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Dairy Farm Atmospheric Emissions Control Using a Microaerobic Biological Nutrient Removal (BNR) Process

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ABSTRACT

A microaerobic biological nutrient removal process has been retrofitted to an existing anaerobic lagoon to manage both atmospheric emissions and nutrients discharged from a 1,250 cow dairy in Central Texas. The system has been operational since September 2003.

An intensive seven month period of system performance evaluation was completed. The design of the sampling system and protocols followed were rigorously reviewed by a team of independent, third party experts comprised of consultants and academics who also audited the analysis of the data collected. Additional oversight was provided by regulatory and governmental specialists.

The BNR waste management system was operated to maximize biological nutrient recovery and successfully removed 74% of the total nitrogen and 79% of the phosphorus load. Simultaneously, the system achieved substantial reductions for five key air emissions. Relative to baseline air emissions from anaerobic lagoons alone, serving similar dairy operations, air emissions directly measured from the BNR process units represented reductions of up to 99% for ammonia, volatile organics (VOCs) by 98%, methane 94%, hydrogen sulfide 95% and oxides of nitrogen 93%.

A simple model was applied which divided the entire farm's waste management system into eleven component units, from manure excretion through and including emissions from crop irrigation. The model used directly measured BNR process emissions, and estimated emissions for all other components (determined by using literature values and process engineering fundamentals), to arrive at cumulative emissions for the entire or whole farm waste management system. On the basis of this model, voluntary maximum whole farm waste management system emission standards have been proposed representing reductions up to 94% for ammonia, 58% for VOCs, methane 83%, hydrogen sulfide 82%, and oxides of nitrogen 44%. The proposed voluntary standards are as follows (all in Kg per cow annually): 8.2 ammonia, 1.5 VOCs, 59 methane, 1.8 hydrogen sulfide and 0.15 oxides of nitrogen.

KEYWORDS: Atmospheric emissions control, animal residuals, biological nutrient removal, odor, dairy, CAFO

INTRODUCTION

Existing waste management facilities at the DeVries Dairy in Dublin, Texas were modified to incorporate a high rate Bion BNR waste management system. The Bion BNR waste management system is a biological nutrient removal process for removal of nitrogen and phosphorus from the waste stream. It comprises flushing wastes from two ± 600 cow dairy barns into a collection contact sump. The wastes are then pumped through an inclined static screen for coarse solids separation. Solids are collected on a concrete pad and removed from the site for

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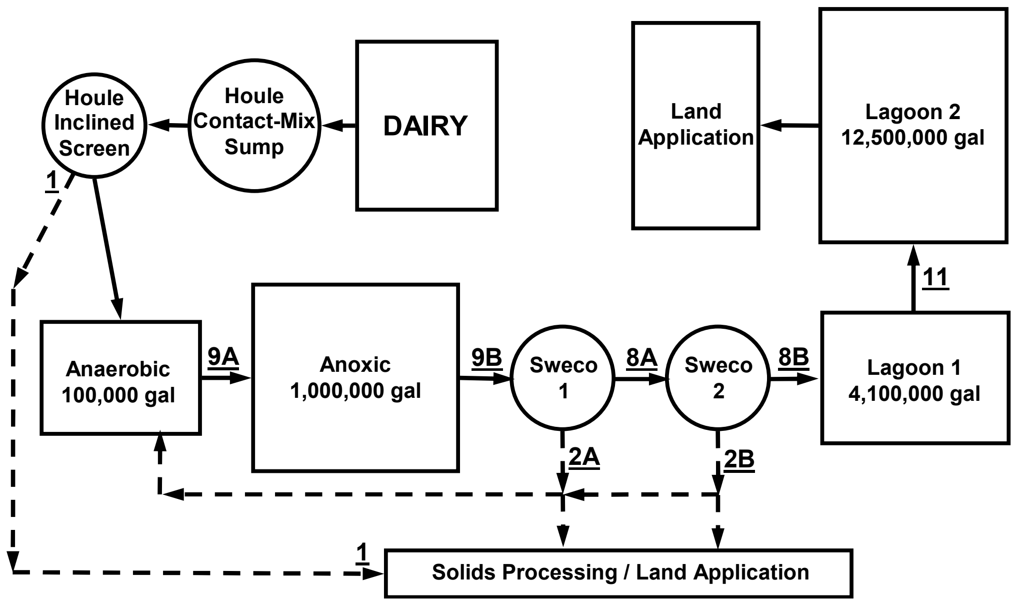
composting or land application. The liquid is piped to a two-stage bioreactor where it first enters an anaerobic zone comprising about one tenth of the total bioreactor volume. After the anaerobic zone the stream enters a microaerobic/anoxic zone for further treatment. Liquid from the end of the microaerobic/anoxic zone is used to flush the barns. Excess liquid is sent to Sweco vibrating screens. Effluent from the vibrating screens is discharged serially to two lagoons and then land applied. The system has been operational since July 2003. A block flow diagram including sampling and metering locations is shown in Figure 1.

Figure 1. Bion BNR Process Flow Diagram.



Nutrients and solids have been analyzed across this system since September 2003 and it has been shown that with appropriate solids separation equipment (decanter centrifuge), that 74% of the total nitrogen and 79% of the phosphorus load can be removed from the waste stream, thereby proportionally reducing the land area required for effluent crop utilization.

To evaluate the total environmental impact of this system, an emissions monitoring system was installed at the DeVries dairy for monitoring and documentation of air emissions from a full-scale high rate Bion BNR waste management system. Detailed sampling and laboratory analysis together with in-situ field analyses were performed to accurately and comprehensively assess the air emissions from the waste management system. These results were then incorporated into a whole farm air emission documentation protocol suitable for the development of quantifiable whole farm air emission standards.

The majority of the air emissions data collection occurred from April 20, 2004 through July 15, 2004 with extensive sampling occurring at weekly intervals for the entire period. For this period of the air emissions study the system was operating at the level of 74 to 79 percent removal, respectively, for nitrogen and phosphorus when centrifuge polishing was operationally added to the Bion System at location 8B, prior to releasing the forward flow of the system to the lagoon. As a result of methodological improvements in VOC analysis the air emissions sampling was repeated from July 12, 2005 through July 14, 2005.

The incorporation of the emissions monitoring system into a working Bion BNR waste management system performing significant nutrient removal allowed the overall project objectives to be expanded to include:

- Quantification of ammonia (NH_3), hydrogen sulfide (H_2S), volatile organic compounds (VOCs) with non-methane organic carbon (NMOC) additionally quantified, oxides of nitrogen (NO_x), and methane (CH_4) emissions from a Bion System.
- Estimation of whole farm emissions for quantified components for a farm utilizing a Bion System. These results could subsequently be compared to the literature-value expected

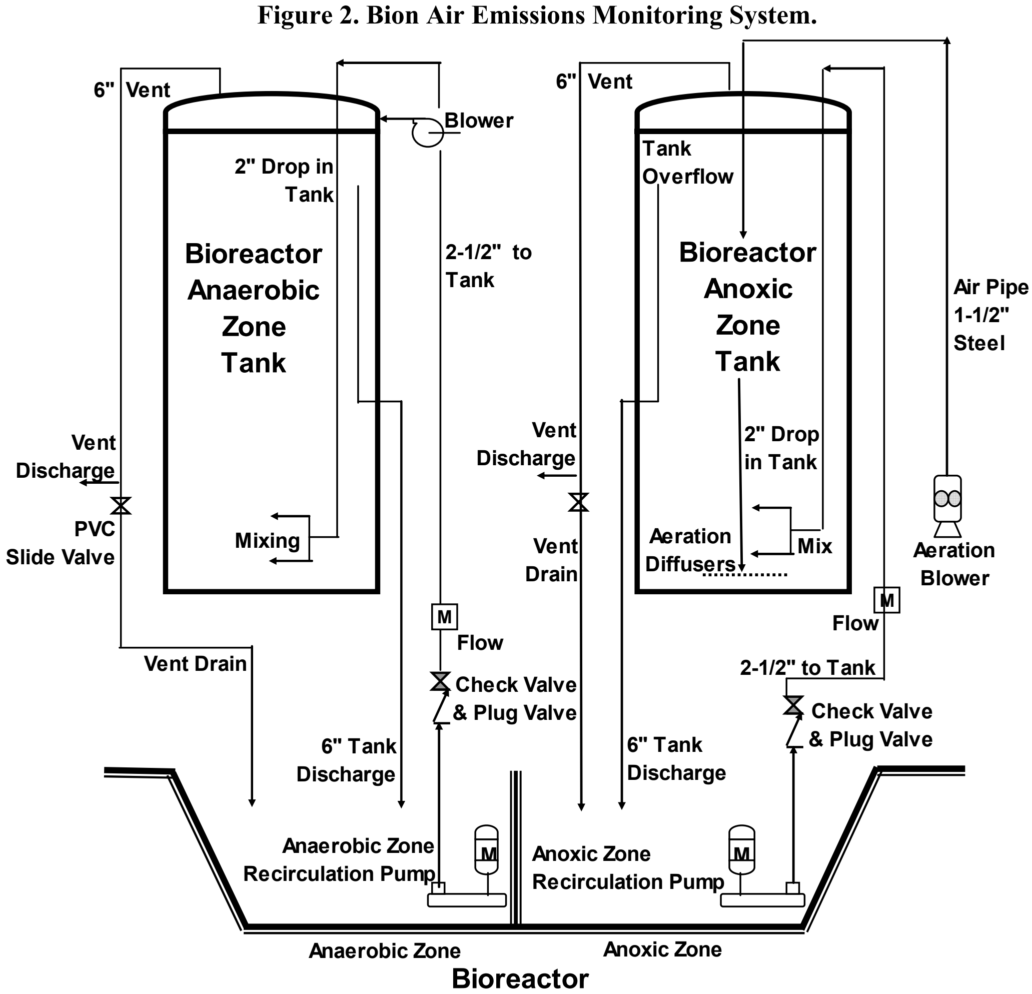
emissions from an identical farm which utilizes an anaerobic lagoon system in place of the Bion system.

- Development of voluntary emission standards based on these analyses. Adopting voluntary emission standards potentially gives several benefits including more flexibility in facility utilization (expansion, land use, crop selection, etc.), monetary gain from nutrient trading and tax credits, and demonstrating active self-regulation with respect to regulatory requirements.

THE AIR EMISSIONS MONITORING SYSTEM

Unlike many other agricultural waste management systems the entire liquid phase of the Bion system is complete mix as verified with TSS and DO readings across the system. Thus, the liquid and suspended solids reactor volumes are homogeneous. Therefore, to determine the emissions generated from the full-scale process, enclosed tanks were installed that became process continuums of the anaerobic and microaerobic/anoxic bioreactor process environments. The enclosed tanks provide total containment, thereby allowing capture of air emissions from the bioreactor anaerobic and anoxic liquor. The bioreactor liquor in the two sealed process tanks behaves the same as in the full-scale unit processes, with biological and physical processes continuing uninterrupted, releasing process off-gasses at the same rate as the full-scale bioreactor anaerobic and anoxic treatment zones. Tank vent lines were monitored for the volume and composition of off-gasses from the bioreactor anaerobic and microaerobic/anoxic treatment zones. The emissions quantified from the enclosed tanks were multiplied by the ratio of the enclosed vessels' size to that of the open bioreactor to obtain an accurate estimate for emissions from the open system, (surface area for anaerobic tank and volume for the microaerobic/anoxic tank). Figure 2 provides a schematic of the tank based air emissions monitoring system described above.

Figure 2. Bion Air Emissions Monitoring System.



The enclosed process tanks were provided with very similar, if not identical, aeration and mixing levels as that used in the full-scale anaerobic and microaerobic/anoxic bioreactor treatment zones. Flow was pumped from the full-scale bioreactor anaerobic and microaerobic/anoxic treatment zones to the respective tanks. Transfer pump rates were sized and controlled to provide hydraulic retention times in the tanks that are a small fraction of those in the full-scale anaerobic and microaerobic/anoxic bioreactor treatment zones.

Due to the elongated geometry (10 feet wide by 160 feet long in the direction of flow), the bioreactor anaerobic treatment zone is similar to a plug flow unit process with gentle mixing sufficient to keep the 2% to 3% solids suspension mixed liquor from settling. Active gas generation from the liquor biomass escapes through the free liquid surface. Thus, the enclosed anaerobic zone process tank had to have a surface area to volume ratio that is similar to that of the full-scale anaerobic treatment zone and be gently mixed at the same level (though higher mixing rates would encourage conservatively higher release rates if any effect were significant / measurable). The headspace was ventilated by a blower at a rate just sufficient to avoid significant concentrations in the gas phase that could slow release of dissolved species, while providing maximum measurement sensitivity.

The bioreactor microaerobic/anoxic treatment zone was actively aerated and mixed by a jet-aeration and mixing system, and two floating surface aerators. The aeration and mixing system was controlled based on dissolved oxygen levels in the microaerobic/anoxic treatment zone. The predominant pathway of air emissions generation in the bioreactor microaerobic/anoxic treatment zone is by the stripping and transport from aerating and mixing the unit process. Therefore the enclosed microaerobic/anoxic process tank was aerated and mixed in a similar manner to the full-scale microaerobic/anoxic treatment zone. Aeration and mixing rates in the tank were adjustable to ensure maintenance of desired dissolved oxygen levels and mixing conditions similar to the full-scale system. The depth of aerated liquid was also similar to that for the full-scale bioreactor microaerobic/anoxic treatment zone.

By satisfying these criteria, the air emissions measured from the anaerobic and microaerobic/anoxic enclosed process tanks provided an accurate qualitative and quantitative estimate of, or perhaps just greater than (thus conservatively high), those emissions occurring in the respective full-scale bioreactor anaerobic and microaerobic/anoxic unit processes being tested. From a process engineering perspective these two tanks functioned as operating sub-volumes of the anaerobic and microaerobic/anoxic zones of the open system.

Quantified air emissions included: ammonia (NH_3), hydrogen sulfide (H_2S), volatile organic compounds (VOCs) with non-methane organic carbon (NMOC) also determined, oxides of nitrogen (NO_X) and methane (CH_4).

SAMPLING AND MONITORING PROGRAM

Primary emissions quality and quantity were determined using rigorous laboratory analysis of composite samples for parameter concentrations and hot wire anemometers for flow quantities. Samples were collected in a manner such that they were representative of the off gas streams generated. All off gas samples were collected in accordance with applicable air quality management district requirements and / or standard protocols. These procedures are described in detail elsewhere (see www.biontech.com).

Analyses

The time composite samples (24, 3, 1 and 0.17-hour canisters) of gasses discharged from the vents of both enclosed vessels were collected two times per week, with collection of additional area whole air samples. All laboratory analyses were performed by an independent certified commercial laboratory using the collected gas from the Summa canisters and following approved specific protocols. All Summa canister evacuation, cleaning, parameter measurement calibration, parameter QA/QC and certification of meters complied with USEPA TO15. Analytical procedures are described in detail at www.biontech.com.

Results

The results expressed in terms of Kg of emissions per 636 Kg cow per year are shown in the following table.

When compared to baseline air emissions from anaerobic lagoons alone, serving similar dairy operations, these air emissions directly measured from the Bion process units represented reductions of up to 99% for ammonia, 98% for volatile organics, 94% for methane, 95% for hydrogen sulfide and 93% for oxides of nitrogen. As stated earlier these results are for a high rate Bion BNR waste management system operating in a configuration which removes 74% of the nitrogen and 79% of the phosphorus from influent waste stream.

Table 1. Summary Results Comparing Total System Air Emissions for 2004 and 2005.

Year	2005	2004
Total Kg VOC per cow-yr	0.03643	NA
Total Kg NMOC[b] per cow-yr	NA	0.01270
Total Kg methane per cow-yr	18.33	17.50
Total Kg ammonia per cow-yr	0.27	0.09
Total Kg hydrogen sulfide per cow-yr	0.30	0.26
Total Kg oxides of nitrogen[a] per cow-yr	0.0045	0.0076

[a] **All NOx values are placeholder numbers based on non detects**

[b] **NMOC is Non Methane Organic Compounds**

Table 2. Summary of Interim Voluntary Pollution Control Standards for a Bion Waste Management System.

	Liquid Effluent Discharge Residual [a]		Atmospheric Emissions				
Parameter	N (Nitrogen)	P (Phosphorous)	NH_3 (Ammonia)	CH_4 (Methane)	H_2S (Hydrogen Sulfide)	NO_X (Nitrogen Oxides)	VOC
Basis	Kg / cow – year [b]						
Bion Process Direct [c]			0.27	23	0.45	0.018	0.068
Whole Farm Bion Waste Management System[d]	48.6 to 59.1[a]	6.8 to 8.2 [a]	8.2	59.1	1.8	0.15	1.45

[a] Effluent from storage to land application / irrigation.

[b] A cow is defined as a 636 Kg lactating production dairy cow.

[c] Emissions from the open surfaces of the complete mix Bion nutrient management system determined from direct monitoring of the Bion process units.

[d] Whole farm waste management system atmospheric emissions are all those generated from the point of waste generation from the animal, milk-house, etc., all waste handling and processing, and emissions produced after land application for crop uptake assuming all residuals, liquid and solids remain on the farm. All non-waste management system emission components such as emissions from animal enteric releases or those generated from feed handling and storage are not included.

The Whole Farm Waste Management System

A simple model which divides an entire farm's waste management system into component units, from manure excretion through and including emissions from crop irrigation, was constructed and reviewed and approved by the San Joaquin Valley Air Pollution Control District (SJVAPCD).

Using the directly measured process emissions reported in this paper for the key Bion BNR waste management system components, and estimated emissions for all other components (determined by using literature values and process engineering fundamentals), cumulative emissions for the entire or whole farm waste management system were determined. These, along with proposed Interim Voluntary Pollution Control Standards, are presented in Table 2.

Table 3. Proposed Interim Voluntary Whole Farm Waste Management System Atmospheric Emission[a] Standards with Comparison to Current Emissions and Potential Reductions.

(1)	Emissions from an Anaerobic Lagoon Only and Bion Process Units Only				Whole Farm Waste Management Emissions for an Anaerobic Lagoon System and a Bion System			
	(2) Typical Anaerobic Lagoon	(3) Direct Bion Process	(4) Proposed Bion Voluntary Process Standard	(5) Proposed Voluntary Process Standard Reduction Comparison	(6) Updated Anaerobic Lagoon System	(7) Bion Whole Farm System	(8) Proposed Bion Voluntary Whole Farm Standard	(9) Proposed Voluntary Standard Reduction Comparison
Parameter	Kg/cow-year[b]			%	Kg/cow-year[b]			%
NH_3 (Ammonia)	20[c] to 40	0.091	0.27	98 to 99	79.1 to 132[d]	2.0	8.2	90 to 94
CH_4 (Methane)	114 to 355	12..5	23	80 to 94	TBD[e]	44.8	59.1	48 to 83
H_2S (Hydrogen Sulfide)	10	0.18	0.45	95	TBD[e]	0.84	1.82	82
NO_X (Nitrogen Oxides)	0.14 to 0.26	0.0073	0.018	87 to 93	TBD[e]	0.13	0.15	0 to 44
VOC	0.68 to 2.9	0.036	0.068	90 to 98	3.5[f]	1.3	1.5	58

[a] Whole farm waste management system atmospheric emissions are all those generated from the point of waste generation from the animal, milk-house, etc., all waste handling and processing, and emissions produced after land application for crop uptake assuming all residuals, liquid and solids remain on the farm. All non-waste management system emission components such as emissions from animal enteric releases or those generated from feed handling and storage are not included.

[b] A cow is defined as a 636 Kg lactating production dairy cow.

[c] Low end literature emissions values ranged from about 23 Kg NH_3/cow-yr for an anaerobic lagoon alone. The (JVAPCD/PD) determined a whole farm value of 20.4 Kg NH_3/cow-yr.

[d] Anaerobic lagoon whole farm waste management system emissions discussed are similar to the value obtained from four randomly selected Kern County California dairy operator Reports of Waste Discharge (ROWD) as submitted recently to the Regional Water Quality Control Board (RWQCB), which indicated approximately 79 to 132 Kg NH_3/cow-yr are emitted annually.

[e] Emission values to update the information presented in column (2) are not readily available and are thus yet to be determined (TBD). Column (2) values are likely to be within the variability or certainty of any updated information TBD for column (6) and column (6) values may well be significantly larger then column (2) similar to current values for NH_3 and VOC.

[f] Current whole farm waste management system baseline value from (JVAPCD/PD).

Table 3 summarizes various emission levels reported for typical anaerobic lagoon systems, whole farm emission estimates, actual emissions directly from the Bion unit processes, and a set of

Proposed Bion Voluntary Interim Standards based on these emission levels. All emissions are presented on a Kg/cow-year basis and are based on the simple model accepted by the San Joaquin Valley Air Pollution Control District (SJVAPCD) as applied to the Bion BNR system. The model uses inputs from direct Bion process measurements and determines expected emissions for each system component unit and the entire cumulative whole farm waste management system.

The emissions in column (2), which may be considered as baseline values, are for long term average atmospheric emissions directly from the surface of an anaerobic lagoon dairy waste management system. The emissions in column (2) are considered whole farm emissions for the existing anaerobic lagoon systems serving dairies, as the quantities from sources other than the lagoon surfaces are insignificant compared to the total range of values reported. The Direct System Bion Results presented in column (3) of Table 3 in parentheses, are emissions from the open surfaces of the complete mix Bion BNR waste management system. Bion has achieved these emissions in practice during long term operation. The Bion Whole Farm Emission Estimates detailed in column (7) are derived by Bion applying a simple model as used by the San Joaquin Valley Unified Air Pollution Control District's Permitting Department (JVAPCD/PD). The emissions shown in column (8) of Table 3 are the emissions which Bion would propose as voluntary interim standards for whole farm waste management systems. These emissions are on a whole farm waste management system basis for a facility applying the Bion process in a typical system configuration. These whole farm waste management system emission standards are met simultaneously with the nutrient removal standards presented in Table 2. Releases from animal enteric sources, feed management and all other emissions from non-waste management sources are excluded.

In reviewing Table 3 also note the following:

- Column (2) values were obtained from published information for releases directly from the lagoon surfaces of an anaerobic lagoon treatment system.
- Column (3) emissions are from the open surfaces of the complete mix Bion nutrient management system determined from direct monitoring of the Bion process units. Bion has achieved these emissions in practice during long term operation. Detailed monitoring system design, sampling and analytical protocols along with details of data analysis are available at www.biontech.com.
- Column (4) presents proposed interim voluntary standards values for direct emissions from the Bion process only.
- Column (5) shows potential reduction in emissions directly from Bion system components, column (4), compared to lagoon emissions in column (2).
- Column (6) emission values updating column (2) are not readily available and are thus yet to be determined (TBD). Column (2) values are quite possibly significantly larger and within the variability or certainty of any such updated information. (See footnote d.)
- Column (7) Bion Whole Farm Emission Estimates detailed are derived by Bion using the simple model approach used by the JVUAPCD/PD to evaluate emissions from each unit of the Bion system, from the feeding lanes to the storage lagoon, all inclusive.
- Column (8) proposed interim voluntary standards for whole farm waste management system emissions from a Bion System are based on applying the simple JVUAPCD/PD accepted modeling approach to each Bion System unit, all inclusive.
- Column (9) details potential reduction in whole farm waste management system emissions from a Bion system, column (8), compared to lagoon emissions in column (6) or column (2) if TBD.

Conclusions

A microaerobic biological nutrient removal process operating on a 1,250 cow dairy reduces nutrient loads in land applied effluents by 74 percent for nitrogen and 79 percent for phosphorus when centrifuge effluent polishing is applied. Concurrently with these effluent nutrient reductions are significant reductions in emissions to the atmosphere for five key gases from the BNR process. Relative to baseline air emissions calculated for an anaerobic lagoon serving a similarly sized dairy operation, air emissions directly measured from the BNR process system represented reductions of up to 99% for ammonia, 98% for volatile organics (VOCs), 94% for methane, 95% for hydrogen sulfide, and 93% for oxides of nitrogen (NOx).

Using this performance data a comprehensive whole farm waste management system model has been proposed to quantitatively monitor air emissions associated with waste management. While air emissions from enteric sources and from feed and feed management areas are not included, all other components of air emissions from the waste handling and waste treatment are accounted for. This allows for the development of voluntary standards for air emissions from whole farm waste management systems which are quantitatively verifiable. The proposed voluntary standards are (in Kg per cow per year): 8.2 for ammonia, 1.45 for VOCs, 59.1 for methane, 1.8 for hydrogen sulfide and 0.15 for NO_X. These emission rates are substantially lower than those reported for flush or scrap systems with lagoon storage and land application. Using a simple model to estimate whole farm waste management system emission reductions (from animal voiding of excrement to application and use of all solids generated and liquid effluent produced), it is estimated that these voluntary standards represent reductions in atmospheric discharges of up to 94% ammonia, 83% methane, 82% hydrogen sulfide, 44% nitrogen oxides, and 58% VOCs when the Bion BNR system is applied.