Appendix J

June 8, 2010 DNR Staff Information Presented to Advisory Group

- Cover Memo – Best Management Practices to Mitigate Air Quality Impacts from Animal Agriculture
- Air Mitigation Measures and Effectiveness Summary Table
- Air Mitigation Measures and Effectiveness Detailed Table

Date: June 8, 2010

To: Agricultural Waste Advisory Group

From: David Panofsky, P.E. david.panofsky@wisconsin.gov

Re: **Best Management Practices to Mitigate Air Quality Impacts from Animal Agriculture**

The purpose of this document is to set expectations for the process and help lead the BMP evaluation discussion as well as:

- Define best management practices (BMPs)
- How BMPs work
- Link BMPs to production methods and successful air quality impacts mitigation
- Provide background on ammonia and hydrogen sulfide
- Remind about BMP-related caveats
- Explain the table
- Identify where help is needed
- Include a short list of technical references

BMPs Defined

In the context of air quality and agricultural waste, BMPs refer to production methods, technologies and waste management practices used to prevent or control air emissions from animal agricultural operations.

How BMPs Work

BMPs, designed to reduce air quality impacts, work in three main ways:

- reducing the actual generation of air emissions in the first place,
- reducing emissions through capture and treatment, and
- increasing dilution and dispersion.

From an air quality perspective, the BMPs developed in other states have addressed more than ammonia and hydrogen sulfide. In fact, many BMPs address odor, VOCs, particulate matter, greenhouse gases and methanol. It is believed that many BMPs identified in the literature (cited below) have been implemented at agricultural operations in Wisconsin and elsewhere.

BMPs, Production Methods, and Successful Air Quality Impacts Mitigation

Different production methods, animals, and manure management systems have the potential to create different qualities and quantities of air emissions and often require different, or a combination of, approaches for successful air emissions mitigation. BMPs which prevent and mitigate air emissions often make sense. In many dairy and beef operations, which integrate cropping systems with animal production, retaining nitrogen (and minimizing ammonia losses) means paying less for off-farm imports of nitrogen.

Successful reduction of nitrogen and hydrogen sulfide losses requires a whole-farm emissions approach for effective selection of BMPs (Rotz, Powell). Reduced loss from one farm component is easily negated by increases in another, if all components are not equally well managed (Rotz 2004). Stated another way, while certain BMPs may be quite effective for controlling emissions from one area of manure management, one must consider the fate of those controlled emissions (Ndgegwa, 2008).

Observations on Ammonia and Hydrogen Sulfide Associated with Animal Ag

Ammonia:

Ammonia is produced as a by-product of the microbial decomposition of the organic nitrogen compounds in manure, the combination of feces and urine that is excreted. Nitrogen occurs as both unabsorbed nutrients in animal feces and as either urea (mammals) or uric acid (poultry) in urine. The formation of ammonia will continue with the microbial breakdown of manure under both aerobic and anaerobic conditions. Because ammonia is highly soluble in water, ammonia will accumulate in manures handled as liquids and semi-solids or slurries, but will volatilize rapidly with drying from manures handled as solids (EPA 2001).

In terms of human health implications, ammonia may be associated with increased respiratory symptoms. Ammonia also contributes to PM2.5 concentrations and resulting health effects of fine particle pollution. Animal productivity, particularly poultry, can be adversely affected by ammonia concentrations significantly lower than ambient air quality standards contained in Chapter NR 445, Wis. Adm.Code (Moore et al 2006).

Large amounts of nitrogen are excreted in the production of all animal species (Rotz 2004). Most excess nitrogen is in a form that is easily transformed into ammonia (Rotz 2004 referencing Han 2001). Nitrogen excretion varies based on animal type and excretion estimates. Ammonia losses are presented in American Society of Agricultural and Biological Engineers (ASABE) Standards and in the literature. Ammonia emissions from animal agriculture can be highly variable depending on many factors including where, when and how animals are housed and how manure is managed (Powell 2008). High pH and temperature favor a higher concentration of ammonia and greater emissions (EPA 2004).

Various estimates reveal that, in terms of ammonia emissions from animal agriculture sectors, dairy is the top ammonia emitter. Broilers, turkeys, other cattle (including heifers and calves), beef, layers, and swine follow. With the exception of larger animal agricultural operations (concentrated animal feeding operations - CAFOs), consolidated information is lacking with respect to how the rest of Wisconsin’s animals are produced and how their manure is managed.

In terms of whole-farm dairy operations, ammonia emissions are substantially less in well-managed grazing systems, when compared to confinement systems, which co-mingle urine and dung in a liquid or slurry manure system. (USDA NRCS Technical Note No.1, May 2007, Rotz 2004, 2009).

Housing:

Rotz, 2004, provides typical nitrogen losses for animal housing, long-term manure storage and manure application methods for a number of animal types. For dairy housing, lower ammonia losses are reported from tie-stall barns, when compared to free-stall barns (Rotz 2004, Powell & Misselbrook 2008, Wattiaux 2010). Bedded pack and feedlots have even greater nitrogen losses (Rotz 2004). In terms of poultry housing, cage and belt systems have lower typical nitrogen/ammonia losses when compared to either “aviary”, deep litter or high rise housing. For swine housing, ammonia emissions are reported as lowest for slatted floor, then free range and the highest losses from deep litter systems.

Storage:

The lowest ammonia losses from long-term manure storage are for enclosed "slurry tanks." Next are solid heap poultry and bottom loaded "slurry tanks." Followed by solid heap cattle and swine and top-loaded "slurry tanks." The next highest nitrogen losses from long-term manure storage are from solid compost, although not all of the nitrogen losses are ammonia. The highest nitrogen and ammonia losses from long-term manure storage are from "anaerobic lagoons."

Land Application:

Ammonia losses from land application of manure can be large.

LOWER
↓
Ammonia Losses
↓
HIGHEST

- The lowest ammonia emissions from land application are from **deep injection** of slurry (although there are higher nitrous oxide emissions associated with this practice and other site specific potential water quality impacts).
- Next is **shallow injection** of slurry, followed closely by **grazing** (though with relatively higher nitrate losses) and **incorporation within 6 hours**.
- Then comes **broadcast of solid poultry** followed by **band or trailing hose of slurry**.
- Next is **broadcast of solid cattle or swine** with ammonia loss approximately equal with **broadcast slurry on bare soil**.
- Next comes **broadcast slurry on grassland**.
- The highest ammonia losses are reported for **irrigated slurry, with spray irrigation** at the top end.

Linkages among Housing, Manure Storage and Land Application:

It is important to note that where manure is allowed to accumulate in concentrated areas, water and air quality impacts can be significant (Powell, 2004). Additionally, for typical tie stall operations with limited manure storage, ammonia losses from broadcast application of semi-solid or solid manure where manure is not soon incorporated can be significant (Rotz, 2006). For large confinement dairy operations, a free stall with bottom-loaded slurry storage and direct injection of manure into soil can reduce ammonia emissions by 33 to 50% (Rotz 2006, Powell).

Hydrogen Sulfide (H2S):

Hydrogen sulfide is a product of the anaerobic decomposition of sulfur-containing organic matter (primarily manure). It is a colorless gas that is heavier than air, highly soluble in water, with odor and health implications. Since hydrogen sulfide is formed from animal waste in anaerobic conditions, production methods (and manure management practices) which keep manure in an aerobic condition will minimize hydrogen sulfide emissions.

Housing:

Liquid manure storage pits (located inside buildings) are a primary source of hydrogen sulfide in animal production (especially swine). In terms of animal housing, Jacobson lists hog finishing barns as having the highest hydrogen sulfide flux (a term for mass per time per area) followed by beef lots and dairy barns

Storage:

The other primary source of hydrogen sulfide in animal production is liquid/slurry manure storage basins (both dairy and swine). Significant quantities of hydrogen sulfide can be released during agitation of stored liquid manure (Jacobson). Manure storage has significantly higher hydrogen sulfide fluxes than animal housing, in general. Practices which avoid agitation during filling (like bottom filling) and reduce surface agitation (basin covers) have been shown to be effective in minimizing storage losses (DATCP/DNR CIG 2009).

Land Application:

Hydrogen sulfide losses from land application of manure have not been documented, although it is expected that losses will occur and land application practices which minimize odor and/or ammonia volatilization will work to mitigate hydrogen sulfide emissions. This would include the following practices:

- Injecting of liquid/slurry manure, and
- Rapid incorporation if surface applied

Some Caveats

Not every BMP will be appropriate for every animal agricultural operation, nor will every BMP be technically or economically feasible. Agricultural operations may use a number of, or a combination of, practices based on animal needs and seasonal and/or market changes. In some cases, BMPs focused on control practices specific for one air quality parameter may actually contribute to an increase in other air emissions or to environmental problems with other media.

For example,

- acidifying of manure may decrease ammonia while increasing hydrogen sulfide emissions;
- the unintended result of frequent cleaning of freestall barns to reduce volatile organic compounds (VOCs) may lead to a possible increase in ammonia emissions; and
- while soil injection or incorporation of liquid manure can substantially reduce ammonia emissions, this practice can potentially contribute to negative impacts on groundwater and surface water quality, as well as cause increased soil erosion and/or compaction, in some situations.

A number of BMPs can also have co-benefits. Practices focused on the prevention of hydrogen sulfide can also provide greenhouse gas (GHG) emissions reduction (by handling manure dry or aerobically). In general, practices which reduce odor tend to reduce ammonia and/or hydrogen sulfide, but not always.

Explaining the BMP Table

The table is a compilation of BMPs found in the literature. This includes the Wisconsin ATCP 51 rule; work done in the states of Minnesota, Iowa, California (primarily from the San Joaquin Valley Air Pollution Control District), Idaho, and Oregon; the Livestock and Poultry Environmental Learning Center; and a number of journal articles such as Rotz 2004 published in the American Society of Animal Science, "Management to Reduce Nitrogen Losses in Animal Production."

The organization of the table is simple and should be considered a work in progress, until the group has been able to add, clarify or consolidate practices listed. The table includes all animal species together, although there are some specific BMPs for swine and poultry, too. It is not organized by how manure is handled, such as slurry/liquid or dry. Nor does it presuppose, or restrict, BMPs for specific production methods and manure handling systems.

The table is divided into the following five farm component categories:

- animal housing and feed,
- manure storage and treatment,
- open lots/corrals,
- pasture systems, and
- land application.

Many BMPs are effective for more than one species and housing choice. For example, biofilters may work on cross-ventilated dairy housing, deep pit swine and any number of tunnel ventilated poultry broiler or layer operations. The primary rationale for inclusion was whether there were reductions in hydrogen sulfide or ammonia. There are some BMPs included which disperse ammonia and hydrogen sulfide through a variety of installed practices like air dams or vegetative or other windbreaks. These practices may have more than a dispersive benefit, as there may be co-benefits of PM reduction and potential capture/treatment of ammonia, hydrogen sulfide or other air quality pollutants (Coletti et al 2006). In some cases BMPs for odor, particulate matter (PM), volatile organic compounds (VOCs), or greenhouse gases (GHGs) have been included for completeness. Where control reductions are provided by sources, the ranges are given.

The original layout of the table was based on ATCP 51 (odor control practices) and work done on the air quality portion of the Environmental Assessment referenced below. Where there is an X in a column, it means there is some reduction for a given pollutant but it is unclear what control reduction to assign. Also, it is important to note that the percent (%) reduction is only for emissions from the farm component category and not a whole-farm % reduction.

<u>Help Needed</u>

We have identified two parts of the BMP identification/evaluation process. The first part involves a series of steps to gather information and to generate a list of all known BMPs and their corresponding control reductions. The draft table of BMPs attached is a first step. If you find the table missing or inappropriately identifying (or referencing) a specific BMP or information in one or more column, especially regarding the percent control reduction, please bring it to my attention. Technical feasibility and cost information is largely incomplete in the table for a variety of reasons. Some of these reasons include the changing nature of BMP costs and how to express those capital and/or management costs, as well as the fact that depending on the farm specifics, some BMPs may be feasible, while at other operations they will be less feasible and possibly ineffective.

It would be valuable to better understand our experiences in Wisconsin with specific BMPs and whether identified BMPs are currently standard operating procedures or practices. - not that this necessarily discounts a BMP's importance in ammonia and hydrogen sulfide emissions mitigation.

The second part of the process is determining how to prioritize, better define, assign value to the BMPs and how to consider an overall emissions reductions framework. How does one assign a control reduction to a specific BMP for which we do not have published reduction control? How does one consider BMPs which are effective at controlling emissions at one farm component only to lose the emissions in another component? How does one address conflicts regarding BMPs for water quality versus air quality or where BMPs for ammonia reduction are at odds with hydrogen sulfide emissions reduction? Is a BMP's effectiveness able to be verified?

References:

The following links take you to a number of references, many used in the preparation of the attached BMP table:

The National Air Quality Site Assessment Tool
http://naqsat.tamu.edu/

The Integrated Farm System Model.
http://www.ars.usda.gov/Main/docs.htm?docid=8519

Iowa State University Air Management Practices Assessment Tool - Home Page
http://www.extension.iastate.edu/airquality/practices/homepage.html

Iowa Concentrated Animal Feeding Operations Air Quality Study Final Report, Iowa State University and The University of Iowa Study Group
http://www.public-health.uiowa.edu/ehsrc/CAFOstudy/CAFO_final2-14.pdf

Chapter 10. Emissions Control Systems
http://www.public-health.uiowa.edu/ehsrc/CAFOstudy/CAFO_10.pdf

Environmental Assessment for a General WPDES Permit for Large CAFOs, Wisconsin Department of Natural Resources (section on air quality on pages 63-81)
http://dnr.wi.gov/runoff/pdf/ag/cafo/LargeCAFOGPEA.pdf

Practices to Reduce Ammonia Emissions from Livestock Operations, Iowa State University Extension
http://www.extension.iastate.edu/Publications/PM1971a.pdf

Practices to Reduce Hydrogen Sulfide from Livestock Operations, Iowa State University Extension
http://www.extension.iastate.edu/Publications/PM1972a.pdf

Manure Management and Air Quality, University of Minnesota Extension
http://www.manure.umn.edu/research/air_quality.html#EmissionsQuantification

Minnesota Generic Environmental Impact Statement on Animal Agriculture
http://www.eqb.state.mn.us/geis/

Ammonia, The Air-Water Interface, Livestock and Poultry Environmental Learning Center
http://www.extension.org/pages/Ammonia,_The_Air-Water_Interface

Hydrogen Sulfide, How Serious an Outdoor Air Quality Concern, Livestock and Poultry Environmental Learning Center

http://www.extension.org/pages/Hydrogen_Sulfide,_How_Serious_an_Outdoor_Air_Quality_Concern

Recommendations to the San Joaquin Valley Air Pollution Control Officer Regarding Best Available Control Technology for Dairies in the San Joaquin Valley

http://www.valleyair.org/busind/pto/dpag/Final%20DPAG%20BACT%20Rep%201-31-06.pdf

Mitigating Air Emissions from Animal Manure: Summaries of Innovative Technologies, Livestock and Poultry Environmental Learning Center

http://www.extension.org/pages/Mitigating_Air_Emissions_from_Animal_Manure:_Summaries_of_Innovative_Technologies#Summaries_Sorted_By:

Air Quality in Animal Agriculture, Livestock and Poultry Environmental Learning Center

http://www.extension.org/pages/Air_Quality_in_Animal_Agriculture

USDA Air Quality Activity Practice 2000

http://www.airquality.nrcs.usda.gov/Documents/files/AirQuality_Activity-Practice_List.pdf

Proceedings from the National Conference on Mitigating Air Emissions from Animal Feeding Operations, Iowa State University

http://www.ag.iastate.edu/wastemgmt/Mitigation_Conference_proceedings/Conference%20Proceedings.htm#Siting_and_Environmental_Barriers

Best Management Practices (BMPs) for Ammonia Emissions Reduction from Animal Feeding Operations: A Colorado Case Study

http://cropandsoil.oregonstate.edu/sites/default/files/WERA103/2007_Proceedings/WNMC07.p124.Elliott.pdf

Reducing Ammonia Emissions from Poultry Litter, USDA-ARS

http://www.airquality.nrcs.usda.gov/AAQTF/Documents/200809_201008/201003_TalahasseeFL/Reducing_Ammonia_Emissions_from%20_Poultry_Litter.pdf

Bioenergy and Manure Management Information, Ammonia Emissions Literature, Ontario Canada,

http://gis.lrs.uoguelph.ca/AgriEnvArchives/bioenergy/ammonia_emissions.html

Idaho Air Quality: Permit by Rule for Dairy Farms

http://www.deq.idaho.gov/air/permits_forms/permitting/pbr_dairies.cfm

Oregon Department of Environmental Quality Task Force on Dairy and Air Quality

http://www.deq.state.or.us/aq/dairy/

Mid-Atlantic Agricultural Ammonia Forums, 2004
http://www.mawaterquality.org/public_education/agri_ammonia_forums.html

Air Mitigation Measures and Effectiveness
Summary Table

Roughly one arrow down means up to 20% reduction, two arrows roughly 40% reduction, three arrows roughly 60% and four arrows down mean greater than 80% control for that practice, for that particular farm component. Where there are question marks, there is uncertainty. Where there are blanks, no assumptions can be made other than information lacking in this summary table.

	P – prevention C – capture T - treat D - dilution	Ammonia	Hydrogen Sulfide	Odor	PM	GHG	VOC, methanol	Notes
Animal Housing and Feed								
1. Feed and nutrient managemenmt	P	↓↓	↓↓	↓	↓	↓	↓	
2. Proper silage/feed management	P, C	↓			↓		↓↓	
3. Bio-filter/filtration	C, T	↓↓↓↓	↓↓↓↓	↓↓↓↓	↓↓↓		↓↓↓	
4. Vegetable oil sprinkling (for swine only)	C, T, P	↓	↓	↓↓	↓↓↓			
5. Floor design for urine-feces segregation	P	↓↓			↓↓↓			
6. Binding Ammonium (w/zeolite, etc) – swine. poultry	P,T	↓						
7. Confine recycled waste water used for flushing barns and alleyways	C	↓						
8. Windbreak (includes man-made berms); landscaping	D, P			↓	↓			
9. Frequent cleaning and/or flushing	D	↓ or ↑ or =		↓			↓	
10. Bedding selection	P	↓						
11. Ozonation	T	↓↓						

Air Mitigation Measures and Effectiveness[1]								
	P – prevention C – capture T - treat D - dilution	Ammonia	Hydrogen Sulfide	Odor	PM	GHG	VOC	Notes
12. Wet scrubber/bioscrubber	C, T	↓↓↓	↓↓↓	↓↓↓	↓↓↓			
13. ESP	C				↓↓↓			
14. Non-thermal plasma	C, T	↓↓↓↓						
15. Concrete freestall and drylot feed lanes and walkways	P	↓		↓	↓		↓	
16. Alum addition to litter (poultry)	P	↓↓		↓				
17. Practices to keep litter/manure dry (poultry)	P	↓↓?		↓				

Air Mitigation Measures and Effectiveness[1]								
	P – prevention C – capture T - treat D - dilution	Ammonia	Hydrogen Sulfide	Odor	PM	GHG	VOC	Notes
Manure Storage and Treatment								
18. Anaerobic digestion with biogas combustion	C	↑?	↑?	↓↓?		↓	↓↓	
19. Chemical or biological additives	T			↓				
20. Composting for solid manure with proper C:N ratio	P	↑?	↓↓	↓↓↓		↓		
21. Maintain dry manure (cattle, swine)	P	↑?	↓↓			↓		
22. Enclosed solids separation and reduction	C?	↓ or ↑ ?		↓↓			↓	
23. pH reduction (acidification) by a variety of methods	P	↓↓↓	↑↑					
24. Water Treatment	C, T	↓ ?		↓↓				
25. Aeration/aerobic lagoon	P	↑?	↑?	↓↓			↓	
26. Phototrophic facultative circulating aerobic system	P, T	↓↓	↓↓	↓			↓	
27. Bio-cover and other mat'ls	C, T	↓↓↓↓ ?	↓↓↓ ↓?	↓↓?				
28. Geotextile/permeable cover	C	↓	↓↓	↓↓				
29. Impermeable cover	C	↓↓↓↓	↓↓↓↓	↓↓↓↓				

Air Mitigation Measures and Effectiveness[1]								
	P – prevention C – capture T - treat D - dilution	Ammonia	Hydrogen Sulfide	Odor	PM	GHG	VOC	Notes
30. Natural crust	C, T	↓↓	?	↓↓				
31. Temperature control	P	↓↓						
32. Bottom fill/avoiding agitation	C	↓	↓	↓				
33. Windbreak; Landscaping	D			↓	↓			
34. Settlingbasins/Weeping Walls BMP	P	↓		↓			↓	

Air Mitigation Measures and Effectiveness[1]								
	P – prevention C – capture T - treat D - dilution	Ammonia	Hydrogen Sulfide	Odor	PM	GHG	VOC	Notes
Open lots/corrals								
35. Frequent Cleaning	P	↓		↓↓				
36. Drag animal lot	P			↓↓				
37. Animal lot moisture control	P			↓				
38. Windbreak (includes man-made berms)	D			↓	↓			
39. Dust control plan	P				↓↓↓			
40. Manage for shade, drainage	P	↓					↓	
41. Acidifier (sodum bisulfate)	T	↓					↓	
Pasture Systems								
42. Stock only appropriate numbers, use appropraite rotational practices	P	↓↓						
43. Move water and feed areas on regular basis to avoid hot spots	P	↓↓						
44. Irrigating immediately after grazing	P,D	↓↓				↑?		
Land Application								
45. Injection	P, C, T	↓↓	↓↓	↓↓			↓	
46. Minimize liquid manure irrigation and broadcast sprinkler irrigation	C	↓↓						
47. Additives	T	?	?					
48. Operational practices including timing, when cooler, less windy, etc.	C, T	↓			↓		↓	
49. Rapid incorporation of manure into the soil after land application (solid	P, C	↓			↓			

Air Mitigation Measures and Effectiveness[1]									
	P – prevention C – capture T - treat D - dilution	Ammonia	Hydrogen Sulfide	Odor	PM	GHG	VOC	Notes
manure, as well)								

Air Mitigation Measures and Effectiveness[1]								
	Cost	Ammonia	Hydrogen Sulfide	Odor	PM	GHG	VOC, methanol	Notes
Animal Housing (see also open lots, corrals), Feed, Production Areas other than Manure Management								
1. Diet manipulation/Reduce protein to match animal need/additional nutrition	Save $? $	12-50% (Lorimor) 10-15% (Powell) 20-30% (Satter, Wattiaux)	to 40% (Lorimor)	20% (ATCP) to 25% (Lorimor)	to 25% (Lorimor)	X		Prevention 1-4. Complex nutritional issue affecting everything – RDP and RUP, amino acids can reduce dietary protein by 10-15%, ammonia 20-30% reduction (Satter)
2. Feed in accordance with NRC guidelines utilizing routine nutritional analysis for rations		X					X	SJVAPCD
3. Lower S feeds for swine			to 40%					Iowa State University – Ext.
4. Feed/nutrient management for lower manure pH (liquid/slurry systems)		X						Wattiaux et al 2010 – may effect mineral content of manure, possibly more H2S, odor
5. Cover or ensile all silage		X			X		X	SJVAPCD
6. Collect leachate from silage piles and send to wastewater treatment		X					X	SJVAPCD

[1] Jacobson – Larry Jacobson, Biosystems & Agricultural Engr and MN GEIS; Lorimor – Jeffery Lorimor, Iowa State University, and Ch. 10 Emission Control System; Iowa State Extension publication; LPELC – Livestock and Poultry Environmental Learning Center, BMPs in Reducing Loss of Ammonia into the Atmosphere, Washington State University Biological Systems Engr.; ATCP – Ch. 51, ATCP, Wis. Adm. Code; Powell – J. Mark Powell, U.S. Dairy Forage Research Center; SJVAPCD refers to San JoaquinValley Air Pollution Control District; Colorado - BMPs for Ammonia Emissions Reduction from AFOs: A Colorado Case Study, Western Nutrient Conference 2007, Vol 7. Salt Lake City, UTCO case study, 2007; Rotz - Management to Reduce Nitrogen Losses in Animal Production; C.A. Rotz, 2004; Iowa – Animal Feeding Operations Technical Workgroup Report on Air Emissions Characterization, Dispersion Modeling, and Best Management Practices, Dec. 15, 2004; Wattiaux – Michel Wattiaux, Dairy Systems Management,Department of Dairy Science, University of Wisconsin-Madison

Air Mitigation Measures and Effectiveness[1]	Cost	Ammonia	Hydrogen Sulfide	Odor	PM	GHG	VOC	Notes
system at least once every 24 hours								
7. Uneaten feed should be re-fed or removed daily to minimize emissions from decomposing feed		X						Prevention SJVAPCD
8. Silage face management – only disturb the required face area		X					X	SJVAPCD
9. Dry Grains to be stored in commodity barn					X			Prevention - SJVAPCD
10. Bio-filter/filtration 11. Freestall enclosure with biogas vented to biofilter 12. Biofilters on pit fans from deep-pit buildings	\$150-200 per 1,000 cfm \$\$	9-99% (MN GEIS) 50-60% (Jacobson) 40-50% (Lorimor) 9-100% (LPELP)	50-90% (MN GEIS) 40-50% (Lorimor) 85-95% (Jacobson)	90% (ATCP) 40-50% (Lorimor) 80-95% (Jacobson)	40-50% (Lorimor) Up to 86% (MN GEIS)		Up to 46% (MN GEIS) 80%	Mostly applicable for mechanically ventilated housing. Does effectively mitigate both H2S and NH3 and VOCs and PM SJVAPCD Rodent problems?
13. Vegetable oil sprinkling (for swine only)		10-30% (Lorimor) 10-30% (Jacobson)	10-30% (Jacobson)	60% (ATCP) 40-50% (Lorimor) 10-30% (Jacobson)	40-50% (Lorimor) 50-70% (Jacobson)			
14. Urine-feces segregation 15. Slatted floors (Powell)		50% (LPELP)			to 80% (Lorimor)			Prevention
16. Binding Ammonium (w/zeolite, etc)		reductions in swine and poultry						
17. Fresh water flush				60% (ATCP)				
18. Treated water flush				30% (ATCP)				
19. Confine recycled waste water used for flushing		X						Colorado

Air Mitigation Measures and Effectiveness[1]								
	Cost	Ammonia	Hydrogen Sulfide	Odor	PM	GHG	VOC	Notes
barns and alleyways								
20. Air dam (for swine only)				10% (ATCP)				
21. Windbreak (includes man-made berms); landscaping	For 3,000 hd hog , $0.68 per pig for shrub/tree			10% (ATCP) 20% (Lorimor)	20% (Lorimor)			Ensure non-invasive plants utilized
22. Frequent cleaning of animal areas				10% (ATCP)				No effect on NH3 emissions (Rotz, 2006)
23. Feed lanes and walkways to be flushed four times a day, scraped four times daily, or vacuumed four times daily		X					X	SJVAPCD Frequent scraping has been identified by some sources as decreasing VOCs, but increasing NH3
24. Weekly scraping and/or manure removal using a pull type manure harvesting equipment, except during periods of rainy weather		X			X		X	SJVAPCD
25. Flush/spray Milking Barn after each batch		X					X	SJVAPCD
26. Bedding selection		relative reductions for sand (Powell)						Some bedding not compatible with ADs; No crust to form
27. Ozonation		15-50% (Jacobson)						Human health hazard, limited positive research (Jacobson)
28. Wet scrubber/bioscrubber		8-94% (Jacobson) 22-54% (Jacobson)						
29. ESP					40-60% (Jacobson)			
30. Non-thermal plasma		to 100% (Jacobson)						
31. Concrete freestall and drylot feed lanes and walkways					X		X	SJVAPCD

Air Mitigation Measures and Effectiveness[1]								
	Cost	Ammonia	Hydrogen Sulfide	Odor	PM	GHG	VOC	Notes
32. Pave feedlane at least 8 feet on corral side of the fence		X						SJVAPCD
33. Poultry specific Buildings Manure Handling and Storage Manure Application Mortality and egg disposal Layers and Duck-specific		X		X				Wisconsin Poultry Producers' Odor/air emissions reduction BMPs
34. Alum addition to litter		X						Philip Moore, USDA-ARS, 2010
35. Wet scrubbers		X						
36. Keep manure dry; drinker maintenance, etc		X						Mitigation Strategies for Ammonia Management, TX A&M Preventive
37. Poultry layer belt drier, pelletizing – Increasing litter DM		X?		X				Innovative Odor control evaluated by DATCP

Air Mitigation Measures and Effectiveness[1]								
	Cost	Ammonia	Hydrogen Sulfide	Odor	PM	GHG	VOC	Notes
Manure Storage and Treatment								
38. Anaerobic digestion with biogas combustion				80% ? (ATCP) 50-80% (Lorimor)		X	SJVAPCD w/95% VOC control of captured biogas	DATCP/DNR CIG study found not as much odor control as expected with two Ads – one mesophilic and other thermophilic; production of other exhaust byproducts such as formaldehyde Need to flare off gases Engine NSPS/NESPAP
39. Manure Gas Safety Gen'l BMPs for Preventing Problems – mostly applicable for liquid/slurry manure storage or handling								Although the scope relates mostly to occupational exposure, H2S, NH3 and CH4 can be of significant concern and DATCP, NRCS has recommendations – Nov 2008
40. Chemical or biological additives – Urease inhibitors 41. Pit additives see Stowell				20% (ATCP)				Land app issues?
42. Composting for solid manure with proper C:N ratio	$$	Other composting BMPs from ID	Up to 45% (IA) Up to 30% for liquid manure	80% (ATCP) to 30% (Lorimor) to 45% (IA Working Group, 2004)		X		Preventive - H2S or CH4 will not be produced in aerobic conditions.
43. Maintain dry manure	$-$$$					X		May increase ammonia – preventive wrt H2S
44. Solids separation and reduction 45. Enclosed mechanical	 $15,000 to	 X		40% (ATCP)			 X	2 streams of manure to manage SJVAPCD ?? at least for NH3, but

Air Mitigation Measures and Effectiveness[1]								
	Cost	Ammonia	Hydrogen Sulfide	Odor	PM	GHG	VOC	Notes
separator – Designs with less turbulent flow 46. Dewatering press to reduce moisture content of separated solids 47. Weekly removal of separated solids	$100,000	 X					 X	where is the N going? ?? SJVAPCD at least for NH3
48. pH reduction (acidification) by a variety of methods		reductions	increases					Decreasing pH will decrease ammonia emissions, yet increase hydrogen sulfide emissions
49. Water Treatment				90% (ATCP)				
50. Aeration/aerobic lagoon	$3,000-$6,000 per aerator; $2-4 per pig marketed $$-$$$	X		70% (ATCP)			X	SJVAPCD Increases ammonia and H2S emissions - CIG
51. Phototrophic facultative circulating aerobic system		95%(Wegner)	90%(Wegner)	X			X	Circul8 System, published data?? WI climate?
52. UV Treatment								Applicable???
53. Bio-cover (straw and other mat'ls) 54. Leka rock	$0.1-$0.26 per sf $2.50 per sf	40-95% (Jacobson) 17-90% (LPELC) X	80-95% (Jacobson)	60% (ATCP) 60-90% (Jacobson)				Potential disposal challenge Wattiaux Peat moss non-renewable
55. Geotextile/permeable cover	$0.25 per sf, plus installation	10-25% (Jacobson) 44% (LPELC) 90% w/zeolite (LPELC)	10-70% (Jacobson) 50-70% (Lorimor)	50% (ATCP) 50-70% (Lorimor) 10-60% (Jacobson)				Potential disposal challenge
56. Impermeable cover	$1.00 to $1.40 per sf installed HDPE (10-yr life)	80-100% (LPELC)	50-80% (Lorimor)	60-80% (Lorimor) 90% (ATCP)				Potential disposal challenge
57. Rigid cover		>80% (Jacobson)						

Air Mitigation Measures and Effectiveness[1]	Cost	Ammonia	Hydrogen Sulfide	Odor	PM	GHG	VOC	Notes
58. Inflatable cover		to 95% (Jacobson)	to 95% (Jacobson)					
59. Floating synthetic		45-90% (Jacobson)						
60. Natural crust		75-90% (Jacobson) 24-32% (LPELC)	N/A (Jacobson)	70% (ATCP) 60-85% (Jacobson)				Not achievable with liquid manure generally or with sand or dewatered solids bedding
61. Clay balls		N/A (Jacobson)	80-90%(Jacobson)	60-90% (Jacobson)				
62. Temperature control		to 50% (Jacobson)						
63. Bottom fill/avoiding agitation		X	X	10% (ATCP)				Recommendation from DATCP/DNR CIG study, Rotz et al
64. Windbreak (includes man-made berms); Landscaping	For 3,000 hd hog , $0.68 $$-$$$ per pig for shrub/tree			10% (ATCP)				
65. Settlingbasins/Weeping Walls BMP								
66. Dry contents in basins within a 2-week period		X					X	SJVAPCD
67. Contents must either be directly incorporated into land or spread in thin layers, harrowed and dried		X					X	SJVAPCD
Open lots/corrals								
68. Frequent Cleaning		X		60% (ATCP)				Powell (2005) notes uncollected manure potential source of N problems
69. Drag animal lot				50% (ATCP)				
70. Animal lot moisture control				20% (ATCP)				
71. Windbreak (includes man-made berms)				10% (ATCP)				
72. Dust control plan with					X			Some measure to increase manure

Air Mitigation Measures and Effectiveness[1]	Cost	Ammonia	Hydrogen Sulfide	Odor	PM	GHG	VOC	Notes
specific BMPs (Yakima Regional Clean Air Authority)								moisture through higher stocking densities will increase NH3 emissions
73. Provide shade for cattle in open lots to encourage movement throughout the pens over the course of the day to disperse manure over the pen surface		X						Colorado
74. Shade structures on open corrals							X	SJVAPCD
75. Drylots sloped to facilitate runoff and drying		X						SJVAPCD
76. Acidifier (sodium bisulfate)	$33-50/week per 1,000sf of corral	X					X	See Milhoehner IA State Mitigation Conference, mineral salt, N20
Pasture Systems								
77. Stock only appropriate numbers		X						Colorado
78. Move water and feed areas on regular basis to avoid hot spots		X						Colorado
79. Irrigating may reduce NH3 immediately after grazing, but could increase emissions of N2O and nitrate to groundwater		X						Colorado
80. Using appropriate rotational practices								
Land Application								
81. Knifing in (direct injection)		90% (Jacobson) 47-100% (LPELC)		50% (Jacobson)				Increase GW contam potential; soil erosion, compaction; drain tile connection surface waters
82. Injecting (slot)	Increase of $0.003/gal	80-92% (LPELC) 50-60% (Lorimor)	50-60% (Lorimor)	50% (Jacobson) 50-60%				Increase GW contam potential; soil erosion, compaction

Air Mitigation Measures and Effectiveness[1]								
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83. Irrigation of crops using liquid or slurry manure from holding/storage pond 84. Liquid injection of manure until crops become tall enough that damage would occur (only applies to slurry)	See Mulbauer, IA State Mitigation Conference	X X		(Lorimor)			X X	SJVAPCD Note that this appears to contradict Powell and other sources. Increase ammonia volatilization, runoff potential SJVAPCD
85. Minimize liquid manure irrigation and broadcast sprinkler irrigation		Rotz Powell						Spray irrigation may be viewed as a water quality BMP in some situations – no point source for ww discharge Contradicts SJVAPCD recommendations?
86. Additives								
87. Timing – when cooler, less windy 88. Rapid incorporation of manure into the soil after land application (solid manure, as well)	$	Rotz					X	SJVAPCD May increase soil erosion, what about no-till?
On-field Crop activities 89. Minimize passes 90. Practice conservation tillage 91. Restrict field activity during high wind events (>20mph) 92. Surface roughening of fallow fields 93. Track-out prevention		X			X			SJVAPCD Some of these practices will mitigate NH3, too. Likely covered issues in the NMP, with CAFO water quality permits.

Air Mitigation Measures and Effectiveness[1]								
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