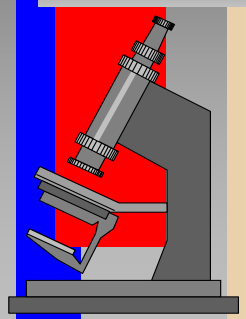
National Air Emissions Monitoring Study



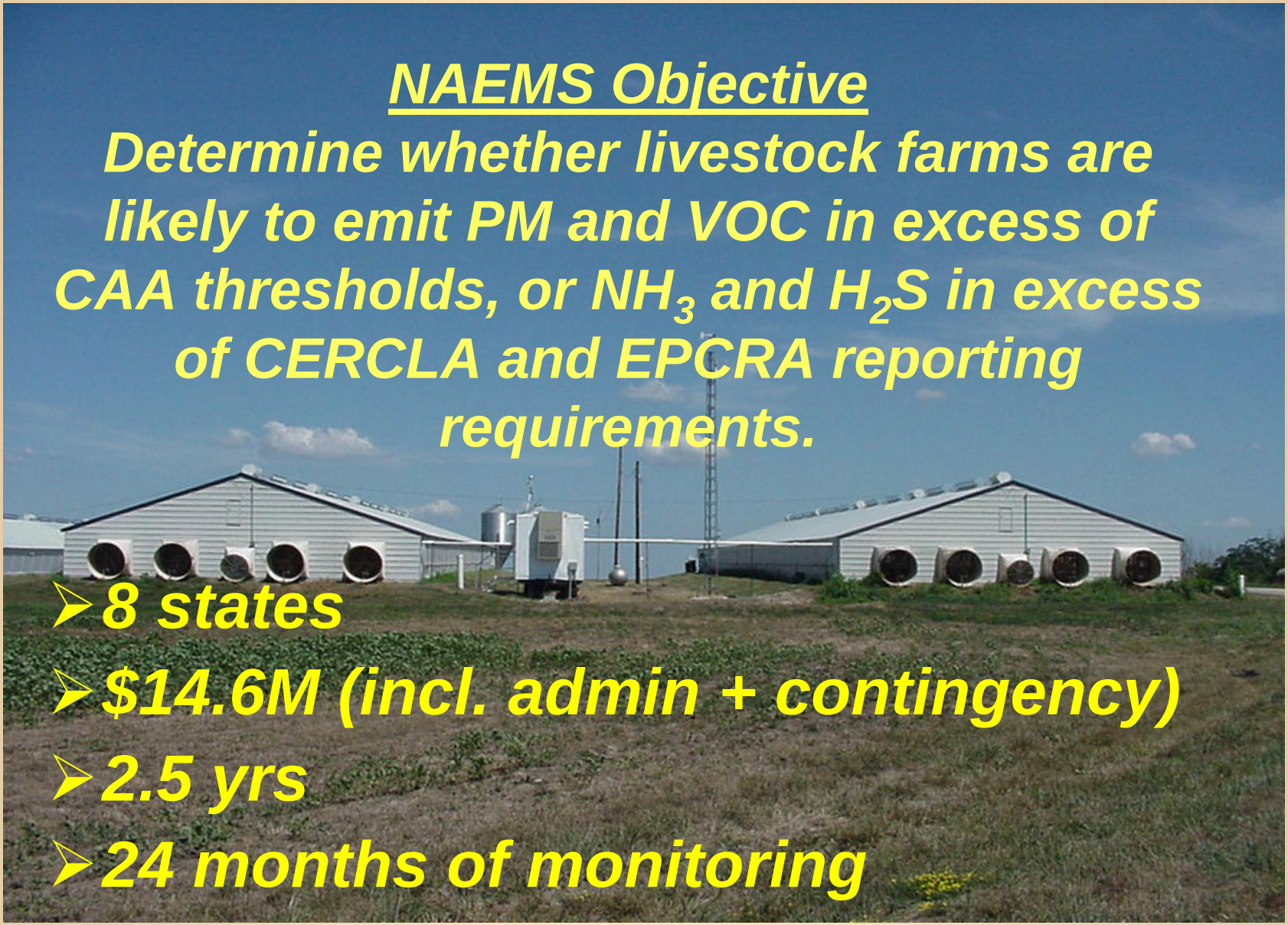
Albert J. Heber, Professor
heber@purdue.edu

Purdue Agricultural Air Quality Laboratory

Agricultural and Biological Engineering

PURDUE UNIVERSITY

Purdue University



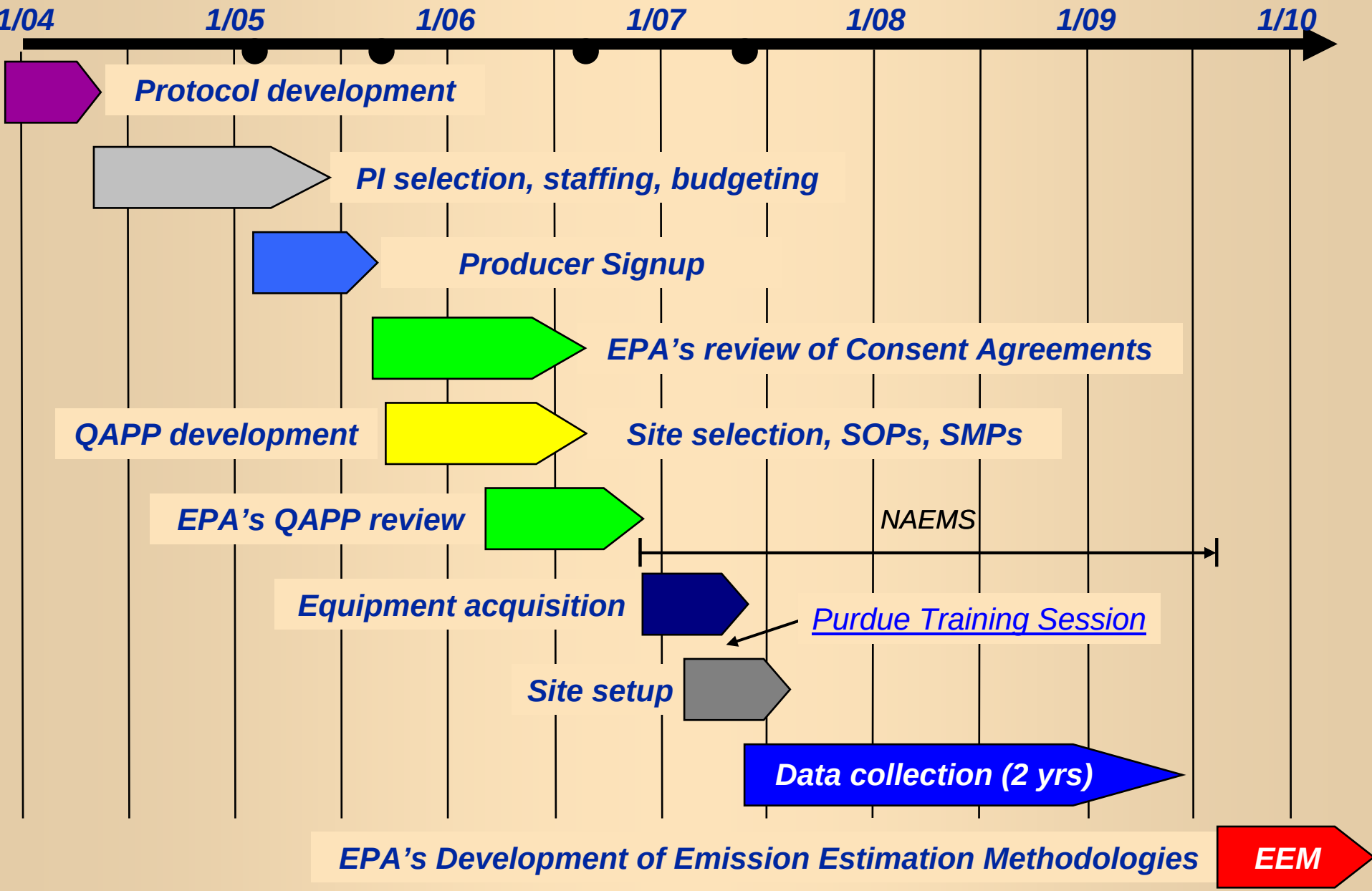
NAEMS Objective

Determine whether livestock farms are likely to emit PM and VOC in excess of CAA thresholds, or NH_3 and H_2S in excess of CERCLA and EPCRA reporting requirements.

- ***8 states***
- ***$14.6M (incl. admin + contingency)***
- ***2.5 yrs***
- ***24 months of monitoring***

Air emissions from two to three barns per site will be measured for 24 months using accepted methods.

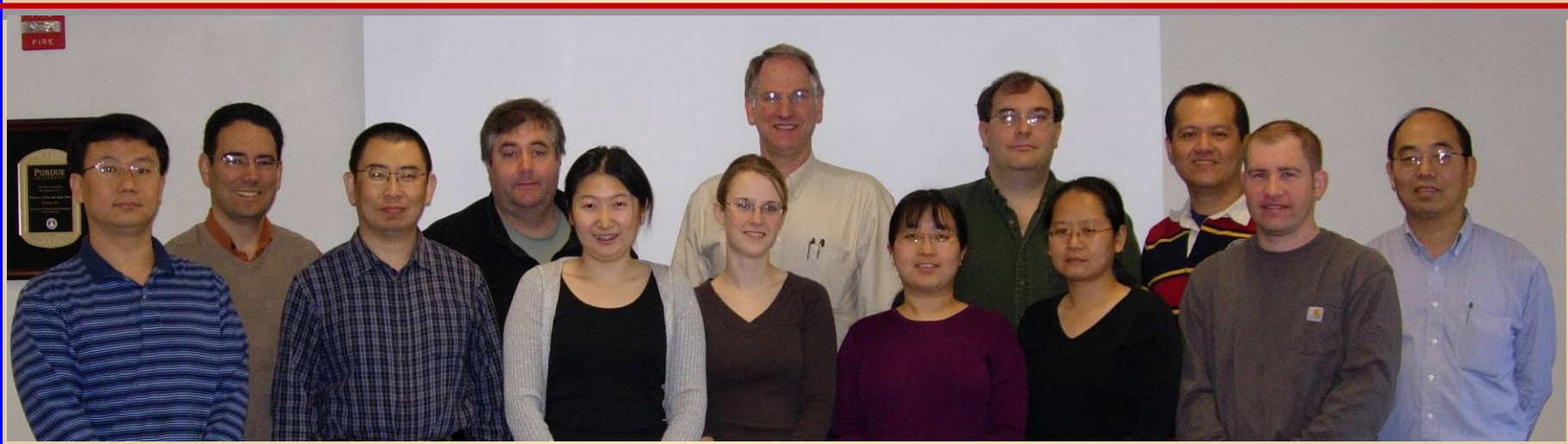
NAEMS Timeline



Study Design Summary

- Twenty representative livestock production sites.
- Outdoor manure facilities (9) and corral (1) monitored every season
  - Hydrogen sulfide (UVDOAS or pulsed fluorescence with S-OP).
  - Ammonia (TDLAS, UVDOAS, photoacoustic spectroscopy)
  - Ethanol, methanol, NMHC (photoacoustic spectroscopy)
  - Tomography or Radial Plume Mapping with TDLAS
  - Backward Lagrangian stochastic (BLS) modeling
- Barns (38) monitored continuously
  - Hydrogen sulfide (pulsed flourescence)
  - Ammonia (photoacoustic spectroscopy)
  - Ethanol, methanol, NMHC (photoacoustic spectroscopy)
  - Non-methane HC (photoacoustic spectroscopy, GC-FID)
  - Carbon dioxide (photoacoustic spectroscopy)
  - TSP, $PM_{2.5}$, PM_{10} (TEOM)
  - Barn airflow (fan speed, pressure, velocity, portable fan tester)
- Integrated Sampling
  - VOCs: GC-MS (canisters, tubes), IC (impingers)
- EPA-approved standard operating procedures

NAEMS Purdue Team for Barn Monitoring



Al Heber

Erin Cortus **Connie Li**

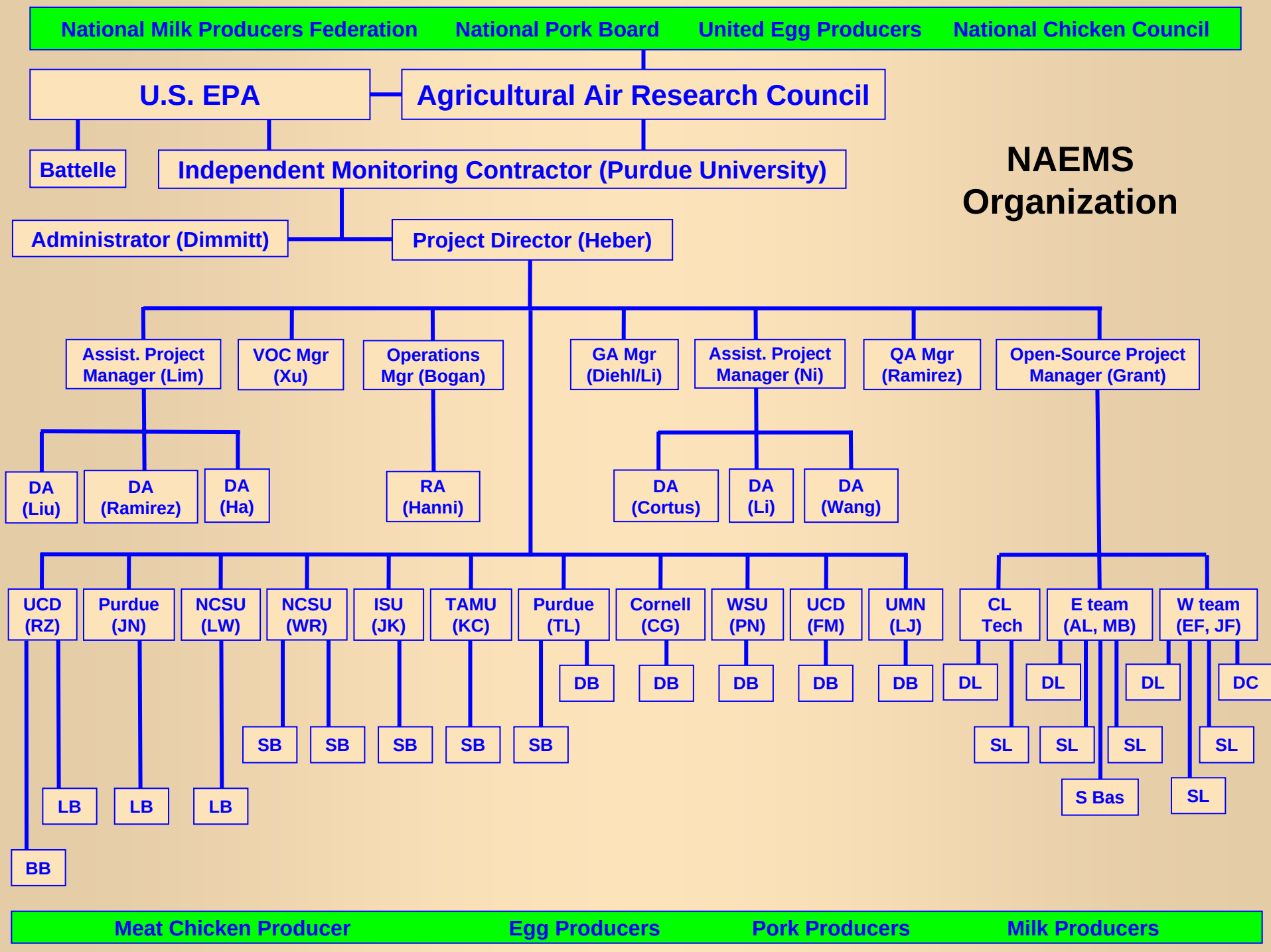
Hua Xu **Bill Bogan**

Claude Diehl **Kaiying Wang**

Richard Liu **Teng Lim**

Juan Carlos Ramirez **Sam Hanni**

Jeong Ha **Jiqin Ni**


National Milk Producers Federation
National Pork Board
United Egg Producers
National Chicken Council
U.S. EPA
Agricultural Air Research Council
Battelle
Independent Monitoring Contractor (Purdue University)
NAEMS Organization
Administrator (Dimmitt)
Project Director (Heber)
Assist. Project Manager (Lim)
VOC Mgr (Xu)
Operations Mgr (Bogan)
GA Mgr (Diehl/Li)
Assist. Project Manager (Ni)
QA Mgr (Ramirez)
Open-Source Project Manager (Grant)
DA (Liu)
DA (Ramirez)
DA (Ha)
RA (Hanni)
DA (Cortus)
DA (Li)
DA (Wang)
UCD (RZ)
Purdue (JN)
NCSU (LW)
NCSU (WR)
ISU (JK)
TAMU (KC)
Purdue (TL)
Cornell (CG)
WSU (PN)
UCD (FM)
UMN (LJ)
CL Tech
E team (AL, MB)
W team (EF, JF)
DB
DL
DC
SB
SL
LB
S Bas
BB
Meat Chicken Producer
Egg Producers
Pork Producers
Milk Producers

Site Principal Investigators at Eight Cooperating Universities

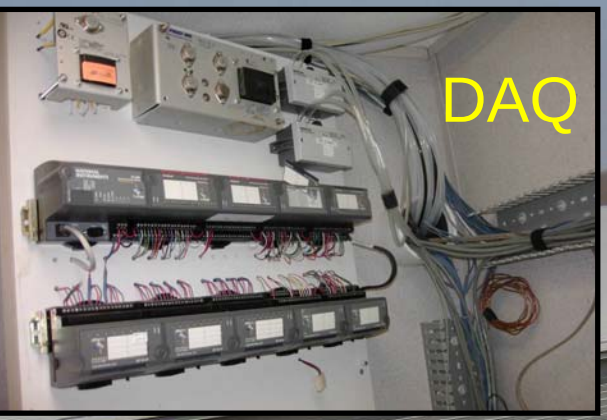
- *Lim/Ni/Grant – Purdue University*
- *Jacobson - University of Minnesota*
- *Mitloehner/Zhang – University of California - Davis*
- *Koziel/Hoff/Harmon – Iowa State University*
- *Casey – Texas A&M University*
- *Ndegwa – Washington State University*
- *Robarge/Wang -North Carolina State University*

National Air Emissions Monitoring Study Sites

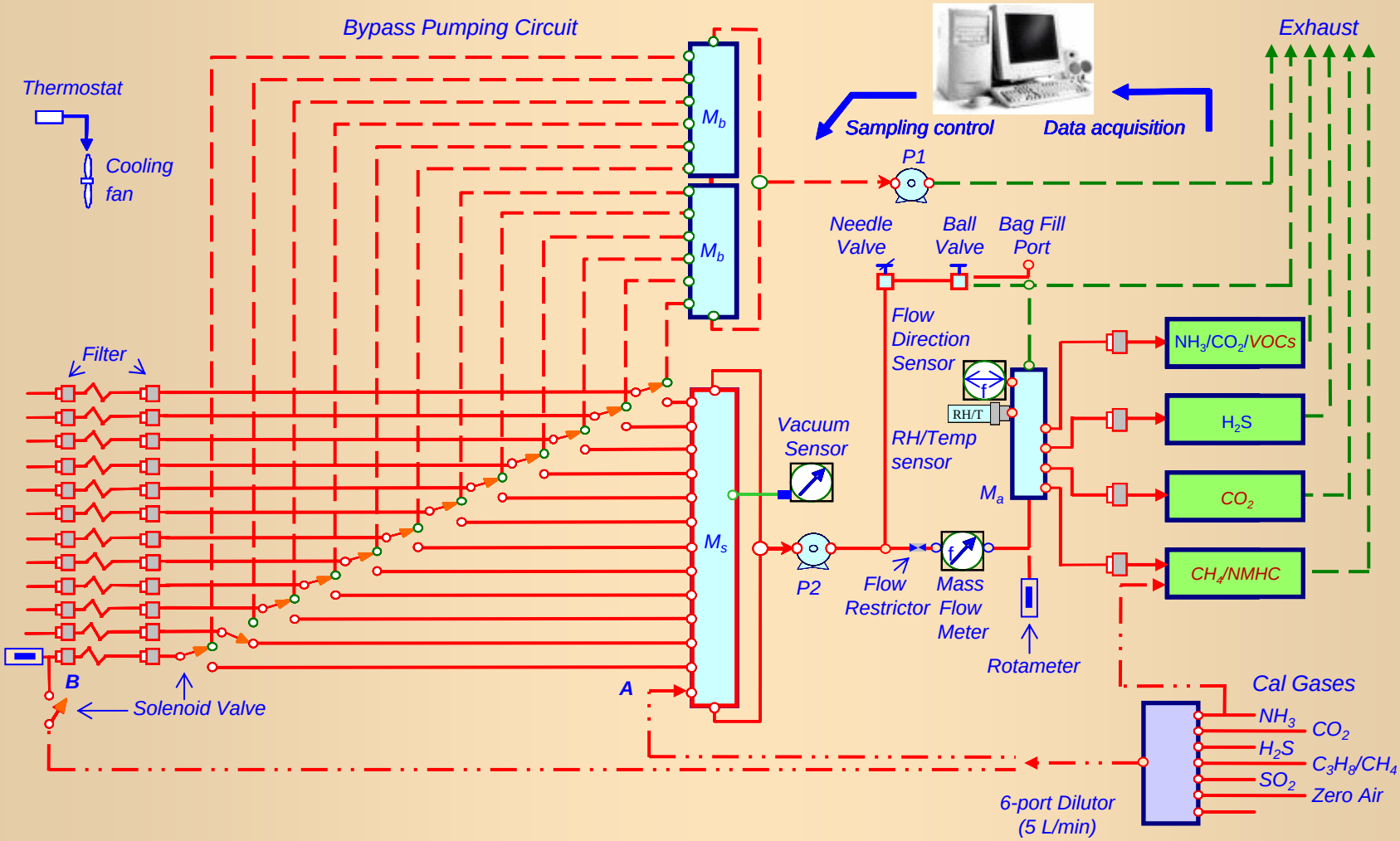
Summary of NAEMS Sites

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	3	2	0	5	12	1	3	0	4
Layers	2	0	1	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

Equipment Acquisition Winding Down



Gas Sampling System



Tubing and Fitting Material:

- Teflon
- Nylon
- Stainless Steel

Type of Line:

- Sampling
- Exhaust
- Calibration

Abbreviation:

P Pump

M Manifold

Purdue Training Session

Equipment Received

- ➢ *Cal gases and regulators (air, SO_2, CO_2, NH_3, H_2S)*
- ✓ *TFS TEOM, Beta Gage, and Partisol PM samplers*
- ➢ *Teflon sampling tubing and static pressure tubing*
- ✓ *Gas diluters from Environics and Thermo Fisher*
- ✓ *Instrument trailers, and most outfitting materials*
- ➢ *Data acquisition computer systems for all sites*
- ➢ *VOC canisters, sorbent tubes, and impingers*
- ✓ *Gas sampling system (GSS) components*
- ➢ *Uninterruptible power supply (UPS) units*
- ➢ *Roof-mounted weather station towers*
- ✓ *Methane/non-methane HC analyzer*
- ➢ *CAPECAB data analysis software*
- ➢ *RH/T chilled mirror hygrometer*
- ➢ *Multi-conductor signal cables*

Instrument Trailers (13)

- Modifications:
  - Steps
  - Compartment vent
  - AC exhaust hoods
  - Shelves, ductwork
  - Lightning arrestor
  - Furniture

Equipment Received

- *Differential pressure sensors*
- *Fan monitoring sensors*
  - *RPM sensors (142/240)*
  - *Current switches (134)*
- *Custom TEOM enclosures*
- *Solar sensors and shields*
- DAQ I/O modules (*93%*)
- *Temperature calibrator*
- *Low pressure calibrator*
- *Thermocouple wires*
- *Airflow calibrators*
- *Activity sensors*
- *H_2S analyzers*
- *Heating cable*

Equipment Ordered

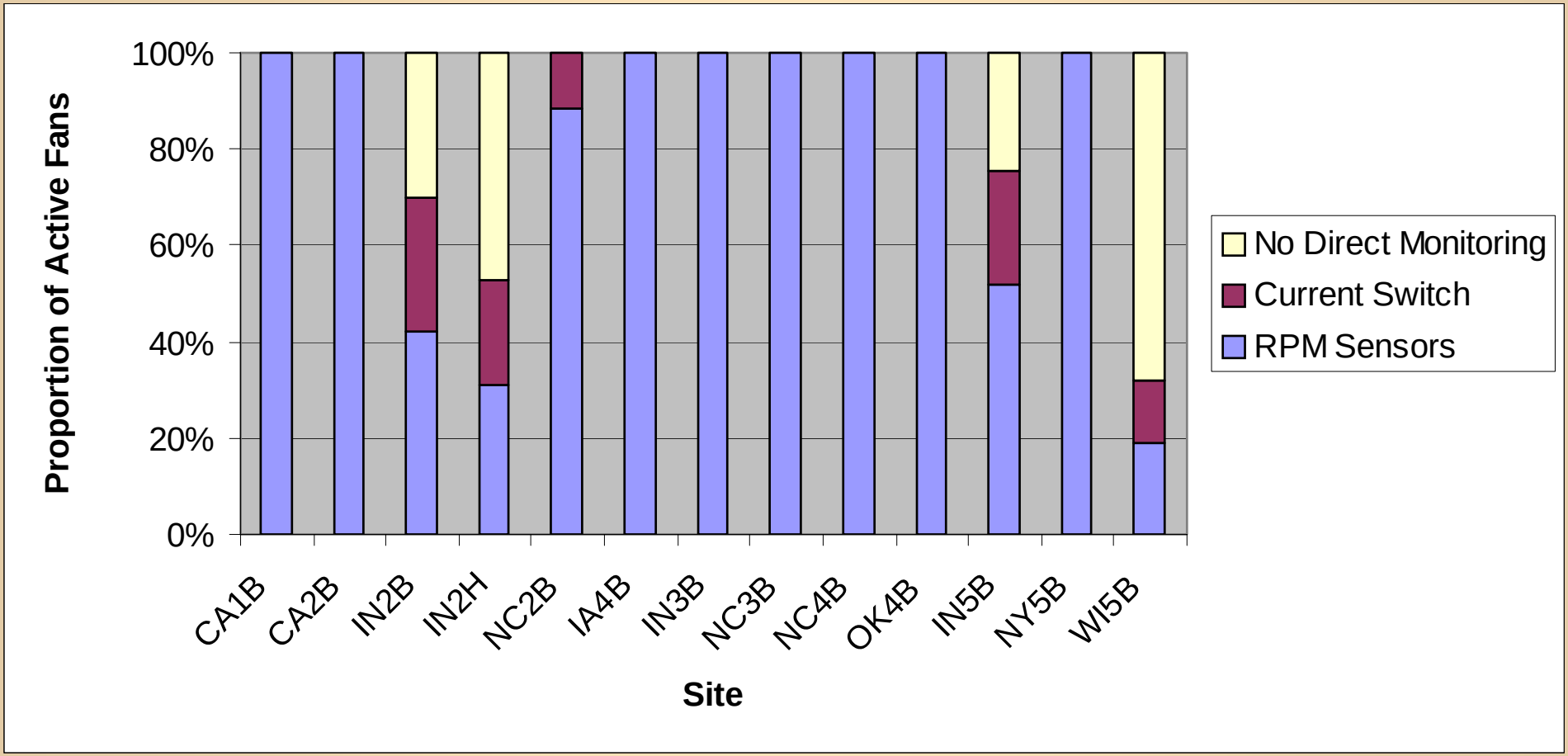
- Multigas (NH_3, CO_2, VOC) analyzers (10/15 rec'd)
- Custom Beta Gage Enclosures (1 rec'd)
- Wind Sentry anemometers (1/14 rec'd)
- VOC calibration gases and regulators
- Ultrasonic anemometers (*50% rec'd*)
- DAQ I/O modules (*7%*)
- Fan monitoring sensors
  - RPM sensors (98/240)
  - Propeller anemometers
- MSA CO_2 analyzers (2)
- FANS analyzers
- RH/T sensors

Equipment to Order

- 55C connection hardware
- Balance of RPM sensors
- RH/T transfer standards
- FANS trailers
- Misc.

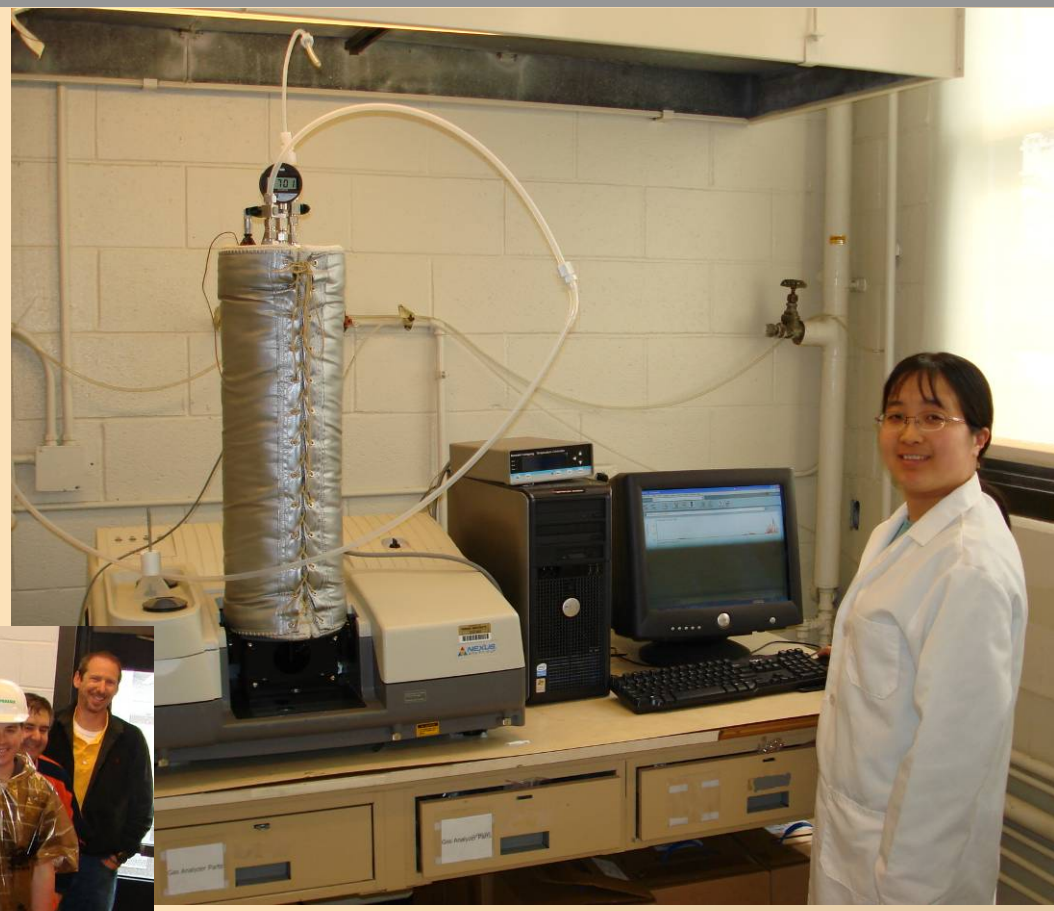
Fan Monitoring Methods

- ***Hall effect sensors (RPM sensors)***
- ***Current switches***
- ***Propeller anemometers***
- ***Vibration sensors***



Cal Gases Checked by FTIR

A closed-cell FTIR is used to check calibration gas cylinders

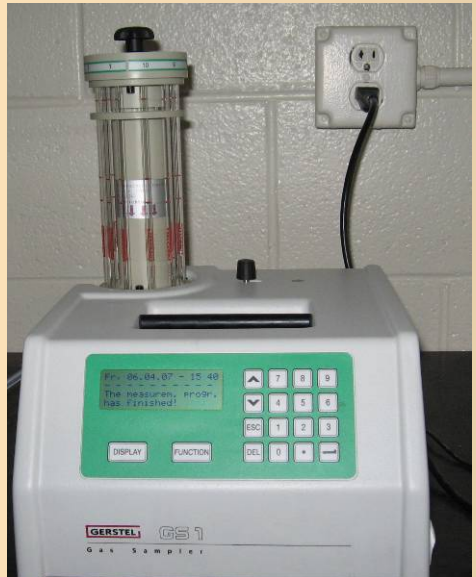


VOC Sampling Methods

Canister

Sorbent tube

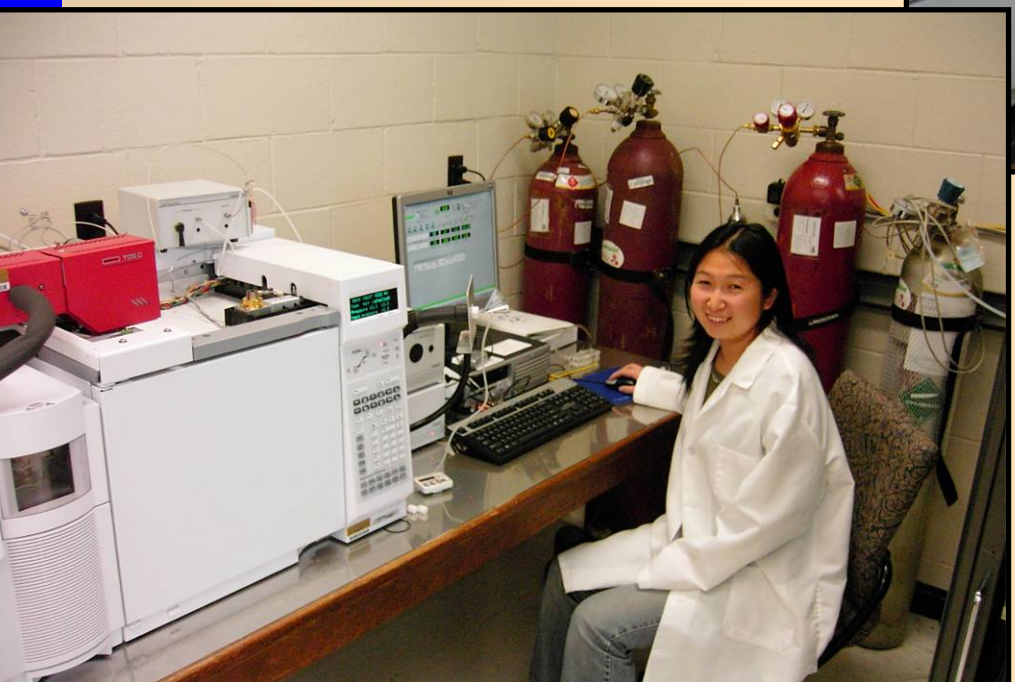
Impinger

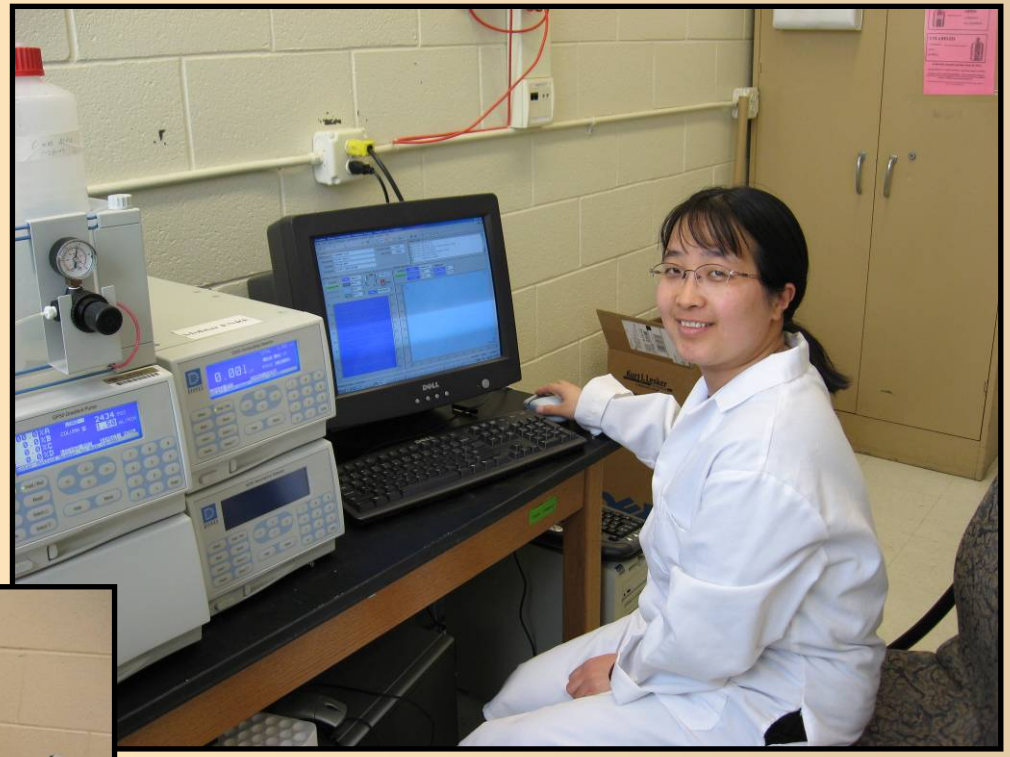


Tube sampler

VOC Analysis

GC-MS (Dr. Hua Xu)





Ion Chromatograph
(Dr. Connie Li)

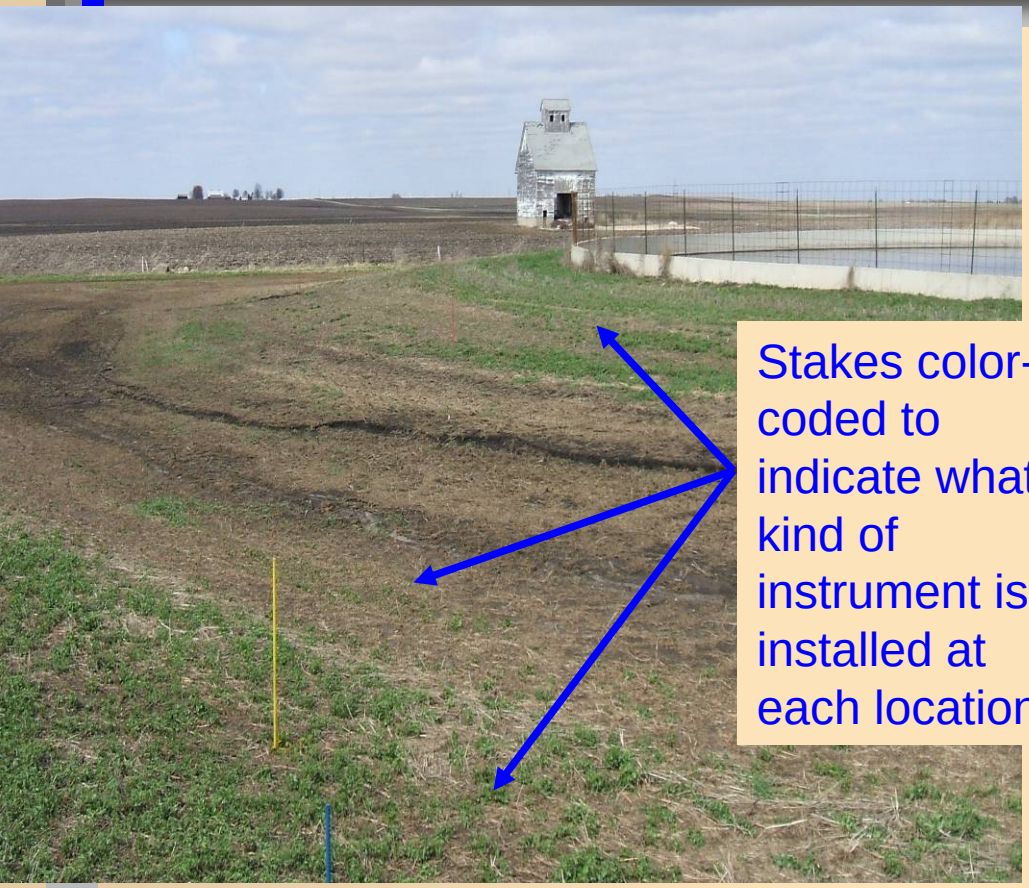
Major Changes to Original Protocol

- ***Use TEOM for PM2.5, PM10, TSP***
- ***Use Innova 1412 for NH3, CO2, VOC***
- ***Use RPM sensors, current switches***
- ***Considering synthetic open path***

TEOM Sampling Inlets

The TEOM air inlets shown here can measure total suspended particulate, PM10 or PM2.5.

Area Site Layouts



All layouts have been staked out on site.

Concrete tower bases & anchors

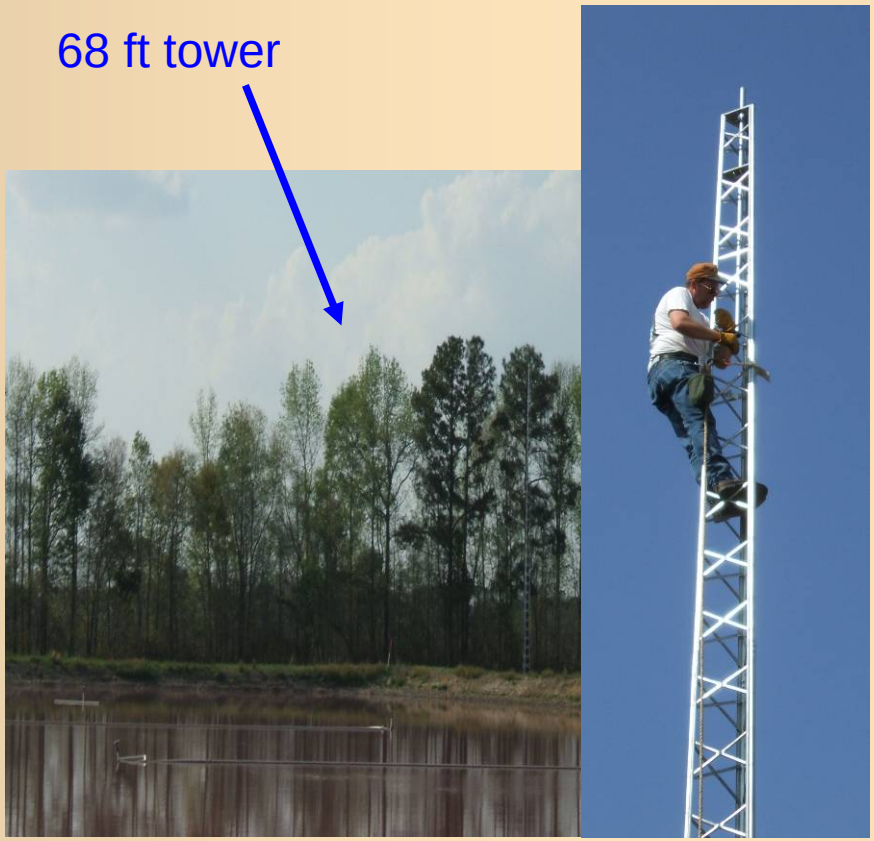
Installing anchors

Installing tower bases in concrete

Site	Status
IN4A	Done
NC3A	Done
NC4A	Done
OK3A	Done
OK4A	Done
WA5A	
WI5A	Done
IA3A	Done

Setup: Erecting towers

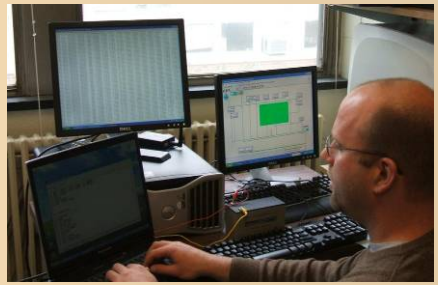
68 ft tower



Site	Status
IN4A	Done
NC3A	Done
NC4A	Done
OK3A	Done
OK4A	Done
WA5A	
WI5A	
IA3A	

Hardware/Software Configuration

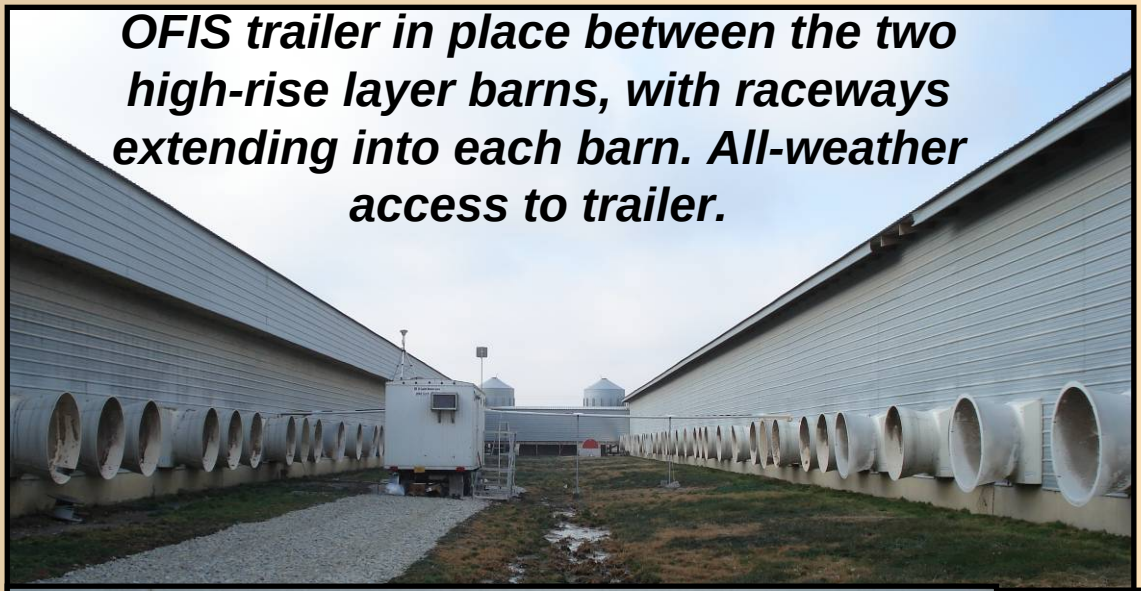
- Wind and meteorological/lagoon sensors (PAML)
  - Quality assurance software near completion
  - Datalogger program developed
  - Testing of RF communications
  - Design & manufacturing of communications & power configurations
- Design lagoon float for pH, redox, and water temperature (PAML)
  - Testing to be done at nearby pond.
- Design and testing of TDLAS communications (Boreal Laser)
- RPM software under development (Arcadis)
  - Final testing by PAML awaiting receipt of one complete scanning TDLAS system from Boreal Laser and installation of towers at IN4A.
- PC systems for in-trailer and lab use under development (PAML)



Open Source Methods Testing

- *Synthetic Open Path vs. UVDOAS*
  - *Testing using release of 10% SO_2 in open field*
  - *10-orifice system w/ flourescence detected SO_2 at 20 m*
  - *UVDOAS calibration verified for SO_2 using function cell.*
  - *UVDOAS 100-m path has alignment problems in winds*
- *Open Path UVDOAS H_2S evaluation*
  - *Current modeling efforts have RMSE at approximately 1 ppm-m for both NH_3 and H_2S.*
  - *Manufacturer testing and modification near completion*
  - *Will be tested against S-OPS at lagoon near Purdue.*
- *TDLAS NH_3 scanning system testing*
  - *Testing at dairy lagoon.*
  - *Scanner reliably moved between 3 retroreflectors (6 h).*
  - *TDLAS detected NH_3 at levels <1ppm-m (measurements failed QA due to sub MDL (5ppm-m) levels).*

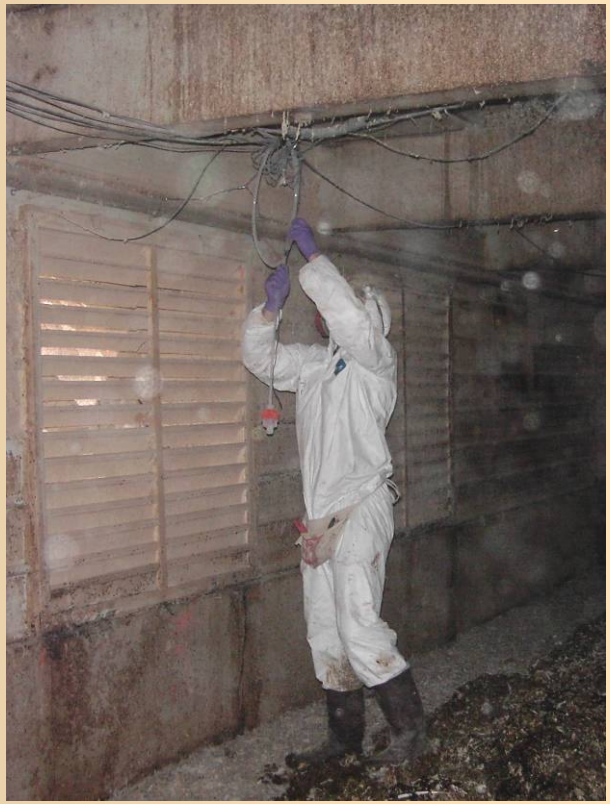
Site IN2B has one OFIS in place



- Setup of high-rise portion completed by Dr. Ni's team in Dec./Jan.

Site IN2B Setup

(High rise houses)



Installing sampling line and port at a fan in the lower level of the HR barn

- *14 inside sampling points*
- *1 outside sampling point*
- *Teflon tubing (3500 ft)*
- *Thermocouples (10)*
- *Static pressure sensors (4)*
- *Activity sensors (4)*
- *Temperature/humidity probes (4)*
- *Propeller anemometers (12)*
- *Vibration sensors (48)*
- *Fan stage relays for automatic stage control (24)*

Site IN3B Progress

- All hardware installed
- Currently troubleshooting DAQ
- Training session site last week.

Trailer Delivery Schedule

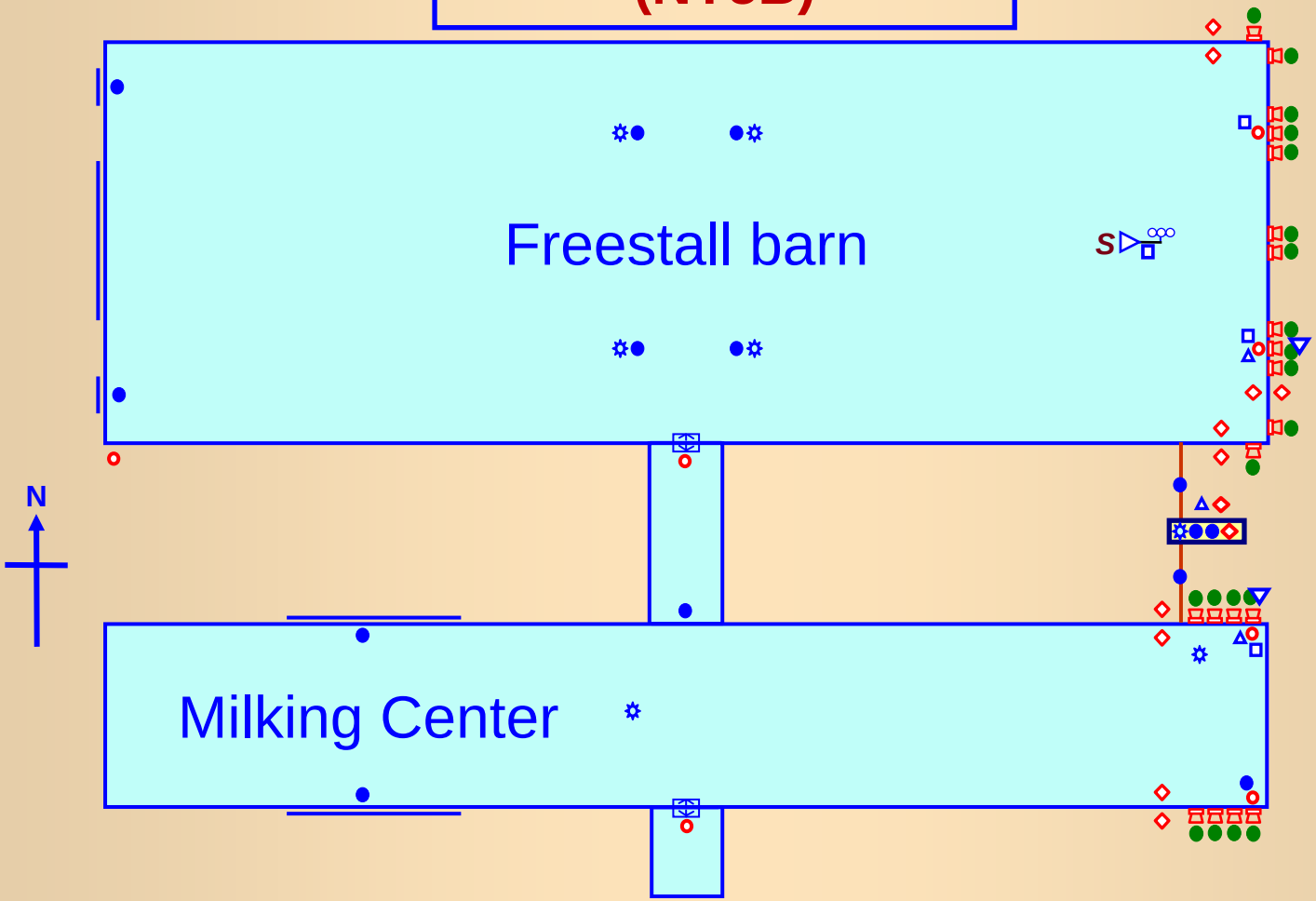
April 1	IN3B
April 30	IA4B
May 7	IN5B, IN2B
May 14	WI5B, CA1B
May 21	NC2B, OK4B
May 28	CA5B
June 4	NC3B, CA2B
June 11	NY5B, WA5B
June 18	NC4B

NAEMS Dairy Sites

Site	Site type	Vent type	# Units Meas.	Manure collection	Manure storage[4]	Bedding type[5]	Places
NY5B	Freestall	MV	2[3]	Scrape	Dig./SS/Basin	SDS	470
IN5B	Freestall	MV	2	Scrape	Dig./SS/Basin	SDS	1600
WI5B	Freestall	MV	3[3]	Flush	SP/Basin	Mattress/ shavings	325
CA5B	Open Freestall[2]	NV	2	Flush	SP/Basin	Soil/MS/ Alm. shells	600
WA5B[1]	Open Freestall[2]	NV	2	Flush	SP/SS/Basin	MS	650

[1]Barn sites that also have measured area sources
[2]Cattle free to walk from open freestall barn into dry lots between barns.
[3]Monitored units include milking center.
[4]SP = settling pond
[5]MS = Manure solids
SDS = Separated digested solids

New York Dairy Site (NY5B)

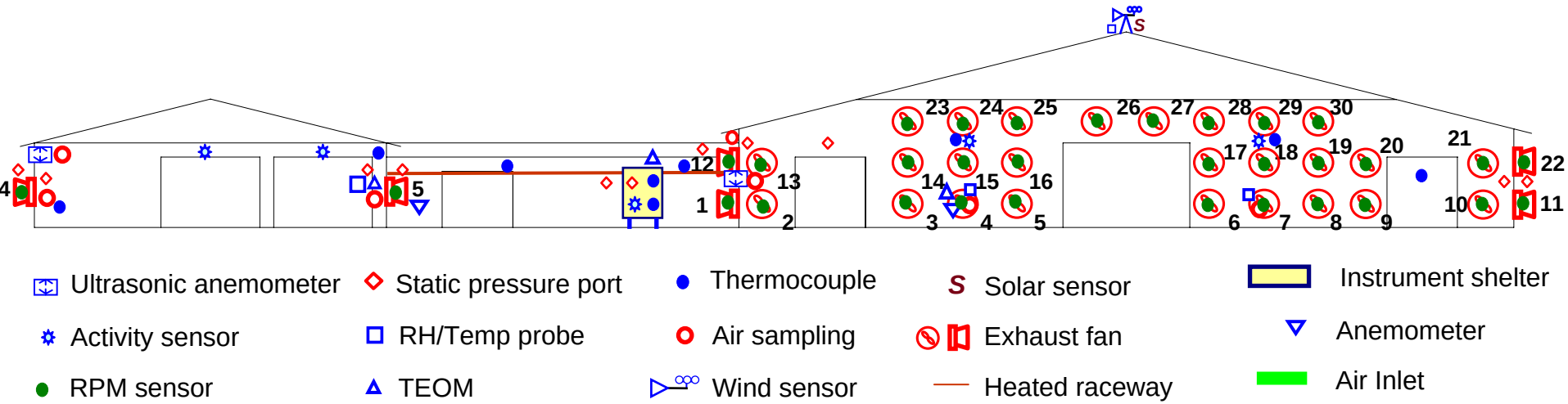


Ultrasonic anemometer
Activity sensor
RPM sensor
Static pressure port
RH/Temp probe
TEOM
Thermocouple
Air sampling
Wind sensor
Solar sensor
Exhaust fan
Heated raceway
Instrument shelter
Anemometer
Air Inlet

Updated April 24, 2007 ELC

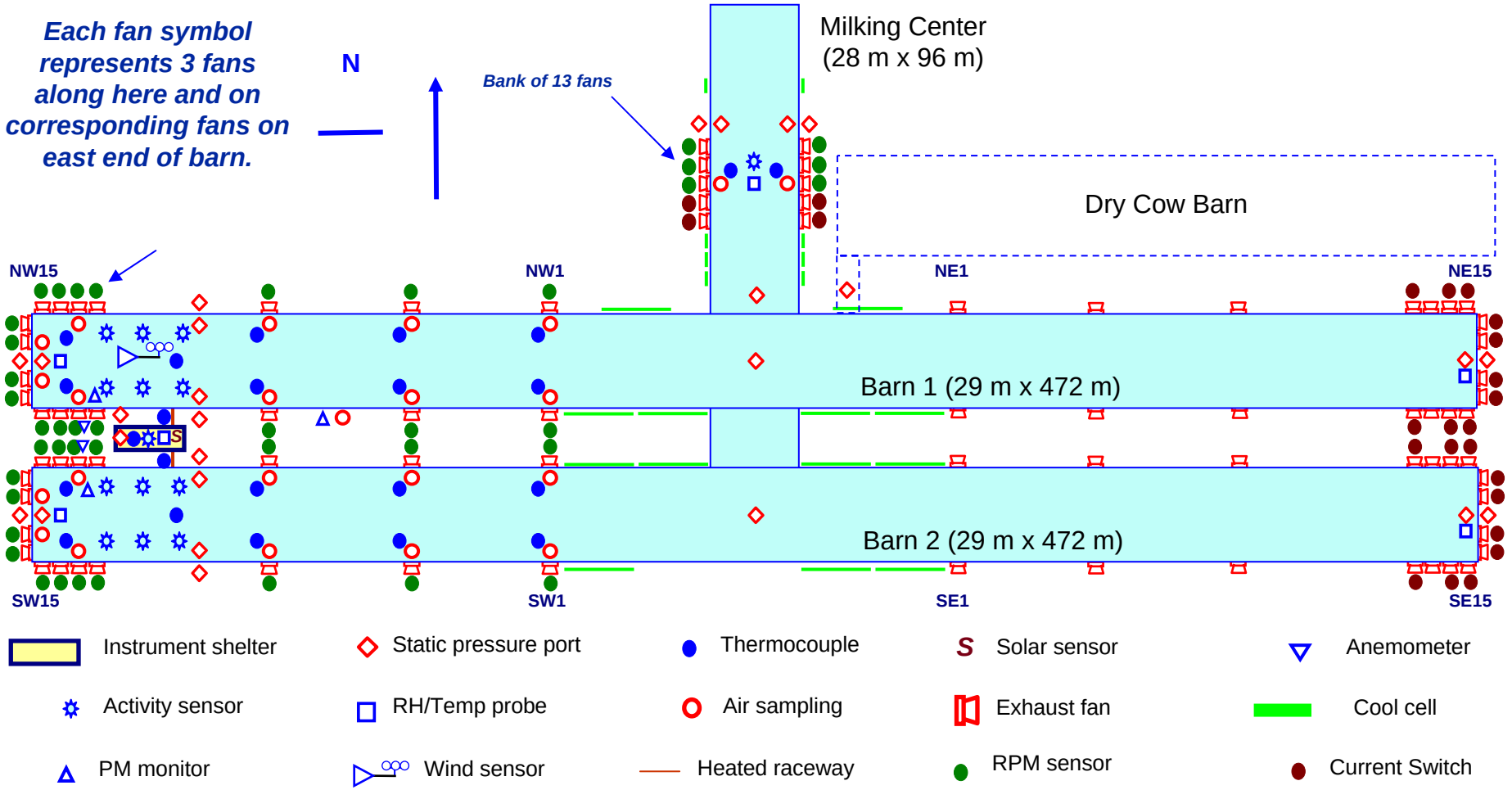
Site monitoring plan for continuous air emission testing.

New York Dairy Site (NY5B)



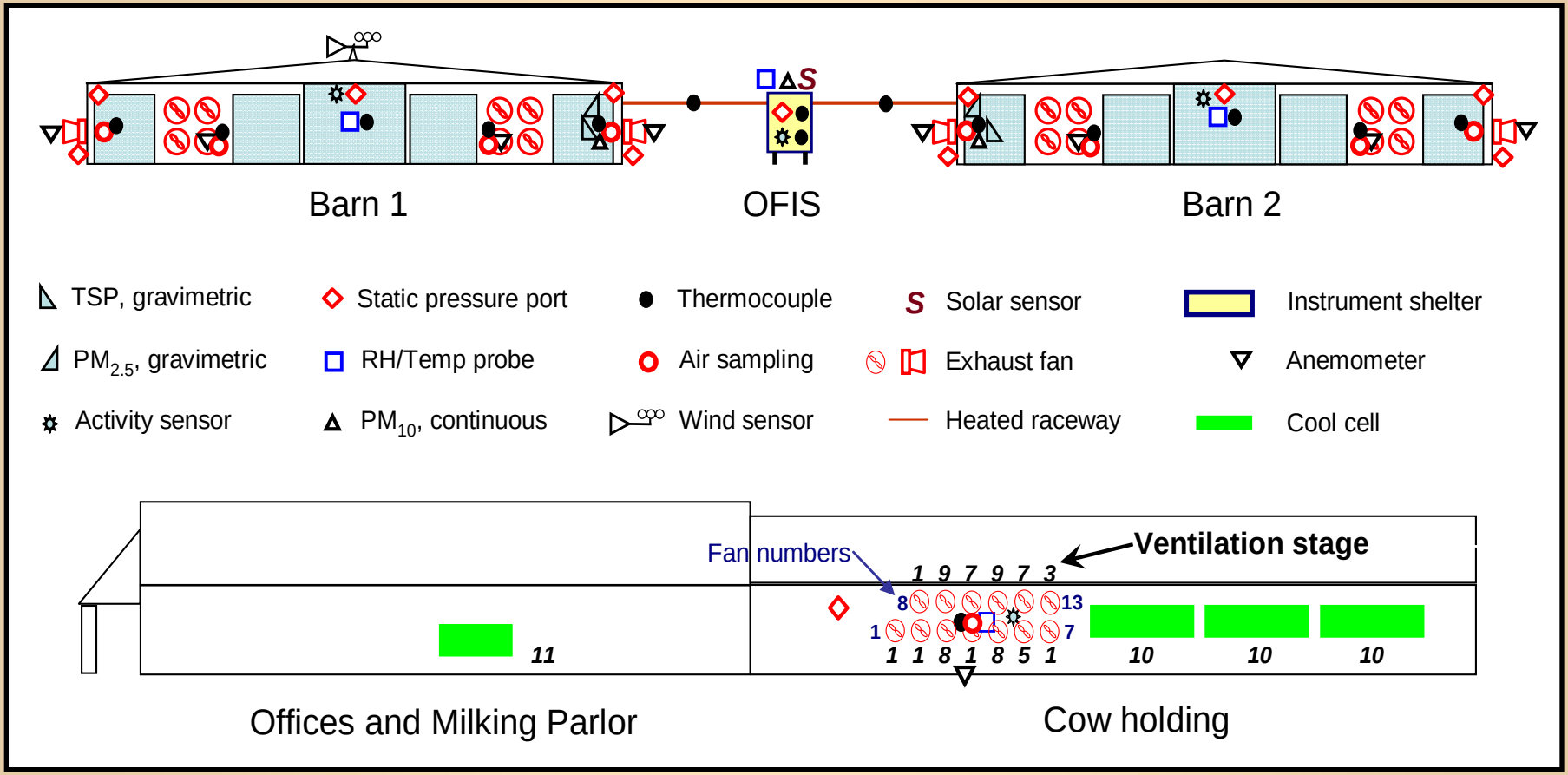
Cross section of the freestall barns showing measurement locations.

Indiana Dairy Site (IN5B)

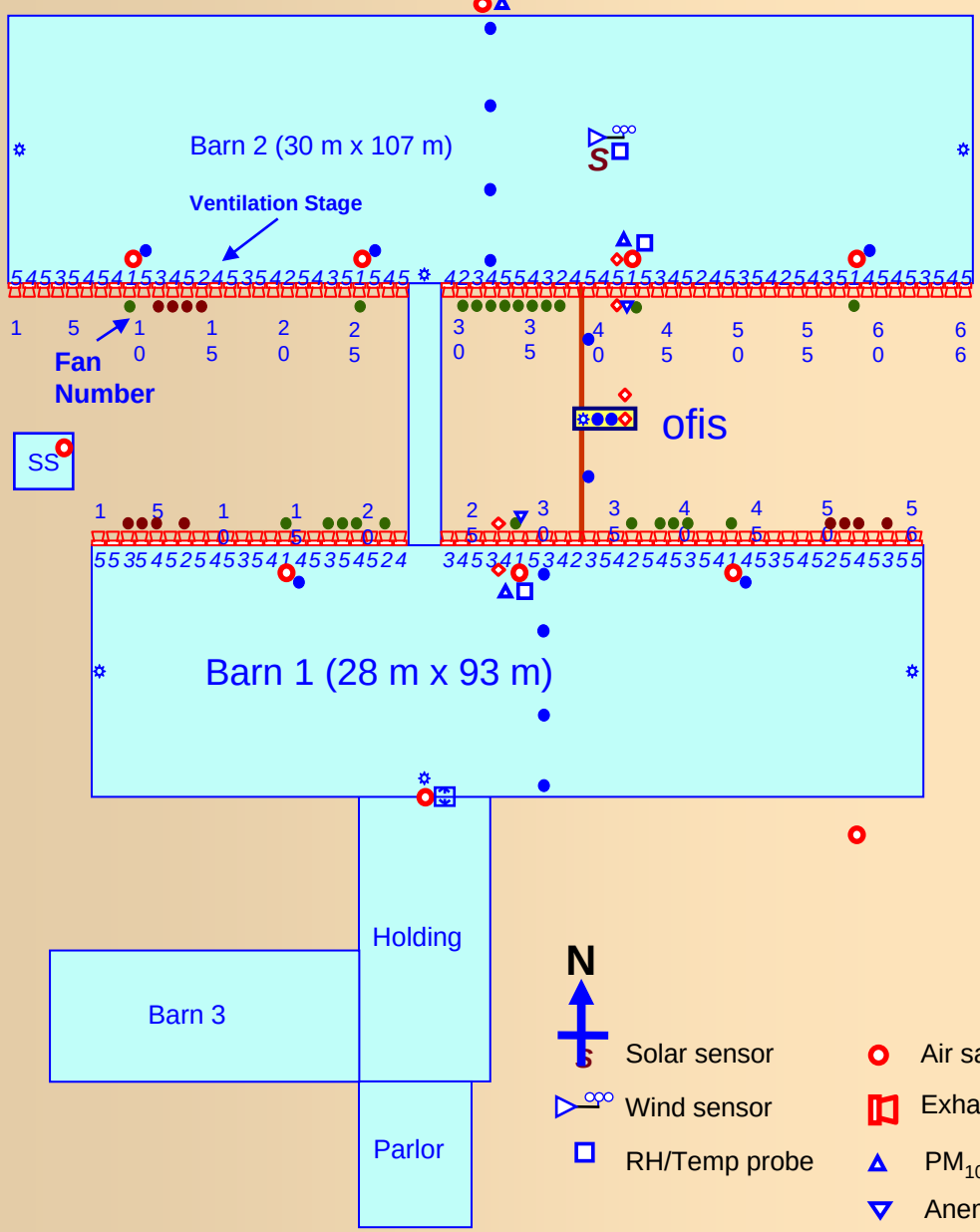


Site monitoring plan for continuous air emission testing at freestall barns 1 and 2, and in the holding barn associated with the milking parlor.

Indiana Dairy Site (IN5B)



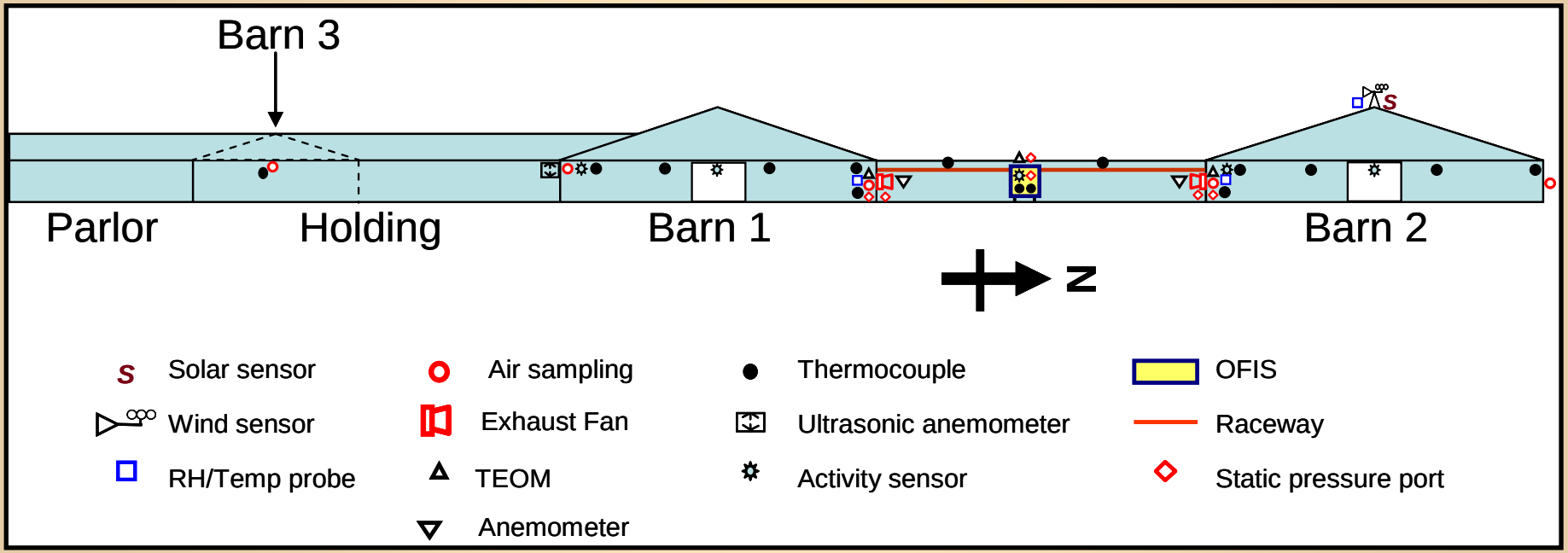
Cross section of freestall barns 1 and 2 and side view of milking center showing measurement locations.

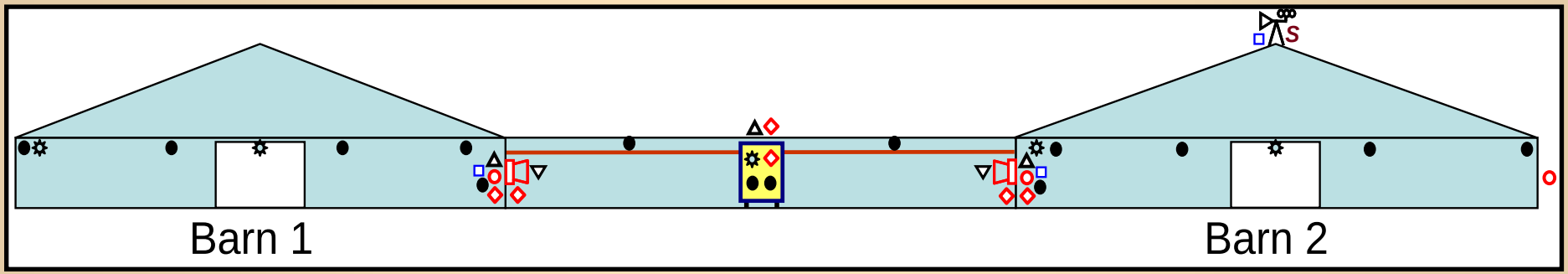


Wisconsin Dairy Site (WI5B)

Site monitoring plan for continuous air emission testing.

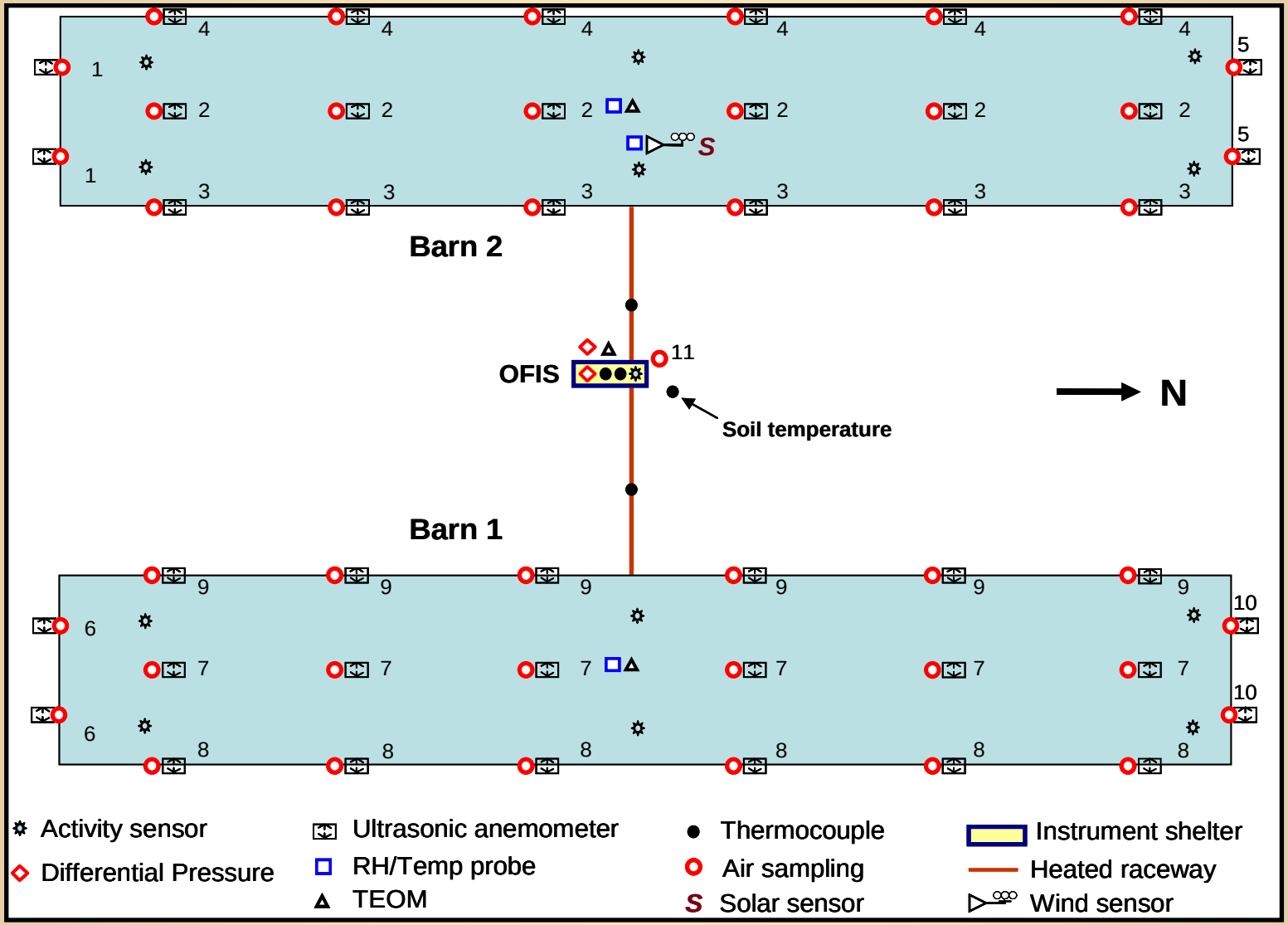
Wisconsin Dairy Site (WI5B)





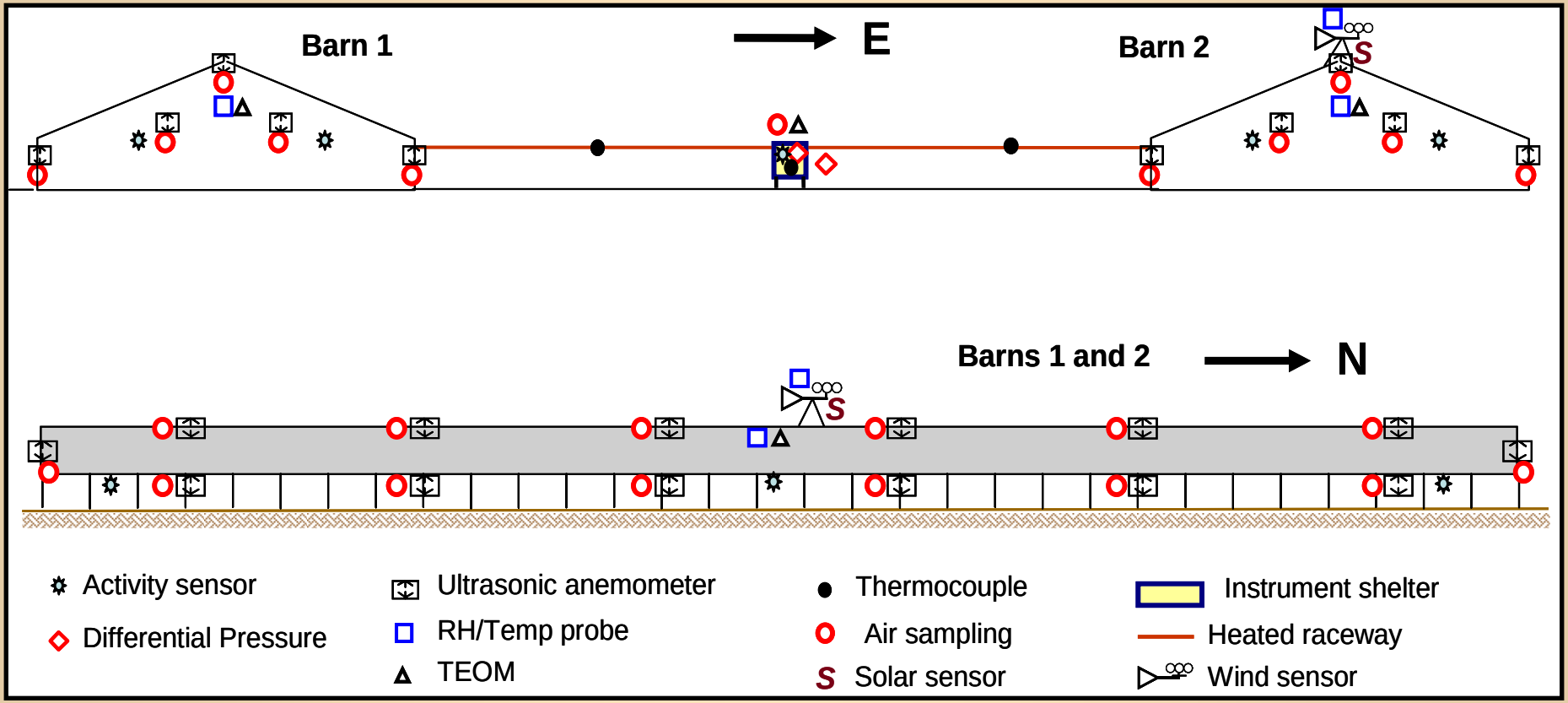
Cross section of the freestall barns showing measurement locations.

California Dairy Site (CA5B)



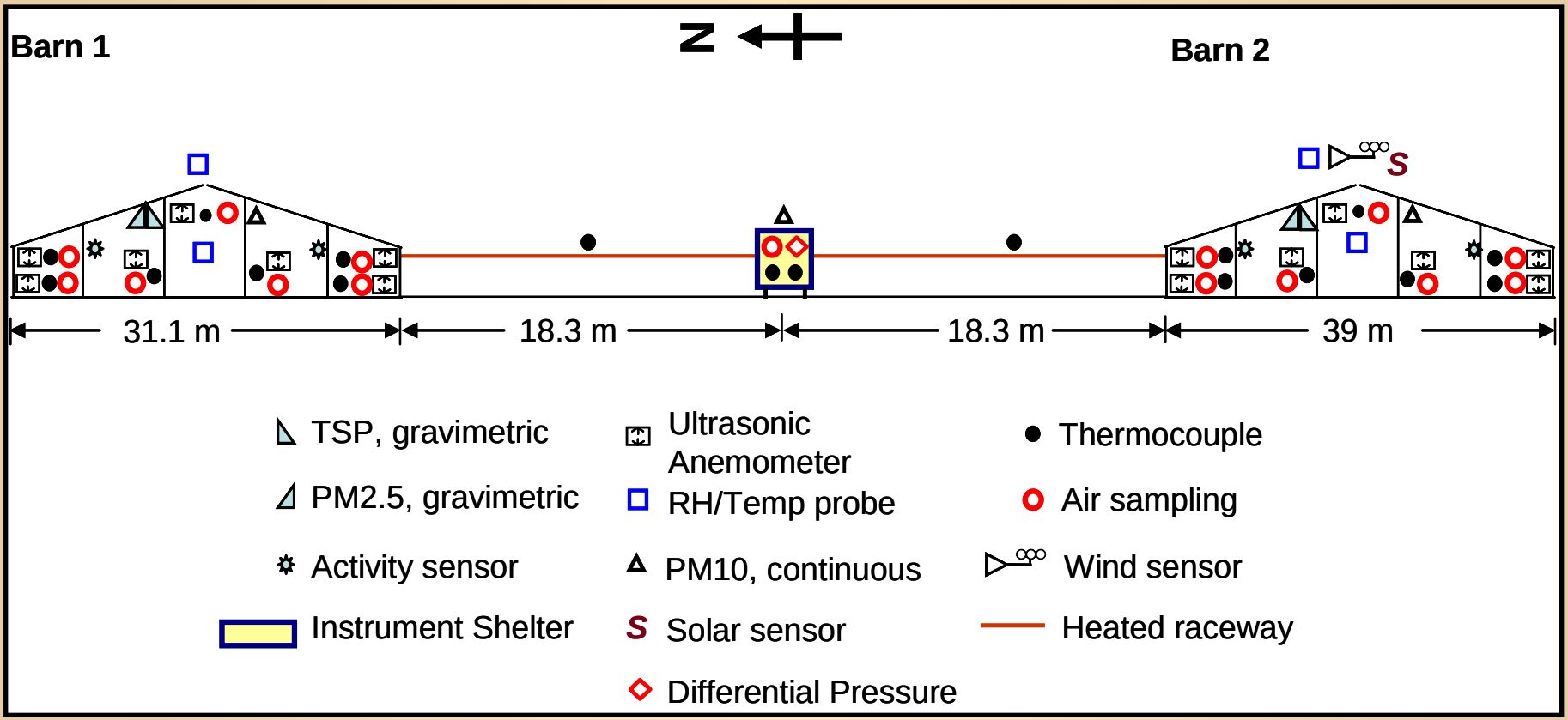
Site monitoring plan for continuous air emission testing.

California Dairy Site (CA5B)



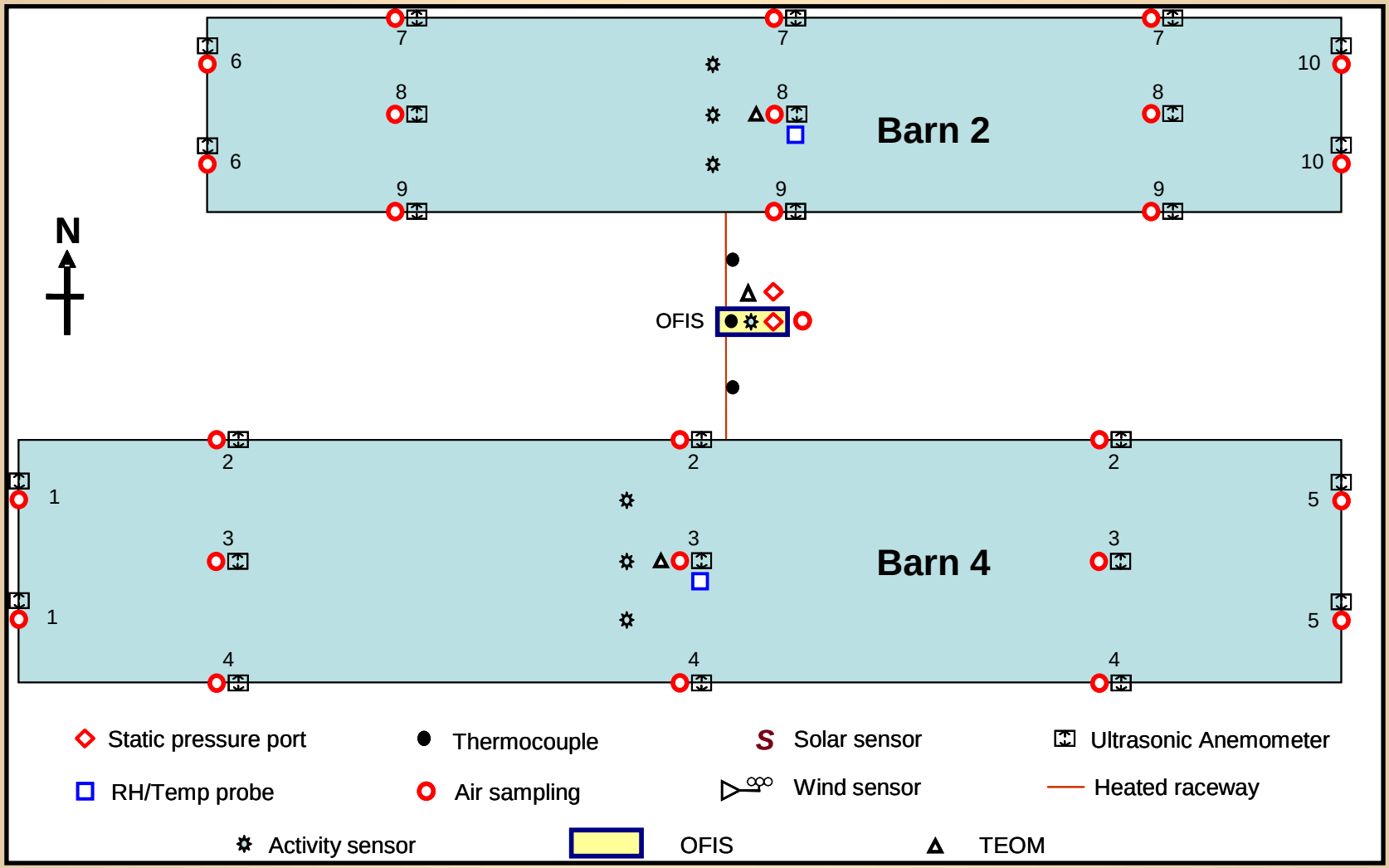
Cross section of the freestall barns showing measurement locations.

Washington Dairy Site (WA5B)



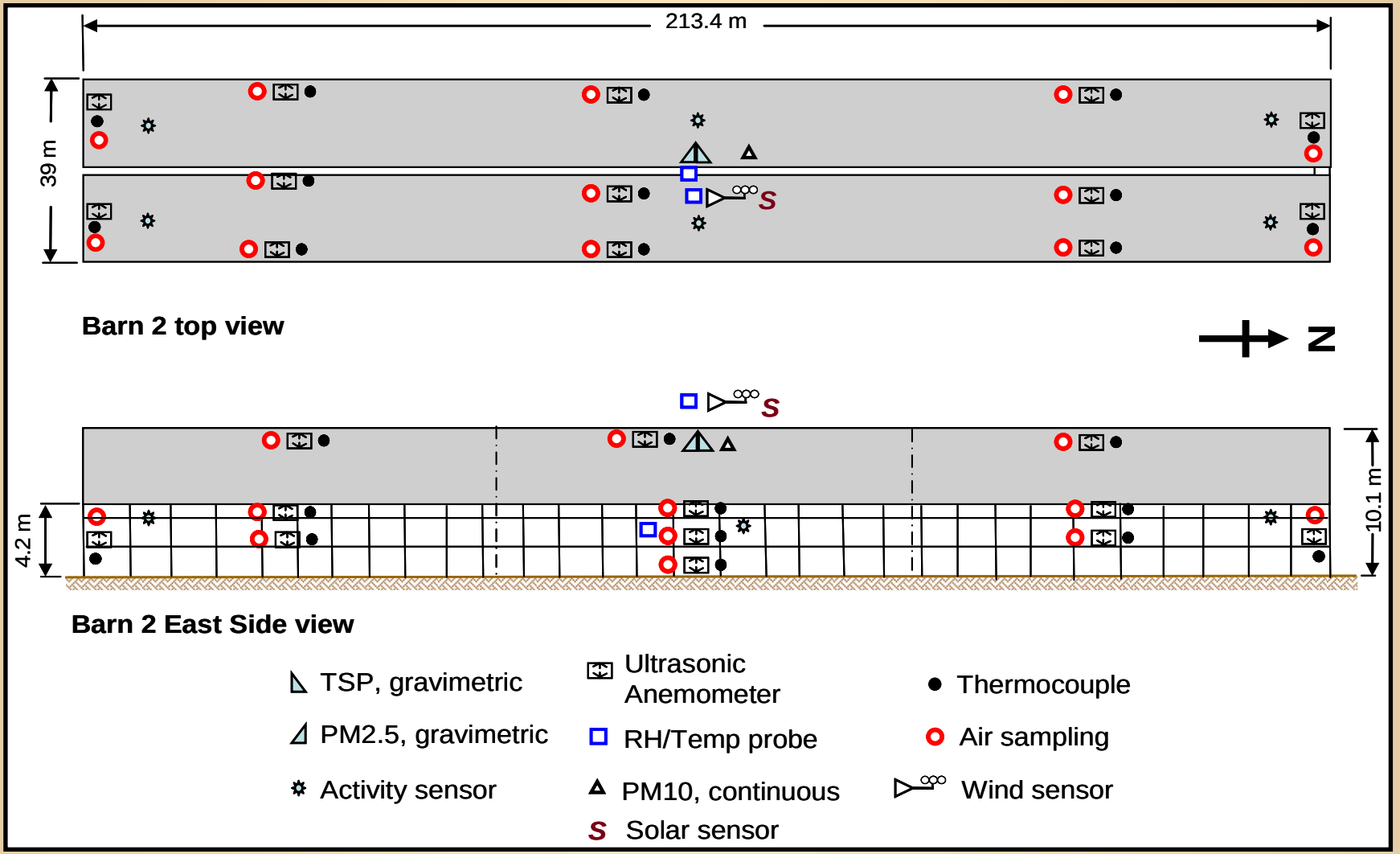
Cross section of the freestall barns showing measurement locations.

Washington Dairy Site (WA5B)



Barn top-view showing measurement locations.

Washington Dairy Site (WA5B)



Barn 2 layout showing measurement locations.

Layer and Broiler Sites

Layer Sites

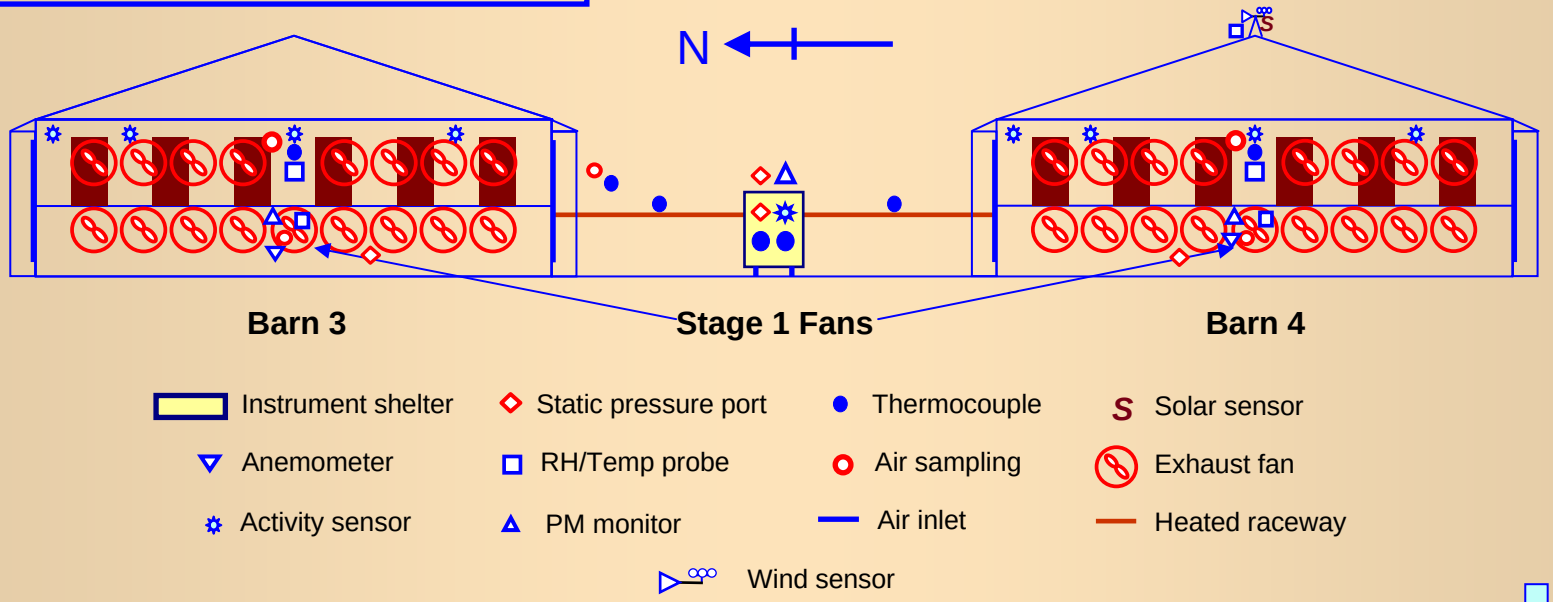
Site	Site Type	Ventilation Type	# of Units Meas.	Manure Collection	Manure Storage	Places
NC2B	**High-rise**	**MV (tunnel)**	**2**	**CBC[1]**	**First floor**	**103,000**
IN2B	**High-rise** **Belt battery** **Manure shed**	**MV (sidewall)** **MV (sidewall)** **MV**	**2** **2** **1**	**CBC** **Belt** **Loader**	**First floor** **Shed** **-**	**250,000** **280,000**
CA2B	**High-rise**	**MV (side wall)**	**2**	**DB[2]**	**First floor**	**74,000**

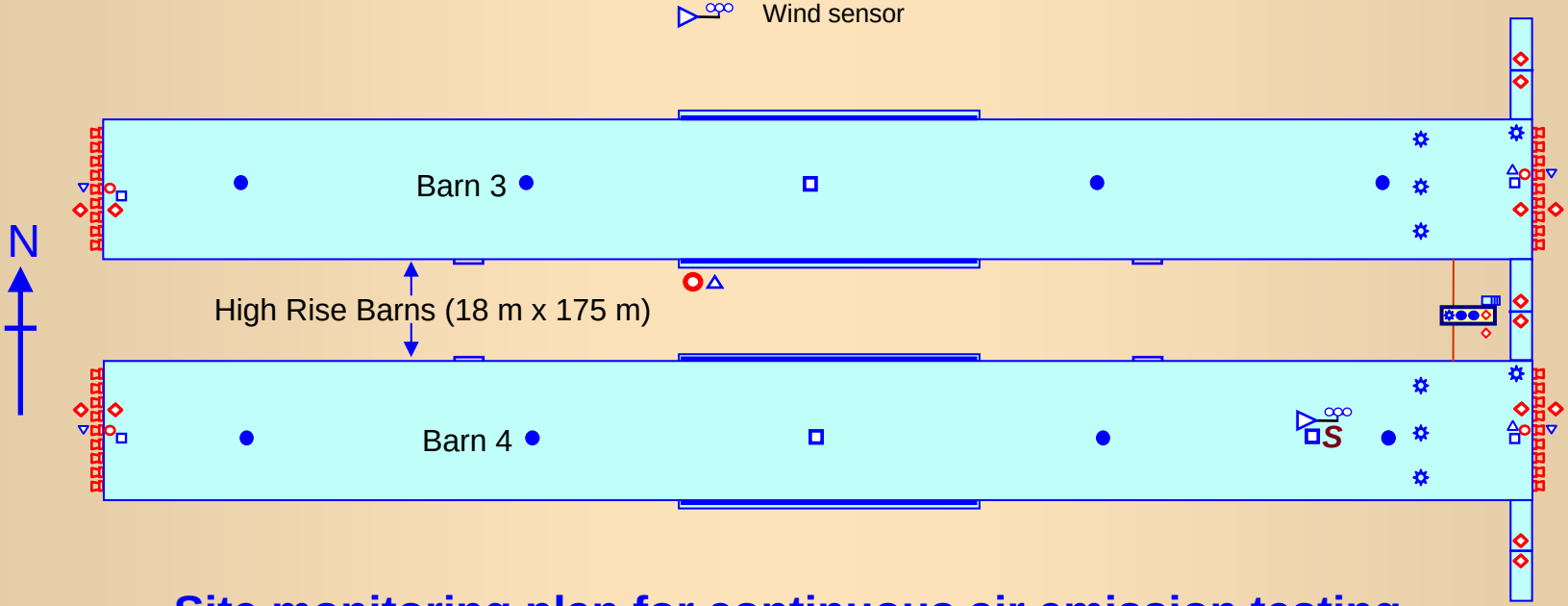
[1]CBC = curtain backed cages
[2]DB = dropping boards under cages

Broiler Site

Site	Site Type	Ventilation Type	# Units Meas.	Manure Collection	Manure Storage	Places
CA1B	**Litter on floor**	**MV (tunnel)**	**2**	**Scraper**	**None**	**21,000**

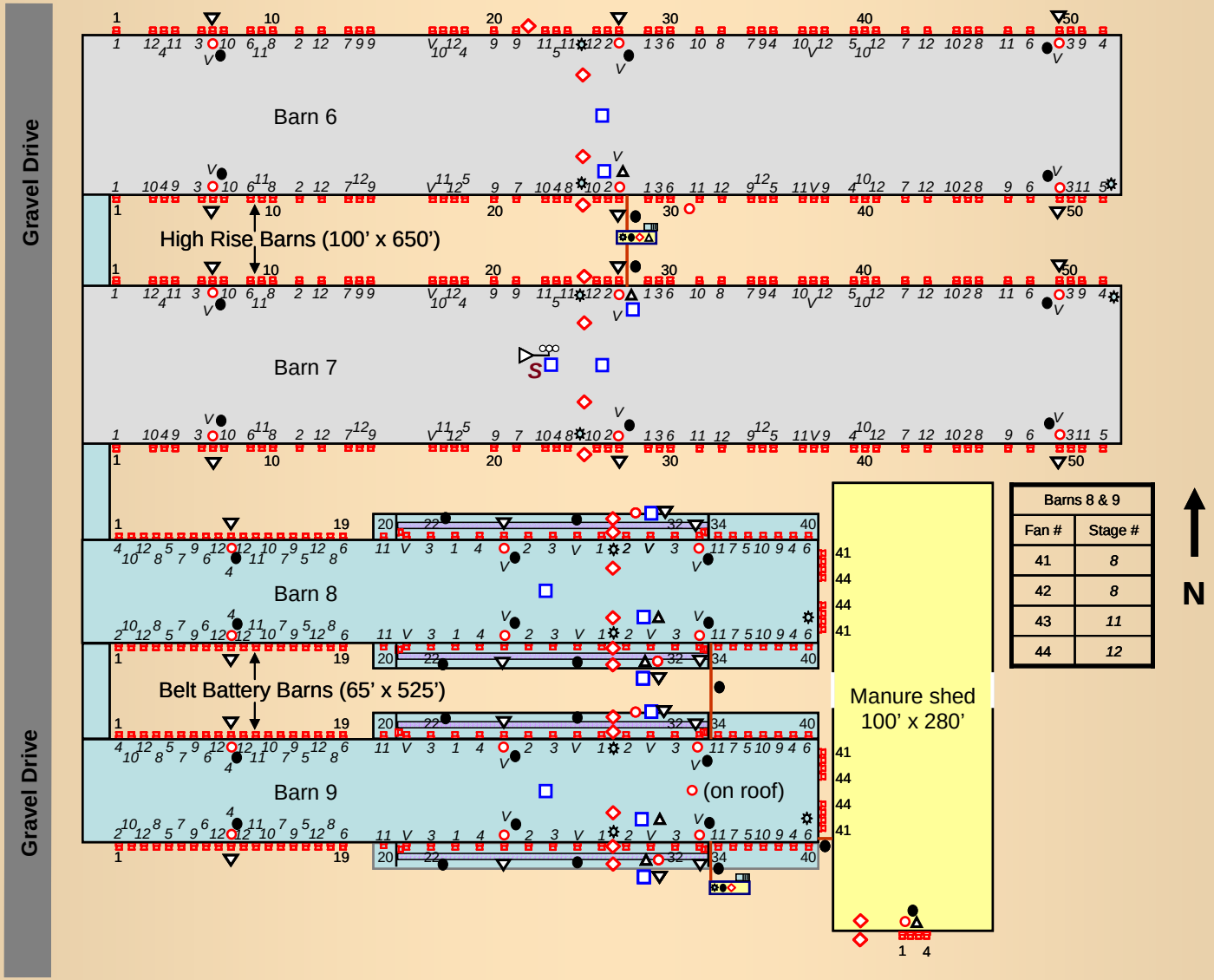
North Carolina Layer Site (NC2B)





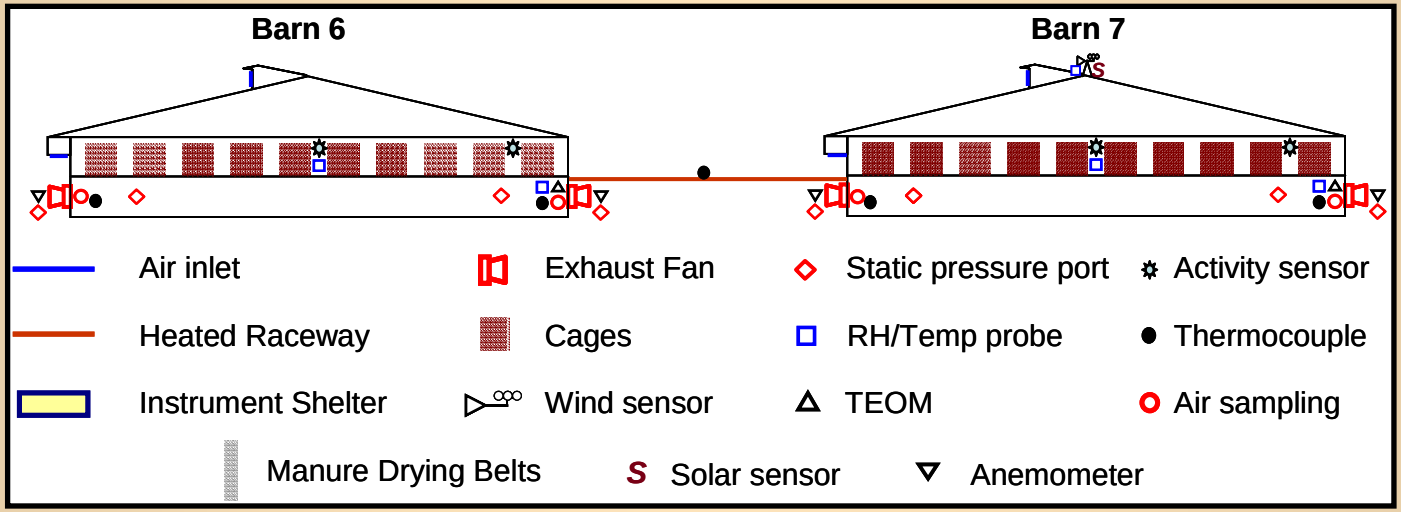
Site monitoring plan for continuous air emission testing.

Indiana Layer Site (IN2B)



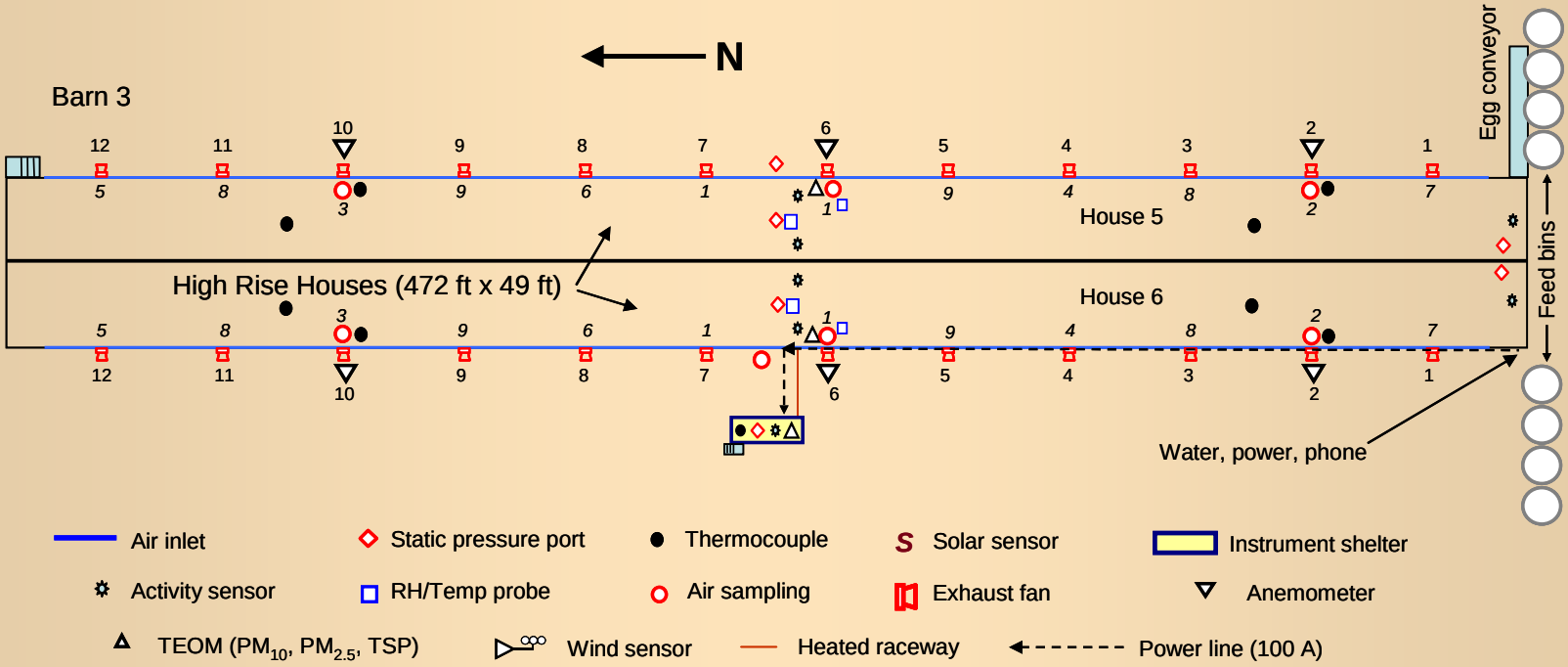
Barn top-view layout showing measurement locations.

Indiana Layer Site (IN2B)

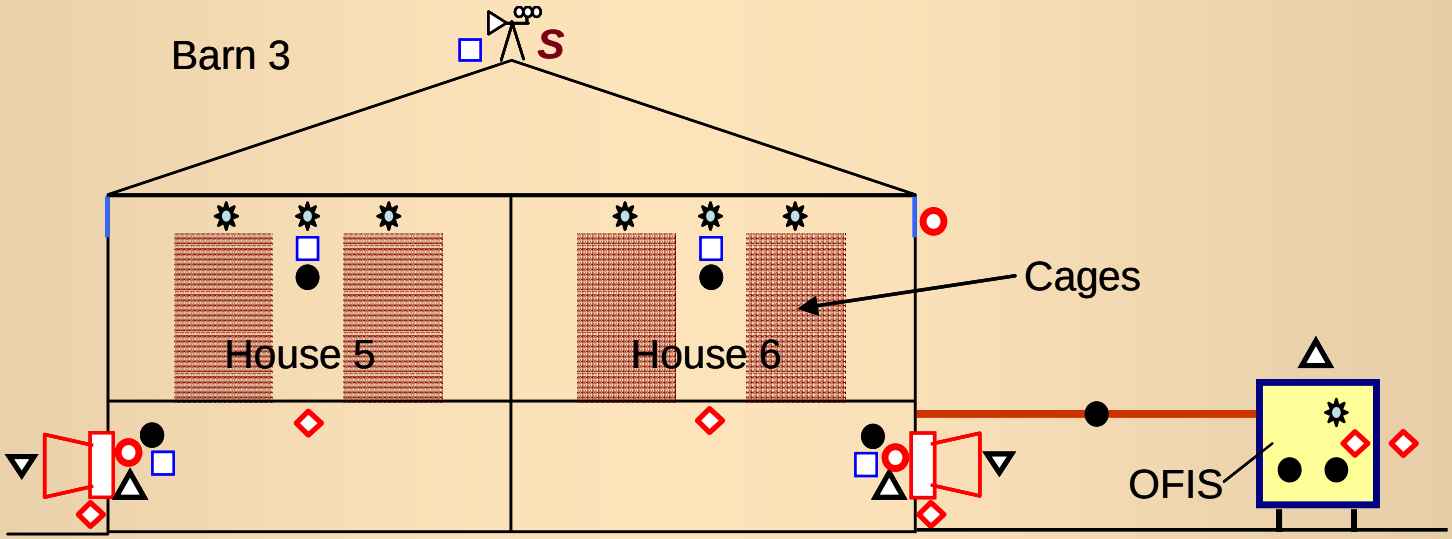


Cross section of the barns showing measurement locations.

California Layer Site (CA2B)



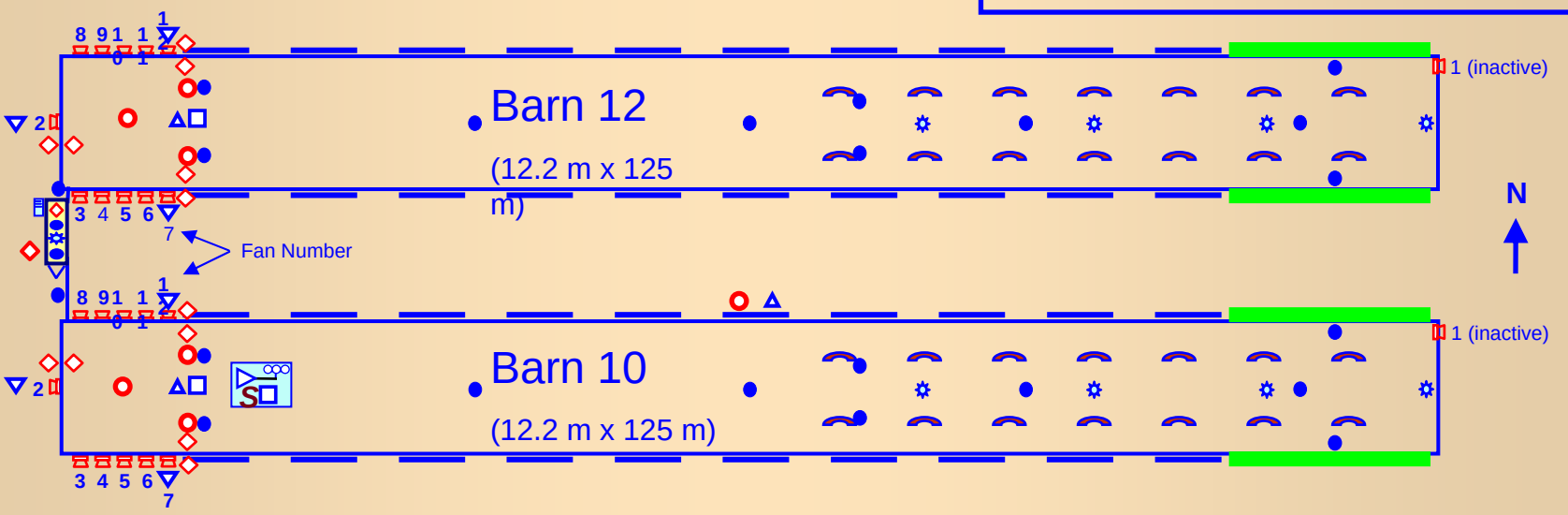
California Layer Site (CA2B)

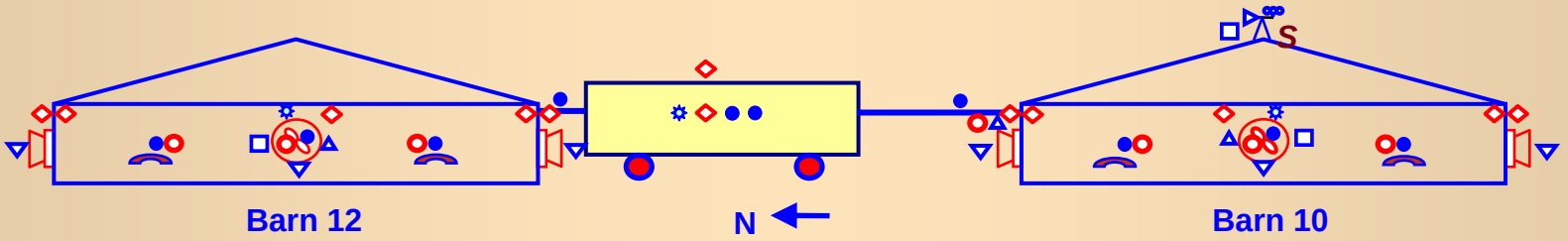


- Static pressure port
- RH/Temp probe
- TEOM
- Anemometer
- Thermocouple
- Air sampling
- Wind sensor
- S Solar sensor
- Heated raceway
- Exhaust fan
- Air inlet
- Activity sensor

Barn cross section showing measurement locations.

California Broiler Site (CA1B)





Ventilation fan
Air sampling
Wind sensor
Brooders
RH/Temp probe
Solar sensor
Air Inlet
PM, continuous
Thermocouple
Anemomete
Cool Cell
Static pressure port
Activity sensor
Instrument Shelter

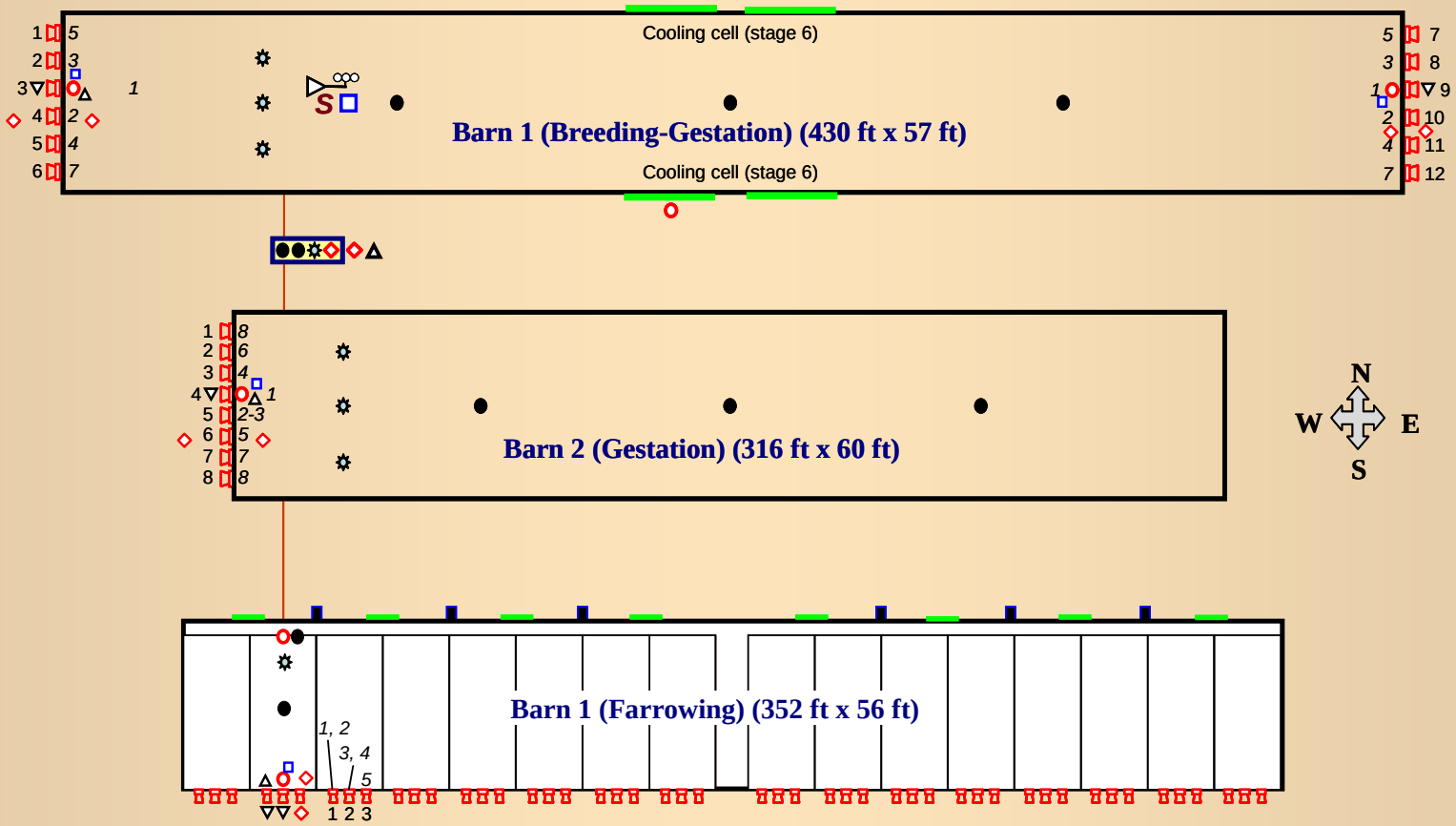
Site monitoring plan for continuous air emission testing.

Swine Sites

Site	Production phase	# units meas.	Places	Manure collection	Manure storage[2]
NC4B[1]	B/GF	2 1	850 20	PPR[3] PPR	Lagoon Lagoon
NC3B	Finisher	3	800	PPR	Lagoon
IA4B	B/GF	2 1	1100 24	Deep pit[4] PPR	Deep pit[4] Gest. pits
IN3B	Finisher	4	1000	Deep pit[4]	
OK4B[1]	B/GF	2 1	1200 24	PPR PPR	Lagoon Lagoon

[1]Barn Sites that also have measured area sources, which are described in the open-source QAPP
[2]Characterizes type of farm, not necessarily a measurement location.
[3]PPR = pull plug with recharge
[4]Storage is inside the barn so separate measurement not needed for storage.

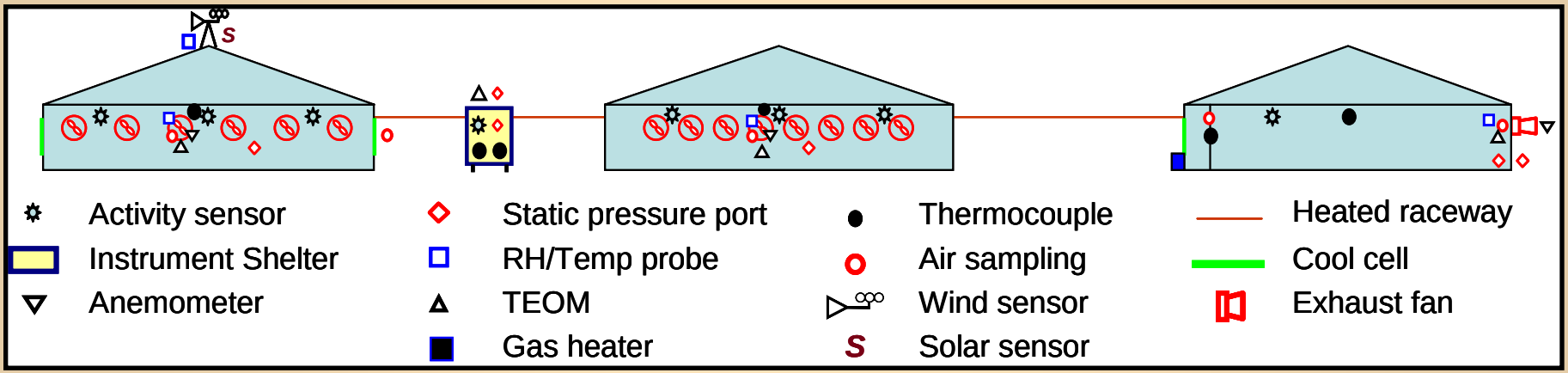
North Carolina Swine Site (NC4B)



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.

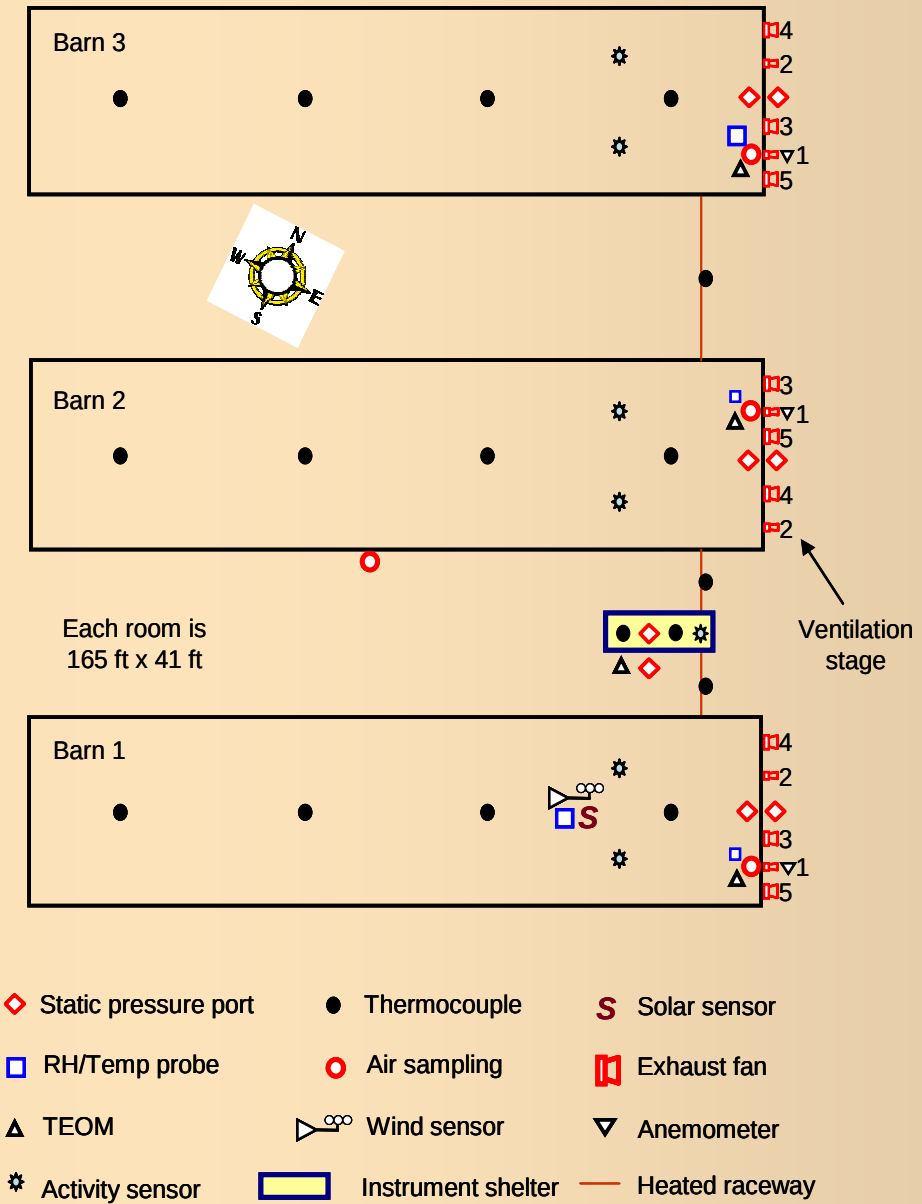
North Carolina Swine Site (NC4B)



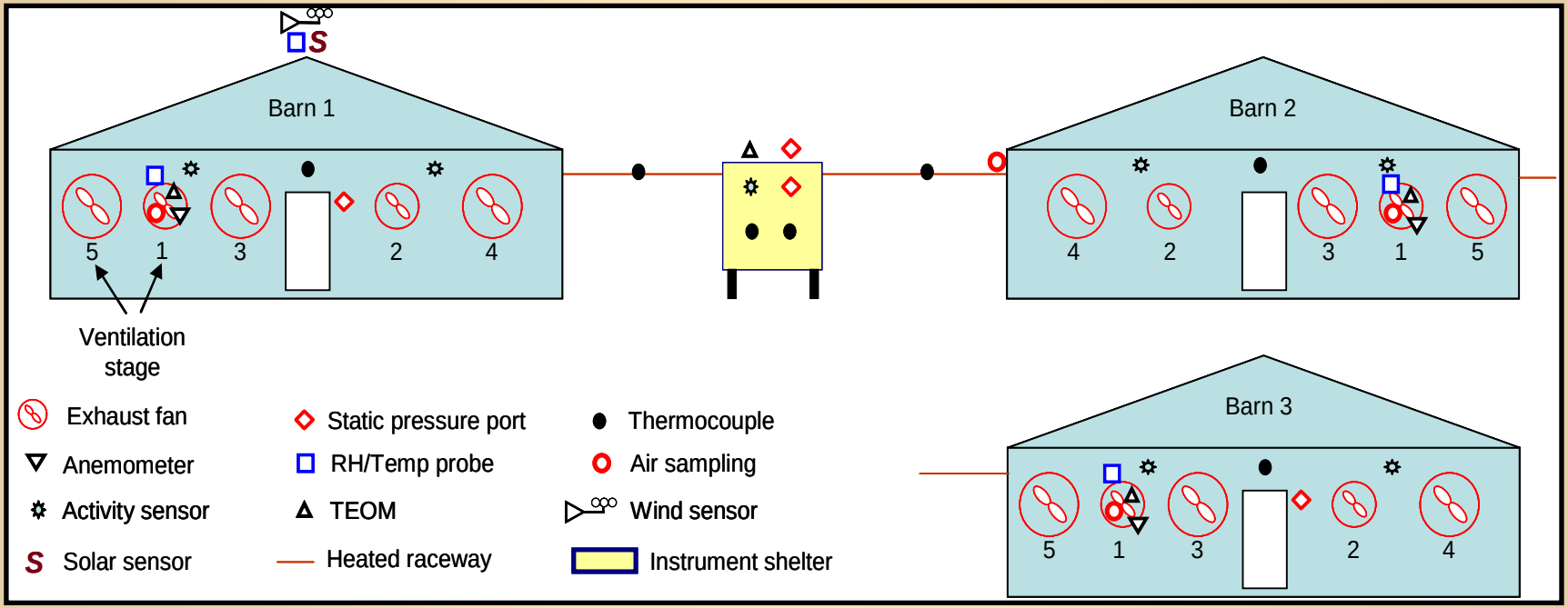
Cross section of the barns showing measurement locations.

North Carolina Swine Site (NC3B)

Barn top-view layout showing measurement locations.

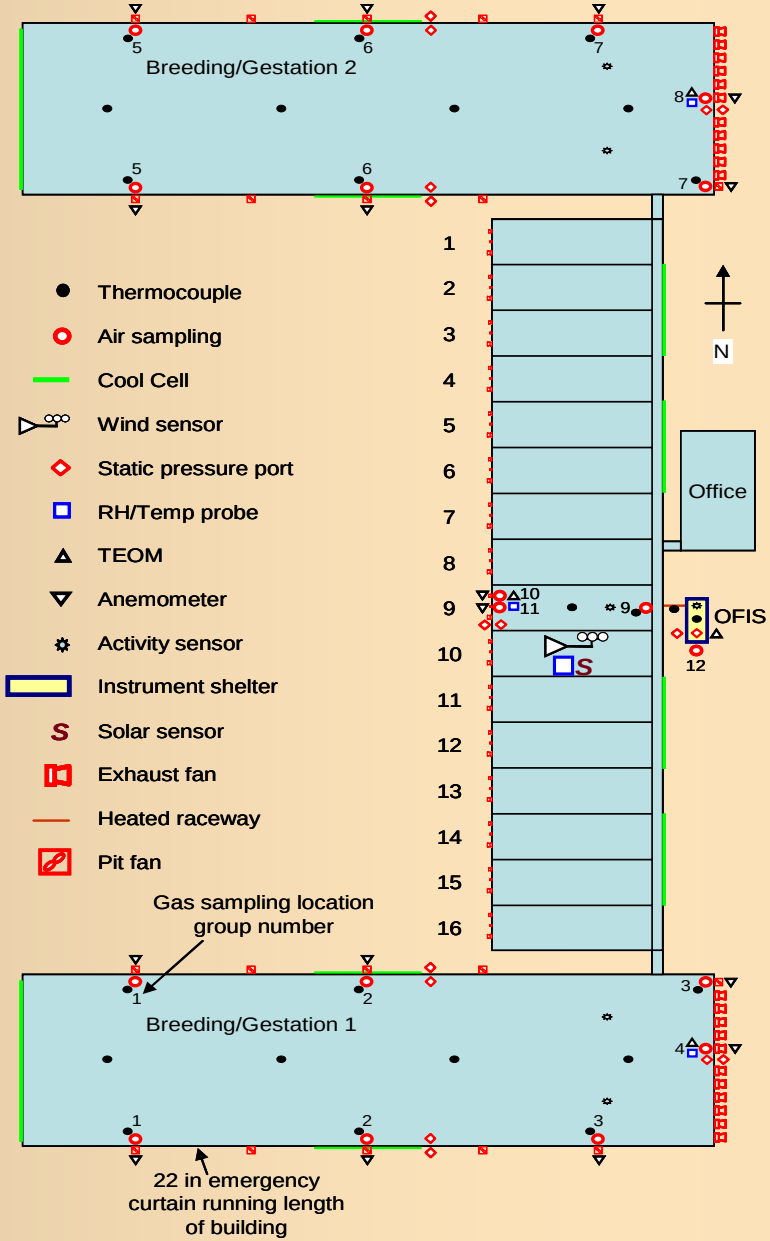


North Carolina Swine Site (NC3B)



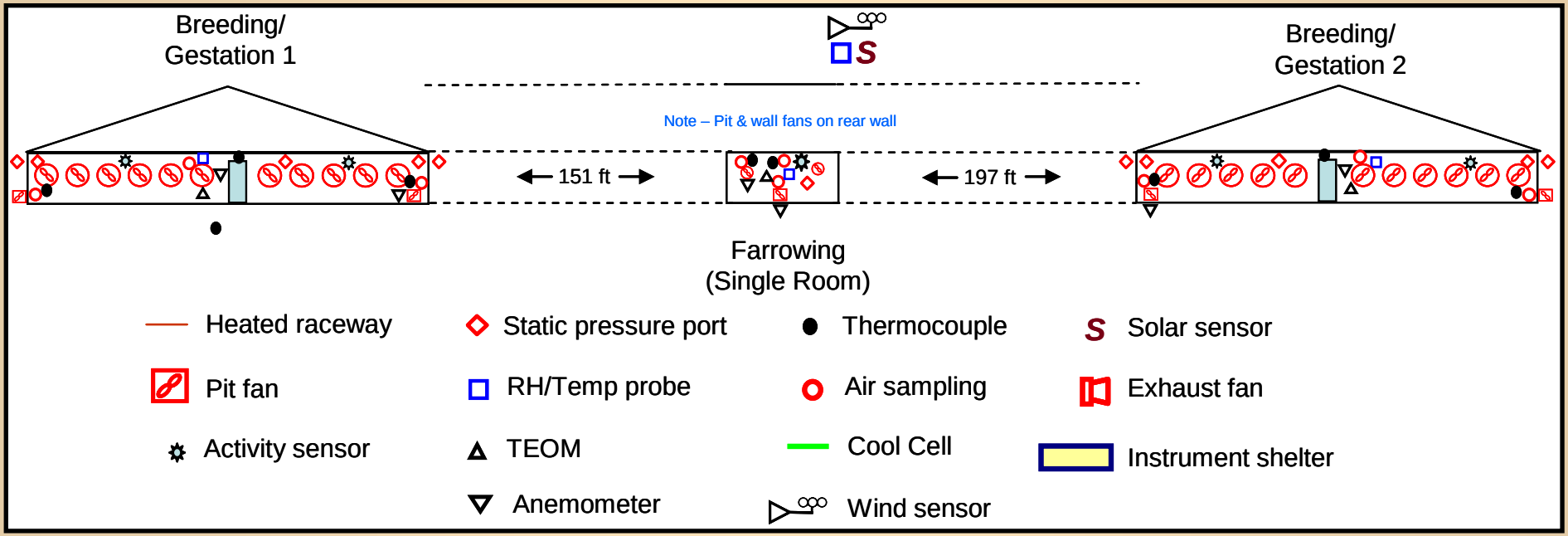
Cross section of the barns showing measurement locations.

Iowa Swine Site (IA4B)



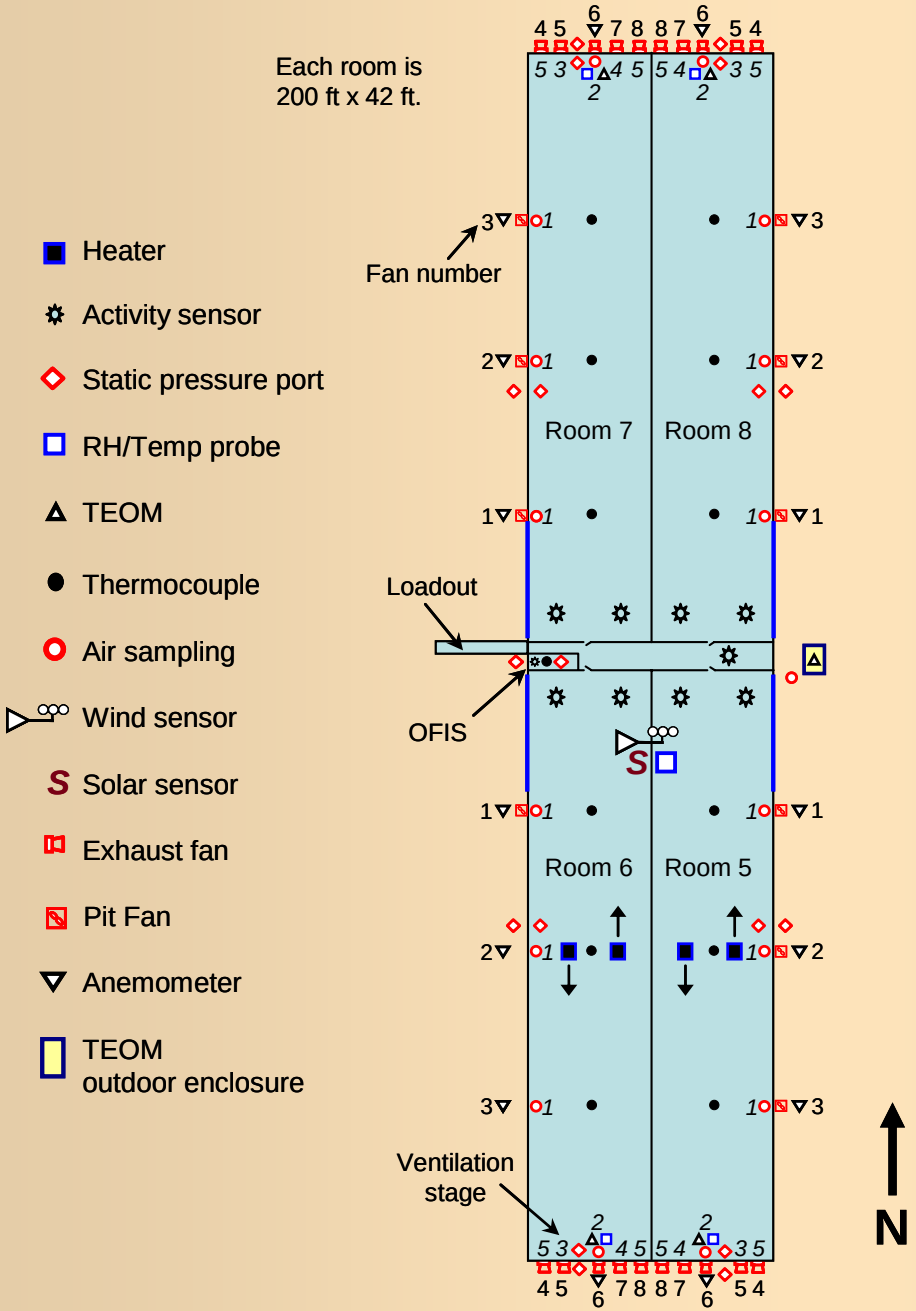
Barn top-view layout showing measurement locations.

Iowa Swine Site (IA4B)



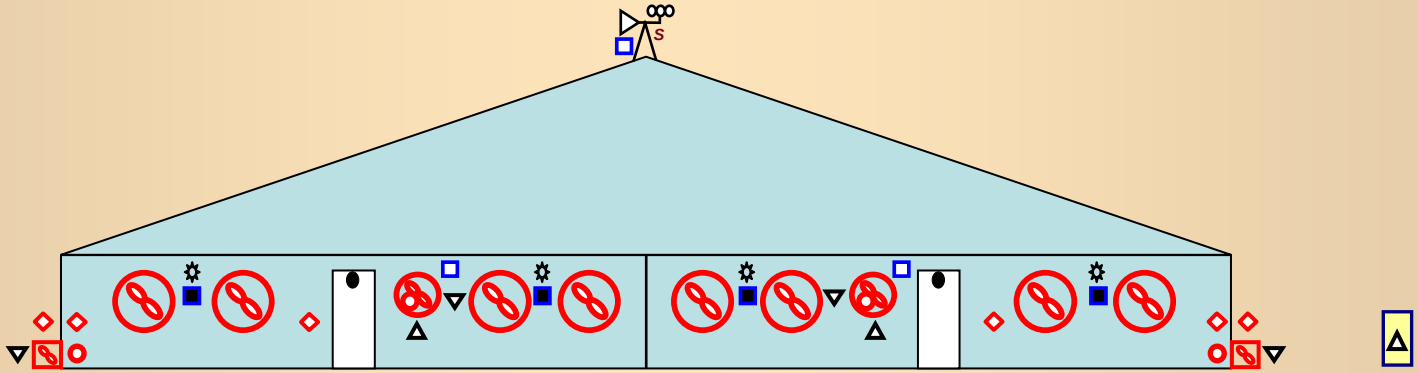
Cross section of the barns showing measurement locations.

Indiana Swine Site (IN3B)



Barn top-view layout showing measurement locations.

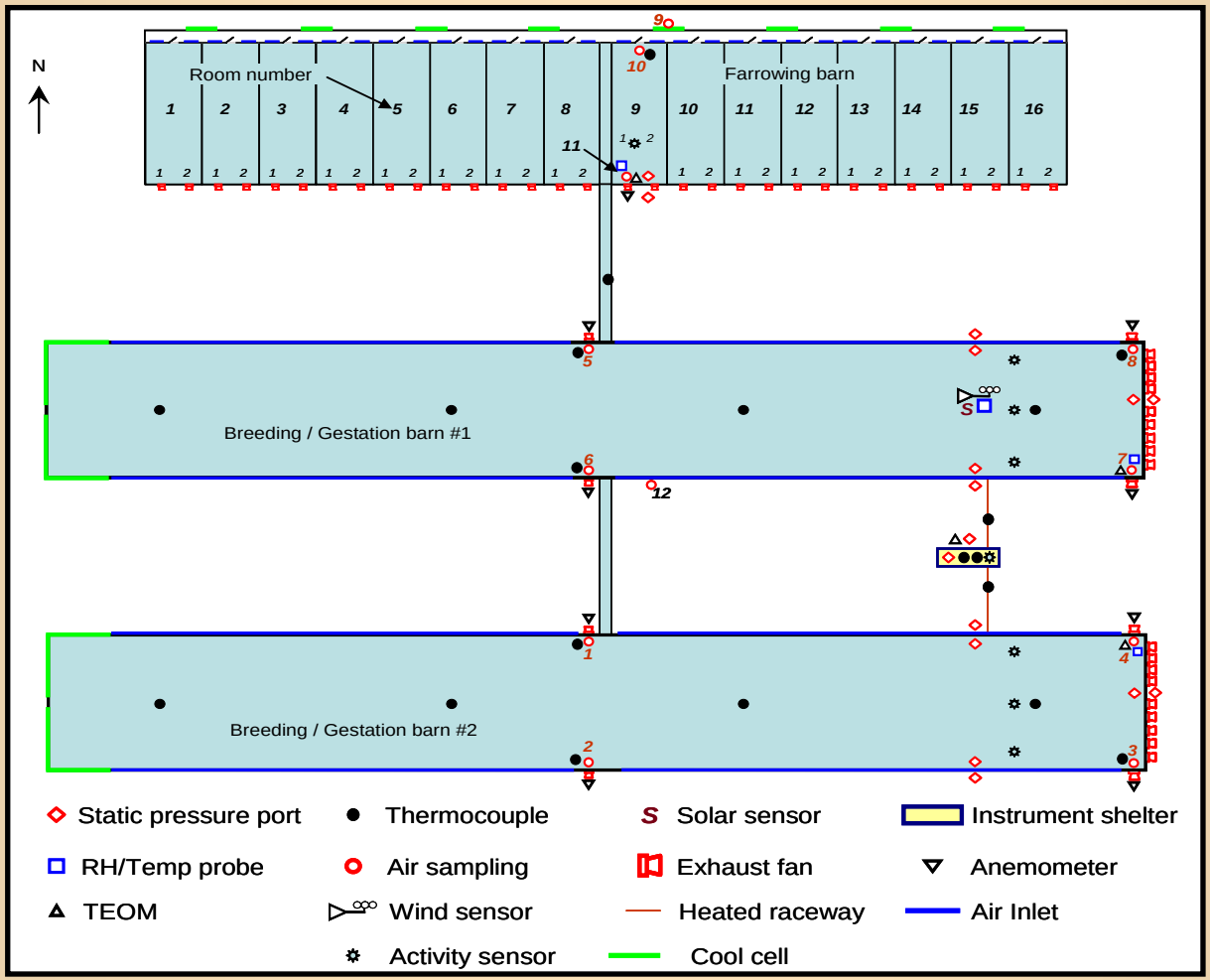
Oklahoma Swine Site (OK4B)



Heater
Activity sensor
Static pressure port
RH/Temp probe
TEOM
Thermocouple
Air sampling
Wind sensor
S Solar sensor
Exhaust fan
Pit Fan
Anemometer
TEOM outdoor enclosure

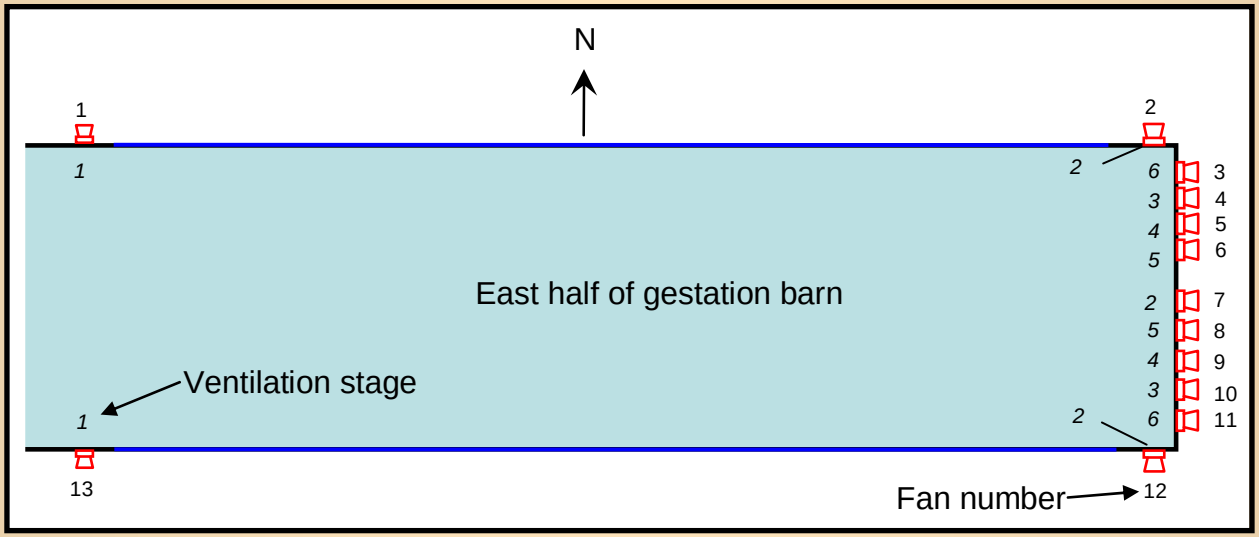
Cross section of a barn showing measurement locations.

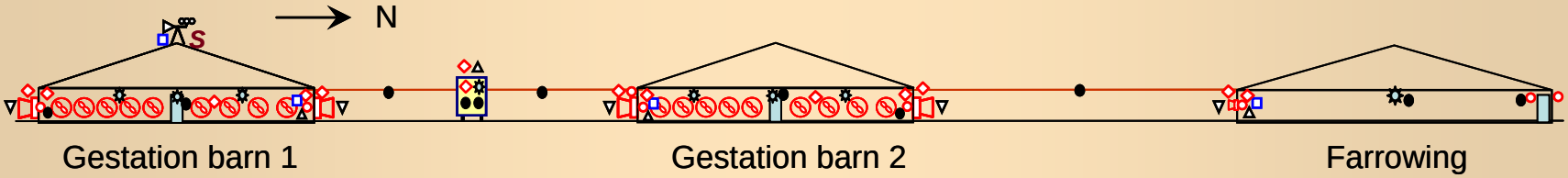
Oklahoma Swine Site (OK4B)



Barn top-view layout showing measurement locations.

Oklahoma Swine Site (OK4B)





Static pressure port
Thermocouple
S Solar sensor
Instrument shelter
RH/Temp probe
Air sampling
Exhaust fan
Anemometer
TEOM
Wind sensor
Heated raceway
Air Inlet
Activity sensor
Cool cell

Site monitoring plan for continuous air emission testing.

What Comes After NAEMS?

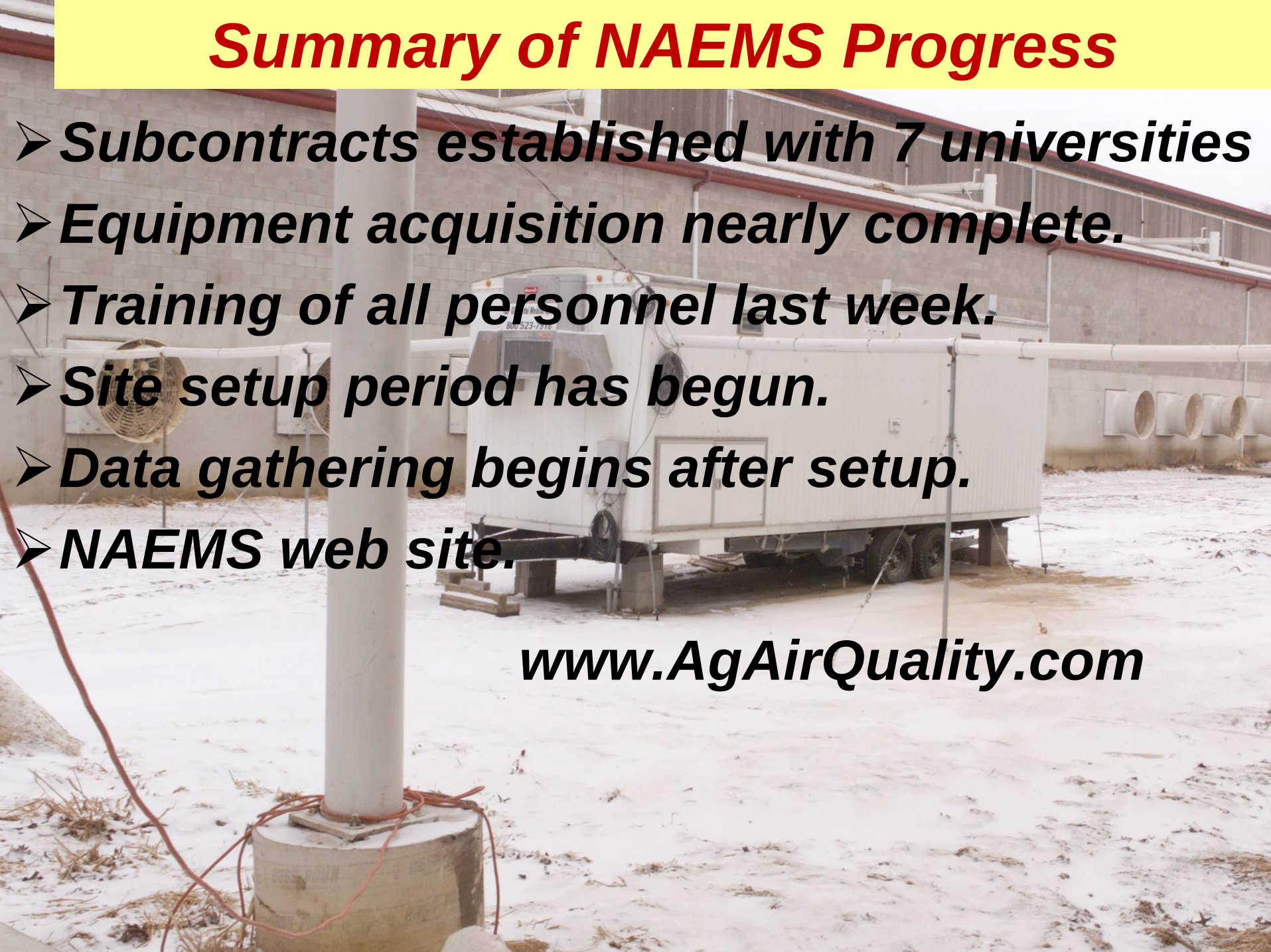
- NAEMS Pollutants?
  - Ammonia as precursor to PM2.5?
  - Hydrogen sulfide: property line limits?
  - TSP: no longer regulated by states?
- Add-on studies
- Greenhouse gas mitigation tests
- Odor mitigation studies
- Atmospheric dispersion studies
- Emission models

Check out www.AgAirQuality.com

Add-on Studies

PI	Topic/Sponsor	Site(s)
Jacobson	*Odor emissions (USDA NRI)*	IA&OK4B, IN&WI5B
Mitloehner	*VOCs @ GHGs (CA Dept. of Food, Ag. & Dairy)*	CA5B
Lim	*Downwind Dairy Odor Survey (Purdue Ag)*	IN5B
Ni	*Air emissions (USDA-NRI)*	IN2B
Koziel	*GHG (ISU)*	IA4B

Summary of NAEMS Progress



- Subcontracts established with 7 universities
- Equipment acquisition nearly complete.
- Training of all personnel last week.
- Site setup period has begun.
- Data gathering begins after setup.
- NAEMS web site.

www.AgAirQuality.com

Data Scalability

- Are the impacts of a single 4000-hd unit the same as the combined impacts of 8 500-hd units?
  - Yes, if all major factors are similar.
    - Manure volume, surface area per animal.
    - Animal-specific floor area
  - No, if the animal-specific parameters change with size.
- NAEMS will not determine these impacts.

Model Properties

- What model parameters will result from this study?
  - We will characterize sites for validation of models.
  - See tables shown previously.

Parameter Definitions

- What are the specific parameter definitions of each monitored site?
  - See tables of site descriptions.

PM and H2S Measurements

Site	Species	PM2.5, PM10, TSP	H2S
CA1B	Broilers	TEOM	TFS 450i
NY5B	Dairy	TEOM	TFS 450i
WA5B	Dairy	TEOM	TFS 450i
WI5B	Dairy	TEOM	TFS 450i
CA5B	Dairy	TEOM	TFS 450i
IN5B	Dairy	TEOM	TFS 450i
CA2B	Layers	TEOM	TFS 450i
IN2B	Layers	TEOM	TFS 450i
NC2B	Layers	TEOM	TFS 450i
IN2H	Layers	TEOM	TEI 45C
NC3B	Swine	TEOM	TFS 450i
NC4B	Swine	TEOM	TFS 450i
OK4B	Swine	TEOM	TFS 450i
IN3B	Swine	TEOM	TFS 450i
IA4B	Swine	TEOM	TFS 450i

NH3 and VOC Measurements

Site	Species	1	2	3	4	5	NMHC	VOC
CA1B	Broilers	NH3	CO2	THC	CH4	Eth		**IC**
NY5B	Dairy	NH3	CO2	None	None	None		
WA5B	Dairy	NH3	CO2	None	None	None		
WI5B	Dairy	NH3	CO2	None	None	None		
CA5B	Dairy	NH3	Meth	THC	CH4	Eth	**55C**	
IN5B	Dairy	NH3	CO2	THC	CH4	Eth		**IC**
CA2B	Layers	NH3	CO2	N2O	CH4	Ethg		
IN2B	Layers	NH3	CO2	None	None	None		
NC2B	Layers	NH3	CO2	None	None	None		
IN2H	Layers	NH3	CO2	THC	CH4	Eth		**IC**
NC3B	Swine	NH3	CO2	None	None	None		
NC4B	Swine	NH3	CO2	None	None	None		
OK4B	Swine	NH3	CO2	None	None	None		
IA4B	Swine	NH3	CO2	THC	CH4	N2O		
IN3B	Swine	NH3	Meth	THC	CH4	Eth	**55C**	**IC**

PM Oversampling

- Does the sampling methodology and analysis of results include measures to address sampler bias?
  - No, but we acknowledge the difference between regulated PM10 and true PM10.
- Will corrections be applied to field measurements?
  - Not unless EPA requires it.
- Will TSP measurements be taken in conjunction with particle size distributions as a point of comparison with PM10 and PM2.5 measurements?
  - No. However, an AARC-approved add-on study has been proposed that will do this for poultry PM.
- If not, what method(s) will be used to ensure measurement of “true” PM?
  - Since EPA regulates based on response of a particular method or instrument rather than “true” PM10 or PM2.5, EPA did not require the assessment of “true” PM for the consent agreement.

PM Related Questions

- Will the measurement timeframe and method for PM2.5 adequately represent the PM2.5 concentrations for subsequent inclusion in a dispersion model?
  - PM2.5 will only be measured for a total of 4 weeks.
  - PM2.5 of layer PM is about 10% of PM10.
- Which models will be used and evaluated for accuracy in the study?
  - Evaluating models is beyond the scope of the study itself.
  - Add-on proposals are expected.

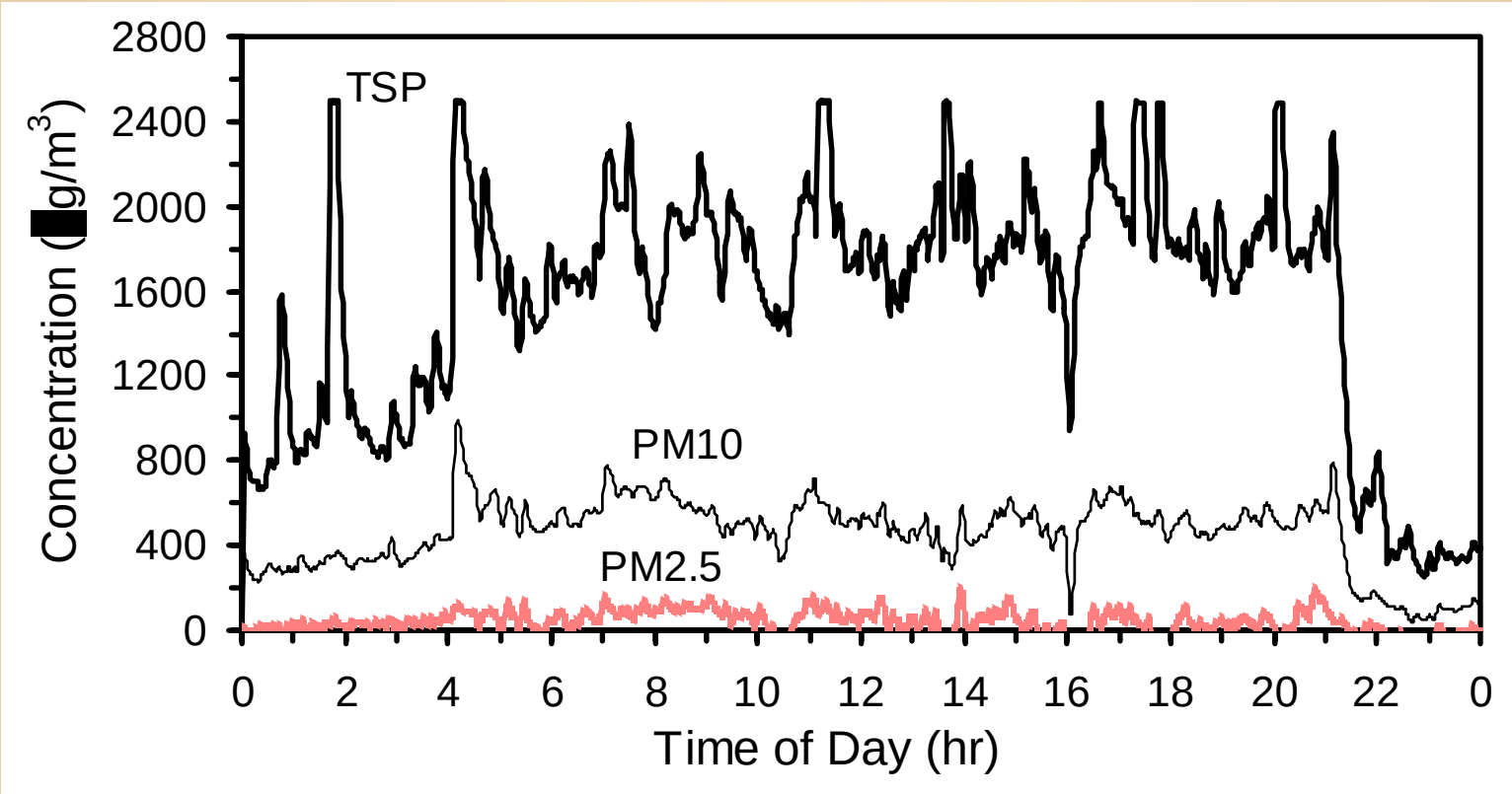


Figure 8. One minute means of TSP, PM_{10}, and $PM_{2.5}$ concentrations in a laying hen house, June 4, 2002.

Fate and Transport

- *What is the fate and transport of any of the pollutants measured? Producers need to know also what is leaving the property and in what quantities.*
  - *The NAEMS will not measure downwind concentrations or pollutant dispersion.*

Conservation Practices

- ***Will conservation management practices be evaluated as part of the study to determine the efficiency of various practices for each pollutant?***
  - ***No. This is beyond the scope of the study.***