APPENDIX A – POLLUTANT-SPECIFIC BEST MANAGEMENT PRACTICES

The purpose of this Appendix is to present a list of Best Management Practices (BMPs) as they apply to reducing emissions from specific air pollutants or pollutant groups. BMPs as they apply to specific dairy operation systems are presented in Appendix B.

General Principles

- The principle mechanism by which most BMPs operate is to maintain conditions which prevent emissions of pollutants addressed by the use of the BMPs; and

- Nothing in this policy should be construed to limit the ability of an Operation to be innovative or to use effective management practices that differ from those offered in this policy.

Following is a list of various BMPs for consideration in reducing emissions from each pollutant or pollutant group. The BMPs have not been prioritized for practicality, economic feasibility, ease of use, or efficacy. These are important factors to consider in the successful selection and implementation of BMPs.

I. Ammonia (NH_3)

NH_3 is formed when urea in the urine and the urease enzyme found in feces and manure laden soils are combined together. The reaction is very quick and the peak to volatilization is just several hours. Volatilization of NH_3 depends primarily on four factors: the protein (N) content in the feed, manure management strategies, the pH or the manure or soil, and the meteorology in general (i.e., temperature and wind speed, etc.). The lifetime of gaseous NH_3 is about 24 hours, after which time the NH_3 may typically deposits near its source. This deposition can lead to eutrophication of surface water, airborne fertilization, and changes in ecosystems.

It is the objective of an NH_3 BMP to reduce NH_3 emissions and thus, its negative effects. Tradeoffs in NH3 reductions must be carefully considered. Tradeoffs are actions which reduce emissions of one pollutant, but cause an increase in another pollutant emission. Tradeoffs could result due to things such as changes in pH or a shift to aerobic conditions. Therefore, the most effective method of reducing NH_3 is to target the source itself. In this case, the source is nitrogen (N) input into the dairy systems. BMPs which reduce NH_3 follow.

1. Reduce the amount of dietary protein (N) in the ration to match, rather than exceed, the animal’s needs.

2. Practice phase-feeding.

3. Ensure proper ventilation of freestall barns.

4. Bedding selection and management.

5. Treat recycled lagoon water used for flushing.

6. Remove and spread (harrow) manure frequently.

7. Modify alleyway floors.

8. Provide shade for cattle.

9. Locate feed and water opposite in pens.

11. Use straw bedding in drylot pens.

12. Incorporate wood chips in surface layer.

13. Urease inhibitors.

14. Surface moisture content.

15. Stock appropriate number of animals.

16. Use rotational grazing.

17. Move water and feeding areas frequently.

18. Irrigate pastures immediately after grazing.

19. Manure solids separation.

20. Lagoon or storage covers.

21. Surface aeration of lagoons.

22. Reduce the pH of lagoons and manure piles.

23. Apply N fertilizer below no-till residue.

24. Inject or incorporate fertilizer into soil within 24 hours of application.

25. Apply nutrients according to agronomic recommendations based on soil test results.

26. Do not over-irrigate.

27. Utilize cover crops.

28. Apply during cool weather and on still rather than windy days.

II. Nitrous Oxide (N_2O)

Emissions of N_2O result from two different biological processes. There is a very small amount of N_2O produced during nitrification (the biological aerobic process of converting ammonium to nitrate) though this source is relatively insignificant. The primary pathway of N_2O formation is the anaerobic process of denitrification (the conversion of nitrate to N_2 or nitrogen gas), in which

N_2O is an obligatory intermediate product. Therefore, many of the emission reduction strategies are associated with minimizing these anaerobic conditions. BMPs which reduce N_2O follow.

1. Reduce the amount of dietary protein (N) in the ration to match, rather than exceed, an animal's needs.

2. Urease inhibitors.

3. Surface moisture content.

4. Stock appropriate number of animals.

5. Use rotational grazing.

6. Move water and feeding areas frequently.

7. Apply nutrients according to agronomic recommendations based on soil test results.

8. Do not over-irrigate.

9. Utilize cover crops.

III. Hydrogen Sulfide (H_2S)

H_2S is produced in anaerobic environments from the microbial reduction of sulfate ~~in water~~ and/or the decomposition of sulfur-containing organic matter in manure. Most atmospheric H_2S is oxidized to sulfur dioxide (SO_2), which is then either dry deposited or oxidized to aerosol sulfate and removed primarily by wet deposition. The residence time of H_2S and its reaction products is of the order of days. BMPs which reduce H_2S follow.

1. Properly manage and minimize overfeeding sulfur in the diet.

2. Bedding selection and management.

3. Surface moisture content management.

4. Manure solids separation.

5. Lagoon or storage covers.

6. Scrub exhaust of enclosed waste containers.

7. Surface aeration of lagoons.

8. Encourage purple sulfur bacterial formation in anaerobic lagoons.

9. Properly manage composted solid manure.

10. Properly manage stockpiled manure.

IV. Volatile Organic Compounds (VOC)

VOCs vaporize easily at room temperature and include fatty acids, nitrogen heterocycles, sulfides, amines, alcohols, aliphatic aldehydes, ethers, *p*-cresol, mercaptans, hydrocarbons, and halocarbons. The major constituents of dairy VOC emissions that have been identified include organic sulfides, disulfides, C_4 to C_7 aldehydes, trimethylamine, C_4 amines, quinoline, dimethylpyrazine, and C_3 to C_6 organic acids, along with lesser amounts of aromatic compounds and C_4 to C_7 alcohols, ketones, and aliphatic hydrocarbons. Fresh manure and fermentation of feedstuffs have been identified as the primary sources of VOC emissions. BMPs which reduce VOC emissions follow.

1. Properly manage ensiled feedstuffs.
2. Store feed in a weatherproof storage structure.
3. Remove spilled and unused feed from feeding area on a regular basis.
4. Remove manure from barns frequently.
5. Modify alleyway floors.
6. Surface moisture content management.
7. Knock down and remove fence line manure.
8. Manure solids separation.
9. Lagoon or storage covers.
10. Surface aeration of lagoons.

V. Odor

Odor from dairies is not caused by a single species but is rather the result of a large number of contributing compounds including NH_3, VOCs, and H_2S. Hundreds of compounds contribute to odor from a dairy. A further complication is that odor involves a subjective human response. Although research is under way to relate olfactory response to individual odorous gases, odor measurement using human panels appears to be the method of choice now and for some time to come. Since odor can be caused by hundreds of compounds and is subjective in human response, estimates of odor inventories are not currently possible. BMPs which reduce odor emissions follow.

1. Properly manage and minimize overfeeding sulfur in the diet.
2. Properly manage ensiled feedstuffs.

3. Store feed in a weatherproof storage structure.
4. Remove spilled and unused feed from feeding area on a regular basis.
5. Ensure proper ventilation of freestall barns.
6. Bedding selection and management.
7. Treat recycled lagoon water used for flushing.
8. Remove manure from barns and pens frequently.
9. Modify alleyway floors.
10. Use straw bedding in drylot pens.
11. Incorporate wood chips in surface layer.
12. Surface moisture content management.

VI. Particulate Matter (PM)

This policy considers particulate matter as $PM_{>10}$, PM_{10} and $PM_{2.5}$. $PM_{>10}$ is commonly defined as airborne particles with aerodynamic equivalent diameters (AEDs) more than 10 µm. PM_{10} is commonly defined as airborne particles with AEDs less than 10 µm. Similarly, $PM_{2.5}$ refers to particles with AEDs less than 2.5 µm. Dairies can contribute directly to primary PM through several mechanisms, including: animal activity; animal housing fans; air entrainment from soil and manure; and indirectly to secondary PM by emissions of NH_3, NO, and H_2S, which are converted to aerosols through reactions in the atmosphere. Particles produced by gas-to-particle conversion generally are small and fall into the $PM_{2.5}$ size range. Key variables affecting the emissions of PM_{10} include the amount of mechanical and animal activity on the soil-manure surface, the moisture content of the surface, and the fraction of the surface material in the 0-10 µm size range.

The diameter of PM is critical to its health and radiative effects. $PM_{2.5}$ can reach and be deposited in the smallest airways (alveoli) in the lungs, whereas larger particles tend to be deposited in the upper airways of the respiratory tract. Smaller particles are also most effective in attenuating visible radiation, causing regional haze. BMPs which reduce PM emissions follow.

1. Store feed in a weatherproof storage structure.
2. Remove spilled and unused feed from feeding area on a regular basis.
3. Do not mix feeds during windy times.
4. Ensure proper ventilation of freestall barns.
5. Provide shade for cattle.

6. Locate feed and water opposite in pens.

7. Remove and spread (harrow) manure frequently.

8. Use straw bedding in drylot pens.

9. Incorporate wood chips in surface layer.

10. Surface moisture content management.

11. Properly manage composted solid manure.

12. Properly manage stockpiled manure.

13. Apply N fertilizer below no-till residue.

14. Utilize cover crops.

15. Apply during cool weather and on still rather than windy days.

16. Installation of windbreaks or shelterbelts.

VII. Oxides of Nitrogen (NO_X)

Nitrification in aerobic soils appears to be the dominant agricultural pathway to Nitric Oxide (NO). Direct emissions of NO from dairy manure are believed to be relatively minor, but a fraction of manure nitrogen applied to soils as fertilizer can be emitted as NO.

The fraction of fertilizer nitrogen released as NO depends on the amount and form of nitrogen (reduced or oxidized) applied to soils, the vegetative cover, temperature, soil moisture, and agricultural practices such as tillage. A small fraction of other reduced nitrogen compounds in animal manure can also be converted to NO by microbial action in soils.

NO and nitrogen dioxide (NO_2) are rapidly interconverted in the atmosphere and the sum of all oxidized nitrogen species (except N_2O) in the atmosphere is often referred to as NO_X. The residence time of NO_X is of the order of days in the lower atmosphere, with the principal removal mechanism involving wet and dry deposition. In terms of environmental effects, NO_X is an important (and often limiting) precursor in tropospheric ozone (O_3) production. Furthermore, NO_3^- aerosol is a contributor to PM2.5, and nitrogen deposition in the forms of HNO_3, and aerosol NO_3^- can have ecological consequences.

NO_X is also emitted as a result of combustion processes (especially at higher temperature combustion), primarily as NO and NO_2. Since nitrification in soils is important to soil health and crop production, no BMPs are presented to reduce NO_X emissions caused by nitrification in soils. Following are BMPs which reduce combustion-caused emissions of NO_X.

1. Replace or retrofit older internal combustion engines.

2. Utilize alternatives to outdoor burning.

VIII. Methane (CH_4)

CH_4 is produced by microbial degradation of organic matter under anaerobic conditions. The primary source of CH_4 from livestock production is enteric fermentation in ruminant animals. Ruminants (sheep, goats, camels, cattle, and buffalo) have unique, four-chambered stomachs. In one chamber, called the rumen, bacteria break down grasses and other feedstuff and generate CH_4 as one of several byproducts. The production rate of CH_4 is affected by energy intake, which is in turn affected by several factors such as quantity and quality of feed, animal body weight, and age.

CH_4 is also emitted during anaerobic microbial decomposition of manure. The most important factor affecting the amount produced is how the manure is managed, because some types of storage and treatment systems promote an oxygen-depleted (anaerobic) environment. Metabolic processes of methanogens lead to CH_4 production at all stages of manure handling. Liquid systems tend to encourage anaerobic conditions and ~~to~~ produce significant quantities of CH_4, while more aerobic solid waste management approaches may produce little or none. Higher temperatures and moist conditions also promote CH_4 production.

Methane is destroyed in the atmosphere by reaction with the hydroxyl (•OH) radical. Because of its long residence time (~8.4 years), CH_4 becomes distributed globally. Methane is a greenhouse gas and, under certain conditions, contributes to global warming with a potential 23 times that of CO_2. Following are BMPs which reduce emissions of CH_4.

1. Increase the level of starch in the diet.

2. Surface moisture content management.

3. Manure solids separation.

4. Lagoon or storage covers.

5. Scrub exhaust of enclosed waste containers.

6. Installation of an anaerobic digester.

7. Reduce the pH of lagoons and manure piles.

8. Properly manage composted solid manure.