Source Category: Agricultural Emissions of Ammonia

INTRODUCTION

Ammonia (NH_3) reacts in the atmosphere to form particulate ammonium sulfates (NH_4HSO_4 and $[NH_4]_2SO_4$) and ammonium nitrate (NH_4NO_3), which are important contributors to ambient $PM_{2.5}$ and regional haze. The sources of sulfur dioxide (SO_2) and nitrogen oxides (NO_X) – the other precursors of sulfate and nitrate particulate matter – are subject to broad air pollution control programs to mitigate ambient $PM_{2.5}$, regional haze, and other pollution problems. Ammonia is not currently subject to similar air pollution control programs; however, some emission reductions have probably been achieved in recent years as a result of voluntary measures and control programs which have been implemented to reduce water pollution. The Midwest Regional Planning Organization (MRPO) has been collecting and analyzing data on ambient ammonia concentrations in order to evaluate the potential impacts of ammonia emission reductions on levels of ambient $PM_{2.5}$ and regional haze.[1,2,3]

The purpose of this document is to provide a forum for public review and comment on the evaluation of candidate control measures for ammonia that may be considered by the States in the MRPO and other neighboring states as part of broader control strategies for $PM_{2.5}$, and regional haze. It must be noted that this document presents preliminary information on potential control measures. The MRPO states have not yet determined which measures will be necessary to meet the requirements of the Clean Air Act. As such, the inclusion of a particular measure here should not be interpreted as a commitment or decision by any State to adopt that measure. No decision has been made on whether or not to regulate ammonia emissions.

Candidate control measures for various sources of SO_2 and NO_X emissions are addressed by MRPO Interim White Papers. This analysis of control measures for ammonia is modeled after these white papers. Each paper includes a description of the source category, brief regulatory history, discussion of candidate control measures, expected emission reductions, cost effectiveness and basis, timing for implementation, rule development issues, other issues, and supporting references. Table S-1 summarizes this information for agricultural ammonia emissions sources.

SOURCE CATEGORY DESCRIPTION

Emissions inventories prepared by the MRPO indicate that agricultural processes account for 91% to over 99% ammonia emissions from human activities in the Midwest states. The bulk of agricultural ammonia emissions emanate from livestock wastes. Microbes convert urea and other nitrogen compounds in animal waste to ammonia, which then volatilizes to produce ammonia emissions. Thus, ammonia is emitted from livestock wastes in pastures, animal confinement areas, and waste handling and storage operations. Ammonia is also emitted when the waste is spread on crop lands of grazing lands as a fertilizer.

Synthetic nitrogen fertilizers also produce ammonia emissions. Some of these fertilizers are ammonium salts, such as ammonium phosphate or ammonium sulfate, which break down to release gaseous ammonia. Synthetic urea fertilizer is also broken down by microbes to produce ammonia emissions.

Table S-1. Summary of Control Measure Information for Agricultural Ammonia Emissions

		Ammonia emissions (1000 tons/year)	
Control measure summary		3-state region [a]	9-state region [b]
10% Emission Reduction	2005 base	351	1,147
Methods of achieving this reduction would be flexible. Potential control measures include vegetative buffers, feed adjustments, incorporation of livestock manures that are spread on fields using disc plows, reduced usage of synthetic nitrogen fertilizer, substitution of lower emission fertilizers in place of urea, and other measures.	Reduction Remaining	35 316	115 1,032
Control cost: $31–1,500 / ton			
Timing of implementation: by 2009			
Implementation area: 3-state or 9-state region [a,b]			
15% Emission Reduction	2005 base	351	1,147
Methods of achieving this reduction would be flexible. Potential control measures include vegetative buffers, feed adjustments, incorporation of livestock manures that are spread on fields using disc plows, reduced usage of synthetic nitrogen fertilizer, substitution of lower emission fertilizers in place of urea, and other measures.	Reduction Remaining	53 298	172 975
Control cost: $31–1,500 / ton			
Timing of implementation: by 2009			
Implementation area: 3-state or 9-state region [a,b]			

[a] The 3-state includes Michigan, Minnesota, and Wisconsin, which are the states closest to four Northern Midwest Class I areas.

[b] The 9-state region includes Michigan, Minnesota, Wisconsin, Illinois, Indiana, Iowa, Missouri, North Dakota, and South Dakota.

Disclaimer: The control measures identified in this document represent an initial set of possible measures. The Midwest RPO States have not yet determined which measures will be necessary to meet the requirements of the Clean Air Act. As such, the inclusion of a particular measure here should not be interpreted as a commitment or decision by any State to adopt that measure. Other measures will be examined in the near future. Subsequent versions of this document will likely be prepared for evaluation of additional potential control measures.

Table 1 summarizes the estimated agricultural emissions of ammonia from Michigan, Minnesota and Wisconsin, which are the three states nearest to four Northern Midwest Class I areas;[a] and from a larger 9-state region which also includes Illinois, Indiana, Iowa, Missouri, North Dakota, and South Dakota (in addition to Michigan, Minnesota and Wisconsin).[4]

Table 1. Estimated Agricultural Emissions of Ammonia in the Midwest in 2005

State and region	Estimated total agricultural emissions (1000 tons/year)
Michigan	58
Minnesota	179
Wisconsin	114
Total for 3-state region	351
Illinois	116
Indiana	98
Iowa	268
Missouri	125
North Dakota	78
South Dakota	111
Total for 9-state region	1,147

Table 2 gives a breakdown of the estimated contributions of ammonia emissions from different animal husbandry operations and different synthetic nitrogen fertilizers.[5] Livestock emissions are estimated to account for over 60% of ammonia emissions in most of the Midwest states and in both the 3-state and 9-state regions as a whole. Within the overall livestock category, the contributions from various types of animals vary from state to state. Dairy cattle operations are estimated to contribute the plurality of emissions in Wisconsin and Michigan; while swine operations are more important Minnesota, Illinois, and Iowa. Beef cattle operations are estimated to contribute the bulk of ammonia emissions in North and South Dakota, and swine and poultry operations are estimated to be of roughly equal importance in Indiana and Missouri.

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[a] Boundary Waters Canoe Area Wilderness and Voyageurs National Park in northern Minnesota, and Isle Royale National Park and the Seney Wilderness Area in northern Michigan.

Table 2. Estimated Breakdown of Ammonia Emissions in the Midwest Among Different Livestock and Fertilizer Sources[a]

	Estimated contribution of category emissions to total agricultural emissions within the state or region (%)										
	Michigan	Minnesota	Wisconsin	Iowa	Illinois	Indiana	Missouri	North Dakota	South Dakota	3-State total[b]	9-State total[c]
Animal husbandry											
Beef cattle, confinement	6.3	6.3	5.8	10.1	7.9	4.3	18.7	14.9	22.4	6.1	10.6
Beef cattle, land application	3.3	3.1	2.1	5.1	3.4	1.6	1.4	0.8	4.8	2.8	3.2
Beef cattle subtotal	***9.6***	***9.4***	***7.9***	***15.2***	***11.3***	***5.9***	***20.1***	***15.7***	***27.2***	***8.9***	***13.8***
Dairy, confinement	9.4	4.8	19.1	1.5	1.8	2.6	2.2	0.8	1.3	10.4	4.4
Dairy, manure storage & handling	9.9	3.8	16.9	1.2	1.6	2.1	1.8	0.6	1.1	9.3	3.9
Dairy, land application	11.9	6.8	27.2	2.1	2.5	3.8	3.2	1.1	1.9	14.6	6.2
Dairy cattle subtotal	***31.2***	***15.4***	***63.2***	***4.8***	***5.9***	***8.5***	***7.2***	***2.5***	***4.3***	***34.3***	***14.5***
Swine, confinement	5.7	13.1	1.6	21.1	12.8	12.8	7.5	0.7	4.6	8.0	11.0
Swine, manure storage & handling	2.1	4.5	0.5	10.5	6.6	6.7	11.1	0.2	1.7	2.7	5.8
Swine, land application	2.3	5.0	0.7	7.6	4.7	4.7	1.5	0.3	1.9	3.1	4.0
Swine subtotal	***10.1***	***22.6***	***2.8***	***39.2***	***24.1***	***24.2***	***20.1***	***1.2***	***8.2***	***13.8***	***20.8***
Poultry, confinement	8.3	8.5	3.8	9.6	2.1	18.6	9.9	0.5	1.9	6.8	7.3
Poultry, other	1.6	5.5	2.0	1.3	0.7	4.0	7.3	0.2	1.1	3.7	2.9
Poultry subtotal	***9.9***	***14.0***	***5.8***	***10.9***	***2.8***	***22.6***	***17.2***	***0.7***	***3.0***	***10.5***	***10.2***
Horses, sheep, and goats	3.4	1.2	1.7	0.8	1.1	1.9	2.2	1.4	2.3	1.7	1.5
Total, animal husbandry	**64.4**	**62.5**	**81.4**	**70.8**	**45.2**	**63.1**	**66.8**	**21.6**	**44.9**	**69.2**	**60.9**
Synthetic fertilizer usage											
Urea	15.4	24.6	8.4	9.4	7.1	6.5	15.0	51.2	45.2	17.6	18.3
Nitrogen solutions	13.6	3.1	5.8	9.6	19.3	16.8	6.2	1.3	5.1	5.7	8.6
Anhydrous ammonia	3.5	6.5	1.4	7.8	19.8	9.9	5.7	20.5	1.9	4.3	8.1
Ammonium phosphates	1.0	2.9	1.1	2.1	7.1	1.5	3.3	4.5	2.3	1.9	2.8
Other fertilizers	2.1	0.4	2.0	0.4	1.5	2.2	2.9	1.0	0.6	1.2	1.2
Total, fertilizers	**35.6**	**37.5**	**18.6**	**29.2**	**54.8**	**36.9**	**33.2**	**78.4**	**55.1**	**30.8**	**39.1**

[b] The breakdown among emission categories is based on the 2002 National Emissions Inventory.

[b] Michigan, Minnesota, and Wisconsin

[c] Michigan, Minnesota, Wisconsin, Illinois, Indiana, Iowa, Missouri, North Dakota, and South Dakota

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Table 2 also shows variations among the Midwest states in the emission contributions from different types of nitrogen fertilizer. Urea is estimated to be the most significant source of fertilizer ammonia emissions for most of the states in the region. However, emissions from nitrogen solutions and anhydrous ammonia are estimated to be more significant than emissions from urea in Illinois and Indiana; and nitrogen solution emissions are estimated to exceed urea emissions in Iowa.

The processes whereby NH_3, NO_X, and SO_2 are converted to secondary particulate matter are complex, and are influenced by meteorological factors, including temperature, humidity, and light intensity. As a consequence, the formation of secondary pollutants is seasonally dependent. Figures 1 and 2 show estimated seasonal variations of ammonia emissions for the 3-state and 9-state regions. The figures show that estimated emissions from livestock wastes are highest in the summer months, when warmer temperatures accelerate the evaporation of ammonia, and also the microbial reactions which form ammonia in the animal waste. The seasonal patterns in emissions from fertilizer emissions are tied to seasonal patterns in fertilizer usage. Estimated emissions from fertilizer application are highest in April; however, smaller peaks are also projected to occur in November, June, and September.

The formation of NH_4NO_3 particulate matter is an equilibrium reaction which is enhanced at colder temperatures.[6] In fact, source apportionment analyses have indicated that light extinction due to NH_4NO_3 particulate matter in the Northern Midwest Class I areas is highest during the months of November through March.[7] Therefore, ammonia emissions in the colder seasons may be of particular importance. However, ammonia can also increase the rate of the SO_2 oxidation reaction,[8] and therefore may have an impact on the formation of sulfate particulates throughout the year.

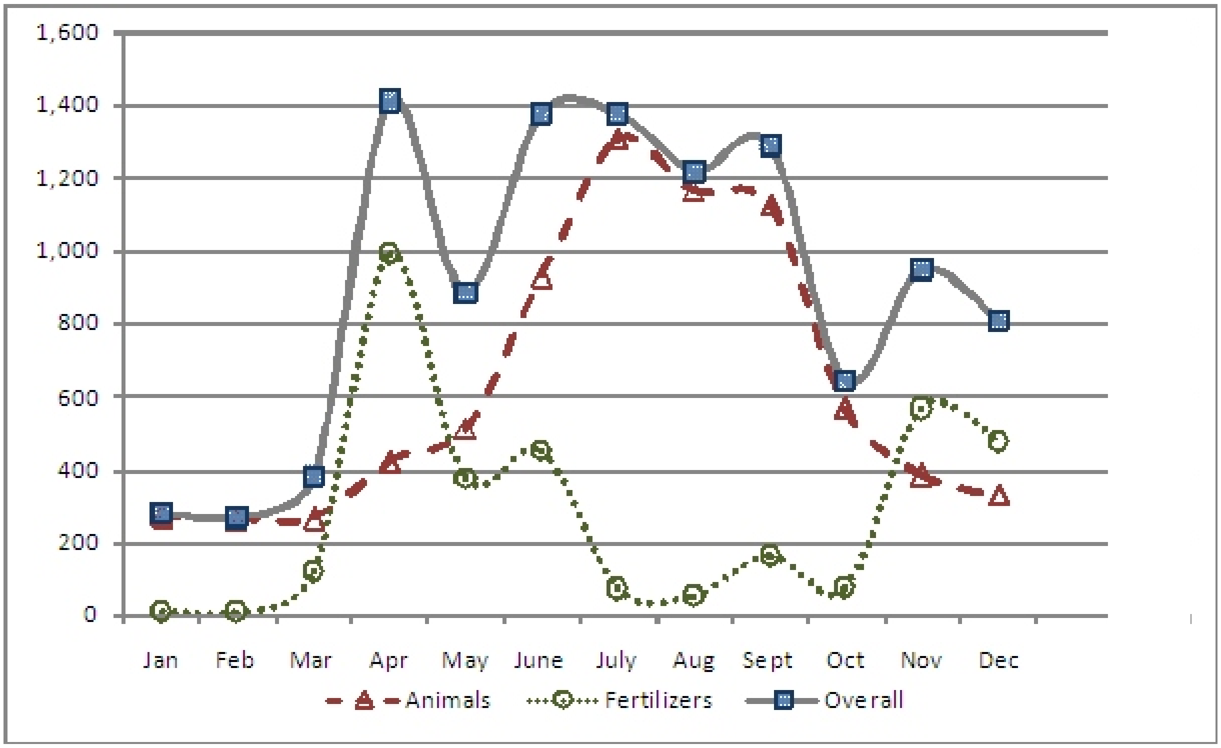

Figure 1. Estimated Seasonal Distribution of Ammonia Emissions from Livestock and Fertilizer in the 3-State Region.

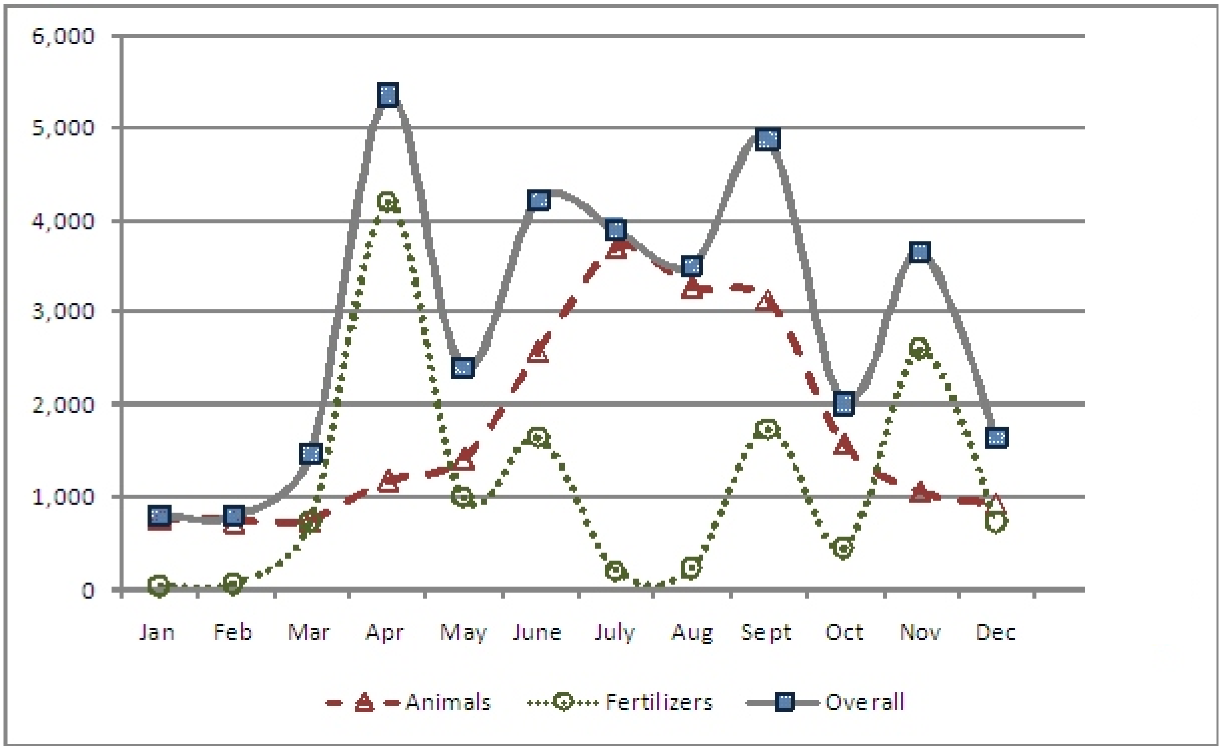

Figure 2. Estimated Seasonal Distribution of Ammonia Emissions from Livestock and Fertilizer in the 9-State Region.

REGULATORY HISTORY

Livestock production facilities are required to obtain permits through the National Pollutant Discharge Elimination System (NPDES) under the Clean Water Act, in order to ensure that the surface water and groundwater surrounding the operations are not negatively impacted by animal waste. In implementing this permit system, states have identified Best Management Practices (BMPs) for the management of animal waste and for the use of synthetic nitrogen fertilizers. Although these practices are designed to reduce water pollution and groundwater pollution impacts, many of the BMPs also act to mitigate ammonia emissions. In general, these practices are not across-the-board requirements. However, some states, such as Minnesota, have required farms to use the recommended BMPs in order to obtain NPDES permits.[9]

CANDIDATE CONTROL MEASURES

The following are BMPs identified by the Midwest states which would mitigate air emissions as well as water pollution from livestock waste management and synthetic fertilizer usage:[10–17]

- For animal houses and waste collection systems:
  - Conveyor belts for removal of waste
  - Daily scrape and haul of manure
  - Transfer pipes to transfer manure to storage or treatment structure
  - Leaving manure to mix with bedding to form manure pack

  - Hopper to transfer manure
  - Outdoor housing of cattle (outwintering)

- For manure storage systems:
  - Stockpiling manure in one area
  - Deep pits to store manure
  - Treatment of waste in lagoons
  - Walled storage facilities or storage tanks
  - Covered storage facilities

- For application of manure to crop lands and grasslands:
  - Incorporation of manure into the soil after apreading
  - Injection of manure using sweeps or knives
  - For general manure management:
  - Planning for manure management
  - Solid-liquid manure separating system
  - Composting of manure

- For nitrogen fertilizer usage:
  - Reduction nitrogen fertilizer usage – through the use of realistic crop yield goals when calculating fertilizer needs, improved recordkeeping, and soil nitrogen tests
  - Adjusting the timing of fertilizer application to meet crop needs
  - Maintaining optimal soil pH
  - Injection or incorporation of fertilizer into the soil
  - Crop rotation and and use of nitrogen-fixing crops in place of nitrogen fertilizer

Other techniques for controlling ammonia emissions have also been evaluated by the U.S. Department of Agriculture and by university researchers. For instance, feed adjustments have been proposed which would reduce the amount of nitrogen compounds excreted by farm animals. This is generally done by improving the mix of amino acids eaten by the animal, reducing the animal's consumption of crude protein, and matching the animal's protein consumption to its needs during different stages of growth. Researchers have also evaluated use of trees to absorb ammonia emissions. These trees would be planted near the ventilation systems of animal houses, or as a buffer around other ammonia emission sources.

Some researchers have proposed the use of additives such as alum to reduce emissions from animal waste. In addition, a manure additive has been shown to reduce ammonia emissions from manure storage and handling.[18] This additive contains benzaldehyde, which binds to ammonia and other nitrogen compounds in the animal waste. However, it must be noted that although these additives reduce emissions in the manure storage area, the ammonia may be released by microbial action once the waste is applied to crop lands or grazing lands.

Research has also been performed on the use of urease inhibitors to delay the conversion of urea to ammonia. The purpose of this control measure is to allow crops to more effectively absorb nitrogen from the animal waste before the nitrogen compounds are converted to ammonia and lost to the atmosphere.

The Midwest RPO and the states of the Midwest are considering a 10–15% reduction in ammonia emissions from agricultural sources. The methods of achieving this emission reduction and the distribution of the reduction among different types of farms would be flexible.

EMISSION REDUCTIONS AND OTHER IMPACTS

Table 3 shows the estimated changes in agricultural ammonia emissions which would result from a 10–15% emission reduction on a state-by-state basis in the 3-state and 9-state regions. Emission reductions associated with individual control measures are discussed in the next section on "Cost Effectiveness and Basis."

Based on source sensitivity modeling carried out by the MRPO using the CAMx model,[19] a 10% decrease in ammonia emissions in the 3-state region is estimated to result in a 0.09–0.11 deciview improvement in visibility in the four Northern Midwest Class I areas (on the worst 20% of visibility day), and a 10% reduction in the 9-state region is estimated to result in a 0.14–0.18 deciview improvement.[19] If the CAMx predictions of light extinction changes are assumed to be linear over a 10–15% ammonia emission reduction, then a 15% reduction in ammonia emissions in the 3-state region would be estimated to improve visibility in the Class I areas by 0.14–0.17 deciviews, and a 15% reduction in the 9-state region would be estimated to improve visibility by 0.23–0.27 deciviews.

Table 3. Estimated Change in Agricultural Ammonia Emissions which Would Result from a 10% to 15% Reduction

State and region	Estimated total 2005 agricultural emissions (tons/year)	Estimated emission reduction (1000 tons/year) 10% reduction	15% reduction
Michigan	58	5.8	8.7
Minnesota	179	17.9	26.9
Wisconsin	114	11.4	17.1
Total for 3-state region	351	35.1	52.7
Illinois	116	11.6	17.4
Indiana	98	9.8	14.7
Iowa	268	26.8	40.2
Missouri	125	12.5	18.8
North Dakota	78	7.8	11.7
South Dakota	111	11.1	16.7
Total for 9-state region	1,147	114.7	172.1

Any control measure to reduce emissions of ammonia will have the benefit of reducing nitrogen deposition. In addition, although ammonia acts as an alkaline buffer in the atmosphere, it can be oxidized to form nitrate once it is deposited to natural landscapes. Thus, control measures to reduce ammonia can also reduce the acidification of soils and waterbodies. The ammonia control measures considered in the current study are designed to reduce the formation of fine particles that impair visibility. Such reductions would also result in decreases in the ambient levels of $PM_{2.5}$, with corresponding health benefits.

COST EFFECTIVENESS AND BASIS

Limited information is available on the cost of control measures for agricultural ammonia emissions. Table 4 analyzes control measures for which cost information is available. The table shows the estimated fraction of the overall ammonia inventory which could be controlled, the emission control efficiency, the potential emission reduction, and the cost effectiveness of each control measure. The options are sorted in increasing order of cost effectiveness.

The costs of tree plantings are based on an analysis by the Iowa Agricultural Extension Service.[20] The potential effectiveness of trees for reducing ammonia emissions is based on measurements by the University of Delaware over a four year period at a poultry house. The wide range of cost effectiveness values for this control measure result from the variability of emission reductions during the measurement study.[21] At least one other research group has been investigating the effectiveness of tree plantings for reducing ammonia emissions, but quantitative emission reduction results are not yet available.[22] It must also be noted that the effectiveness of tree plantings has not been measured in winter. In fact, one investigator indicated that the tree plantings near animal houses may not reduce emissions in winter, since warm air ventilated from the animal houses would rise above the tree level.[23] The cost estimates for tree plantings are based on planting trees about 6 feet in height, at about $25 each. These trees would require a number of years to reach their full emission reduction effectiveness. Taller trees, at about 12 feet, could be purchased for about $150 each. The Delaware study evaluated a planting of three rows of trees over an area about 30 feet wide and 22 feet deep. The first row was 30 feet from the exhaust fans and consisted of bald cypress trees about 16 feet tall at the outset of the study. The second row was made up of 14 foot Leyland cypress trees (at the start of the study) about 40 feet from the fans; and the third row was made up of 8 foot Eastern red cedar trees about 48 feet from the fans.

The emission reductions for feed adjustments are based on measured changes of nitrogen levels in animal waste and ammonia levels in animal confinement areas.[24,25] Cost estimates for feed adjustments varied over a broad range. Information on the effectiveness of feed adjustments at reducing ammonia emissions is also limited and subject to considerable uncertainty. One U.S. researcher indicated that a diet adjustment designed to reduce the amount of crude protein could be made at little or no cost and with no adverse impacts on animal growth rates.[25] However a British study gives a cost estimate of about $21,000 per ton of ammonia emission reduction for a staged feeding program designed to reduce the levels of nitrogen in animal waste.[26] Other studies have also indicated that while ammonia emissions decreased due to diet adjustment, animal weight gain may be negatively affected.[27, 28] One study also showed an increase in sulfur excretion and volatilization with a change in diet.[29]

The British cost study also estimated the cost effectiveness of a number of other control options, including the incorporation of animal waste into the soil. However, the emission reduction reported for these measures in the British study were considerably higher than those reported in BMP guidelines from the Minnesota Agricultural Extension Service. The broad ranges of cost effectiveness values for these measures generally reflect the differences in estimated efficiencies between the British study and the BMP guideline estimates. For instance, the British study estimates that an emission reduction of 70% can be achieved by incorporating pig slurry into the soil when it is applied to crop lands. With an emission reduction of 70%, the cost effectiveness of this control measure is estimated at $600/ton of emission reduction. However, the Minnesota Agricultural Extension service estimates the efficiency of this control measure at only 36%. This lower estimate would increase the cost per unit of emission control to about $1200/ton.

Table 4. Estimated Cost Effectiveness of Control Measures for Agricultural Ammonia Emissions

Control measure description	Inventory subcategories amenable to this control measure	Estimated fraction of the agricultural inventory within applicable subcatetories [a] (%)	Estimated reduction efficiency for the affected category (%)	Potential reduction in overall inventory (%)	Cost effectiveness ($/ton)
Vegetative buffers for concentrated emission sources	Livestock confinement areas and waste storage facilities	43	15 – 77	7 – 33	31 – 160
Vegetative buffers at the edge of the farm	Entire farm	100	9 – 21	9 – 21	not available
Feed adjustments for swine	All swine emissions	14 – 21	4 – 16	1 – 3	0 – 21,000
Feed adjustments for poultry	All poultry emissions	10	17 – 31	2 – 3	not available
Incorporation of pig slurry by disc	Land application for swine waste	3 – 4	36 – 70	1 – 3	600 – 1,200
Incorporation of poultry manure by disc	Land application of poultry waste	3 – 4	36 – 80	1 – 2	600 – 1,500
Incorporation of beef cattle manure by disc	Land application of cattle waste	3	36 – 70	1 – 2	2,500 – 4,000
Incorporation of dairy manure by disc	Land application of dairy waste	6 – 15	36 – 70	4 – 5	2,700 – 5,200
Manure additives	Confinement areas and waste storage areas for all animals	31-33	24 [b]	7 – 8 [b]	not available
Manure storage pit water cover	Waste storage and handling for all animals	3-6	51-62 [b]	1 – 4 [b]	not available
Reduce usage of nitrogen fertilizer	All synthetic fertilizer emissions	31 – 40	50	15 – 20	potential savings
Replace urea with lower emission fertilizer	Urea fertilizer emissions	18	66 – 85	12 – 15	400 – 600

[a] This column reflects the total fraction of ammonia emissions from all subcategories in the overall agriculture inventory that are amenable to each control measure. Ranges reflect the different percentages for the 3-state and 9-state region.

[b] These measures are designed to reduce retain nitrogen compounds in the waste. This nitrogen may be released as ammonia at later stages of the process.

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The use of synthetic nitrogen fertilizer is estimated to account for a significant fraction of ammonia emissions in the Midwest states, as shown in Table 2. In addition, because of the seasonal patterns in fertilizer use, the emissions from fertilizer are projected to exceed animal waste emissions at some times of the year (Figures 1 and 2). BMPs include a number of nutrient management measures aimed at optimizing the delivery of nitrogen to crops. These measures can result in the use of smaller amounts of synthetic fertilizer, thereby reducing the potential for ammonia emissions. In particular, animal wastes can frequently be substituted for synthetic fertilizers. Other important nitrogen nutrient management measures include making better use of nitrogen added to the soil during crop rotations, making more realistic estimates of crop nitrogen requirements, measuring soil nitrogen levels before applying fertilizer or animal waste, matching the timing of fertilizer and waste application to the timing of crop nitrogen requirements, collecting and storing animal wastes to minimize nutrient loss prior to spreading, and incorporating fertilizer and animal wastes into the soil to reduce volatilization. With these measures, we have estimated that ammonia emissions could be reduced at a cost savings, since less synthetic fertilizer would be needed.

A number of different nitrogen fertilizers are used, and the prevalence of the different fertilizers varies from state to state (Table 2). The fertilizers also emit different amounts of ammonia per ton of nitrogen applied, suggesting that overall ammonia emissions could be reduced by shifting to lower-emitting fertilizers. Emissions of ammonia are typically expressed as a percentage of the nitrogen applied in the fertilizer. The LADCO emissions inventory uses the following average emission factors:[30]

- urea – 15% of the fertilizer nitrogen
- nitrogen solutions – 8%
- ammonium phosphates and ammonium sulfate – 5%
- anhydrous ammonia and aqueous ammonia – 4%
- ammonium thiosulfate – 2.5%
- ammonium nitrate, calcium ammonium nitrate, and potassium nitrate – 1%
- miscellaneous nitrogen fertilizers and mixtures – 6%

These values are based on underlying measurements which are subject to considerable variability. In addition, emissions from any particular fertilizer will also depend on a number of other factors, including soil moisture, pH, soil carbonate content, temperature, and depth of tilling. Nevertheless, there is general agreement that ammonia emissions from urea are higher than emissions from other nitrogen fertilizers.[31,32,33] Under some conditions, 50% or more of the nitrogen applied in urea may be emitted as ammonia.[34,35,36] Table 2 shows that urea accounts for a large share of fertilizer ammonia emissions in the Midwest. Based on the average ammonia emission factor for urea (15%), we have estimated that an emission reduction of 66–85% could be achieved by the use of lower-emission nitrogen fertilizers. The estimated cost effectiveness of this option is based on typical price differentials between urea and these fertilizers.

It must be noted that, although a wide array of fertilizers can be used to meet crop nitrogen requirements, the various nitrogen fertilizer options also have differences which affect selection process. Many of the options include other nutrients besides nitrogen (phosphorus, sulfur, potassium, and calcium), which some crops and soils may not need. In addition, plants require more energy to make use of the nitrogen in nitrate fertilizers than in the case of urea, ammonia, or ammonium fertilizers. Nonetheless, anhydrous ammonia and aqueous ammonia provide nitrogen in an ammonia form, without other nutrients, and with an estimated emission factor considerably lower than urea.

Anhydrous ammonia and nitrogen solutions also account for a large share of the estimated ammonia emissions from fertilizer in some states (Table 2). As shown in the list above, the emission factors for these fertilizers are somewhat higher than emission factors for some other nitrogen fertilizers, particularly nitrates. However, the emission factor for anhydrous ammonia is also subject to considerable uncertainty. Measurements with anhydrous ammonia have shown emissions as low as 1% when the fertilizer is properly used,[37] and as high as 20% if the soil is too dry or too wet.[33] In addition, the emission factor for nitrogen solutions is not based on specific measurement, but on an average of the factors for urea and ammonium nitrate. Because of these uncertainties, we have not estimated an emission reduction for switching from nitrogen solutions or anhydrous ammonia to other nitrogen fertilizers.

Based on the information presented in Table 4, the cost effectiveness of achieving a 10–15% reduction in agricultural emissions could be as low as $31 per ton, corresponding with the low end of the cost estimate and a moderate efficiency for tree plantings. A number of other options are available for less than $1,500 per ton.

TIMING OF IMPLEMENTATION

The emission control measures for ammonia do not require the installation of pollution control equipment. Therefore, most of these measures could be implemented at the farm within a year. However, one option involves the use of trees to absorb ammonia emissions. This option would require more time. We have estimated the time required for tree plantings to reach their full effectiveness at 3–10 years, depending on the size of trees planted.

Generally, sources are given a 2-4 year phase-in period to comply with new rules. Under the NOx SIP Call for Phase I sources, EPA provided a compliance date of about 3½ years from the SIP submittal date. Most MACT standards allow a 3-year compliance period. Under Phase II of the NOx SIP Call, EPA provided a 2-year period after the SIP submittal date for compliance. States generally provided a 2-year period for compliance with RACT rules. For the purposes of this White Paper, we have assumed that SIP rules would be adopted in early 2007 and that a 2-year period after SIP submittal is adequate for the specific RACT regulations for specific sources or categories of sources.

GEOGRAPHIC APPLICABILITY

The suggested control measure would apply either in a 3-State region, consisting of Michigan, Minnesota and Wisconsin; or in a larger 9-state region made up of these three states as well as Illinois, Indiana, Iowa, Missouri, North Dakota, and South Dakota. The 3-state region includes the states closest to the four Northern Midwest Class I areas; while the 9-state region covers a larger region upwind of the Class I areas. In either case, the measures would apply not only in nonattainment areas, but throughout the applicable region.

SEASONAL APPLICABILITY

Reductions in $PM_{2.5}$ are needed throughout the year to address the $PM_{2.5}$ NAAQS and regional haze. However, as noted earlier, the formation of ammonium particulate matter is seasonally dependent. Because the formation of NH_4NO_3 particulate matter is favored at lower temperatures, ammonia emissions in the colder seasons may be of particular importance. However, ammonia can impact the formation of secondary $PM_{2.5}$ throughout the year. Thus, the candidate control measures are intended to be applied on an annual basis. An alternative scenario could be developed to create separate ozone season and non-ozone season emission budgets if more stringent control is needed during the winter.

AFFECTED SCCs

Agricultural emissions of ammonia are listed primarily in the area source section of the NEI under the following blocks of Source Classification codes: 28-01-700-xxx, "Miscellaneous Area Sources, Agricultural Production - Crops, Fertilizer Application;" and 28-05-xxx-xxx, "Miscellaneous Area Sources, Agriculture Production - Livestock." The volatilization of ammonia from fertilized crops or pasture land may also be listed by some states under SCCs 27-01-220-xxx, "Natural Sources, Biogenic, Vegetation/Agriculture;" 27-01-420-xxx through 27-01-424-xxx, "Natural Sources, Biogenic, Agricultural Land;" or 27-10-020-030, "Natural Sources, Agriculture Production - Livestock, Horses and Ponies Composite."

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Disclaimer: The control measures identified in this document represent an initial set of possible measures. The Midwest RPO States have not yet determined which measures will be necessary to meet the requirements of the Clean Air Act. As such, the inclusion of a particular measure here should not be interpreted as a commitment or decision by any State to adopt that measure. Other measures will be examined in the near future. Subsequent versions of this document will likely be prepared for evaluation of additional potential control measures.

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