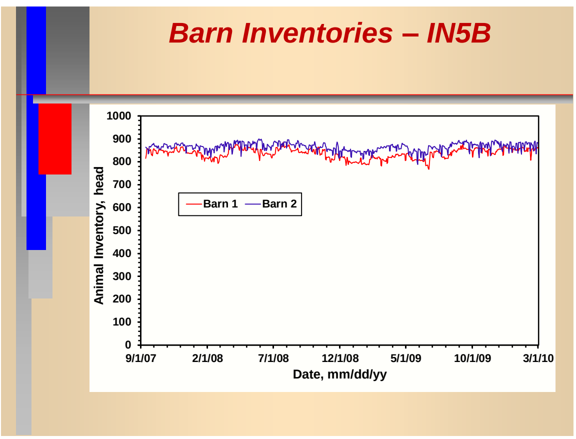
Monitored Dairy Freestall Sites

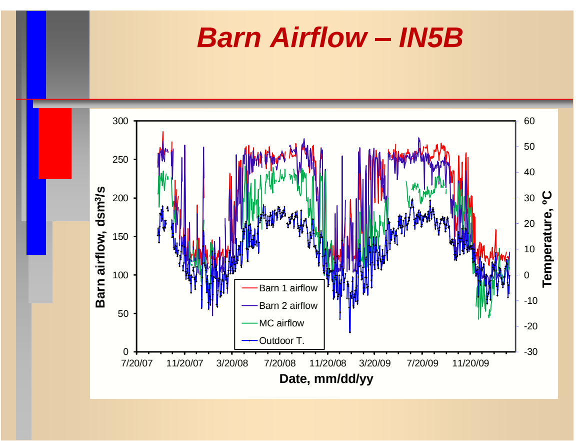
- IN5B
  - 2 MV barns and a milking center, manure scraping, 1600 cows/barn.
  - Bedding: separated digested manure solids
- NY5B
  - 1 MV freestall barn and 1 milking center, manure scraping
  - 493 cows per barn
  - Bedding: separated digested manure solids
- WI5B
  - 2 MV freestall barns with 275 and 375 cows.
  - First-year flushing system and second-year scraping system
  - Bedding: mattress/shavings
- WA5B
  - 2 NV freestall barns with curtains, flushing (400 and 850 cows/barn)
  - Bedding: separated manure solids
  - Dry exercise lots

NAEMS Dairy Sites

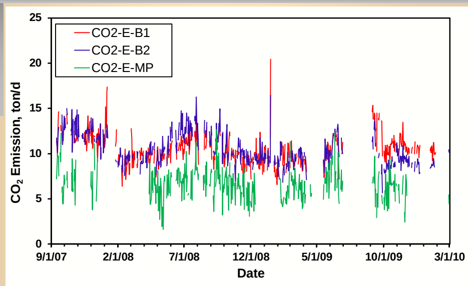



IN5B
Fan w/ speed sensor
Fan w/ current switch
Open anemometer
Activity sensor
RH/T sensor
Thermocouple
Solar sensor
Wind sensor
Milking center
(28 x 96 m)
Parlor
Holding area
Each fan symbol represents 3 fans here
ΔP port
Each barn is 29 x 472 m
N
Barn 2 west end
East end
OFIS
PM monitor
Cool cells
Walkway
Barn 1 west end
GSL
East end


Barn Inventories – IN5B
Animal Inventory, head
Barn 1
Barn 2
Date, mm/dd/yy
9/1/07
2/1/08
7/1/08
12/1/08
5/1/09
10/1/09
3/1/10


Barn Airflow – IN5B
Barn airflow, dsm³/s
Temperature, °C
Barn 1 airflow
Barn 2 airflow
MC airflow
Outdoor T.
Date, mm/dd/yy
7/20/07
11/20/07
3/20/08
7/20/08
11/20/08
3/20/09
7/20/09
11/20/09

CO_2 Emission – IN5B



Daily Mean Emission Rates

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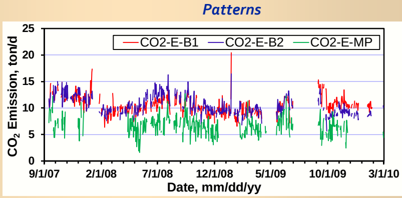
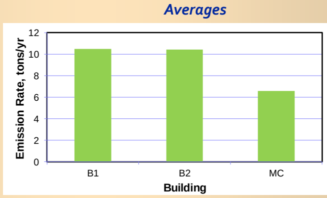
Average Daily Mean Emission Rates

Patterns

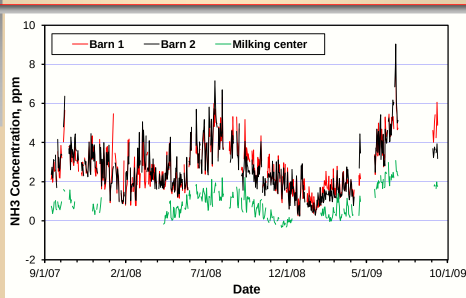


Averages

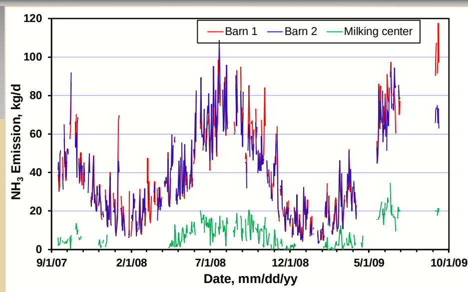


Source: Erin Cortus, SDSU

NH_3 Concentrations – IN5B



Barn NH_3 Emission – IN5B



Emission Normalization

Emission Rates

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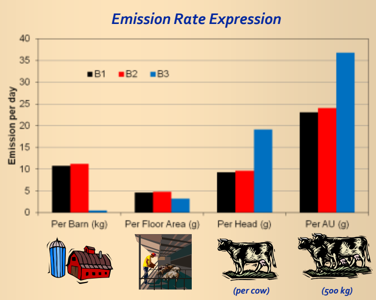
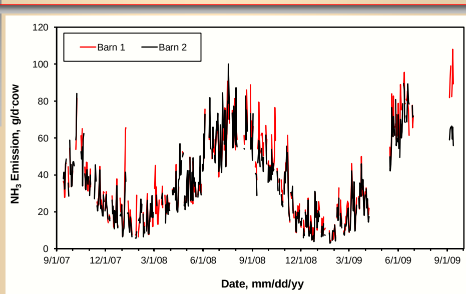
Variable-Specific Emission Rates

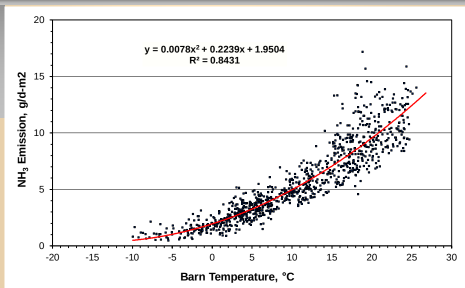


Source: Erin Cortus, SDSU

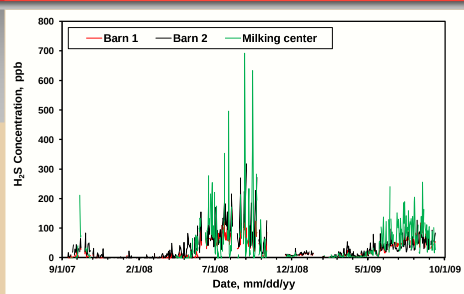
Cow-Specific Ammonia Emissions - IN5B



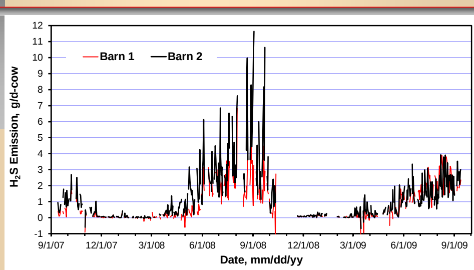
Ammonia Emission vs. Barn Temperature – IN5B

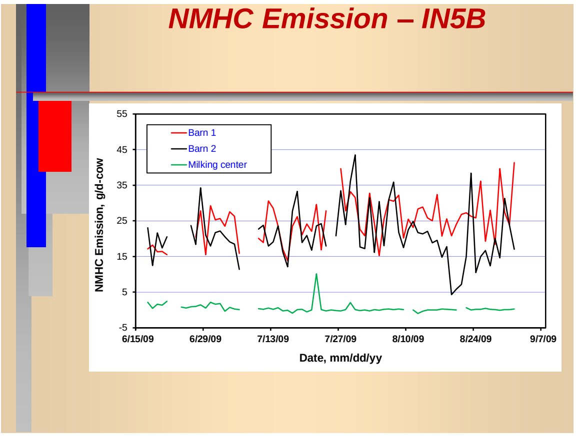


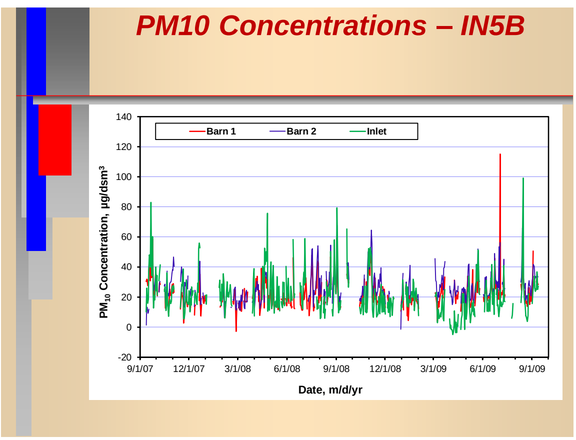
H_2S Concentration – IN5B

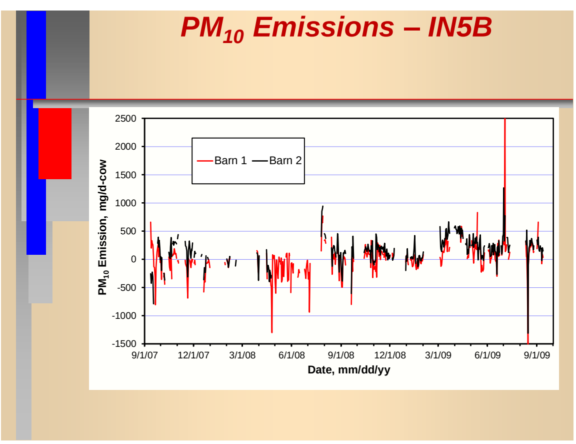


H_2S Emission – IN5B

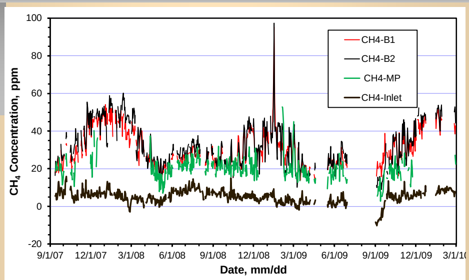



NMHC Emission – IN5B
Barn 1
Barn 2
Milking center
NMHC Emission, g/d-cow
55
45
35
25
15
5
-5
6/15/09
6/29/09
7/13/09
7/27/09
8/10/09
8/24/09
9/7/09
Date, mm/dd/yy

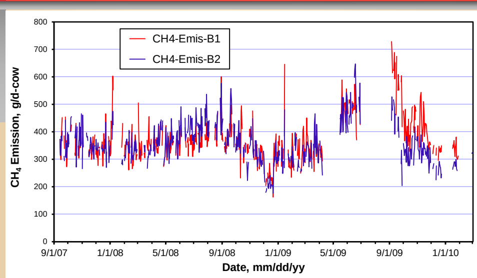

PM10 Concentrations – IN5B
Barn 1
Barn 2
Inlet
PM10 Concentration, µg/dsm3
140
120
100
80
60
40
20
0
-20
9/1/07
12/1/07
3/1/08
6/1/08
9/1/08
12/1/08
3/1/09
6/1/09
9/1/09
Date, m/d/yr


PM10 Emissions – IN5B
Barn 1
Barn 2
PM10 Emission, mg/d-cow
2500
2000
1500
1000
500
0
-500
-1000
-1500
9/1/07
12/1/07
3/1/08
6/1/08
9/1/08
12/1/08
3/1/09
6/1/09
9/1/09
Date, mm/dd/yy

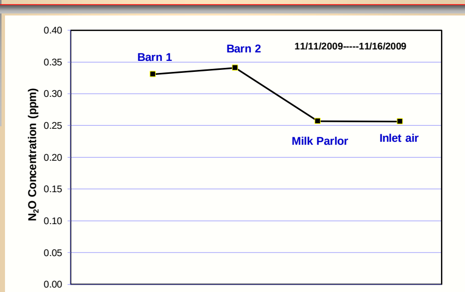
Methane Concentrations – IN5B



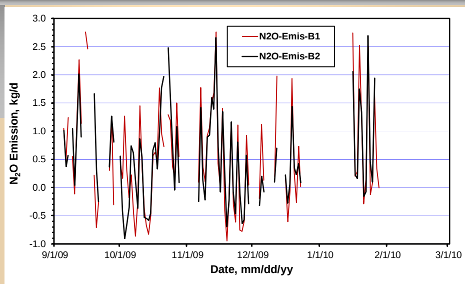
Methane Emission – IN5B



N2O Concentrations – IN5B

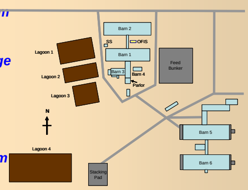


N_2O Emission – IN5B

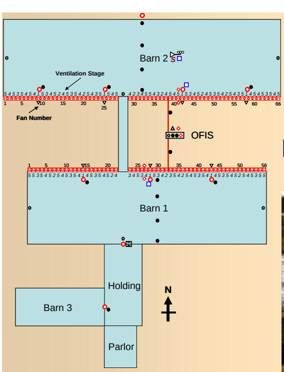


WI Dairy

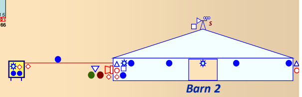
- **Barn 1**
  - 275-hd capacity; average 210 cows
  - Includes emissions from parlor
- **Barn 2**
  - 375-hd capacity; average 350 cows
- **Barn Features**
  - Retrofitted cross-flow ventilation
- **Key events**
  - Manure handling system change
  - Bedding change
  - Other farming operations



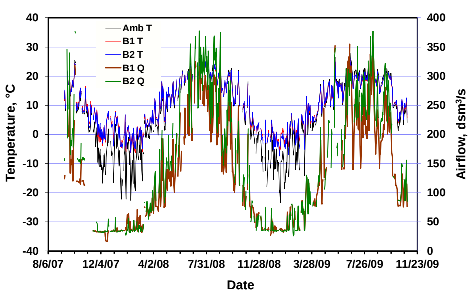
Source: Erin Cortus, SDSU



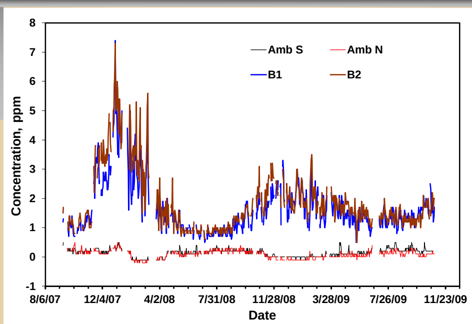
Wisconsin Dairy Site WI5B (Dr. Larry Jacobson)



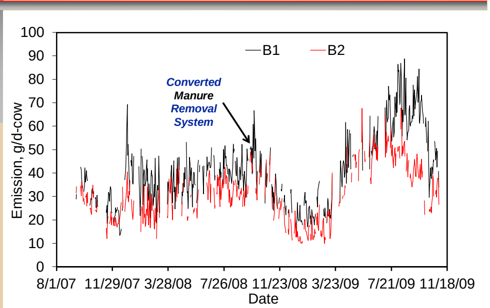
Temperature and Airflow - WI5B



Ammonia Concentration - WI5B

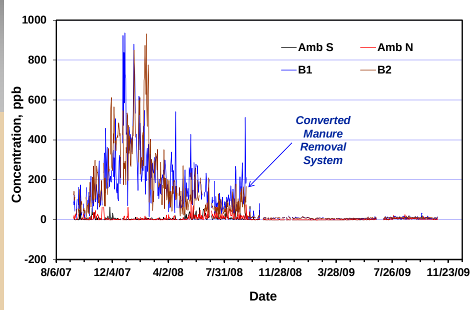


Ammonia Emission – WI5B

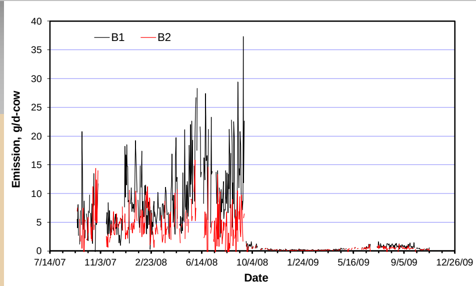


Source: Erin Cortus, SDSU

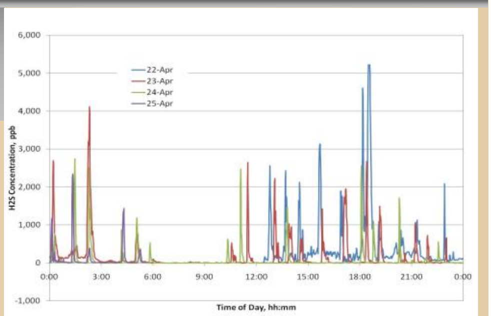
H_2S Concentration - WI5B



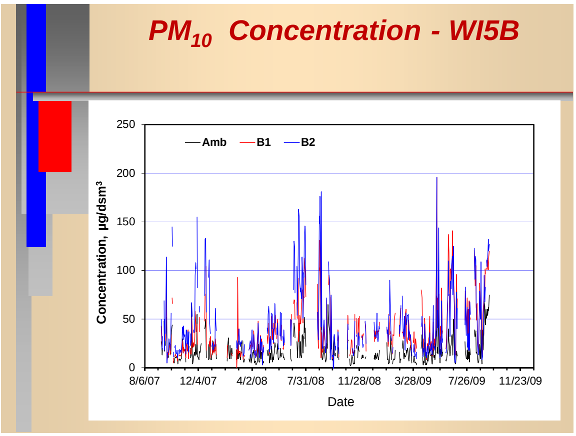
H_2S Emission - WI5B

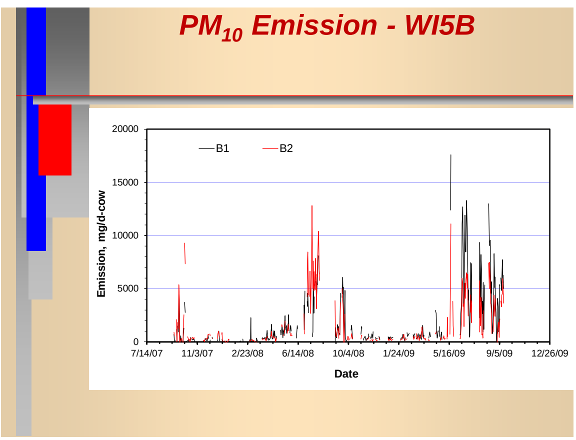


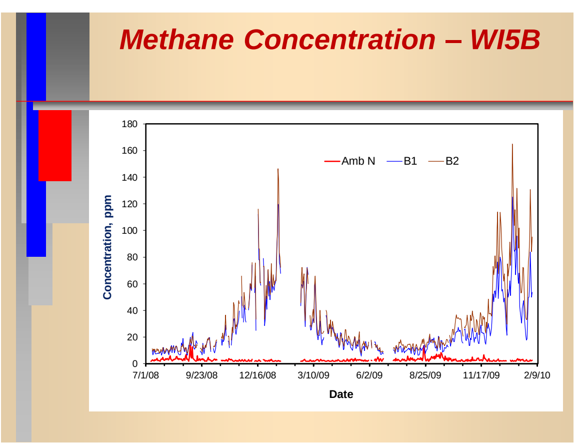
H2S Concentrations at WI5B with Flushing System



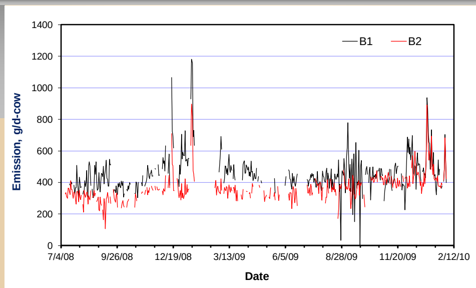
Source: Erin Cortus, SDSU


PM10 Concentration - WI5B
Amb
B1
B2
Concentration, µg/dsm³
250
200
150
100
50
0
8/6/07
12/4/07
4/2/08
7/31/08
11/28/08
3/28/09
7/26/09
11/23/09
Date

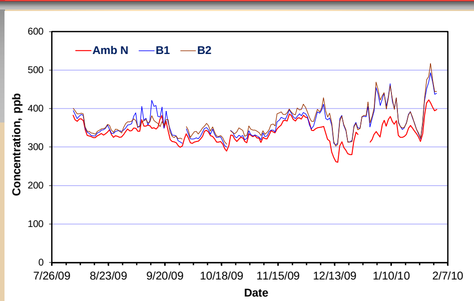

PM10 Emission - WI5B
B1
B2
Emission, mg/d-cow
20000
15000
10000
5000
0
7/14/07
11/3/07
2/23/08
6/14/08
10/4/08
1/24/09
5/16/09
9/5/09
12/26/09
Date


Methane Concentration – WI5B
Amb N
B1
B2
Concentration, ppm
180
160
140
120
100
80
60
40
20
0
7/1/08
9/23/08
12/16/08
3/10/09
6/2/09
8/25/09
11/17/09
2/9/10
Date

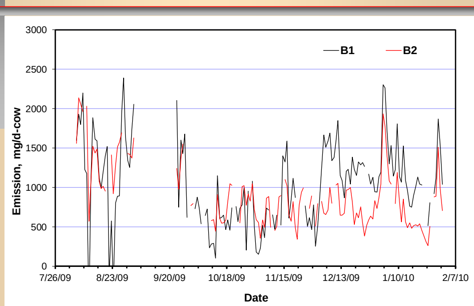
Methane Emission – WI5B



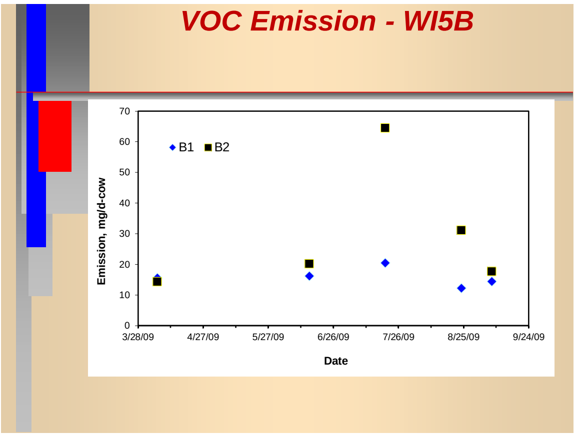
N_2O Concentration – WI5B

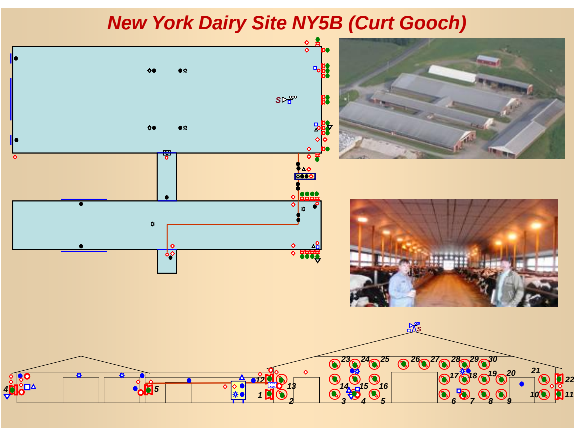


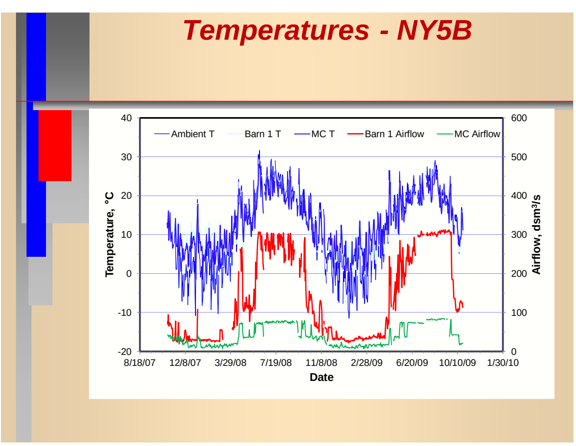
Nitrous Oxide Emission – WI5B



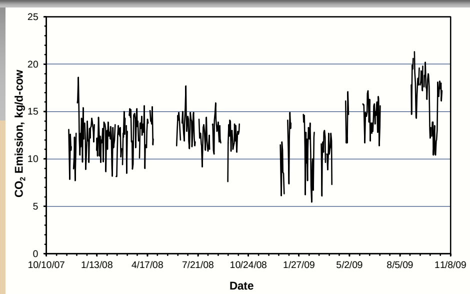
Source: Erin Cortus, SDSU


VOC Emission - WI5B
B1
B2
Emission, mg/d-cow
70
60
50
40
30
20
10
0
3/28/09
4/27/09
5/27/09
6/26/09
7/26/09
8/25/09
9/24/09
Date

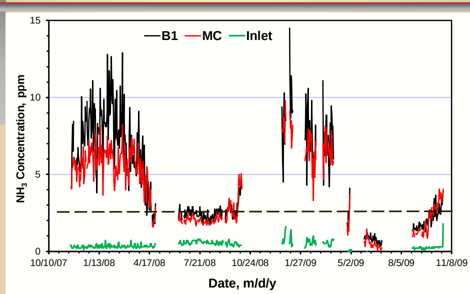

New York Dairy Site NY5B (Curt Gooch)


Temperatures - NY5B
Ambient T
Barn 1 T
MC T
Barn 1 Airflow
MC Airflow
Temperature, °C
Airflow, dsm³/s
40
30
20
10
0
-10
-20
600
500
400
300
200
100
0
8/18/07
12/8/07
3/29/08
7/19/08
11/8/08
2/28/09
6/20/09
10/10/09
1/30/10
Date

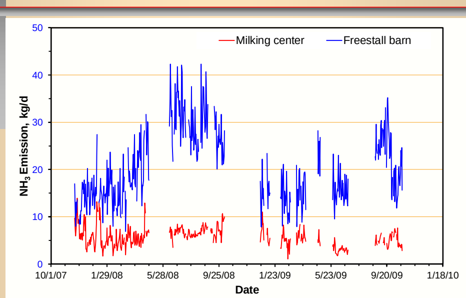
CO_2 Emissions – NY5B



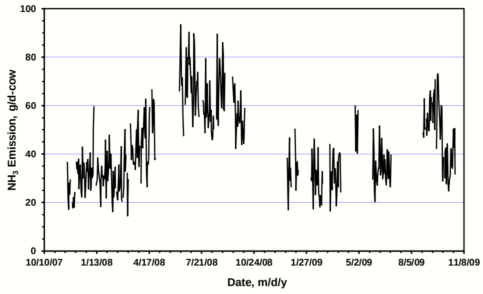
NH_3 Concentrations – NY5B



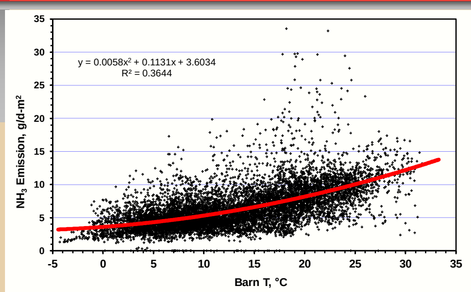
Barn-Specific NH_3 emissions – NY5B



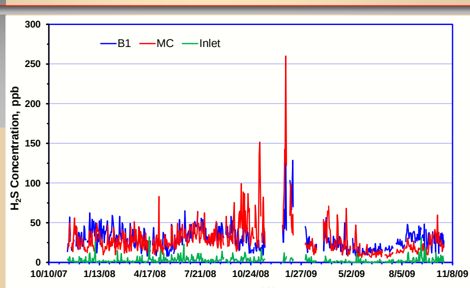
Freestall NH_3 Emissions – NY5B



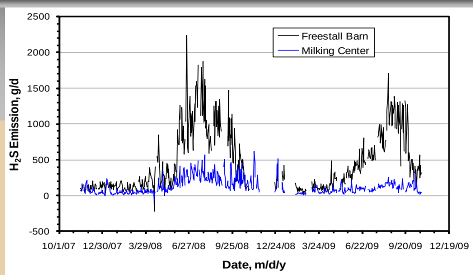
NH_3 Emissions v. Barn T - NY5B



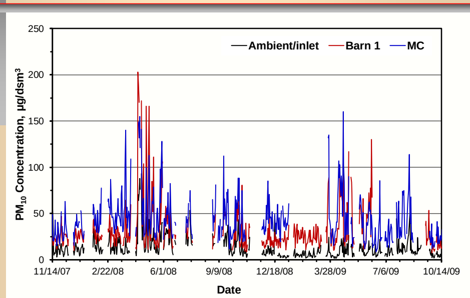
Mean H_2S Concentrations – NY5B



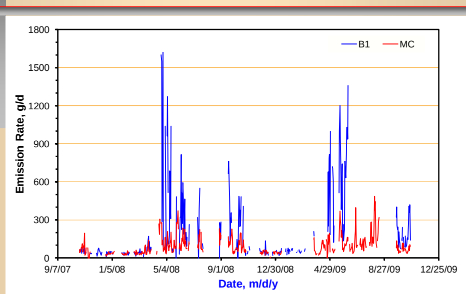
Freestall H_2S Emissions - NY5B

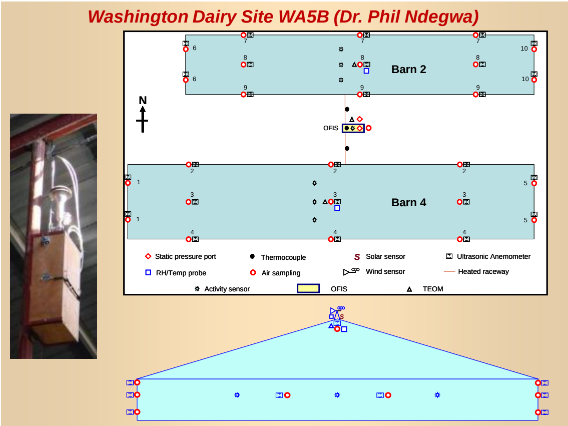


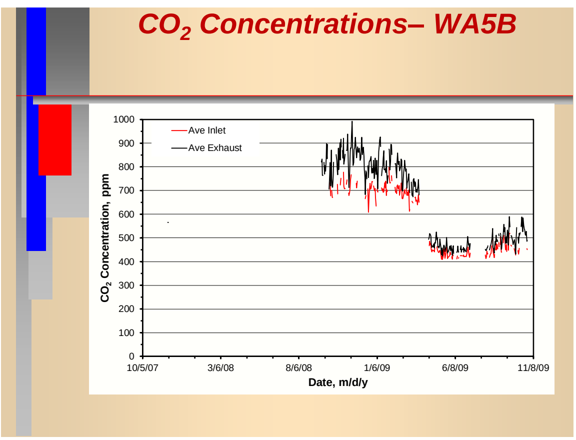
PM_{10} Concentrations – NY5B

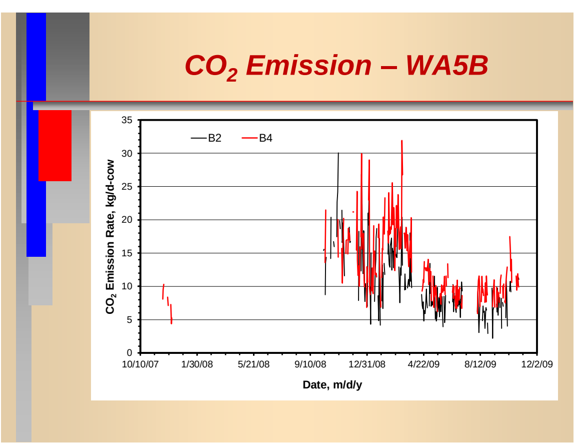


PM_{10} Emission Rate - NY5B

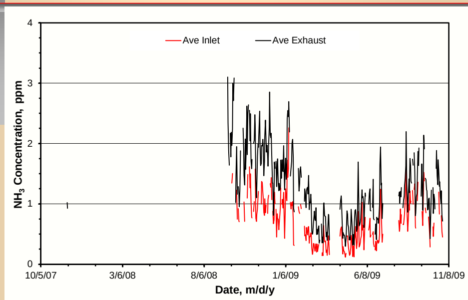



Washington Dairy Site WA5B (Dr. Phil Ndegwa)
Barn 2
Barn 4
N
OFIS
Static pressure port
Thermocouple
Solar sensor
Ultrasonic Anemometer
RH/Temp probe
Air sampling
Wind sensor
Heated raceway
Activity sensor
OFIS
TEOM

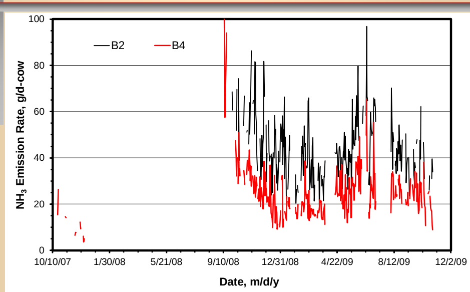

CO2 Concentrations– WA5B
Ave Inlet
Ave Exhaust
CO2 Concentration, ppm
1000
900
800
700
600
500
400
300
200
100
0
10/5/07
3/6/08
8/6/08
1/6/09
6/8/09
11/8/09
Date, m/d/y


CO2 Emission – WA5B
B2
B4
CO2 Emission Rate, kg/d-cow
35
30
25
20
15
10
5
0
10/10/07
1/30/08
5/21/08
9/10/08
12/31/08
4/22/09
8/12/09
12/2/09
Date, m/d/y

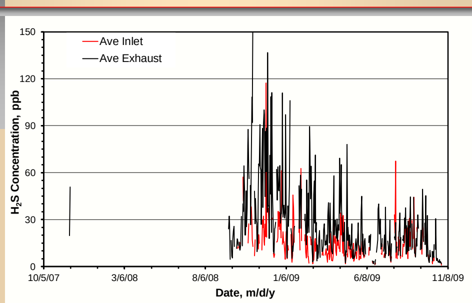
NH_3 Concentrations – WA5B

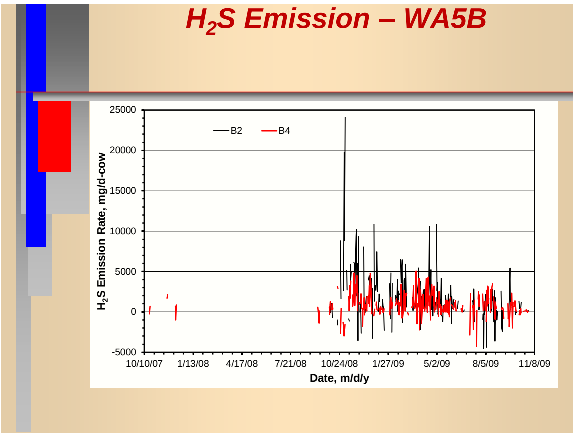


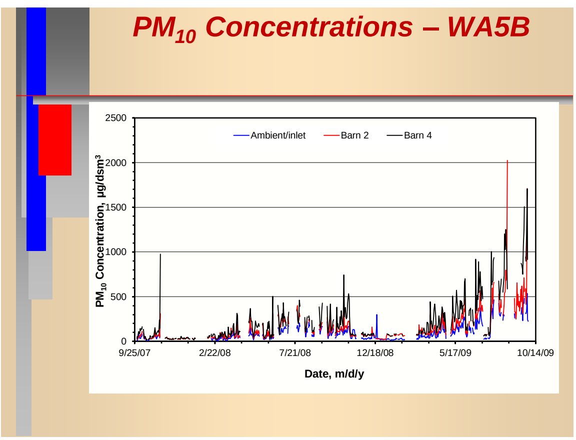
NH_3 Emission – WA5B

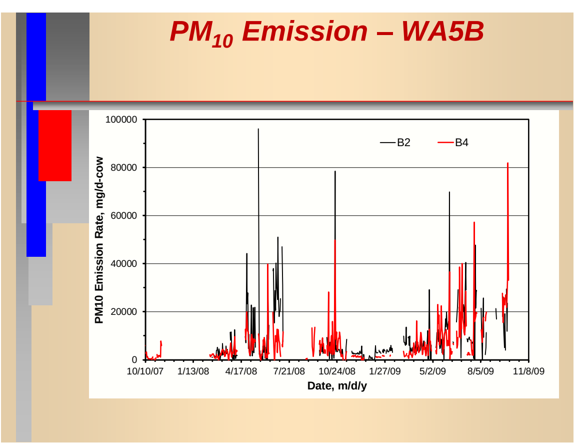


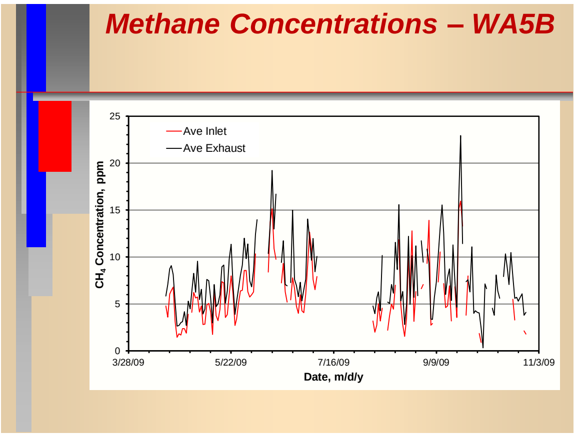
H_2S Concentrations – WA5B

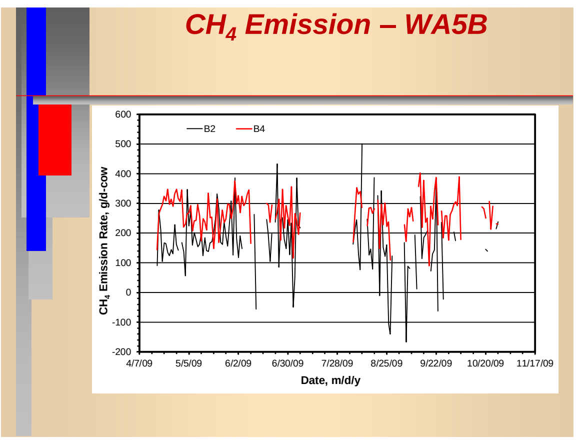


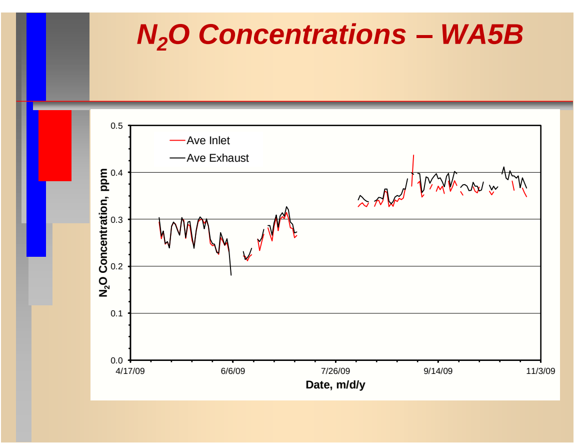

H2S Emission – WA5B
B2
B4
H2S Emission Rate, mg/d-cow
25000
20000
15000
10000
5000
0
-5000
10/10/07
1/13/08
4/17/08
7/21/08
10/24/08
1/27/09
5/2/09
8/5/09
11/8/09
Date, m/d/y


PM10 Concentrations – WA5B
Ambient/inlet
Barn 2
Barn 4
PM10 Concentration, µg/dsm3
2500
2000
1500
1000
500
0
9/25/07
2/22/08
7/21/08
12/18/08
5/17/09
10/14/09
Date, m/d/y

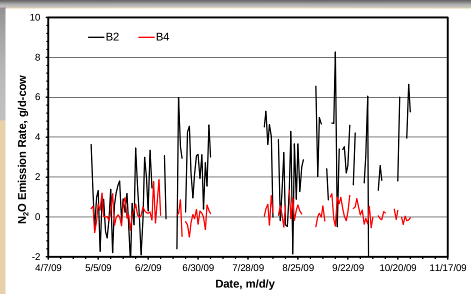

PM10 Emission – WA5B
B2
B4
PM10 Emission Rate, mg/d-cow
100000
80000
60000
40000
20000
0
10/10/07
1/13/08
4/17/08
7/21/08
10/24/08
1/27/09
5/2/09
8/5/09
11/8/09
Date, m/d/y


Methane Concentrations – WA5B
Ave Inlet
Ave Exhaust
CH4 Concentration, ppm
Date, m/d/y
3/28/09
5/22/09
7/16/09
9/9/09
11/3/09

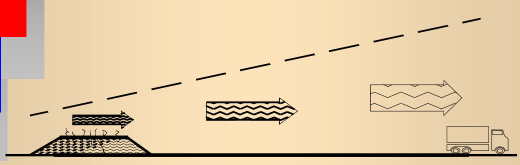

CH4 Emission – WA5B
B2
B4
CH4 Emission Rate, g/d-cow
Date, m/d/y
4/7/09
5/5/09
6/2/09
6/30/09
7/28/09
8/25/09
9/22/09
10/20/09
11/17/09


N2O Concentrations – WA5B
Ave Inlet
Ave Exhaust
N2O Concentration, ppm
Date, m/d/y
4/17/09
6/6/09
7/26/09
9/14/09
11/3/09

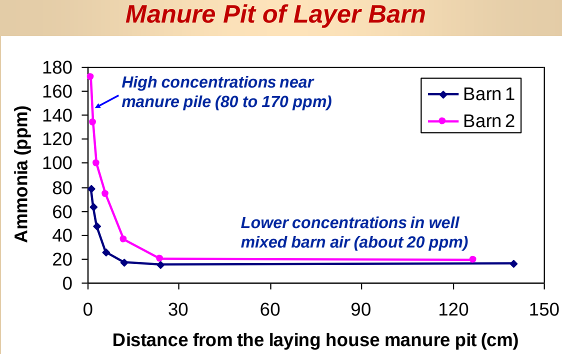
N_2O Emission – WA5B



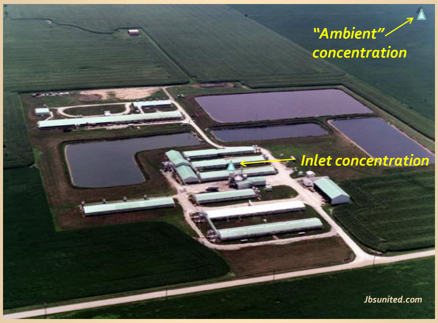
Pollutant Dispersion



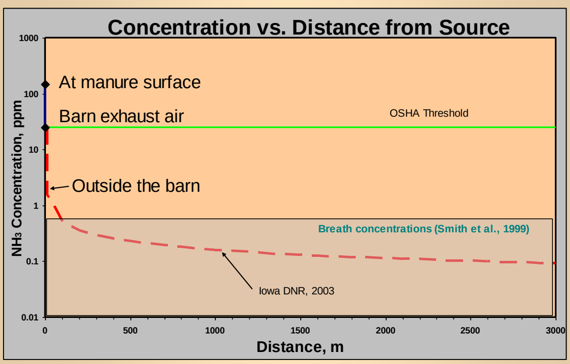
Vertical Gradients of Ammonia in in the Manure Pit of Layer Barn



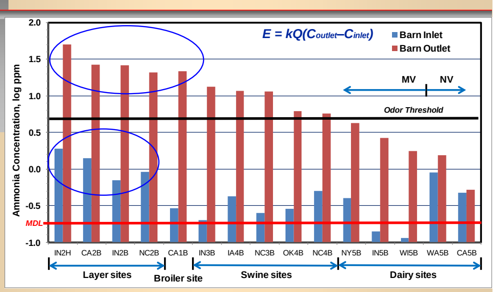
Inlet vs. Ambient Concentrations



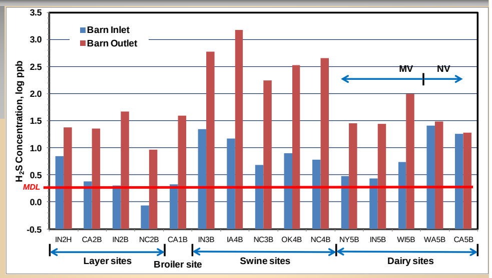
Typical Ammonia Concentrations



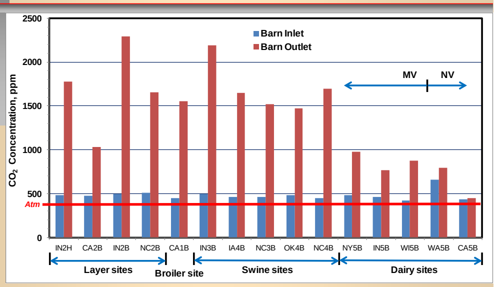
Mean Ammonia Concentrations Inlets vs. Outlets



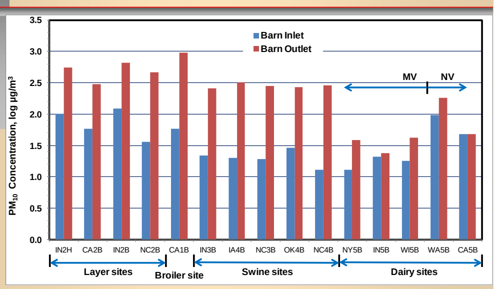
Mean H_2S Concentrations Inlets vs. Outlets



Mean CO_2 Concentrations Inlets vs. Outlets



Mean PM_{10} Concentrations Inlets vs. Outlets

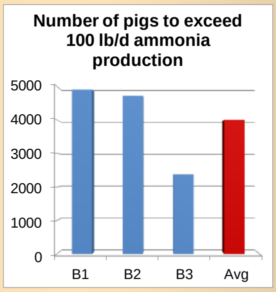


Inventory to Exceed Regulatory Threshold

Average Emission Rate Per Head

⇩

Number to Exceed Regulatory Threshold



Note: A lower inventory means a higher emission rate.

Source: Erin Cortus, SDSU

Average CO_2 emission rates, kg/d-cow

Site	Barn 1	Barn 2	Barn Avg	Lagoon	Farm
Indiana (scrape) incl. MC	14.6	14.2	14.4	0.50	14.9
New York (scrape) incl. MC	14.8	-	14.8	0.50	15.3
Wisconsin (scrape)	18.6	13.6	16.1	**0.50**	16.6
Average (scrape)			15.1	0.50	15.6
Wisconsin (flush)	18.4	13.4	15.9	**0.50**	16.4
Washington (flush)	11.1	13.3	12.2	0.50	12.7
Average (flush)			14.1	0.50	14.6
Overall average			14.6	0.50	15.1

Literature: 11.5 to 12.7 g/d-cow

Average NH_3 Emission Rates, g/d-cow

Site	Barn 1	Barn 2	Barn Avg	Storage	Farm	NEET, hd
Indiana (scrape) incl. MC	53.3	48.6	51.0	25.1	76.1	597
New York (scrape) incl. MC	50.0	-	50.0	25.1	75.1	605
Wisconsin (scrape)	45.4	33.2	39.3	25.1	64.4	705
Average (scrape)			46.8	25.1	71.9	632
Wisconsin (flush)	36.3	28.3	32.3	25.1	57.4	791
Washington (flush)	44.2	24.5	34.4	10.9	45.2	1003
Average (flush)			33.3	18.0	51.3	885
Overall average	40.0			21.5	61.6	737
Texas (corral)	-				193	235

Literature: 1.1 to 98.4 g/d-cow

NEET=Number (of cows) to Exceed Emission Threshold

Average H_2S Emission Rates, mg/d-cow

Site	Barn 1	Barn 2	Barn Avg	Storage	Farm	NEET, hd
Indiana (scrape)*	1515	1989	1752	2100	3852	11,786
New York (scrape)*	1164	-	1164	2100	3264	13,909
Wisconsin (scrape)	496	310	403	*2100*	2503	18,138
Average (scrape)			1106	2100	3206	14,159
Wisconsin (flush)	9320	4720	7020	2100	9120	4,978
Washington (flush)	1830	871	1351	*3145*	4496	10,099
Average (flush)			4185	2623	6808	6,669
Overall average			2646	2361	5007	9,067
Texas (corral)		-			3241	14,008

*Includes milking center (per place)

Literature: 0.8 to 733 mg/d-cow

NEET=Number (of cows) to Exceed Emission Threshold

Average PM_{10} emission rates, mg/d-cow

Site	Barn 1	Barn 2	Barn Avg	NEET, hd
Indiana (scrape) incl. MC	11	153	82	7,575,126
New York (scrape) incl. MC	473	-	473	1,314,837
Wisconsin (scrape)	2629	1537	2083	298,568
Average (scrape)			879	707,234
Wisconsin (flush)	923	1610	1266	491,246
Washington (flush)	8060	6500	7280	85,428
Average (flush)			4273	145,546
Overall average			2576	241,411

Literature: very limited: 192 (PM10), 360-1000 (respirable), and 600-9600 (inspirable) mg/d-cow

NEET=Number (of cows) to Exceed Emission Threshold

Relative Significance of Pollutants among Species

- ***Dairy: Ammonia > Hydrogen Sulfide > PM***
- ***Swine: Ammonia > Hydrogen Sulfide > PM***
- ***Poultry: Ammonia > PM > Hydrogen Sulfide***

Average VOC Emission Rates, g/d-cow

Site	Barn 1	Barn 2	Barn Avg	NEET, hd
Indiana (scrape) incl. MC	82.0	71.0	76.5	8130
New York (scrape) incl. MC	147	-	147	4231
Wisconsin (scrape)	75.0	69.0	72.0	8638
Average (scrape)			99	6314
Wisconsin (flush)	Not measured			
Washington (flush)	184	222	203	3064
Average (flush)			203	3064
Overall average			151	4125

Literature: 24-89 g/d-cow (very limited and partial VOC)

NEET=Number (of cows) to Exceed Emission Threshold

Average CH_4 emission rates, g/d-cow

Site	Barn 1	Barn 2	Barn Avg	Lagoon	Farm
Indiana (scrape) incl. MC	433	419	426	200	626
New York (scrape) incl. MC	453	-	453	200	653
Wisconsin (scrape)	465	379	422	**200**	622
Average (scrape)			434	200	634
Wisconsin (flush)	457	367	412	**200**	612
Washington (flush)	175	267	221	200	421
Average (flush)			317	200	517
Overall average			375	200	575

Literature: 360 to 420 g/d-cow (four studies).

Average N_2O emission rates, g/d-cow

Site	Barn 1	Barn 2	Barn Avg	Lagoon	Farm
Indiana (scrape) incl. MC	0.38	0.43	0.41	0.13	0.54
New York (scrape) incl. MC	6.16	-	6.16	0.13	6.29
Wisconsin (scrape)	1.04	0.89	0.97	**0.13**	1.10
Average (scrape)			2.51	0.13	2.64
Wisconsin (flush)	Not measured				
Washington (flush)	2.03	0.20	1.12	0.13	1.25
Average (flush)			1.12	0.13	1.25
Overall average			1.81	0.13	1.94

Literature: 1-2 g/d-cow

Summary of Dairy Portion of NAEMS

- First long-term NH_3, H_2S, CO_2, CH_4, N_2O, PM_{10}, $PM_{2.5}$, TSP, VOC, and odor emissions – most comprehensive ever
- Freestall barns (9), milking centers (2), manure storage basins (3) and a corral (1) – most representative ever
- High level of oversight from U.S. EPA Office of Air Quality
- Collected extensive "metadata" (weather, milk production, etc.)
- MV freestalls producted the best quality data.
- Mean NH_3 emission > 100 lb/d with > 740 cows at freestall dairies and >240 cows at dairy corrals.
- Mean H_2S emission > 100 lb/d with > 9000 cows at freestall dairies and 14,000 cows at corral dairies.
- CAA's 250 tpy VOC threshold would be exceeded with >3100 cows (flushing) and 6300 cows (scraping) based on relatively limited number of samples.
- PM emissions were insignificant with respect to regulations.
- Average whole farm CH_4 emissions ~ 575 g/d-cow.
- Average whole farm N_2O emissions ~ 2 g/d-cow.

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  - Data Analysts (SDSU, Univ of MO, Univ Idaho)