March 15, 2024

Via email to dana.ashford@usda.gov

Dana Ashford-Kornburger
National Climate Coordinator
U.S. Department of Agriculture
1400 Independence Ave., SW
Washington, DC 20250

Re: NRCS's Climate-Smart Agriculture and Forestry Mitigation Activities List for FY2025

Dear Dana,

Together with the over 50 undersigned environmental, community advocacy, animal welfare, and farmer organizations, Earthjustice writes to urge the Natural Resources Conservation Service ("NRCS") to exclude anaerobic digesters from its upcoming Climate-Smart Agriculture and Forestry Mitigation Activities List for FY2025 ("Climate-Smart List"), thereby ensuring that digesters do not improperly receive funding under the Inflation Reduction Act ("IRA"). NRCS has included digesters on prior climate-smart lists, meaning that digesters likely have received IRA funds in the past.[1] However, IRA funds are restricted to agricultural practices that mitigate climate change, and NRCS must rely on scientific literature to develop the Climate-Smart List. For the reasons discussed below, NRCS lacks authority to deem digesters eligible for IRA funding.

NRCS has not identified *any* peer-reviewed studies supporting its prior conclusions that digesters mitigate climate change. In fact, a significant and growing body of scientific evidence demonstrates that digesters' short-term benefits are uncertain at best, because digesters and associated infrastructure leak methane, and their byproduct digestate emits methane and nitrous oxide, another powerful greenhouse gas. Studies suggesting that digesters reduce emissions frequently fail to compare digesters to other methods of manure management and, therefore, calculate emissions reductions from an inappropriate baseline. And, over the long term, producers who install digesters often counteract any climate benefits by increasing animal herds or shutting down digesters altogether. In light of this uncertainty, a decision to include digesters on the Climate-Smart List would conflict with IRA. In addition, funding digesters would divert money from proven climate-smart practices, while exacerbating environmental injustice.

We also urge NRCS to improve transparency and public participation with respect to its annual process for preparing the climate-smart list. NRCS must uphold its commitment to

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[1] *See* NRCS, USDA, *Climate-Smart Agriculture and Forestry (CSAF) Mitigation Activities List for FY2024*, at 2 (2023), https://www.nrcs.usda.gov/sites/default/files/2023-10/NRCS-CSAF-Mitigation-Activities-List.pdf (including digesters); *see also* NRCS, USDA, *Climate-Smart Agriculture and Forestry (CSAF) Mitigation Activities List FY2023*, at 2 (2023), https://www.nrcs.usda.gov/sites/default/files/2023-03/Climate-Smart-Agriculture-and-Forestry-%28CSAF%29-Mitigation-Activities-2023.pdf (same).

"making publicly available the underpinning literature, methodology, and assumptions."[2] In addition, NRCS must provide the public with a meaningful opportunity to comment on the process and selected practices. As a result of the current lack of transparency and public participation, it is difficult to determine whether NRCS is properly allocating the nearly $20 billion in IRA funds made available for climate change mitigation.

I. NRCS must not make digesters eligible for IRA funding because doing so conflicts with IRA's express requirement and NRCS's own criteria.

A. IRA funds are available only for agricultural practices that mitigate climate change, and NRCS must rely on scientific literature to develop the Climate-Smart List.

IRA is a groundbreaking law that aims to reduce agriculture's significant contributions to climate change by linking approximately $20 billion in public funding for agriculture to the adoption of climate-smart agricultural practices.[3] Congress has made clear that IRA funds are available *only* for agricultural practices that "directly improve soil carbon, reduce nitrogen losses, or reduce, capture, avoid, or sequester carbon dioxide, methane, or nitrous oxide emissions, associated with agricultural production."[4] NRCS is responsible for identifying practices eligible for IRA funding, and each year, it includes eligible practices on its climate-smart list.[5]

NRCS applies a two-part test to determine whether a practice satisfies IRA's requirements: "(1) The activity must result in a direct impact on net greenhouse gas emission reduction or removal within a given scope as supported by the scientific literature, and (2) NRCS must have a science-based methodology for quantitatively estimating mitigation benefits using available NRCS activity data."[6] In applying this test, NRCS reviews the "scientific literature demonstrating expected climate change mitigation benefits" of the practice.[7] It follows that when the scientific literature shows that a practice's ability to mitigate climate change is uncertain—or worse—the practice cannot be eligible for IRA funding.

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[2] Georgina Gustin, *The Biden Administration is Spending its 'Climate Smart' Funding in the Wrong Places, According to New Analyses*, Inside Climate News (Mar. 4, 2024), https://insideclimatenews.org/news/04032024/biden-administration-spending-climate-smart-funding-in-wrong-places/.

[3] *See* Inflation Reduction Act of 2022, Pub. L. No. 117-169, § 21001, 136 Stat. 1818, 2015 (2022).

[4] *Id.* § 21001(a)(1)(B)(iii).

[5] *See* NRCS, USDA, *NRCS Climate-Smart Mitigation Activities*, https://www.nrcs.usda.gov/conservation-basics/natural-resource-concerns/climate/climate-smart-mitigation-activities (last visited Mar. 5, 2024).

[6] NRCS, USDA, *FAQs: Climate-Smart Agriculture and Forestry Mitigation Activities and Inflation Reduction Act Funding*, https://www.nrcs.usda.gov/faqs-climate-smart-agriculture-and-forestry-mitigation-activities-and-inflation-reduction-act (last visited Nov. 8, 2023).

[7] *See* NRCS, USDA, *NRCS Climate-Smart Mitigation Activities*, https://www.nrcs.usda.gov/conservation-basics/natural-resource-concerns/climate/climate-smart-mitigation-activities (last visited Mar. 5, 2023); *see also* NRCS, USDA, *FAQs: Climate-Smart Agriculture and Forestry Mitigation Activities and Inflation Reduction Act Funding*, https://www.nrcs.usda.gov/faqs-climate-smart-agriculture-and-forestry-mitigation-activities-and-inflation-reduction-act (last visited Nov. 2, 2023) (explaining that evaluation teams evaluate conservation practice standards based on "available scientific literature for the practice").

B. NRCS's process for selecting climate-smart practices is not transparent, and NRCS has not identified any peer-reviewed scientific literature underlying its conclusion that digesters support climate change mitigation.

NRCS provides little transparency with respect to its annual process for preparing the climate-smart list. Although NRCS recently stated that it is "in the process of making publicly available the . . . literature, methodology, and assumptions" that "underpin" its selection of eligible practices,[8] it has failed to make this information public during the more than two years that it has prepared climate-smart lists. As a result, the public has no idea how NRCS gathers, compares, or weighs the information it considers. In addition, NRCS has not provided the public with a meaningful opportunity to comment on its selection process. To our knowledge, NRCS did not announce the present opportunity for comment in the Federal Register, a failure that likely prevented many interested organizations and individuals from commenting.

NRCS's general lack of transparency also infects its decision to include digesters on climate-smart lists.[9] NRCS has not made publicly available *any* information supporting its previous conclusions that digesters mitigate climate change. In response to a Freedom of Information Act request seeking the evidence upon which NRCS relied to include digesters on the climate-smart list for FY2024,[10] NRCS produced just four studies, none of which offer adequate support. Two of the studies purport to show that digesters reduce methane emissions from industrial animal operations.[11] However, these studies are approximately two decades old, are not peer reviewed, and evaluate only one digester each. In addition, they inflate emissions reductions attributable to digesters by also assessing the reductions in carbon dioxide emissions that would result from using digester-generated biogas, rather than fossil fuels, to generate electricity.[12] But the carbon dioxide reductions are hypothetical and untethered to any actual emission reductions at the operations where the digesters were installed. Further, the studies conflict with more recent, peer-reviewed work that casts doubt on digesters' climate benefits, discussed in more detail below. The third study considered by NRCS, while peer-reviewed, in fact shows that the digestate remaining after the digestion process has significantly *increased* ammonium nitrogen concentrations relative to conventional manure,[13] which can cause water pollution. This study does not shed light on digesters' climate benefits—or lack thereof. And

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[8] Gustin, *supra* note 2.

[9] *See* NRCS, USDA, *Climate-Smart Agriculture and Forestry (CSAF) Mitigation Activities List for FY2024*, at 2 (2023), https://www.nrcs.usda.gov/sites/default/files/2023-10/NRCS-CSAF-Mitigation-Activities-List.pdf (including digesters); *see also* NRCS, USDA, *Climate-Smart Agriculture and Forestry (CSAF) Mitigation Activities List FY2023*, at 2 (2023), https://www.nrcs.usda.gov/sites/default/files/2023-03/Climate-Smart-Agriculture-and-Forestry-%28CSAF%29-Mitigation-Activities-2023.pdf (same).

[10] The request sought the scientific literature, white papers, or reports that NRCS relied upon to conclude that anaerobic digesters reduce greenhouse gas emissions, among other things.

[11] *See* John H. Martin, *A Comparison of Dairy Cattle Manure Management with and without Anaerobic Digestion and Biogas Utilization* (2003), attached as Exhibit 1; *see also* John H. Martin, *An Evaluation of Mesophilic, Modified Plug Flow Anaerobic Digester for Dairy Cattle Manure* (2005), attached as Exhibit 2.

[12] *See, e.g.*, Exhibit 1, *supra* note 11, at 3, 26.

[13] *See* Xiaoquian Zhang et al., *Long-Term Performance of Three Mesophilic Anaerobic Digesters to Convert Animal and Agro-Industrial Wastes into Organic Fertilizer*, 307 J. Cleaner Prod. 1 (2021).

the fourth study assessed the conditions necessary for venting hydrogen sulfide from digesters without risking worker safety,[14] which also does not bear on digesters' climate impacts.

NRCS's inability to provide meaningful support for its previous determinations that digesters mitigate climate change demonstrates that those determinations were not grounded in recent, reliable science. Therefore, NRCS's previous determinations are inconsistent with NRCS's own two-part test, which requires not only that a practice result in a scientifically supported direct reduction or removal of greenhouse gas emissions, but also that NRCS identify a science-based methodology for quantitatively estimating the practice's mitigation benefits. Without scientific support, NRCS lacks authority to deem digesters eligible for IRA funds—and as described below, the scientific literature shows that digesters' benefits are uncertain at best.

C. Peer-reviewed scientific literature casts doubt on whether anaerobic digesters mitigate climate change.

1. The short-term benefits of digesters are uncertain.

Ample scientific evidence shows that there is serious uncertainty as to whether digesters mitigate climate change. In the short term, digesters may not mitigate climate change for at least three reasons: (1) digesters and biogas transportation infrastructure release methane due to leaks and malfunctions, (2) digestate emits both methane and nitrous oxide, and (3) many studies suggesting that digesters offer climate benefits—including two of the studies on which NRCS has relied—are flawed because they fail to compare digesters to other methods of manure management and, therefore, calculate emissions reductions from an inappropriate baseline.

First, numerous studies show that digesters and biogas transportation infrastructure release methane due to leaks and malfunctions.[15] Indeed, during the digestion process, digesters can leak 15 percent of the methane they initially capture.[16] And during periods of repair, maintenance, malfunction, or other suboptimal performance, digesters can release 13 to 25 percent of methane initially captured.[17] In addition, infrastructure used to transport biogas also leaks, releasing more methane.[18] Energy companies typically transport biogas through existing

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[14] *See* Memorandum from Paul Wade, Montrose Air Quality Servs., LLC to Cal. Bioenergy, LLC (June 12, 2020), attached as Exhibit 3.

[15] *See* Thomas K. Flesch et al., *Fugitive Methane Emissions from an Agricultural Biodigester*, 35 Biomass & Bioenergy 3927 (2011); *see also* Nicole D. Miranda. et al., *Meta-Analysis of Greenhouse Gas Emissions from Anaerobic Digestion Processes in Dairy Farms*, 49 Env't Sci. & Tech. 5211 (2015); Felipe Montes et al., *Mitigation of Methane and Nitrous Oxide Emissions from Animal Operations: A Review of Manure Management Mitigation Options*, 91 J. Animal Sci. 5070 (2013); Semra Bakkaloglu et al., *Methane Emissions Along Biomethane and Biogas Supply Chains are Underestimated*, 5 One Earth 724 (2022).

[16] *See* Jin Zeng et al., *Evaluation of Methane Emission Flux from a Typical Biogas Fermentation Ecosystem in China*, 257 J. Cleaner Prod. 120441 (2020).

[17] *See* Flesch et al., *supra* note 15.

[18] *See* Bakkaloglu et al., *supra* note 15.

natural gas pipelines,[19] which leak as much as 2.6 million tons of methane each year in the United States.[20] Even relatively small leakage rates from digesters and their associated infrastructure can undermine any climate benefit attributed to digesters, especially when considered along with methane and nitrous oxide emissions from digestate, discussed below.

Second, digestate left over after the digestion process emits both methane and nitrous oxide when stored in open pits and applied to fields.[21] Digestate emits methane because digestion does not eliminate all the methane-generating organic matter in animal manure.[22] And digestate emits *more* nitrous oxide than manure[23] because biogas generation consumes manure carbon, leaving relatively high-nitrogen digestate as a byproduct.[24] Nitrous oxide emissions are particularly concerning from a climate perspective because nitrous oxide is 300 times more potent than carbon dioxide over a 100-year period.[25] Methane and nitrous oxide emissions from digestate thus further erode any climate benefits that digesters offer. Indeed, a recent report found that, after considering emissions from all stages of biogas production and using "worst case scenario" leakage rates, the methane-only component of biogas—known as biomethane—likely "provide[s] minimal to zero climate benefits on a 100-year timescale."[26]

Third, many studies suggesting that digesters help to mitigate climate change are flawed because they fail to consider less climate-harming methods of manure management and, therefore, calculate emissions reductions from an inappropriate baseline. Digesters are best suited to operations that employ liquid manure management systems with uncovered, anaerobic waste storage pits. Because anaerobic environments facilitate methane generation,[27] these systems are unquestionably the most climate-harming method of managing manure.[28] Other

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[19] *See* Cameron Oglesby, '*This Plan Is a Lie': Biogas on Hog Farms Could Do More Harm than Good*, Energy News Network (Mar. 28, 2022), https://energynews.us/2022/03/28/this-plan-is-a-lie-biogas-on-hog-farms-could-do-more-harm-than-good/.

[20] *See* Renee McVay, *Methane Emissions from Gas Pipeline Leaks*, at 5 (2023), https://www.edf.org/sites/default/files/documents/Pipeline%20Methane%20Leaks%20Report.pdf.

[21] *See* Bakkaloglu et al., *supra* note 15.

[22] *See* Carlos Rico et al., *Anaerobic Digestion of the Liquid Fraction of Dairy Manure in Pilot Plant for Biogas Production: Residual Methane Yield of Digestate*, 31 Waste Mgmt. 2167 (2011).

[23] *Id.*

[24] *See* Fanjing Kong et al., *Does the Application of Biogas Slurry Reduce Soil N20 Emissions and Increase Crop Yield?—A Systematic Review*, 342 J. Env't Mgmt. 118339 (2023).

[25] *See* Ann Marie Gardner, *Understanding Greenhouse Gases* (July 7, 2022), https://climatetrace.org/news/understanding-greenhouse-gases. Methane is 80 times more potent than carbon dioxide over a 100-year period. *Id.*

[26] Yuanrong Zhou et al., *Life-Cycle Greenhouse Gas Emissions of Biomethane and Hydrogen Pathways in the European Union* 19 (2021), https://theicct.org/sites/default/files/publications/lca-biomethane-hydrogen-eu-oct21.pdf; *see* A. R. Ravishankara et al., *Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions* 13 (2021), https://www.unep.org/resources/report/global-methane-assessment-benefits-and-costs-mitigating-methane-emissions (concluding that technological measures like digesters have "limited potential" to address agricultural methane emissions).

[27] *See* Frederik R. Dalby et al., *Understanding Methane Emission from Stored Animal Manure: A Review to Guide Model Development*, 50 J. Env't Quality 817 (2021).

[28] *See* Olga Gavriolova et al., *Emissions from Livestock and Manure Management* 10.58, Tbl. 10.14 (2019), https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch10_Livestock.pdf.

manure management systems, such as solid-liquid separation and dry manure management, generate far less methane in the first instance.[29] But many studies evaluating emissions reductions from digesters—including two of the studies on which NRCS relied—fail to account for the high-pollution baseline associated with liquid manure management, meaning that they do not compare emissions reductions from digesters with emissions levels associated with alternative methods of manure management. If emissions reductions from digesters were compared to baseline emissions from a dry-manure system, for example, as opposed to baseline emissions from a liquid-manure system, digesters would appear far less beneficial.

2. The long-term benefits of digesters are uncertain.

Over the long term, digesters may not mitigate climate change for at least two reasons: (1) digesters incentivize operations to increase their herd sizes, and larger herds result in increased methane emissions that are not captured by digesters, and (2) nearly a quarter of digesters tracked by the Environmental Protection Agency ("EPA") have stopped operating, leaving behind their methane-emitting liquid manure management systems.

First, offering public funds for digester installation maximizes opportunities for industrial animal operations to profit from methane generation, thereby incentivizing them to generate more methane, which in turn, encourages them to confine additional animals. A recent study of 73 dairy operations across eight states indicates that digesters often drive operations to increase herd sizes.[30] The study found that herd sizes at facilities with digesters grew 3.7 percent year-over-year, or by an average of 177 cows per year, which was 24 times the growth rates for overall dairy herd sizes.[31] But in addition to manure methane, cattle and other ruminants also generate methane due to enteric fermentation. When the number of cows at an industrial dairy increases, so too do the dairy's methane emissions from enteric fermentation, and enteric emissions cannot be captured by digesters. Increased enteric emissions can offset any climate benefits that digesters offer. For example, each year, 177 cows emit 23 metric tons of methane through enteric fermentation alone;[32] by a conservative calculation, these enteric emissions are equivalent to the emissions from over 150 gas-powered cars.[33]

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[29] *Id.*; *see also* Ruthie Lazenby, *Mitigating Emissions from California's Dairies: Considering the Role of Anaerobic Digesters*, UCLA Law Emmett Inst., at 8 (2024), https://law.ucla.edu/news/mitigating-emissions-californias-dairies-considering-role-anaerobic-digesters.

[30] *See* Chloe Waterman & Molly Armus, *Biogas or Bull****? The Deceptive Promise of Manure Biogas as a Methane Solution* 35–38 (2024), https://foe.org/wp-content/uploads/2024/02/Factory-Farm-Gas-Brief_final-v2.pdf.

[31] *Id.* at 38.

[32] *See* Hongmin Dong et al., *Emissions from Livestock and Manure Management* 10.29, Tbl. 10.11 (2006), https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf.

[33] *See* EPA, *Greenhouse Gas Equivalencies Calculator* (Jan. 2024), https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator#results.

Second, EPA data suggests that digesters often shut down, definitively eliminating any climate benefits.[34] A review of the 441 digesters that EPA has tracked in its Livestock Anaerobic Digester Database shows that 22 percent, or 98 digesters, have shut down.[35] The reasons for the shut-downs vary but include poor economic returns from the digesters, digester equipment failures, and odor issues from the digesters.[36] Operations that shut down their digesters but continued operating likely reverted to their original, methane-heavy liquid manure management systems, eroding any benefit provided by the digesters. Given the uncertainty around digesters' longevity, their climate benefits also are highly uncertain.

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In light of the uncertainty around whether digesters support climate change mitigation, NRCS must not include digesters on the Climate-Smart List. As discussed above, it is at best unclear whether digesters result in net greenhouse gas reductions in the short term, as digesters and their associated infrastructure leak methane, and digestate emits methane and *more* nitrous oxide than conventional manure. And over the long term, producers who install digesters often counteract any climate benefits by increasing animal herds or shutting down digesters altogether. Thus, including digesters on the Climate-Smart List directly conflicts with IRA's requirement that funds go *only* to practices that reduce, capture, avoid, or sequester methane emissions.[37] It also contravenes NRCS's own requirement that the practice result in a direct impact on net greenhouse gas emission reduction, as supported by scientific literature.[38] For these reasons, NRCS must not allow IRA funds to go to digesters.

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[34] *See* Waterman & Armus, *supra* note 30 at 34 (citing EPA's Livestock Anaerobic Digester Database). Although NRCS can terminate a contract for funding if an operator fails to install, operate, or maintain a digester in accordance with the contract, NRCS may only do so during the duration of the contract. *See* 7 C.F.R. §§ 1466.21, 1466.26 After the contract expires, NRCS cannot require an operator to return the funding it received. *See id.* § 1466.26. Contracts for funding under the Environmental Quality Incentives Program, which supports digesters, can last up to 10 years, but most last for just one to three years. *See* Nat'l Sustainable Agric. Coal., *Environmental Quality Incentives Program* (May 2019), https://sustainableagriculture.net/publications/grassrootsguide/conservation-environment/environmental-quality-incentives-program/. Thus, many operators that receive public funding for digesters likely are free to shut down the digesters after one to three years.

[35] Waterman & Armus, *supra* note 30 at 34.

[36] *See* EPA, *Livestock Anaerobic Digester Database*, https://www.epa.gov/agstar/livestock-anaerobic-digester-database (last visited Mar. 6, 2024).

[37] *See* Inflation Reduction Act of 2022, Pub. L. No. 117-169, § 21001(a)(1)(B)(iii), 136 Stat. 1818, 2016 (2022).

[38] *See* NRCS, USDA, *FAQs: Climate-Smart Agriculture and Forestry Mitigation Activities and Inflation Reduction Act Funding*, https://www.nrcs.usda.gov/faqs-climate-smart-agriculture-and-forestry-mitigation-activities-and-inflation-reduction-act (last visited Nov. 8, 2023).

II. NRCS must not make digesters eligible for IRA funding because doing so takes funds away from proven climate-smart practices and exacerbates environmental injustice.

A. NRCS must not make digesters eligible for IRA funding because doing so takes funds away from proven climate-smart practices.

In addition to conflicting with IRA and NRCS's criteria, making digesters eligible for IRA funding will divert funds from practices that are truly climate smart. Digesters are extremely costly to construct[39] and, as a result, they threaten to deplete a sizeable portion of IRA funding. For example, a review of federal funding awarded under the Environmental Quality Incentives Program ("EQIP")—which receives additional funding under IRA—found that digesters were the single costliest practice eligible for funding in 2022.[40] EQIP awarded a total of $1,983,965 to just seven digesters that year,[41] which could have been used instead to help 238 farmers plant cover crops,[42] a practice that offers clear climate benefits.[43] EQIP and other federal conservation programs are consistently oversubscribed—indeed, in 2020 and 2022, approximately 70 percent of producers were turned away from EQIP funding.[44] For example, Charlene Gatson, a cattle farmer in Mississippi, applied for EQIP funding to build fencing that would have allowed her to practice rotational grazing, which protects the soil from erosion and increases its ability to sequester carbon,[45] but her application was rejected.[46] Allowing IRA funds to support digesters means that truly climate-smart practices likely will continue to go unfunded, despite Congress' express intent that IRA funds support those practices. NRCS should not undermine the purpose of IRA in this way.

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[39] *See, e.g.*, Michael Boerman et al., *Anaerobic Digestion at Swiss Valley Dairy: Case Study*, Cornell Univ. Env't Systems Program, at 4 (2014), https://ecommons.cornell.edu/server/api/core/bitstreams/5be73af9-0f29-422a-89c2-213754f5b7e5/content (describing a digester system that cost $1.7 million to construct).

[40] *See* Michael Happ, *Waste and Water Woes: Popular Conservation Programs Should Focus on Small-Scale and Sustainable Farms, Not Industrial-Scale Farms*, Inst. for Agric. & Trade Pol'y, at 3 (2023), https://www.iatp.org/sites/default/files/2023-10/Wastewaterwoes_combinedfinal.pdf.pdf.

[41] *Id.*

[42] *Id.* at 4.

[43] *See* Jason P. Kaye & Miguel Quemada, *Using Cover Crops to Mitigate and Adapt to Climate Change. A Review*, 37 Agronomy for Sustainable Dev. 3 (2017); *see also* Jinshi Jian et al., *A Meta-Analysis of Global Cropland Soil Carbon Changes Due to Cover Cropping*, 143 Soil Biology & Biochemistry 107735 (2020).

[44] *See* Michael Happ, *Still Closed Out*, Inst. for Agric. & Trade Pol'y (2023), https://www.iatp.org/still-closed-out.

[45] *See* Peter H. Lehner & Nathan A. Rosenberg, *Farming for Our Future: The Science, Law, and Policy of Climate-Neutral Agriculture* 91 (2021).

[46] *See* Erin Jordan et al., *Farmers Left Wondering Why They Were Denied Federal Conservation Grants*, Star Tribune (Nov. 20, 2023), https://www.startribune.com/farmers-left-wondering-why-they-were-denied-federal-conservation-grants/600321213/.

B. NRCS must not make digesters eligible for IRA funding because doing so exacerbates environmental injustice.

Finally, digesters worsen the environmental injustice that industrial animal operations cause. A well-established and growing body of scientific evidence shows that these operations are located disproportionately in communities of color and low-income communities across the country.[47] For example, in North Carolina—where numerous swine operations have contracted with energy companies to produce biogas[48]—the percent of Black, Hispanic, and American Indian residents living within three miles of a swine operation is disproportionately high, at 1.34, 1.37, and 2.05 times higher, respectively, than the percent of non-Hispanic Whites.[49] And the percent of North Carolina residents in low-income census blocks living within three miles of a swine operation is up to nine times higher than the percent of residents in higher-income census blocks.[50] As a result, the air and water pollution that these operations generate unequally burdens environmental justice communities.

NRCS acknowledges that digesters cause additional air and water pollution. In the digester conservation practice standard, NRCS explains that "digestate has increased potential for some air and nutrient emissions compared to raw manure,"[51] and "compounds such as nitrogen, phosphorus, and other elements become more soluble due to anaerobic digestion and therefore have higher potential to move with water."[52] Numerous studies support NRCS's conclusions.[53] In light of the additional harms that digesters cause, a group of North Carolina residents living near industrial swine operations with digesters filed a complaint with EPA under Title VI of the Civil Rights Act of 1964, alleging that the state's issuance of permits for the

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[47] *See* Julia Lenhardt & Yelena Ogneva-Himmelberger, *Environmental Injustice in the Spatial Distribution of Concentrated Animal Feeding Operations in Ohio*, 6 Env't Just.133 (2013); *see also* Arbor J.L. Quist et al., *Disparities of Industrial Animal Operations in California, Iowa, and North Carolina* 5 (2022), https://earthjustice.org/wp-content/uploads/quistreport_cafopetition_oct2022.pdf; Ji-Young Son et al., *Distribution of Environmental Justice Metrics for Exposure to CAFOs in North Carolina, USA*, 195 Env't Rsch. 110862 (2021); Sacoby M. Wilson et al., *Environmental Injustice and the Mississippi Hog Industry*, 110 Env't Health Persps. 195, 199 (2002); Steve Wing et al., *Environmental Injustice in North Carolina's Hog Industry*, 108 Env't Health Persps. 225, 229 (2000).

[48] *See* Food & Water Watch, *The Big Oil and Big Ag Ponzi Scheme: Factory Farm Gas* 3, 10 (2024), https://www.foodandwaterwatch.org/wp-content/uploads/2024/01/RPT2_2401_GreenwashingBiogas-WEB3.pdf.

[49] *See* Quist, *supra* note 41, at 27, Supp. Tbl. 1.

[50] *Id.* at 28, Supp. Tbl. 2.

[51] NRCS, USDA, Conservation Practice Standard Anaerobic Digester 366-CPS-8 (2023), https://nrcs.usda.gov/sites/default/files/2023-08/366_NHCP_CPS_Anaerobic_Digester_2023.pdf.

[52] *Id.* at 366-CPS-9.

[53] *See* F. Battini et al., *Mitigating the Environmental Impacts of Milk Production via Anaerobic Digestion of Manure: Case Study of a Dairy Farm in the Po Valley*, 481 Sci. Total Env't 196 (2014); *see also* Marc Carreras-Sospedra et al., *Assessment of the Emissions and Air Quality Impacts of Biomass and Biogas Use in California*, 66 J. Air & Waste Mgmt. Ass'n 134 (2015); Adel Ghoneim et al., *Analysis of Nitrogen Dynamics and Fertilizer Use Efficiency in Rice Using the Nitrogen-15 Isotope Dilution Method Following the Application of Biogas Slurry or Chemical Fertilizer*, 3 Int'l J. Soil Sci. 11 (2008); Roger Nkoa, *Agricultural Benefits and Environmental Risks of Soil Fertilization with Anaerobic Digestates: A Review*, 34 Agronomy for Sustainable Dev. 473 (2014).

digesters had discriminatory impacts.[54] EPA accepted the complaint for investigation, meaning that if the allegations are true, they may violate EPA's prohibitions against discrimination.[55] Other digesters likewise threaten to worsen the environmental injustice that industrial animal operations cause.

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Deeming anaerobic digesters eligible for IRA funding contravenes the statute's express requirements, diverts money from proven climate-smart practices, and exacerbates environmental injustice. We therefore urge NRCS to exclude digesters from the Climate-Smart Agriculture and Forestry Mitigation Activities List for FY2025. We also ask NRCS to make publicly available the scientific literature and methods it relies upon to select the practices on the list and provide the public with a meaningful opportunity to comment on the selection process.

Respectfully submitted,

Animal Kind Alliance Inc.
Animal Legal Defense Fund
Anthropocene Alliance
Buffalo River Watershed Alliance
Campaign for Family Farms and the Environment
Cape Fear River Watch
Catskill Mountainkeeper
Center for Biological Diversity
Center for Food Safety
Climate Land Leaders
Coastal Carolina Riverwatch
Dakota Rural Action
Earthjustice
Endangered Habitats League
Environment America
Environmental Justice Community Action Network
Environmental Law & Policy Center
Family Farm Defenders
Farm Aid
FarmSTAND
Food & Water Watch

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[54] *See* Letter from Blakely Hildebrand, Staff Att'y, S. Env't Law Ctr., to Michael S. Regan, Adm'r, EPA & Lilian S. Dorka, Dir., External Civil Rights Compliance Off., EPA (Sept. 27, 2021), https://www.southernenvironment.org/wp-content/uploads/2021/09/2021-09-27-Title-VI-Complaint-Index-DEQ-Biogas-Permits.pdf.

[55] *See* Letter from Lilian S. Dorka, Dir., External Civil Rights Compliance Off., EPA, to Blakely Hildebrand, Staff Att'y, S. Env't Law Ctr., at 1 (Jan. 13, 2022), https://www.southernenvironment.org/wp-content/uploads/2022/01/2022.01.13-Final-CP-Acceptance-Ltr.-EPA-Complaint-No.-05RNO-21-R4-NCDEQ-copy.pdf.

Food Animal Concerns Trust
Friends of the Earth
Friends of Toppenish Creek
GreenLatinos
Illinois Stewardship Alliance
Institute for Agriculture and Trade Policy
Kansas Rural Center
Lake Erie Waterkeeper
Land Stewardship Project
Latino Farmers & Ranchers International, Inc.
Maine Organic Farmers and Gardeners Association
Michigan Organic Food and Farm Alliance
Milwaukee Riverkeeper
Missouri Coalition for the Environment
National Sustainable Agriculture Coalition
Northeast Organic Dairy Producers Alliance
Northeast Organic Farming Association of New Hampshire
Northeast Organic Farming Association Massachusetts Chapter
Ohio Environmental Council
Organic Farming Research Foundation
Pesticide Action Network
Rural Coalition
Sierra Club
Socially Responsible Agriculture Project
Southern Environmental Law Center
Sprout
Upper Valley Super Compost Project
Vermont Healthy Soils Coalition
Virginia Association for Biological Farming
Waterkeepers Chesapeake
Women, Food and Agriculture Network

Exhibit 1

A Comparison of Dairy Cattle Manure Management with and without Anaerobic Digestion and Biogas Utilization

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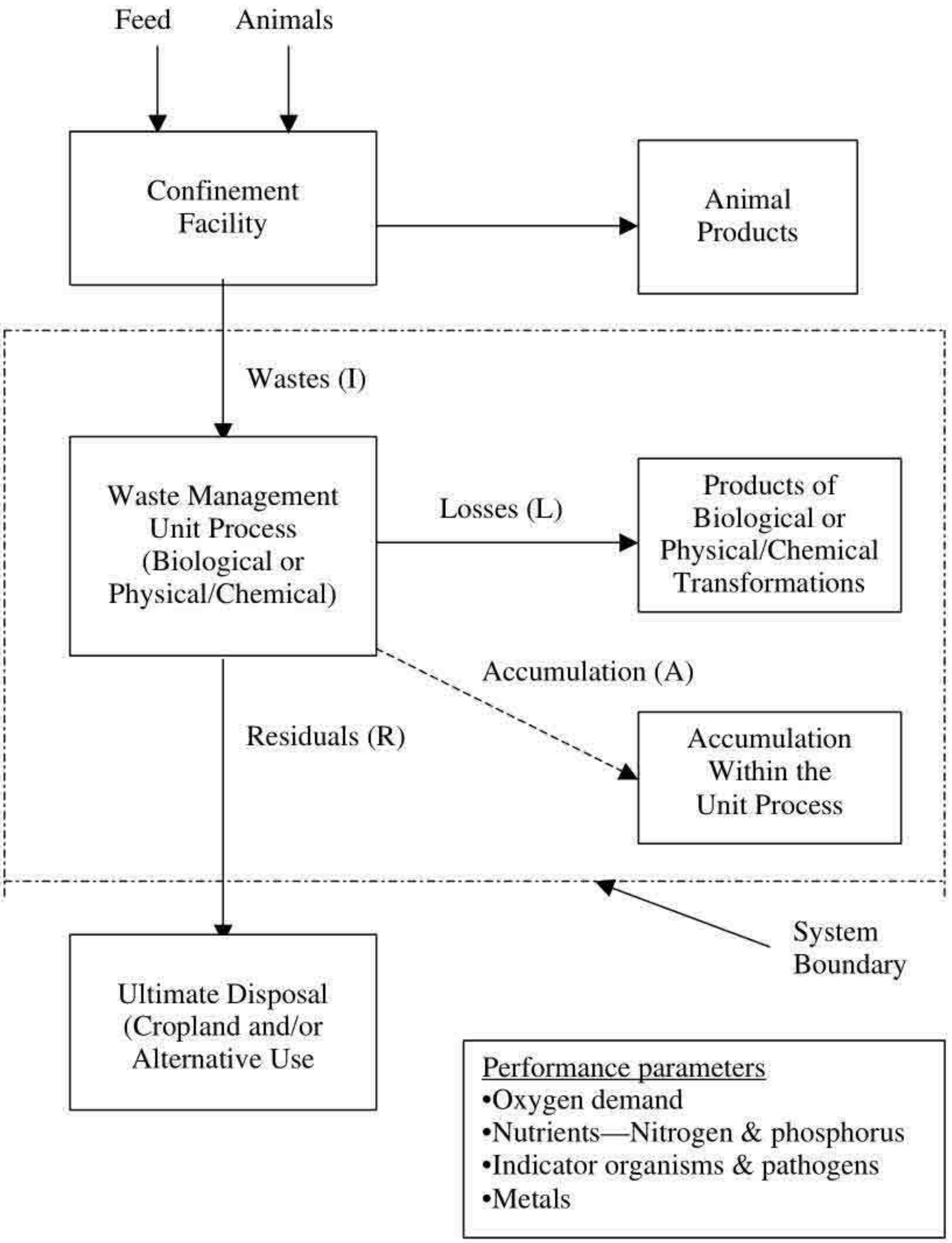
Task Order 400

PREFACE

This report summarizes the results from one of a series of studies designed to: 1) more fully characterize and quantify the protection of air and water quality provided by waste management systems currently used in the swine and dairy industries and 2) delineate associated costs. The overall objective of this effort is to develop a better understanding of: 1) the potential of individual system components and combinations of these components to ameliorate the impacts of swine and dairy cattle manures on environmental quality and 2) the relationships between design and operating parameters and the performance of the biological and physical/chemical processes involved. A clear understanding of both is essential for the rational planning and design of these waste management systems. With this information, swine and dairy producers and their engineers as well as the regulatory community will have the ability to identify specific processes or combinations of processes that will effectively address air and water quality problems of concern.

The following schematic illustrates the comprehensive mass balance approach that is being used for each unit process in these performance evaluations. When a system is comprised of more than one unit process, the performance of each process is characterized separately. Then the results are aggregated to characterize overall system performance. This is the same approach commonly used to characterize the performance of domestic and industrial wastewater treatment and chemical manufacturing unit processes. Past characterizations of individual process and systems performance frequently have been narrowly focused and have ignored the generation of side streams of residuals of significance and associated cross media environmental quality impacts. A standardized approach for cost analysis using uniform boundary conditions also is a key component of this comparative effort.



Where: $L = I - (R + A)$
(I and R are measured and
L and A are estimated)

Figure 1. Illustration of a standardized mass balance approach to characterize the performance of animal waste management unit processes.

SECTION 1

SUMMARY AND CONCLUSIONS

The objectives of this study were to compare: 1) the reductions in the potential air and water quality impacts of scraped dairy manure by preceding liquid-solids separation and storage with mesophilic anaerobic digestion in a plug-flow reactor with a flexible geotextile membrane, and 2) the associated cost differential. These reductions and the associated cost differential were determined from characterizations of performance and associated costs for these two dairy manure management strategies on two typical upstate New York dairy farms, AA Dairy and Patterson Farms, Inc. The characterizations of performance were based on materials balances developed for both systems and the cost differential was based on the differential between the cost of anaerobic digestion and the income generated through biogas utilization.

AA Dairy, with an average milking herd of 550 cows, uses anaerobic digestion with biogas utilization to generate electricity, followed by separation of solids, using a screw press separator, in their system of manure management. Patterson Farms also employs solids separation, using a drum type separator, in their manure management system but not anaerobic digestion. Both farms compost separated solids and store the liquid manure remaining after solids separation in earthen storage ponds.

The results of this study provide further confirmation of the environmental quality benefits realized by the anaerobic digestion of dairy cattle manure with biogas collection and utilization for the generation of electricity. These results also confirm that these environmental quality benefits can be realized while concurrently generating revenue adequate to recover capital invested and increase farm net income through the on-site use and sale of electricity generated. In Table 1-1, the impacts of anaerobic digestion on semisolid dairy cattle manure management with solids separation and storage, which are discussed below, are summarized.

Odors

The most readily apparent difference between the AA Dairy and Patterson Farms manure management systems is the effectiveness of anaerobic digestion at AA Dairy in reducing odors. This is the direct result of the degree of waste stabilization provided by anaerobic digestion under controlled conditions. As shown in Table 4-2, average reductions in total volatile solids, chemical oxygen demand, and volatile acids during anaerobic digestion were 29.7, 41.9, and 86.1 percent, respectively. With these reductions, additional degradation during storage under uncontrolled anaerobic conditions and the associated odors are minimized.

Table 1-1. Impacts of anaerobic digestion on a semisolid dairy cattle manure management systems with solids separation and storage.

Parameter	With anaerobic digestion (AA Dairy vs. Patterson Farms)
Odor	Substantial reduction
Greenhouse gas emissions	Methane—substantial reduction (8.16 tons per cow-yr) Nitrous oxide—No evidence of emissions with or without anaerobic digestion
Ammonia emissions	No significant reduction
Potential water quality impacts	Oxygen demand—substantial reduction (8.4 lb per cow-day) Pathogens—substantial reduction (Fecal coliforms: ~99.9%) (*M. avium paratuberculosis*: ~99%) Nutrient enrichment—no reduction
Economic impact	Significant increase in net farm income ($82 per cow-yr)

Greenhouse Gas Emissions

Methane—Perhaps the most significant impact of the anaerobic digestion of dairy cattle manure with biogas capture and utilization is the reduction of the emission of methane, a greenhouse gas with 21 times the heat-trapping capacity of carbon dioxide, to the atmosphere. The reduction in methane emissions, on a carbon dioxide equivalent basis, was determined to be 7.13 tons per cow-year, or 3,924 tons per year for the 550-cow AA Dairy milking herd. If this herd were expanded to the anaerobic digestion-biogas utilization system design value of 1,034 cows, this reduction would increase to 6,076 tons per year. In addition, the electricity generated using biogas has the potential of reducing carbon dioxide emissions from the use of fossil fuels for generating electricity. Under current operating conditions, this reduction is estimated to be 1.03 tons per cow-year and would increase to 1.29 tons per cow-year with herd expansion.

Nitrous Oxide—Analyses of samples of the stored liquid phase of dairy cattle manure after separation at both AA Dairy and Patterson Farms showed that no oxidized forms of nitrogen (nitrite or nitrate nitrogen) were present. Given that conditions required for nitrification, residual concentrations of dissolved oxygen and the absence of inhibitory concentrations of unionized or free ammonia (NH_3), the absence of evidence of nitrification was not surprising. Thus, the expectation of nitrous oxide emissions, as an end product of denitrification, from dairy cattle manure storage structures seemingly has no theoretical basis given the absence of the necessary prerequisite of nitrification.

Other Gaseous Emissions

Analysis of the biogas produced at AA Dairy indicated the presence of only a nominal concentration, 15±5 ppm, of NH_3. The results of this analysis in combination with the total Kjeldahl nitrogen balance results (Table 4-2) indicate the loss of nitrogen via ammonia volatilization during anaerobic digestion of dairy cattle manure is negligible. Thus, it appears reasonable to conclude that ammonia is insignificant as a source of emissions of oxides of nitrogen during biogas combustion. However, the concentration of hydrogen sulfide found in the AA Dairy biogas, 1,930 ppm, indicates that emissions of oxides of sulfur during biogas combustion potentially are significant.

Although anaerobic lagoons used for animal waste stabilization are generally considered significant sources of NH_3, emissions to the atmosphere, the results of this study suggest that at least structures used for the storage of dairy cattle manure are not. For both anaerobically digested and unstabilized manure, nitrogen losses were minimal but somewhat greater (30.2 lbs per cow-year) for the unstabilized manure. However, estimating nitrogen losses from both the AA Dairy and Patterson Farms manure storage structures was confounded by significant spatial variation in total Kjeldahl nitrogen concentrations in both storage structures. Thus, the losses reported in here may be underestimates.

Water Quality Impacts

Oxygen Demand—As mentioned above, the results of data collected at AA Dairy show (Table 4-2) that anaerobic digestion can substantially reduce dairy cattle manure total volatile solids and chemical oxygen demand. These reductions translate directly into a lower potential for depletion of dissolved oxygen in natural waters. Although anaerobically digested dairy cattle manure clearly is not suitable for direct discharge to surface or ground waters, these reductions still are significant due to the potential for these wastes to enter surface waters by nonpoint source transport mechanisms.

Pathogens—As shown in Table 4-4, mesophilic anaerobic digestion at a hydraulic retention time of 34 days was found to provide a mean reduction in the density of members of the fecal coliforms group of enteric bacteria that approached 99.9 percent. For the pathogen, *Mycobacterium avium paratuberculosis*, reduction slightly exceeded 99 percent. *M. avium paratuberculosis* is responsible for paratuberculosis (Johne's disease) in cattle and other ruminants and is suspected to be the causative agent in Crohn's disease, a chronic enteritis in humans. No regrowth of either organism during storage was observed. Thus, it appears that anaerobic digestion of dairy cattle manure also can reduce the potential for the contamination of natural waters by both non-pathogenic and pathogenic microorganisms. . No reductions were observed in the Patterson Farm manure management system.

Nutrient Enrichment—Both nitrogen and phosphorus mass balance results (Table 4-2) demonstrate that anaerobic digestion in a plug flow reactor without the accumulation of settleable solids provides no reduction of the potential impact of these nutrients on water quality.

In addition, results of this study indicate that separation of coarse solids with or without anaerobic digestion only reduces the masses of nitrogen and phosphorus in the remaining liquid fraction by about five percent (Tables 4-9 and 4-14) even though a 17 percent reduction in volume is realized.

Economic Impact

As noted above, the results of this study also confirm that anaerobic digestion with biogas utilization can produce revenue adequate to recover the required capital investment and increase farm net income through the on-site use and sale of electricity generated. Because the AA Dairy anaerobic digester-biogas utilization system was designed for a milking herd of 1,054 cows but currently is being operated with a herd of only 550 cows, the maximum potential of the system to produce biogas and generate electricity currently is not being realized. One of the more significant ramifications of the current operation of this system at less than design capacity is the reduction in the efficiency of the conversion of biogas energy to electrical energy from 30 to 20 percent. Even under these sub-optimal operating conditions, the net income produced by the on-site use and sale of electricity generated is such that the required capital investment can be recovered or repaid in approximately 11 years and then add $32,785 annually to net farm income over the remaining useful life of the system, a period of at least nine years. At the design herd size of 1,034 cows, the capital invested would be recovered in approximately three years and would then add $86,587 annually to net farm income over the remaining useful life of system. Recovery or repayment of the required capital investment over the useful life of the system, estimated conservatively to be 20 years, would somewhat reduce total additions to net farm income but still provide a satisfactory rate of return management and labor. Thus, it can be concluded that there is a significant economic incentive to realize the environmental quality benefits that the anaerobic digestion of dairy cattle manure can provide.

In this study, it was found that anaerobic digestion prior to the separation of course solids does not enhance the separation process or alter the characteristics of the separated solids or the remaining liquid fraction with one notable exception. With anaerobic digestion, the densities of fecal coliforms and *M. avium paratuberculosis* in both fractions were substantially lower.

Therefore, dependence on composting for effective pathogen reduction in the separated solids is lessened.

SECTION 2

INTRODUCTION

Anaerobic digestion is a controlled biological process that can substantially reduce the impact of liquid livestock and poultry manures and manure slurries on air and water quality. Unlike comparable aerobic waste stabilization processes, energy requirements are minimal. In addition, a relatively small fraction of the energy in the biogas produced and captured is adequate to satisfy process needs with the remaining biogas energy available for use as a boiler fuel or to generate electricity. Thus, anaerobic digestion with biogas utilization produces a source of revenue that will at least partially offset process costs and may increase farm net income.

Past interest in anaerobic digestion of livestock and poultry manures was driven primarily by the need for conventional fuel substitutes. For example, interest intensified in France and Germany during and immediately after World War II in response to disruptions in conventional fuel supplies (Tietjen, 1975). This was followed by a renewal of interest in anaerobic digestion of livestock and poultry manures in the mid-1970s stimulated primarily by the OPEC oil embargo of 1973 and the subsequent price increases for crude oil and other fuels. In both instances, this interest dissipated rapidly, however, as supplies of conventional fuels increased and prices declined.

A substantial majority of the anaerobic digesters constructed for biogas production from livestock and poultry manures in the 1970s failed for a variety of reasons. However, the experience gained during this period allowed the refinement of both system design and operating parameters and the demonstration of technical viability.

In the early to mid-1990s, a renewal of interest in anaerobic digestion by livestock and poultry producers occurred. Three primary factors contributed to this renewal of interest. One factor was the need for a cost-effective strategy for reducing manure-related odors from storage facilities, including anaerobic lagoons and land application sites. Another factor was the re-emerging concern about the impacts of livestock and poultry manures on water quality. Finally, the level of concern about global climate change was intensifying and the significance of methane emissions to the atmosphere was receiving increased attention. Recognition of the magnitude of methane emissions resulting from the uncontrolled anaerobic decomposition of livestock and poultry manures led to the creation of the U.S. Environmental Protection Agency's AgSTAR Program. The primary mission of this program is to encourage the use of anaerobic digestion with biogas collection and utilization in the management of livestock and poultry manures.

Although aerobic digestion also was demonstrated in the 1960s and 1970s to be an effective strategy for controlling odors from and water quality impacts of livestock and poultry manures (Martin and Loehr, 1976 and Martin *et al*., 1981), the cost is prohibitively high due primarily to the electrical energy required for aeration and mixing. In addition, the reduction in methane emissions is at least partially negated by the greenhouse gas emissions associated generation of the electricity required.

Objectives

The objectives of this study were to compare: 1) the reductions in the potential air and water quality impacts of scraped dairy manure by preceding liquid-solids separation and storage with mesophilic anaerobic digestion in a plug-flow reactor, and 2) the associated cost differential. These reductions and the associated cost differential were determined from characterizations of performance and associated costs for these two dairy manure management strategies on two typical upstate New York dairy farms. The characterizations of performance were based on materials balances developed for both systems and the cost differential was based on the differential between the cost of anaerobic digestion and the income generated through biogas utilization.

SECTION 3

METHODS AND MATERIALS

Study Sites

As indicated above, two typical upstate New York dairy farms served as sites for this study. Below is a brief description of each farm and its manure management system.

AA Dairy—AA Dairy is a 2,200-acre dairy farm located in Candor, New York. Candor is in Tioga County, a southern tier county in upstate New York. The AA Dairy milking herd consists, on average, of 550 Holstein-Friesian cows. Average yearly milk production is 23,000 lb per cow. The milking herd is housed in a naturally ventilated free-stall barn, which is connected to a milking parlor.

Manure is removed from the alleys in the free-stall barn daily by scraping into a cross-alley with step dams. In this cross-alley, the manure then moves by gravity to a mixing tank/lift station containing a chopper-type pump for mixing. After mixing, manure is then transferred daily to a mesophilic plug-flow anaerobic digester using a piston pump. After digestion, the coarse solids in the digester effluent are removed mechanically using a FAN screw press separator with the remaining liquid discharged to a 2.4 million-gallon lined earthen storage pond. Both tank wagons and a traveling gun irrigation system are used for application to cropland of manure from the storage lagoon.

The separated solids, consisting primarily of fibrous materials, are transported to a site adjacent to the free-stall barn-milking parlor complex for further stabilization and drying by windrow composting. The finished compost is sold in bulk and bags for use as a soil amendment and mulch material. Approximately 1,825 yd^3 are sold annually at an average of \$16 per yd^3.

The plug-flow anaerobic digester was designed and constructed by RCM Digesters, Inc., of Berkley, California, with the expectation of a future herd expansion to 1,054 cows. The digester dimensions are 112 ft long by 28 ft wide by 14 ft deep, and it has an operating volume of 39,568 ft^3. The design hydraulic retention time (HRT) for the digester, based on an expected herd expansion to 1,054 cows, is 24 days with a predicted rate of biogas production of 64,720 ft^3 per day. The digester channel is covered with an impermeable flexible geotextile membrane, which is inflated to a nominal positive pressure by the biogas collected to maintain a semi-rigid surface. The digester has been in operation since mid-1998 and has addressed the odor problems that were the catalyst for considering anaerobic digestion.

Captured biogas is used to fuel a 130 kW engine generator set. The engine, a Caterpillar 3306, is a diesel engine modified by the addition of spark ignition system to use low pressure/low energy biogas as a fuel. The generator is an induction type unit with the following specifications: three phase, 208 volts, and 430 amps at 1,835 rpm. The electricity generated is used to satisfy on-farm demand with any excess energy sold at wholesale rates to the local electric utility, the New York State Electric and Gas (NYSEG) Corporation. Waste heat from the engine cooling system is recovered through a heat exchanger and used to maintain digester temperature at approximately 95 to 98°F. A fuel oil fired hot water boiler is available to maintain digester temperature if the engine-generator set is out of service for maintenance or repairs for an extended period. Biogas produced during such periods is flared to prevent an excessive increase in digester pressure.

Patterson Farms, Inc.—Patterson Farms, Inc. is 1,500-acre dairy farm located in Union Springs, New York. Union Springs is in Cayuga County, a central Finger Lakes county in upstate New York. During this study, the average size of the milking herd increased from 600 to 800 cows. Average yearly milk production is 24,000 lbs per cow. The milking herd is housed in two naturally ventilated free-stall barns, which are connected to a milking parlor.

Manure is removed from the alleys in two free-stall barns daily using alley scrapers, which deposit the scraped manure into a cross alley for transport by gravity into a piston pump reception pit. The manure is then transferred to a holding tank that provides temporary storage before separation of coarse solids. A Houle drum-type separator is used for solids separation with the remaining liquid discharged to a 5.4 million-gallon unlined earthen storage pond. All of the manure from the storage pond is applied to cropland by tank wagon type spreaders. Due to odor problems and the cost of electricity, Patterson Farms is currently is considering the construction of a plug-flow anaerobic digester.

The separated solids, consisting primarily of fibrous materials, are transported by conveyor to a mechanical distribution system in a covered static pile composting facility with forced-air aeration. The finished compost is used as bedding and reduces bedding costs by approximately $60 per cow-year.

Data Collection

The basis for comparing the performance of the two dairy cattle waste management systems evaluated in this study was materials balances developed from measured concentrations of selected parameters in combination with mass flow estimates. At AA Dairy, the following four waste streams; anaerobic digester influent, effluent, and liquid and solid phase effluents from the liquid-solids separation unit; were sampled semi-monthly from late May 2001 through early June 2002. At Patterson Farms, the influent to and the liquid and solid phase effluents from the liquid-solids separation unit also were sampled semi-monthly during the same period. Each sample collected for analysis was a composite of several sub-samples collected over a 15 to 20 minute period of flow to insure that the samples analyzed were representative.

In addition, the storage pond at each farm were sampled at the end of months four, eight, and twelve of the study. For each sampling event, samples were collected at three locations along the axis of the pond perpendicular to the location of the influent discharge. At each location, samples were collected at three depths: the top, middle, and bottom of the liquid column. Each sample was analyzed separately.

As noted earlier, a piston pump is used to initially transfer manure at each farm. This enabled estimation of the volume of manure produced daily by determining the average number of piston strokes per day using a mechanical counter and the manufacturers specification for volume displaced per stroke. The liquid and solid fraction volumes after separation were estimated based the partitioning of total solids between the two fractions assuming conservation of mass through the separation process.

Additional data collection at AA Dairy included volume of biogas utilized and kilowatt-hours (kWh) of electricity generated between days of collection of manure samples. The kWh of biogas-generated electricity used on-site and sold to the local public utility, the NYSEG Corporation, were determined from farm records.

Sample Analyses

Physical and Chemical Parameters—All manure samples collected were analyzed to determine concentrations of the following: total solids (TS), total volatile solids (TVS), chemical oxygen demand (COD), soluble chemical oxygen demand (SCOD), total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_4-N), total phosphorus (TP), orthophosphate phosphorus (PO_4-P), and pH. U.S. Environmental Protection Agency (1983) methods were used for TS, TVS, TKN, TP, PO_4-P, and pH determinations. American Public Health Association (1995) methods were used to determine COD, SCOD, and NH_4-N concentrations. All analyses were performed by an analytical laboratory certified by the New York State Department of Environmental Conservation.

Biodegradability—A 55-day batch study was conducted to estimate the biodegradable and refractory fractions of TVS in a random sample of as excreted manure from AA Dairy. The study was a laboratory scale study in which two liters of AA Dairy manure was maintained at 95 °F (35 °C) in a glass reactor. A water trap was used to vent the biogas produced and maintain anaerobic conditions in the reactor. The contents of the reactor were sampled and analyzed to determine TVS on days 0, 7, 10, 15, 30, and 55 of the batch study.

Microbial Parameters—Two parameters were used to characterize the fate and transport of indicator and pathogenic microorganisms in the AA Dairy and the Patterson Farms waste management systems. One parameter was the fecal coliform group of bacteria (fecal coliforms), a group of bacteria that includes *Escherichia coli*, *Klebsiella pneumoniae*, and other species, which are common inhabitants of the gastro-intestinal tract of all warm-blooded animals. The presence of fecal coliforms is commonly used as an indicator of fecal contamination and the possible presence of pathogenic microorganisms. In addition, a reduction in fecal coliform density serves as an indicator of reductions in the densities of pathogenic microorganisms. Densities of fecal coliforms were estimated using the multiple tube fermentation technique (American Public Health Association, 1995) by the same laboratory that performed determinations of physical and chemical characteristics.

The second microbial parameter was the pathogen *Mycobacterium avium paratuberculosis*, which is the microorganism responsible for paratuberculosis (Johne's disease) in cattle and other ruminants. Paratuberculosis is a chronic, contagious enteritis characterized eventually by death. *M. avium paratuberculosis*, formerly known as *M. paratuberculosis* or *M. johnei*, is also suspected to possibly be the causative agent in Crohn's disease, a chronic enteritis in humans (Merck and Company, Inc., 1998). Thus, *M. avium paratuberculosis* is considered a possible zoonotic risk. Determinations of densities of *M. avium paratuberculosis* were performed by the New York Animal Health Diagnostic Laboratory, Cornell University College of Veterinary Medicine using the "Cornell Method," which has been described by Stabel (1997). Although Stabel reported the Cornell Method to be less sensitive than other methods, it satisfies the requirements of the U.S. Department of Agriculture (USDA) National Veterinary Services Laboratory proficiency-testing program.

Biogas Composition—A random sample of AA Dairy biogas was analyzed by gas chromatography using ASTM Method D1946 (ASTM International, 1990) to determine methane and carbon dioxide content. The same sample was analyzed using EPA Method 16 to determine hydrogen sulfide content and using Sensidyne ammonia detection tubes to determine ammonia (NH_3) content.

Data Analysis

Each data set generated in this study was analyzed statistically for the possible presence of extreme observations or outliers using Dixon's criteria for testing extreme observations in a single sample (Snedecor and Cochran, 1980). If the probability of the occurrence of a suspect observation based on order statistics was less than five percent ($P<0.05$), the suspect observation was considered an outlier and not included in subsequent statistical analyses.

With the exception of bacterial densities, all data sets were found to be approximately normally distributed and the null hypothesis that two means do not differ significantly ($P<0.01$) was tested using the Student's *t* test. For multiple comparisons, one-way analysis of variance (ANOVA) was used. If the null hypothesis that the means do not differ significantly ($P<0.01$) was rejected, Tukey's Honest Significance Test for pairwise comparisons of means (Steel and Torrie, 1980) was used. To equalize variances, densities of fecal coliform bacteria and *Mycobacterium avium* *paratuberculosis* were transformed logarithmically before calculation of means and standard deviations and comparisons of means to determine the statistical significance of differences. A $\log_{10}$ (Y+1) transformation was used because the presence of *M. avium paratuberculosis* was not always detected.

The procedure used to estimate the biodegradable and refractory fractions of TVS in as excreted AA Dairy manure from the results of the batch biodegradability study is based on the assumption that the biodegradable fraction of TVS approaches zero as the solids retention time (SRT) approaches infinity. Therefore, the refractory fraction of TVS can be determined graphically by plotting a time series of ratios of TVS concentrations to the initial TVS concentration versus the inverse products of the initial TVS concentration and the corresponding unit of time. The resulting relationship should be linear with the ordinate axis intercept representing the refractory fraction of TVS.

SECTION 4

RESULTS

AA Dairy

Manure Production and Characteristics—As shown in Table 4-1, the volume of manure produced per cow-day at the AA Dairy is somewhat higher than the standard reference values proposed by the American Society of Agricultural Engineers (2001) and the U.S. Department of Agriculture (1992). However, both the American Society of Agricultural Engineers (ASAE) and the USDA estimates are as excreted values. Thus, they do not include any water used for cleaning or accidental spillage from drinkers, which are included in the AA Dairy value.

Generally, the AA Dairy manure characteristics, on a kg per cow-day basis, are within the ranges of the ASAE and USDA values suggesting any dilution is minimal. COD is, however, the one notable exception. The reason or reasons for the substantially higher AA Dairy value are unclear but may reflect differences in feeding practices or differences in analytical precision and accuracy. Because of the presence of particulate matter in a variety of sizes (undigested fiber) in dairy cow manure and the degree of sample dilution necessary prior to COD determination, obtaining a representative subsample, even after sample homogenization, is a difficult process. Finally, the absence of significant differences in rates of excretion of TKN and total TP between the AA Dairy and the standard reference values is noteworthy.

Digester Operating Conditions—Based on manure production rate of 2.1 ft^3 per cow-day and the herd size of 550 cows, the HRT of the AA Dairy anaerobic digester as operated during this study was 34 days. This is 10 days longer than the design HRT of 24 days, which was based on planned expansion of the herd size of 1,054 cows. If future herd expansion to 1,054 cows does occur, the digester HRT will be reduced to approximately 18 days, which is 75 percent of the design HRT.

Waste Stabilization—An assessment of the AA Dairy plug-flow anaerobic digester performance, based on comparisons of mean influent and effluent concentrations, is presented in Table 4-2. As shown, there were substantial and statistically significant ($P<0.01$) reductions in TS, TVS, COD, SCOD, and TVA. Conversely, concentrations of NH_4-N and PO_4-P increased while there were no statistically significant differences between influent and effluent concentrations of fixed solids (FS), TKN, organic nitrogen (ON), and TP. The lack of significant differences between influent and effluent concentrations of FS and TP indicate that this digester is operating in an ideal plug-flow mode with no accumulation of total solids and related parameters occurring. The one anomaly in these data is the absence of a statistically significant reduction in ON concentration comparable to the increase in the concentration of NH_4-N. The reason for this anomaly is not clear, but the lack of a statistically significant difference between influent and effluent TKN concentrations indicates that nitrogen loss through desorption of NH_4-N in the digester is at most minimal. The differences between influent and effluent concentrations of TVS and COD (Table 4-2) translate into the mass reductions presented in Table 4-3. It should be noted that the mass reductions in TS and TVS essentially are the same providing further evidence of the validity of the data set.

Biodegradability—The results of the batch study to estimate AA Dairy manure TVS biodegradability indicate that 30 percent of the TVS are readily biodegradable and 70 percent are refractory.

Indicator Organism and Pathogen Reduction—As shown in Table 4-4, the $\log_{10}$ densities of both the fecal coliform group of bacteria and *M. avium paratuberculosis* were reduced substantially in the AA Dairy anaerobic digester. On a colony-forming unit (CFU) per g of manure basis, the reduction in the density of fecal coliforms was almost 99.9 percent while the reduction in *M. avium paratuberculosis* density was slightly greater than 99 percent.

Biogas Production—As described earlier, AA Dairy uses the biogas produced to generate electricity with waste heat from the engine-generator set used to heat the digester. When the engine-generator set is out of service, biogas is flared and a fuel oil-fired hot water boiler is used to maintain digester temperature. Only the biogas utilized to fuel the engine-generator set is metered. During this study, this meter failed in late November 2001 and was not replaced until early January 2002. This failure resulted in the loss of a little over two months of biogas production data. This failure was followed by an engine-generator set controller problem resulting in the unit being shut down from January through March 2002. However, resolution of this problem by installing a new controller with a cumulative kWh meter also resolved the problem of accurately determining cumulative engine-generator set electrical output. Originally, it was planned to acquire and install a commercial type kilowatt-hour meter at the beginning of the study to obtain this information. It was found, however, purchases of these meters from manufacturers now are limited to public utilities, and the local public utility, the NYSEG Corporation, was unable to locate a suitable reconditioned meter.

Because of the gas meter failure followed by the failure of the engine-generator set failure, determination of biogas production from late November 2001 through early April 2002 was not possible. Thus, there were two separate periods for which biogas production was determined. For the period of the study prior to the gas meter and engine-generator set controller problems (21 May through 26 November 2001), biogas production averaged 38,907 ± 13,386 ft^3 per day. For the period of the study after the resolution of the gas meter and engine-generator set controller problems discussed earlier (2 April through 17 June 2002), biogas production was 42,868 ± 3,144 ft^3 per day. Although the difference between these two periods in average daily biogas production is relatively small, the accuracy of the biogas production estimate for the 21 May through 26 November time is suspect because of a high degree of daily variability. The coefficient of variation for this period was approximately 34 percent, probably reflecting the gradual failure of the gas meter that eventually was replaced. In contrast, variability in daily biogas production for the period after gas meter replacement was only approximately seven percent. Therefore, it seems reasonable to conclude that the estimate of average daily biogas production of 42,868 ft^3 based on data collected from 2 April through 17 June 2002 is the more accurate estimate of biogas production at AA Dairy. This translates into a rate of biogas production of 78 ft^3 per cow-day, which is 28 percent higher than the originally anticipated rate of biogas production of 61 ft^3 per cow-day based on a herd size of 1,054 cows.

Previously, the methane content of the biogas produced by the AA Dairy anaerobic digester has been reported to vary between 50 to 55 percent with a variation in hydrogen sulfide content from 0.1 to 0.36 percent (Peranginangin and Scott, 2002). Results (Table 4-5) of the analysis of a random sample of the AA Dairy biogas indicated a slightly higher methane content of 59.1 percent. The concentration of hydrogen sulfide in that sample was 1,930 ppm. The NH_3. concentration, based on five replicate determinations, was found to be 15±5 parts per million, confirming the conclusion, based on mass balance results, that NH_3 desorption during anaerobic digestion is nominal.

Based on a methane content of 59.1 percent (Table 4-5) and the previously discussed rate of biogas production of 42,868 ft^3 per day, the rate of methane production by the AA Dairy anaerobic digester is 25,335 ft^3 per day. Theoretically, the destruction of one lb of ultimate biochemical oxygen demand (BOD_u) under anaerobic conditions should result in the generation of 5.62 ft^3 of methane (Metcalf and Eddy, 1991). Although not all COD is biodegradable, it can be assumed that a microbially mediated reduction of COD is equal to a reduction of the same magnitude in BOD_u. Thus, the 41.9 percent reduction in COD in the AA Dairy anaerobic digester (Table 4-2) is equivalent to a 4,641 lb per day (Table 4-3) reduction in BOD_u. As shown in Table 4-6, this translates into a rate of methane production of 5.46 ft^3 per lb of COD destroyed, which is slightly more than 97 percent of the theoretical value. Based on the ratio COD to TVS destroyed of 2.25 (Table 4-3), 12.64 ft^3 of methane should have been produced per lb of TVS destroyed. Thus, observed value of 12.30 ft^3 of methane produced per lb of TVS destroyed also compares favorably with the theoretical value. Anaerobic digestion of municipal wastewater treatment sludges (biosolids) typically yields between 12 and 18 ft^3 of methane per lb TVS destroyed (Metcalf and Eddy, Inc., 1991).

Biogas Utilization—For the period 2 April through 17 June 2002, 1,433±133 kWh of electricity was generated daily. The on-line efficiency of the engine-generator set during this time period was 96.8 percent and 33.29 ± 1.13 kWh were generated per 1,000 ft^3 of biogas utilized. The validity of this estimate of electricity was confirmed by the subsequent determination that the rate of electricity generation for the 180-day period from 2 April though 30 September 2002 was 1,429 kWh per day with an on-line efficiency of 98.8 percent. Thus, only about 20 percent of biogas energy is being recovered as electrical energy. This low conversion efficiency is probably is the result of the utilization of somewhat less than 50 percent of the engine-generator set's rated capacity of 130 kW. At full load, conversion of biogas energy to electrical energy should approach 30 percent with the added potential of recovering up to 60 percent of biogas energy as heat energy (Koelsch and Walker, 1981).

Solids Separation—As mentioned earlier, AA Dairy uses a screw press separator to recover coarse solids from the digester effluent for sale after composting as a mulch material or soil amendment. On a volume basis, 196 ft^3 of separated solids are generated daily, which reduces the digester effluent flow to the storage pond by approximately 17 percent. In Table 4-7, the characteristics of the digester effluent and the separated liquid and solid fractions are compared.

As indicated in Table 4-7, the digester effluent, separated liquid, and separated solid concentrations of TS, TVS, FS, and COD differ significantly ($P<0.01$) from each other, whereas there are no statistically significant differences in SCOD, TKN, NH_4-N, and PO_4-P concentrations. For ON, there is no statistically significant difference between the digester effluent (separator influent) and the separated liquid and separated solids concentrations. However, the difference between the separated liquid and separated solids concentrations is significant statistically indicating the concentration of ON in the separated solids. For TP, the digester effluent and separated liquid concentrations are not significantly different statistically but the differences between these concentrations and the concentration in the separated solids fraction is significant statistically. This is probably a reflection of the concentration of the organic fraction of TP in the separated solids.

As shown in Table 4-8, the digester effluent and separated liquid densities of fecal coliforms and *M. avium paratuberculosis* are not significantly different statistically ($P<0.01$), but the digester effluent and separated solids densities do differ significantly. However, there are no statistically significant differences in separated liquid and separated solids densities. Therefore, it only can be concluded that separation provides no statistically significant reductions in fecal coliform and *M. avium paratuberculosis* densities as would be expected.

As indicated earlier, the solids separated from the AA Dairy digester effluent represent about 17 percent of the digester effluent volume with the liquid fraction remaining after separation constituting the remaining 83 percent. As shown in Table 4-9, the separated solids, on a mass basis, also contain 17 percent of the TS and TVS present before separation with the remaining 83 percent in the liquid fraction. The partitioning of COD is similar to that of TS and TVS. However, the separated solids contain only about five percent of the nitrogen and phosphorus present before separation.

As previously mentioned, the separated solids at the AA Dairy are composted for further stabilization prior to sale as a mulch material or soil amendment. Assuming that the organic carbon content of the separated solids can be estimated with a reasonable degree of accuracy as approximately 55.5 percent of TVS (Haug, 1980 and Rynk *et al*., 1992), the carbon to nitrogen (C:N) ratio of the AA Dairy separated solids is approximately 23:1. At this C:N ratio, nitrogen availability will not limit the rate of stabilization but some nitrogen loss through NH_3-N volatilization should occur. A C:N ratio of 30 to 35:1 generally is considered optimal for minimizing nitrogen loss without limiting the rate of stabilization.

<u>Storage Pond Transformations</u>—As mentioned earlier, the AA Dairy earthen structure used to store the liquid fraction of the digester effluent after separation was sampled at the end of months four, eight, and twelve of this study. The results of the analyses of these samples showed significant variation in concentrations of both physical and chemical parameters with depth and to a lesser degree with location relative to the point of influent discharge to the storage structure. To provide a general characterization of the contents of the storage structure, a mean value was calculated for each parameter that was calculated for each sampling event. Then, mean values were calculated from the mean values for each sampling event. The results of these calculations are compared to the characteristics of the storage pond influent (separator liquid phase effluent) in Table 4-10. As shown, there are substantial differences in the concentrations of all of the parameters listed between storage pond influent and the pond contents. Because there is no microbial or physical/chemical process that could cause the loss of TP, it is apparent that significant dilution is occurring in this storage pond. To adjust for the effect of dilution, each storage pond influent concentration was multiplied by the ratio of storage pond influent TP concentration to the storage pond TP concentration. Based on these transformations, it appears that only minimal reductions in TS and TVS and no reduction in COD are occurring. Nitrogen loss also appears to be minimal and translates into a loss of about 5.5 lbs per cow-year.

Patterson Farms, Inc.

<u>Manure Production and Characteristics</u>—As shown in Table 4-11, the volume of manure produced per cow-day at Patterson Farms also is somewhat higher than the standard reference values proposed by the ASAE (2001) and the USDA (1992). However, the Patterson Farms

manure characteristics, on a kg per cow-day basis, also are within the ranges of the ASAE and USDA values with COD again being the one notable exception. The reason or reasons for the substantially higher Patterson Farm value are unclear but again may reflect differences in feeding practices or differences in analytical precision and accuracy for the reasons discussed earlier. The somewhat lower PO_4-P value is noteworthy but does not appear to be significant.

Solids Separation— As noted earlier, Patterson Farms uses a drum-type separator to remove the coarse solids fraction from their manure for use as a bedding material after composting. On a volume basis, about 38 ft^3 of separated solids per 100 cows are generated daily, which reduces manure storage requirements by approximately 16 percent. In Table 4-12, the characteristics of the digester effluent and the separated liquid and solid fractions are compared. As indicated, the separator influent, separated liquid, and separated solid concentrations of TS, TVS, and COD differ significantly ($P<0.01$) from each other, whereas there are no statistically significant differences in, TKN, ON, TP, and PO_4-P concentrations. For SCOD and NH_4-N, separator influent and separated liquid concentrations did not differ significantly, but separated solids concentrations were significantly but not substantially lower.

As shown in Table 4-13, fecal coliform densities in separator influent and separated liquid and solids do not differ significantly ($P<0.01$). However, separation appears to significantly reduce the density of *M. avium paratuberculosis* with mean separated liquid and solids densities approximately one $\log_{10}$ (90 percent) lower than the mean influent density. Given that there was no observed reduction in fecal coliform density, it is not clear what mechanism or mechanisms could be responsible for the reduction in *M. avium paratuberculosis* density. However, it may be some function the higher influent density, 4.00 ± 0.48 $\log_{10}$ CFU per gram, versus 1.94 ± 0.62 CFU $\log_{10}$ per gram in the separator influent at AA Dairy.

As indicated earlier, the solids separated from Patterson Farms manure represent about 16 percent of the volume of manure produced daily. As shown in Table 4-14, the separated solids, on a mass basis, also contain 16 percent of the TS and TVS present before separation with the remaining 84 percent in the liquid fraction. The partitioning of COD is similar to that of TS and TVS. However, the separated solids contain only about six percent of the nitrogen and four percent of the phosphorus present before separation, which is similar to the AA Dairy partitioning values (Table 4-9).

As discussed earlier, the separated solids at Patterson Farms are used after stabilization by composting. The C:N ratio of the separated solids of 32:1 suggests that nitrogen availability should not limit the rate of stabilization and nitrogen loss via NH_3 volatilization should be minimal.

Storage Pond Transformations—The earthen structure used to store the liquid fraction of the separator effluent also was sampled at the end of months four, eight, and twelve of this study. The results of the analyses of these samples also showed significant variation in concentrations of both physical and chemical parameters with depth, and to a lesser degree, with location relative to the point of influent discharge to the storage structure. Using the same approach described above for the AA Dairy storage pond, mean values to characterize the storage pond contents were calculated. The results of these calculations are compared to the characteristics of the storage pond influent (separator liquid phase effluent) in Table 4-15. As shown, there are some differences in the concentrations of all of the parameters listed between storage pond influent and the pond contents. However, the difference between the TP concentrations in the storage pond influent and contents is significantly less than that for the AA Dairy storage pond, indicating much less dilution for reasons that are not clear. However, the storage pond influent concentrations also were adjusted using the previously described approach to provide for direct comparisons.

Based on these transformations, it appears again that only minimal reductions in TS and TVS and no reduction in COD are occurring. However, nitrogen loss is greater than that from the AA Dairy storage pond and translates into a loss of about 29.5 lbs per cow-year but is only approximately six percent of the nitrogen excreted. It should be noted that the densities of fecal coliforms and *M. avium paratuberculosis* in the storage pond influent adjusted for dilution and the storage pond contents are essentially the same. This suggests that storage provides no reduction in pathogen densities.

SECTION 5

DISCUSSION

Manure Production and Characteristics

As shown in Table 5-1, there is little difference between AA Dairy and Patterson Farms rates of production of manure and its various constituents. In addition, there is little difference, as previously discussed, between these rates and the standard reference values published by the ASAE (2001) USDA (1992). This suggests that the two farms involved in this study are representative of typical U.S. dairy operations with respect to rates of production of manure and its various constituents. In addition, there is little difference between the AA Dairy and Patterson Farms in raw manure concentrations of solids, COD, nitrogen, and phosphorus (Table 5-2).

AA Dairy Anaerobic Digester Performance and Biogas Utilization

Waste Stabilization—As indicted earlier, the AA Dairy plug-flow anaerobic digester was designed to operate at a HRT of 24 days but operated at a HRT of 34 days during this study because the anticipated herd expansion from 550 to 1,054 cows has not yet occurred. At this HRT, TVS and COD reductions averaged 29.7 and 41.9 percent, respectively (Table 4-2). The 29.7 percent reduction in TVS observed in this study is significantly lower than the reduction reported by Morris (1976) of 37.6 percent at a HRT of 30 days in a bench-scale anaerobic digester. However, the 41.9 percent reduction in COD is essentially the same as the 40.6 percent reduction reported by Morris. The 29.7 percent reduction in TVS observed in this study also is significantly lower than the reduction reported by Jewell *et al.* (1991) for a 65-cow plug-flow digester of 40.6 percent at a HRT of 30 days. However, Jewell *et al.* also reported a TVS reduction of 31.7 percent in a 65-cow completely mixed digester operated at the same HRT. A possible explanation for this difference between the plug-flow and the completely mixed digester in TVS reduction is that the plug-flow digester was not operating in an ideal plug-flow mode and accumulation of settleable solids in the digester was occurring. The approximately 10 percent higher rates of biogas and methane production per unit of TVS destroyed in the completely mixed digester provide some support for the validity of this hypothesis. Thus, the 29.7 percent reduction of TVS observed in this study does seems reasonable and may simply reflect differences in dairy cattle feeding programs. The lack of statistically significant differences in influent and effluent concentrations of FS and TP (Table 4-2) suggests that such accumulation was not occurring in the AA Dairy digester during this study.

The results of the batch biodegradability study indicate that 30 percent of AA Dairy manure TVS are readily biodegradable with the remaining 70 percent being refractory. Thus, it appears that essentially all (99.0 percent) of the biodegradable volatile solids (BVS) in AA Dairy manure are being degraded at the digester HRT of 34 days. The linear regression relationship developed from the batch biodegradability data (Equation 1) also suggests that reducing digester HRT to the design value of 24 days would reduce TVS reduction from 29.7 to 26.0 percent and BVS reduction to 86.7 percent. Therefore, increasing herd size to the design value of 1,054 cows would only marginally reduce the degree of waste stabilization.

$$TVS_t/TVS_0 = 0.12\ (1/TVS_0{}^{*}\ t) + 0.70 \qquad (1)$$

where: TVS_t = total volatile solids concentration at time t,
TVS_0 = total volatile solids concentration at time 0,
t = time (SRT).

Pathogen Reduction—Given that paratuberculosis is a major problem in the dairy industry with transmission by fecal-oral contact and the possibility that *M. avium paratuberculosis* is the pathogen responsible for the development of Crohn's disease in humans, the 99 percent reduction in the density of this pathogen during anaerobic digestion is highly significant. In addition, the 99.9 percent reduction in the density of fecal coliforms suggests that significant reductions in other pathogens also are possible. The impact of a reduction in digester HRT from 34 to 18 days on fecal coliforms and *M. avium paratuberculosis* reductions is less clear. However, it is probable that some decrease in the reductions of the densities of these microorganisms could occur.

Biogas Production—As noted earlier, the mean rate of biogas production observed in this study was 78 ft^3 per cow-day, which is 28 percent higher than the design value of 61 ft^3 per cow-day for the anticipated herd size of 1,054 cows and a digester HRT of 24 days. However, the rate of manure production for AA Dairy of 2.10 ft^3 per cow-day determined in this study would result in an HRT of only 18 days if herd expansion to the design value of 1,054 cows occurs in the future. While it is probable that some reduction in TVS and COD reduction and biogas production per cow-day would occur, the work of Morris (1976) and Jewell *et al.* (1991) suggests that any reductions should be minimal. Morris reported a slight decrease in TVS reduction from 37.6 to 35.1 percent when HRT was reduced from 30 to 20 days. He also reported that COD reduction increased, which probably was an anomaly, from 40.6 to 42.9 percent. If these TVS and COD reductions at 20 and 30 day HRTs could be compared statistically, it is probable that there would be no significant differences. In addition, Jewell *et al.* reported only nominal decreases in TVS reductions in both a plug-flow and completely mixed digester as HRTs were reduced from 30 to 15 days. The reductions for the plug-flow and completely mixed digester were respectively from 40.6 to 34.1 percent and from 31.7 to 27.8 percent.

Based on the linear regression relationship derived from the batch biodegradability study (Equation 1), a reduction in the HRT of the AA Dairy plug-flow digester from 34 to 18 days would reduce TVS reduction from 29.7 to 24.0 percent. This translates into a reduction in biogas production from 78 ft^3 to approximately 63 ft^3 per cow-day, which is close to the original design value of 61 ft^3 per cow-day noted above. However, it also would result in an increase in the daily rate of biogas production from 42,868 ft^3 per day for 550 cows to 63,840 ft^3 per day for the design herd size of 1,054 cows.

Biogas Utilization—As previously discussed, less than 50 percent of the AA Dairy engine-generator set capacity for the conversion of biogas energy to electrical energy currently is being utilized. Thus, the efficiency of conversion of biogas energy to electrical energy is only about 20 percent as opposed to a potential conversion efficiency approaching 30 percent if the 130 kW engine-generator set was being operated at or near full load. An increase in conversion efficiency from 20 to 30 percent would increase the kWh of electricity generated per 1,000 ft^3 of biogas from 33.29 to 49.94 kWh. Therefore, the anaerobic digestion-biogas utilization infrastructure currently in place at AA Dairy has the capacity with the design herd size of 1,054 cow of generating 3,315 kWh of electricity per day. This estimate is conditioned on the validity of the previously stated assumption that biogas production per cow-day only would decrease from 78 to 63 ft^3 per cow-day with a reduction of digester HRT from 34 to 18 days.

Methane Emissions—At the observed rate of methane production by the AA Dairy digester of 25,335 ft^3 per day, 9,247,275 ft^3 of methane per year is being captured and utilized to generate electricity. Because methane has 21 times the heat trapping capacity of carbon dioxide (U.S. Environmental Protection Agency, 2002), the reduction in methane emission being realized is equal to a reduction in the emission of an equivalent of 4,120 tons of carbon dioxide per year or 7.49 tons per cow-year. Although carbon dioxide emissions do occur with methane combustion, this only decreases the impact of the reduction in methane emissions by roughly five percent or 206 tons per year. Therefore, the net reduction in methane emission on a carbon dioxide equivalent basis is 3,924 tons per year or 7.13 tons per cow-year. At the design herd size of 1,054 cows, the net reduction in methane emission on a carbon dioxide equivalent basis would be 6,076 tons per year.

However, the reduction in greenhouse gas emissions due to biogas production and utilization at AA Dairy is not limited to the reduction in methane emissions. The use of the biogas produced and captured to generate electricity reduces the demand for electricity generated using fossil fuels. Thus, carbon dioxide emissions resulting from the use of fossil fuels to generate electricity also are reduced. Assuming 2,249 lbs of carbon dioxide are emitted per megawatt-hour (MWh) of electricity generated from coal (Spath *et al.*, 1999), the estimated 501,510 kWh of electricity generated annually by AA Dairy using biogas potentially reduces fossil fuel derived carbon dioxide emissions by an additional 564 tons per year or 1.03 tons per cow-year. At the design herd size of 1,054 cows, the reduction in fossil fuel derived carbon dioxide emissions would be an additional 1,361 tons per year or 1.29 tons per cow-year.

Therefore, the current total reduction in greenhouse gas emissions, on a carbon dioxide equivalent basis, is 4,488 tons per year or 8.16 tons per cow-year. The potential reduction at the design herd size of 1,054 cows would be 7,437 tons per year or 7.06 tons per cow-year. In this analysis, the emission during combustion of the carbon dioxide component of biogas is not considered since it is not a carbon dioxide emission derived from a sequestered carbon source. Rather, it is an emission that is part of the natural short-term carbon cycle where carbon dioxide is fixed by photosynthesis and then is regenerated as the plant matter produced is degraded microbially and by higher animals.

Nitrous Oxide Emissions—The results of analyses of samples of the stored liquid phase of dairy cattle manure after separation at both AA Dairy and Patterson Farms showed that no oxidized forms of nitrogen (nitrite or nitrate nitrogen) were present. This finding was not surprising given the absence of residual dissolved oxygen concentrations required for nitrification and the high unionized ammonia (NH_3.)concentrations, which inhibits nitrification, in both storage structures. Thus, the expectation of nitrous oxide emissions, as an end product of denitrification, from dairy cattle manure storage structures seemingly has no theoretical basis given the absence of the necessary prerequisite of nitrification. In addition, any nitrite or nitrate nitrogen, which is rarely present in dairy cattle manure when excreted, would be denitrified before storage due the high level of carbonaceous oxygen demand in these wastes.

Separator Performance

As discussed earlier, AA Dairy uses a screw press separator to separate coarse solids from the effluent from the anaerobic digester while Patterson Farms uses a drum-type unit to remove coarse solids from raw manure before storage of the separated liquid fraction. Due to the anaerobic digestion prior to solids separation, the influent to the AA Dairy separator has substantially lower concentrations of solids and COD than the influent to the Patterson Farm's separator. Thus, an expectation that the efficiency of separation would differ would be reasonable. However, the distribution of influent constituents between liquid and solid phases after separation was remarkably similar as shown previously in Tables 9 and 13. In addition, there was little difference between the two farms in the characteristics of the separated solids with the exception of concentrations of nitrogen and phosphorus and densities of fecal coliforms and *M. avium paratuberculosis* (Table 5-3). In contrast, there were significant differences in the characteristics of the separated liquids (Table 5-4). Generally, these differences were reflections of the differences in separator influent characteristics (Tables 7 and 11). The similarities in the characteristics of the AA Dairy and Patterson Farms separated solids (Table 5-3) as well the distributions of the influent constituents between liquid and solid phases (Tables 9 and 13) suggest that anaerobic digestion of dairy manure prior to separation neither enhances nor negatively impacts the efficiency of separation. However, qualification of this conclusion is necessary because it is based on the assumption that the efficiencies of screw press and drum-type separators are equal.

Storage Pond Transformations

Based on comparisons of the physical, chemical, and microbiological characteristics of the influents to and the contents of the AA Dairy and Patterson Farms storage ponds (Tables 10 and 15), there is no evidence of any significant transformations occurring in either structure. With respect to reductions in TS, TVS, and COD, this finding is not entirely surprising given that these structures are designed for solely for storage. If designed as an anaerobic lagoon with the objective of waste stabilization following the USDA (1992) suggested TVS loading rate for central New York State, a structure with approximately six times the volume of the AA dairy storage pond would be required. The Patterson Farms structure would have to be approximately four times larger. Therefore, it seems reasonable to conclude, with the following caveat, that the lack of significant reductions in TS, TVS, and COD are reflections of the absence of conditions suitable for anaerobic waste stabilization processes. The comparisons of characteristics of the influents to and the contents of both storage ponds may have been unintentionally biased, however, by the schedule for storage pond sampling. The first sampling events where in October following reductions in stored manure volume to provide adequate storage capacity through early spring. Therefore, the characteristics of these sets samples did not necessarily reflect transformations that occurred during warm weather when microbial activity would have been highest. In addition, the second set of samples from each storage structure was collected in January and the third set was collected in early April. Thus, the results obtained may have been unintentionally biased by not proportionally reflecting the effect of low temperature on microbial activity.

It was expected that there would be a significant loss of nitrogen as the result of NH_3. volatilization from both storage structures given the influent NH_4-N concentrations (Tables 10 and 15). However, there appear to be at least two factors contributing to the lack of any significant NH_3. volatilization from either storage pond. In the contents of both storage ponds, NH_4-N concentrations increased as TS concentrations increased with depth. This indicates sorption of NH_4-N to particulate matter was significant and thereby limited the potential for nitrogen loss by NH_3. volatilization. In addition, mean pH values for both storage ponds (Tables 10 and 15) were near neutral, which also limited the potential for NH_3. volatilization. The sampling schedule discussed above also may have unintentionally biased the estimations of nitrogen losses because NH_3. volatilization potential also decreases with temperature.

The results from this phase of the study do demonstrate, however, that storage does not provide significant reductions in fecal coliform or *M. avium paratuberculosis* densities. This finding is further evidence of the merit of anaerobic digestion as a component of dairy cattle manure management systems.

Economic Analysis

Introduction—One of the objectives of this study was to quantify the impact of anaerobic digestion with biogas capture and utilization to generate electricity on the cost of dairy cattle manure management. In previous cost analyses of anaerobic digestion with biogas utilization at AA Dairy, the costs associated with liquid solids separation and the revenue generated from the sale of the composted solids have been included (Moser and Mattocks, 2000 and Peranginangin and Scott, 2002). However, the results of this study indicate that anaerobic digestion prior to liquid solids separation neither enhances nor adversely impacts separation of solids. In addition, the volume of the liquid fraction is not reduced by anaerobic digestion prior to separation. Thus, the required storage capacity for the separated liquid fraction and the associated cost is not reduced. This reduces the assessment of the attractiveness of the investment in anaerobic digestion with biogas utilization at AA Dairy simply to a comparison of costs of biogas production and utilization and income derived from biogas utilization.

Capital Cost—Moser and Mattocks (2000) reported the total capital cost of the AA Dairy anaerobic digester, including the engine-generator set and electrical intertie, to be $295,700. As shown in Table 5-5, this sum includes the cost of a lift station pump including electrical work. However, this pump would be required without anaerobic digestion to transfer manure scraped from the free-stall barn alleys to the storage lagoon. It also includes the cost of the facilities required for liquid solids separation, which is not dependent on anaerobic digestion as discussed above. Therefore, the capital cost of anaerobic digestion and biogas utilization actually is $245,200 or $446 per cow as the system currently is being operated. However, the system was designed for 1,054 cows, which reduces the capital cost per cow to $233. This difference becomes highly significant because revenue from the generation of electricity will more than double if herd expansion to 1,054 cows occurs. It should be noted, however, that the engine-generator set used at AA Dairy is a used, reconditioned unit. The cost of a new unit is approximately $120,000. With a new engine-generator set the cost of the AA Dairy system would have been $300,000 or $285 per cow based on the design herd size of 1,054 cows.

Value of Electricity Generated—As previously discussed, AA Dairy currently generates an average of 1,429 kWh of electricity per day at the conversion efficiency of biogas energy to electrical energy of about 20 percent and an on-line efficiency of 98.8 percent. However, the conversion efficiency of 20 percent is a reflection of the less than maximum utilization of the engine-generator set capacity, which would approach 30 percent if fully utilized. Thus, AA Dairy would be able to generate one-third more electricity (2,144 kWh per day) with an engine-generator set sized for the current rate of biogas production of 42,868 ft^3 per day and 4,211 kWh per day with the engine-generator set currently in use at the system design herd size of 1,054 cows.

AA Dairy purchases electricity from the NYSEG Corporation under Service Classification No. 7 at a on-peak rate (7:00 AM to 11:30 PM) of $0.06868 per kWh and at a off-peak rate (11:30 PM to 7:00 AM) of $0.04060 per kWh with a on-peak demand charge of $11.68 per kW and a reactive charge of $0.00095 per billing reactive kilovolt-ampere hour. Based on pre-digester electricity use (i.e., prior to mid-1998) and current rates, the cost per kWh of electricity without on-site generation would range between $0.09 and $0.12 due to variation in time of use and demand charges. This range of cost per kWh reflects the increased consumption of electricity from May through October for free-stall barn ventilation for cow cooling and from September through May for increased free-stall barn lighting (Minott and Scott, 2001). For this analysis, it seems reasonable to consider $0.105 per kWh to be the fair value of the biogas-derived electricity used on site at AA Dairy.

Prior to mid-2001, AA Dairy received an average $0.025 per kWh for the electricity sold to the NYSEG Corporation. As of mid-2001, this rate was increased to $0.0525 per kWh, which is the value that will be assumed in this analysis. Because of the previously discussed problem with the engine-generator set during from January through March 2002, a continuous record of typical monthly sales of electricity to the NYSEG Corporation reflecting seasonal variation in total on-farm electricity use was not available. However, such records for 2000 and 2001 were available. During 2000 and 2001, AA Dairy respectively sold 178,970 and 191,380 kWh of electricity to the NYSEG Corporation or an average of 185,175 kWh per year. Thus, the average revenue being generated by sale of electricity at $0.0525 per kWh is estimated to be $9,722 per year.

Although electricity purchases from and sales to the NYSEG Corporation are metered, there is no metering to determine the amount of biogas-generated electricity consumed by AA Dairy. However, this value is simply the difference between the estimate biogas derived electricity generated, 521,585 kWh, and sold, 185,175 kWh, annually, which is 336,410 kWh per year. At the assumed price of $0.105 per kWh, the additional revenue generated from on-site biogas generated electricity use is estimated to be $35,323 per year. Thus, the total income produced by the AA Dairy anaerobic digester-biogas utilization system is $45,045 per year.

The current capacity for generating electricity at AA Dairy, 521,585 kWh per year, substantially exceeds the farm's estimated annual demand of 413,869 kWh per year (Minott and Scott, 2001). However, only about 64 percent of the electricity generated is consumed on site due to the inability to always satisfy demand. Yet periods when generation capacity exceeds demand also occur. Thus, an opportunity to increase revenue through load management appears to exist.

As noted earlier, AA Dairy has the potential to generate 3,315 kWh of biogas-derived electricity per day or 1,209,975 kWh per year if herd expansion to 1,054 cows occurs. Assuming on-site electrical use would double, the value of biogas-derived electricity used on site would double, increasing to $70,646 per year. The revenue generated by sale of excess electricity, 537,155 kWh per year, to the NYSEG Corporation also would increase to $28,201 per year. Thus, total income produced by the AA Dairy anaerobic digester-biogas utilization system would be $98,847 per year.

Annual Operation and Maintenance Costs—Because the AA Dairy anaerobic digester and engine-generator set have only been in operation since mid-1998, there is no long-term record on which to base an estimate of annual operating and maintenance costs. Previously, Wright and Perschke (1998) and Nelson and Lamb (2002) have estimated operation and maintenance costs for the anaerobic digestion of dairy cattle manure with biogas utilization to generate electricity to be $0.015 per kWh of electricity generated. With this approach, the operating and maintenance cost for the AA Dairy system under current operating conditions would be $7,824 per year, which is approximately three percent of the capital cost of the system. However, the operating and maintenance cost would increase to $23,055 per year or 9.4 percent of the capital cost of the system with a herd expansion to 1,054 cows. The magnitude of this increase seems unreasonable since the only significant change in operation would be an increase in the volume of manure pumped. The hours of engine-generator set operation would not change since this unit currently is being operated 24 hours per day at a partial load.

Based on the work of Moser and Langerwerf (2000), estimating annual operating and maintenance cost at five percent of the system capital cost seems like a more accurate approach. The value of five percent reported by Moser and Langerwerf was based on 16 years of operation of an anaerobic digester and engine-generator set for a herd of 400 dairy cattle and includes periodic rebuilding of the engine-generator set and renovation of the digester after 16 years of operation. For the AA Dairy system, an operating and maintenance cost rate of five percent of the system capital cost per year translates into a cost of $12,260 per year.

Economic Viability—The attractiveness of any investment generally depends on the ability of the capital investment required to generate income adequate to recover the capital invested with a rate of return on the capital invested and for management and labor that is competitive with other investment opportunities. If there is no other reason for considering anaerobic digestion, such as the need for odor control, this should be the basis for evaluating the option of adding anaerobic digestion with biogas utilization to any animal waste management system. If, however, odor control or some other benefit provided by anaerobic digestion is a necessity to continue the general farm operation, acceptance of a rate of return that is somewhat less than competitive than other investment alternatives may be acceptable if the general farm operation remains profitable.

As currently operated, the gross revenue produced by the AA Dairy anaerobic digestion-biogas utilization system from on-site use and sale of the electricity generated, as discussed above, is estimated to be $45,045 at a cost for operation and maintenance of $12,260 per year. Thus, net revenue generated is $32,785 per year. However, the AA Dairy system has the potential of producing gross revenue of $98,847 and net revenue of $86,587 per year if expansion of herd size of 1,054 cows occurs. Thus, current net revenue is adequate to recover the capital invested,

$245,200, in approximately 7.5 years if the time value of money is not considered. If the system were being operated at design capacity, the payback period would be reduced to approximately 2.8 years. At an interest rate of seven percent, these payback periods increase to approximately 11 and 4 years, respectively. Beyond these payback periods, all net revenue from biogas utilization represents net income. Assuming a system life of 20 years, the income generated by the AA Dairy system as currently operated would be approximately $295,000 or an average of $14,750 per year. With herd expansion, income would increase to approximately $1,385,250 or $69,260 per year.

If the AA Dairy system was financed over a 20-year period at the same interest rate of seven percent, the net income generated would be somewhat less, but there would be a steady stream of net income over the life of the system. Under current operating conditions, the net income would be $9,641 per year or a total of $192,820 over the life of the system. With herd expansion to the design value of 1,054 cows income would increase to $63,443 per year or a total of $1,268,860 over the life of the system.

The results of these cost analyses clearly demonstrate that anaerobic digestion of dairy cattle manure with biogas collection and utilization can provide significant environmental quality benefits as previously described while concurrently producing a significant source of income. Although the alternative of aerobic digestion can provide some of the same environmental quality benefits, no income is produced to offset capital and operating costs. Thus, total farm income is decreased rather than enhanced, as is the case with anaerobic digestion.

Under both the short-term and long-term financing scenarios described above, it appears that there would be considerable merit in replacing the current engine-generator set with unit sized for the current rate of biogas production if the plan for herd expansion is being abandoned. This system modification would increase electricity generated by 33 percent with a somewhat lower but still significant increase in net income. It probably would be most logical to make this change when the current engine-generator set requires rebuilding.

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Table 4-1. Comparison of AA Dairy manure production and characteristics with standard reference values assuming a live-weight of 1,400 lb per cow.

Parameter	**AA Dairy**	**ASAE (2001)**	**USDA (1992)**
Volume, ft^3/cow-day	2.10	1.94	1.82
Total solids, kg/cow-day	6.7	7.6	6.4
Total volatile solids, kg/cow-day	5.7	6.4	5.4
Fixed solids, kg/cow-day	1.0	1.2	1.0
Chemical oxygen demand, kg/cow-day	9.1	7.0	5.7
Total Kjeldahl nitrogen, kg/cow-day	0.28	0.29	0.29
Total phosphorus, kg/cow-day	0.048	0.060	0.044
Orthophosphate phosphorus, kg/cow-day	0.027	0.039	—
pH	7.4	7.0	—

Table 4-2. AA Dairy anaerobic digester performance summary, mg/L[*].

Parameter	Influent	Effluent	Reduction, %
Total solids	113,186^{a}±10,097	84,739^{b}±5,993	25.1
Total volatile solids	96,080^{a}±9,477	67,518^{b}±4,446	29.7
Fixed solids	17,106^{a}±1,495	17,221^{a}±2,461	—
Chemical oxygen demand	153,496^{a}±77,178	89,144^{b}±23,185	41.9
Soluble chemical oxygen demand	24,239^{a}±6,568	16,961^{b}±7,073	30.0
Total volatile acids	3,687^{a} ±806	513^{b}±227	86.1
Total Kjeldahl nitrogen	4,631^{a}±513	5,111^{a}±894	—
Organic nitrogen	2,500^{a}±491	2,268^{a}±891	—
Ammonia nitrogen	2,159^{a}±387	2,881^{b}±322	+33.4[†]
Total phosphorus	813^{a}±124	838^{a}±124	—
Orthophosphate phosphorus	457^{a}±104	562^{b}±90	+23.0[†]
pH	7.4^{a}±0.3	7.9^{b}±0.1	—

[*] Means in a row with a common superscript are not significantly different ($P<0.01$).

[†] Increase in concentration.

Table 4-3. AA Dairy anaerobic digester reductions of total solids, total volatile solids, chemical oxygen demand, and soluble chemical oxygen demand.

Parameter	Reduction, lb/day
Total solids	2,052
Total volatile solids	2,060
Chemical oxygen demand	4,641
Soluble chemical oxygen demand	525

Table 4-4. Comparison of AA Dairy anaerobic digester $\log_{10}$ influent and effluent densities of fecal coliform bacteria and *M. avium paratuberculosis*.

	Influent	Effluent	Reduction
Fecal coliforms			
CFU/g[*]	6.08±0.59	3.30±0.73	2.78
M. avium paratuberculosis			
CFU/g	3.94±0.72	1.86±0.72	2.08

[*] Log_{10} colony-forming units per g of manure

Table 4-5. AA Dairy Biogas Composition.

Parameter	% by volume
Methane	59.1
Carbon dioxide	39.2
Hydrogen sulfide	0.193
Ammonia	0.0015
Other gases	1.5055

Table 4-6. Methane and total biogas production as functions of chemical oxygen demand and total volatile solids destruction.

Parameter	Biogas	Methane
$ft^3/lb\ COD_D$	9.24	5.46
$ft^3/lb\ TVS_D$	20.81	12.30

Table 4-7. Comparison of the characteristics of the AA Dairy anaerobic digester effluent (separator influent) with the separated liquid and solid fractions, mg/L[*].

Parameter	Digester effluent	Separated liquid	Separated solids
Total solids	84,739^{a}±5,993	51,088^{b}±1,357	247,444^{c}±18,153
Total volatile solids	67,518^{a}±4,446	35,763^{b}±1,280	220,982^{c}±18,235
Fixed solids	17,221^{a}±2,461	15,325^{b}±988	26,463^{c}±2,906
Chemical oxygen demand	89,144^{a}±23,185	54,744^{b}±6,068	224,040^{c}±78,277
Soluble chemical oxygen demand	16,961^{a}±7,073	15,185^{a}±4,474	16,350^{a}±5,160
Total Kjeldahl nitrogen	5,111^{a}±894	4,723^{a}±601	5,374^{a}±1,076
Ammonia nitrogen	2,881^{a}±322	2,964^{a}±305	2,656^{a}±502
Organic nitrogen	2,268^{a}±891	1,837^{ab}±570	2,625^{ac}±755
Total phosphorus	838^{a}±124	802^{a}±90	1,106^{b}±308
Orthophosphate phosphorus	526^{a}±90	538^{a}±96	620^{a}±156
pH	7.9^{a}±0.1	7.9^{a}±0.2	8.5^{b}±0.2

[*] Means in a row with a common superscript are not significantly different (P<0.01).

Table 4-8. Comparison of AA Dairy $\log_{10}$ densities of fecal coliform bacteria and *M. avium paratuberculosis* in the anaerobic digester effluent with separated liquid and solid fraction densities[*].

	Digester effluent	Separated liquid	Separated solids
Fecal coliforms			
CFU/g[†]	$3.30^{a} \pm 0.73$	$2.66^{ab} \pm 0.88$	$2.55^{b} \pm 0.88$
M. avium paratuberculosis			
CFU/g	$1.94^{a} \pm 0.62$	$1.26^{ab} \pm 0.95$	$0.56^{b} \pm 0.88$

[*] Means in a row with a common superscript are not significantly different (P<0.01).

[†] Log_{10} colony-forming units per g of manure.

Table 4-9. Distributions of constituents of AA Dairy anaerobic digester effluent following separation.

Parameter	Liquid fraction, %	Solid fraction, %
Total solids	83	17
Total volatile solids	83	17
Fixed solids	93	7
Chemical oxygen demand	85	15
Total Kjeldahl nitrogen	95	5
Ammonia nitrogen	96	4
Organic nitrogen	94	6
Total phosphorus	95	5
Orthophosphate phosphorus	96	4

Table 4-10. Comparison of the characteristics of the AA Dairy storage pond influent with the pond contents.

Parameter	Storage pond influent	Storage pond influent (adjusted for dilution)	Storage pond
Total solids, mg/L	51,088±1,357	29,239	28,407±2,892
Total volatile solids, mg/L	35,763±1,280	20,468	18,634±2,268
Fixed solids, mg/L	17,221±2,461	9,856	9,774±794
Chemical oxygen demand, mg/L	54,744±6,068	31,331	31,399±1,396
Soluble chemical oxygen demand, mg/L	15,185±4,474	8,691	12,233±2,837
Total Kjeldahl nitrogen, mg/L	4,723±601	2,702	2,564±126
Ammonia nitrogen, mg/L	2,964±305	1,696	1,553±690
Organic nitrogen, mg/L	1,837±570	1,051	1,012±566
Total phosphorus, mg/L	802±90	459	459±42
Orthophosphate phosphorus, mg/L	538±96	308	356±47

Table 4-10. Continued.

pH	7.9±0.2	—	7.6±01
Fecal coliforms, CFU/g*	2.66±0.88	1.52	2.75±0.36
M. avium paratuberculosis, CFU/g	1.26±0.95	—	No data

*Log_{10} colony-forming units per g of manure.

Table 4-11. Comparison of Patterson Farms manure production and characteristics with standard reference values assuming a live-weight of 1,400 lb per cow.

Parameter	Patterson Farms	ASAE (2001)	USDA (1992)
Volume, ft^3/cow-day	2.35	1.94	1.82
Total solids, kg/cow-day	7.1	7.6	6.4
Total volatile solids, kg/cow-day	5.8	6.4	5.4
Fixed solids, kg/cow-day	1.3	1.2	1.0
Chemical oxygen demand, kg/cow-day	9.4	7.0	5.7
Total Kjeldahl nitrogen, kg/cow-day	0.28	0.29	0.29
Total phosphorus, kg/cow-day	0.045	0.060	0.044
Orthophosphate phosphorus, kg/cow-day	0.020	0.039	—
pH	7.4	7.0	—

Table 4-12. Comparison of the characteristics of Patterson Farms separator influent with the separated liquid and solid fractions, mg/L[*].

Parameter	Separator influent	Separated liquid	Separated solids
Total solids	107,063^{a}±5,972	79,463^{b}±8,961	248,600^{c}±11,716
Total volatile solids	87,490^{a}±5,333	61,389^{b}±7,374	227,622^{c}±11,071
Fixed solids	19,572^{ab}±1,564	18,074^{a}±1,697	20,978^{b}±2,401
Chemical oxygen demand	141,871^{a}±21,057	96,513^{b}±24,649	280,842^{c}±65,196
Soluble chemical oxygen demand	22,668^{a}±9,821	22,290^{a}±5,057	18,701^{b}±6,926
Total Kjeldahl nitrogen	4,237^{a}±609	4,015^{a}±522	3,942^{a}±785
Ammonia nitrogen	1,999^{a}±310	1,938^{a}±297	1,496^{b}±301
Organic nitrogen	2,239^{a}±597	2,078^{a}±409	2,444^{a}±594
Total phosphorus	677^{a}±109	608^{a}±96	510^{b}±129
Orthophosphate phosphorus	306^{a}±98	280^{a}±84	214^{a}±107
pH	7.5^{a}±0.2	7.5^{a}±0.2	8.2^{b}±0.2

[*] Means in a row with a common superscript are not significantly different ($P<0.01$).

Table 4-13. Comparison of Patterson Farms $\log_{10}$ densities of fecal coliform bacteria and *M. avium paratuberculosis* in the anaerobic digester effluent with separated liquid and solid fraction densities*.

	Separator influent	Separated liquid	Separated solids
Fecal coliforms			
CFU/g[†]	$5.68^{a} \pm 0.47$	$5.86^{a} \pm 0.53$	$5.28^{a} \pm 0.64$
M. avium paratuberculosis			
CFU/g	$4.00^{a} \pm 0.48$	$3.05^{b} \pm 0.50$	$2.71^{b} \pm 1.13$

[*] Means in a row with a common superscript are not significantly different ($P<0.01$).

[†] Log_{10} colony-forming units per g of manure.

Table 4-14. Distributions of constituents of Patterson Farms separator influent following separation.

Parameter	Liquid fraction, %	Solid fraction, %
Total solids	84	16
Total volatile solids	84	16
Fixed solids	48	52
Chemical oxygen demand	85	15
Total Kjeldahl nitrogen	94	6
Ammonia nitrogen	96	4
Organic nitrogen	93	7
Total phosphorus	96	4
Orthophosphate phosphorus	97	3

Table 4-15. Comparison of the characteristics of the AA Dairy storage pond influent with the pond contents.

Parameter	Storage pond influent	Storage pond influent (adjusted for dilution)	Storage pond
Total solids, mg/L	79,463±8,961	71,752	71,630±7,250
Total volatile solids, mg/L	61,389±7,374	55,432	54,493±4,992
Fixed solids, mg/L	18,074±1,697	16,320	17,134±2,265
Chemical oxygen demand, mg/L	96,513±24,649	87,147	84,819±7,291
Soluble chemical oxygen demand, mg/L	22,290±5,057	20,127	20,032±4,078
Total Kjeldahl nitrogen, mg/L	4,015±522	3,625	3,315±504
Ammonia nitrogen, mg/L	1,938±297	1,750	1,531±798
Organic nitrogen, mg/L	2,078±409	1,875	1,784±301
Total phosphorus, mg/L	608±96	549	549±53
Orthophosphate phosphorus, mg/L	280±84	252	301±51

Table 4-15. Continued.

pH	7.5±0.2	—	7.2±0.2
Fecal coliforms, CFU/g[*]	5.86±0.53	5.29	4.63±0.25
M. avium paratuberculosis, CFU/g	3.05±0.50	2.75	2.85±0.06

[*] Log_{10} colony-forming units per g of manure.

Table 5-1. Comparison of AA Dairy and Patterson Farms rates of production of manure and its various constituents.

	AA Dairy	Patterson Farms
Volume, ft^3/cow-day	2.10	2.35
Total solids, kg/cow-day	6.7	7.1
Total volatile solids, kg/cow-day	5.7	5.8
Fixed solids, kg/cow-day	1.0	1.3
Chemical oxygen demand, kg/cow-day	9.1	9.4
Total Kjeldahl nitrogen, kg/cow-day	0.28	0.28
Total phosphorus, kg/cow-day	0.048	0.045
Orthophosphate phosphorus, kg/cow-day	0.027	0.020
pH	7.4	7.4

Table 5-2. Comparison of AA Dairy anaerobic digester and Patterson Farms separator influent characteristics, mg/L.

Parameter	AA Dairy	Patterson Farms
Total solids	113,186±10,097	107,063±5,972
Total volatile solids	96,080±9,477	87,490±5,333
Fixed solids	17,106±1,495	19,572±1,564
Chemical oxygen demand	153,496±77,178	141,871±21,057
Soluble chemical oxygen demand	24,239±6,568	22,668±9,871
Total Kjeldahl nitrogen	4,631±513	4,237±609
Ammonia nitrogen	2,159±387	1,999±310
Organic nitrogen	2,500±491	2,239±597
Total phosphorus	813±124	677±109
Orthophosphate phosphorus	457±104	306±98
pH	7.4±0.3	7.5±0.2

Table 5-3. Comparison of the characteristics of the AA Dairy and Patterson Farms separated solids, mg/L.

Parameter	AA Dairy	Patterson Farms
Total solids, mg/L	247,444±18,153	248,600±11,716
Total volatile solids, mg/L	220,982±18,235	227,622±11,071
Fixed solids, mg/L	26,463±2,906	20,978±2,401
Chemical oxygen demand, mg/L	224,040±78,277	280,842±65,196
Soluble chemical oxygen demand, mg/L	16,350±5,160	18,701±6,926
Total Kjeldahl nitrogen, mg/L	5,374±1,076	3,942±785
Ammonia nitrogen, mg/L	2,656±502	1,496±301
Organic nitrogen, mg/L	2,625±755	2,444±594
Total phosphorus, mg/L	1,106±308	510±129
Orthophosphate phosphorus, mg/L	620±156	214±107
pH	8.5±0.2	8.2±0.2
Fecal coliforms, CFU/g*	2.55±0.88	5.28±0.64
M. avium paratuberculosis, CFU/g	0.56±0.88	2.71±1.13

*Log_{10} colony-forming units per g of manure.

Table 5-4. Comparison of the characteristics of the AA Dairy and Patterson Farms separated liquid, mg/L.

Parameter	AA Dairy	Patterson Farms
Total solids, mg/L	51,088±1,357	79,463±8,961
Total volatile solids, mg/L	35,763±1,280	61,389±7,374
Fixed solids, mg/L	15,325±988	18,074±1,697
Chemical oxygen demand, mg/L	54,744±6,068	96,513±24,649
Soluble chemical oxygen demand, mg/L	15,185±4,474	22,290±5,057
Total Kjeldahl nitrogen, mg/L	4,723±601	4,015±522
Ammonia nitrogen, mg/L	2,964±305	1,938±297
Organic nitrogen, mg/L	1,837±570	2,078±409
Total phosphorus, mg/L	802±90	608±96
Orthophosphate phosphorus, mg/L	538±96	280±84
pH	7.9±0.2	7.5±0.2
Fecal coliforms, CFU/g*	2.66±0.88	5.86±0.53
M. avium paratuberculosis, CFU/g	1.26±0.95	3.05±0.50

* Log_{10} colony-forming units per g of manure.

Table 5-5. Cost of the AA Dairy anaerobic digestion with biogas utilization and liquid solids separation system (Moser and Mattocks, 2000).

Item	Cost
Lift station/Mix tank[*]	$12,500
Digester	$121,000
Engine-generator set[†]	$32,000
Electrical and intertie	$33,200
Structure for engine-generator set, piping, etc.	30,500
Liquid solids separation	$38,000
Engineering	$24,000
Start-up	$4,500
Total	$295,700

[*] Only pump and electrical work.

[†] Used, reconditioned unit.

Exhibit 2

FINAL

AN EVALUATION OF A MESOPHILIC, MODIFIED PLUG FLOW ANAEROBIC DIGESTER FOR DAIRY CATTLE MANURE

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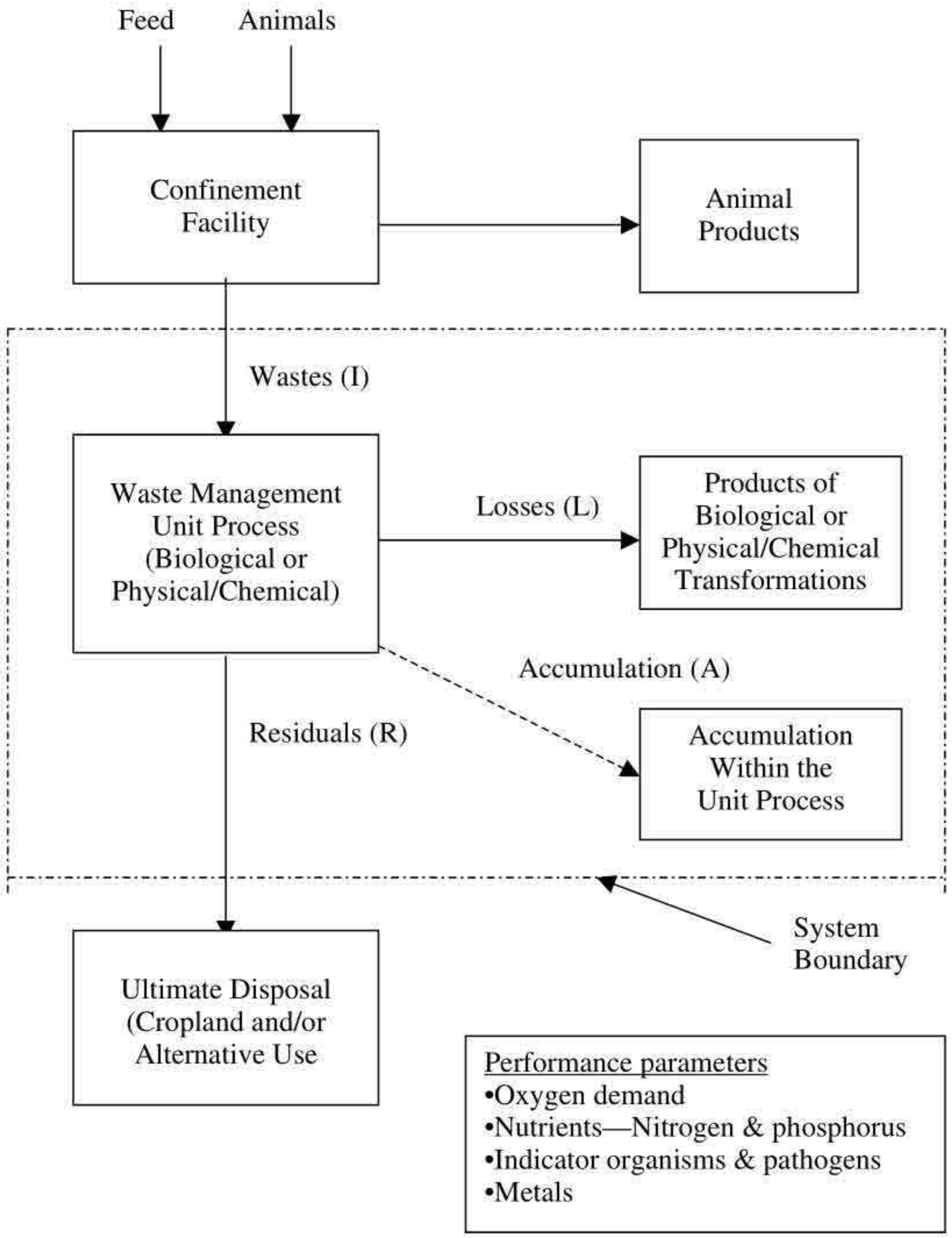
TABLES

PREFACE

This report summarizes the results from one of a series of AgSTAR studies designed to more fully characterize: 1) the air and water quality improvements provided by anaerobic digesters for managing manure and other wastes in the swine and dairy industries, and 2) the associated costs. The objective of this effort is to develop a better understanding of: 1) the potential of individual system components and combinations of these components to ameliorate the impacts of swine and dairy cattle manures on environmental quality, and 2) the relationships between design and operating parameters and the performance of the biological and physical/chemical processes involved. A clear understanding of both is essential for the rational planning and design of these waste management systems. With this information, swine and dairy producers, engineers, and the regulatory community can better identify specific processes that will effectively address air and water quality problems of concern.

The following schematic illustrates the comprehensive mass balance approach that is being used for each unit process in these performance evaluations. When a system is comprised of more than one unit process, the performance of each process is characterized separately. Then the results are aggregated to characterize overall system performance. This is the same approach commonly used to characterize the performance of domestic and industrial wastewater treatment and chemical manufacturing unit processes. Past characterizations of individual process and systems performance frequently have been narrowly focused and have ignored the generation of side streams of residuals of significance and associated cross media environmental quality impacts. A standardized approach for cost analysis using uniform boundary conditions also is a key component of this comparative effort.



Where: $L = I - (R + A)$
(I and R are measured and
L and A are estimated)

Figure 1. Illustration of a standardized mass balance approach to characterize the performance of animal waste management unit processes.

ACKNOWLEDGEMENTS

The cooperation of Gordondale Farms, Nelsonville, Wisconsin, and the assistance of GHD, Inc., Chilton, Wisconsin, are gratefully acknowledged as is the financial support of the Wisconsin Division of Energy through Wisconsin Focus on Energy.

SECTION 1

SUMMARY AND CONCLUSIONS

The objective of this study was to characterize the performance under commercial conditions of: 1) a modified form of a full-scale, plug-flow anaerobic digester for dairy cattle manure in a cold climate, and 2) a screw press type separator for recovery of coarse solids from the digester effluent. The performance of this waste management system was characterized based on the: 1) reductions in potential air and water quality impacts, 2) net energy recovered from the biogas produced, and 3) differential between capital and operating costs and the income realized from the biogas and separated solids produced.

The site of this 12-month study was Gordondale Farms, a 3,200-acre dairy farm located in Nelsonville, Wisconsin. At the beginning of this study in January 2004, the average size of the Gordondale Farms milking herd was 750 Holstein-Friesian cows. On 15 July, the average milking herd size was increased to 860 cows and then remained constant through the end of the study in December 2004. The milking herd is housed in a naturally ventilated free-stall barn, which is connected to a milking center.

Gordondale Farms uses a modified form of a plug-flow anaerobic digester with vertical gas mixing. The biogas produced is delivered to an on-site engine-generator set owned and operated by Alliant Energy, the local electric utility. Gordondale Farms is paid for the biogas delivered at the rate of $0.015 per kilowatt-hour generated and delivered to Alliant's transmission system. The anaerobic digester, which has been in operation since March 2002, was designed and constructed by GHD, Inc. of Chilton, Wisconsin.

After digestion, the coarse solids in the digester effluent are removed mechanically using a FAN screw press separator. The remaining liquid is discharged to a holding tank for short-term storage before land application to cropland. The separated solids are stacked for partial drying and then are either used on-site or sold as bedding.

The results of this study confirm-the environmental quality benefits realized by the anaerobic digestion of dairy cattle manure with biogas collection for the generation of electricity. These results also confirm that the economic value of the electricity generated and the stabilized solids recovered can be adequate to recover the capital investment in a reasonable period and then generate a long-term income stream. The findings of the study are summarized in Table 1-1 and discussed below.

Table 1-1. Summary of observed impacts of anaerobic digestion on semisolid dairy cattle manure management at Gordondale Farms.

Parameter	**Impact**
Odor	Substantial reduction
Greenhouse gas emissions	Methane—substantial reduction (2.32 tons per cow-yr on a carbon dioxide equivalent basis) Carbon dioxide—1.33 tons per cow-yr associated with the reduction in fossil fuel use to generate electricity
Ammonia emissions	No significant reduction
Potential water quality impacts	Oxygen demand—substantial reduction (5.1 lb per cow-day) Indicator organisms and potentially pathogens—significant reduction (Fecal coliforms: >99%) (Fecal streptococcus: >90%) Nutrient enrichment—no reduction
Economic impact	Significant increase in net farm income ($101 per cow-year after recovery of capital invested in 6.3 years)

Odors

The most readily apparent benefit of the use of anaerobic digestion at Gordondale Farms is the low level of the noxious odors commonly associated with dairy cattle manure management systems. This is the direct result of the degree of waste stabilization provided by anaerobic digestion under controlled conditions. As shown in Table 4-2, average reductions in total volatile solids, chemical oxygen demand, and volatile acids during anaerobic digestion were 39.6, 38.5, and 87.8 percent, respectively. With these reductions, additional degradation during storage under uncontrolled anaerobic conditions and the associated odors are minimized.

Greenhouse Gas Emissions

Perhaps the most significant air quality impact is the reduction of methane emissions. Methane-is a greenhouse gas with 21 times the heat-trapping capacity of carbon dioxide. The reduction in methane emissions, on a carbon dioxide equivalent basis, was determined to be 3.03 tons per cow-year (2,610 tons per year for the current 860-cow Gordondale farms milking herd). In addition, the electricity generated using biogas has the potential of reducing carbon dioxide emissions by displacing fossil fuel combustion that otherwise would have been used to generate the electricity. Under current operating conditions, this emission reduction is estimated to be 1,077 tons per year, which translates into 1.33 tons per cow-year. Given the absence of oxidized forms of nitrogen in dairy cattle manure and the requirement of anaerobic conditions for methane production, the potential for nitrous oxide emissions is nil.

Other Gaseous Emissions

Analysis of the biogas produced at Gordondale Farms indicated the presence of only a nominal concentration, 0.000347 percent by volume, of ammonia (Table 4-5). The results of this analysis in combination with the total Kjeldahl nitrogen balance results (Table 4-2) indicate that the loss of nitrogen via ammonia volatilization during anaerobic digestion of dairy cattle manure is negligible. Thus, it appears reasonable to conclude that ammonia is insignificant as a source of emissions of oxides of nitrogen during biogas combustion. However, the concentration of hydrogen sulfide found in the Gordondale Farms biogas, 0.310 percent by volume, indicates that emissions of oxides of sulfur during biogas combustion potentially could be significant. However, the increase in pH occurring digestion (Table 4-2) should reduce the potential for emissions of hydrogen sulfide and the associated noxious odor from the digester effluent during storage and land application.

Water Quality Impacts

Oxygen Demand—The study results show (Table 4-2) that anaerobic digestion can substantially reduce dairy cattle manure total volatile solids (39.5 percent) and chemical oxygen demand (38.5 percent). These reductions translate directly into a lower potential for depletion of dissolved oxygen in natural waters. Although anaerobically digested dairy cattle manure clearly is not suitable for direct discharge to surface or ground waters, these reductions still are significant due to the potential for these wastes to enter surface waters by nonpoint source transport mechanisms.

Pathogens—As shown in Table 4-4, mesophilic anaerobic digestion at an average hydraulic retention time of 29 days reduced the mean densities of the fecal coliform group of enteric bacteria by 99 percent and fecal streptococcus group by 90 percent. These groups of bacteria serve as indicators of pathogen destruction potential and suggest that anaerobic digestion also can achieve significant reductions in the densities of any pathogens present, such as *Mycobacterium avium paratuberculosis. M. avium paratuberculosis* is responsible for chronic enteritis (paratuberculosis or Johne's disease) in cattle and other ruminants and is suspected to be the causative agent in Crohn's disease in humans. Thus, it appears that anaerobic digestion of dairy cattle manure also can reduce the potential for the contamination of natural waters by both non-pathogenic and pathogenic microorganisms.

Nutrient Enrichment—Both nitrogen and phosphorus mass balance results (Table 4-2) demonstrate that anaerobic digestion in a plug flow reactor without the accumulation of settleable solids provides no reduction of the potential impact of these nutrients on water quality. However, results of this study indicate that separation of coarse solids after anaerobic digestion-reduces the mass of nitrogen and phosphorus in the remaining liquid fraction by about 18 and 38 percent, respectively (Table 4-8).

Economic Impact

The results of this study also confirm that the modified plug flow anaerobic digester with biogas utilization is an economically attractive approach. The system can produce revenue adequate to recover the capital investment and increase farm net income through the revenue derived from electricity generated and the coarse solids recovered from the digester effluent. Under the current contractual agreement with Alliant Energy, it is estimated that Gordondale Farms will recover their capital investment without interest in 6.3 years and then have an increase annual net farm income of $101 per cow. If Gordondale Farms had purchased the engine-generator set (Alliant Energy currently owns and operates the engine-generator set), their capital investment would have increased from $550,000 to $748,000, but only six years would have been required to recover their capital investment due to the additional revenue from electricity generated. In addition, the annual net farm income after capital recovery would have increased to $144 per cow. Thus, it can be concluded that there is a significant economic incentive to realize the environmental quality benefits that the anaerobic digestion of dairy cattle manure can provide. This study also showed, however, that income from this system could be increased beyond that currently recognized by Gordondale Farms. Improving-the efficiency of the conversion of biogas to electricity would increase electricity generation and the associated income. It should be noted, however, that the economic attractiveness of anaerobic digestion with biogas utilization at Gordondale Farms is due, at least partially, to the relatively high fraction of total volatile solids (47 percent) that are readily biodegradable.

SECTION 2

INTRODUCTION

Anaerobic digestion is a controlled biological process that can substantially reduce the air and water quality impacts of livestock and poultry manures that are managed as a liquid or slurry. Unlike comparable aerobic waste stabilization processes, energy requirements are minimal. A relatively small fraction of the biogas energy produced is required to operate an anaerobic digestion system. The remaining biogas energy is available for use as a boiler fuel or to generate electricity. Thus, anaerobic digestion with biogas utilization produces a source of revenue to offset some or all process costs and possibly increase farm net income.

Past interest in anaerobic digestion of livestock and poultry manures was driven primarily by the need for conventional fuel substitutes. For example, interest intensified in France and Germany during and immediately after World War II in response to disruptions in conventional fuel supplies (Tietjen, 1975). This was followed by a renewal of interest in anaerobic digestion of livestock and poultry manures in the mid-1970s, stimulated primarily by the OPEC oil embargo of 1973 and the subsequent price increases for crude oil and other fuels. In both instances, this interest dissipated rapidly, however, due to technical problems and as supplies of conventional fuels increased and prices declined. A substantial majority of the anaerobic digesters constructed at livestock and poultry operations in the 1970s failed for a variety of reasons. However, the experience gained during this period led to refined system design and operating parameters and the demonstration of technical viability.

In the early to mid-1990s, a renewal of interest in anaerobic digestion by livestock and poultry producers occurred. Four primary factors contributed to this renewal of interest. One was the need for a cost-effective strategy for reducing manure-related odors from storage facilities, including anaerobic lagoons and land application sites. Another was the re-emerging concern about the impacts of livestock and poultry manures on water quality. The third was recognition that many of the technical problems encountered in the 1970s had been resolved. Finally, the level of concern about global climate change was intensifying and the significance of methane emissions to the atmosphere was receiving increased attention. Recognition of the magnitude of methane emissions resulting from the uncontrolled anaerobic decomposition of livestock and poultry manures led to the creation of the U.S. Environmental Protection Agency's AgSTAR Program. The primary mission of this program is to encourage the use of anaerobic digestion with biogas collection and utilization in the management of livestock and poultry manures.

Although aerobic digestion also was demonstrated in the 1960s and 1970s to be an effective strategy for controlling odors and water quality impacts of livestock and poultry manures (Martin and Loehr, 1976 and Martin *et al*., 1981), the cost was prohibitively high due primarily to the electrical energy required for aeration and mixing. In addition, the reduction in methane emissions is at least partially negated by the increased greenhouse gas emissions associated with the generation of the electricity required.

Objective

The objective of this study was to characterize the performance under commercial conditions of: 1) a modified form of a full-scale, plug-flow anaerobic digester described below for dairy cattle manure in a cold climate and 2) a screw press type separator for recovery of coarse solids from the digester effluent. Characterization of the performance of this waste management system was based on the: 1) reductions in potential air and water quality impacts, 2) net energy recovered from the biogas produced, and 3) differential between capital and operating costs and income realized from the biogas and separated solids produced.

SECTION 3

METHODS AND MATERIALS

Study Site

The site of this study was Gordondale Farms, a 3,200-acre dairy farm located in Nelsonville, Wisconsin. Nelsonville is in Portage County near Stevens Point in central Wisconsin. At the beginning of this 12-month study in January 2004, the average size of the Gordondale Farms' milking herd was 750 Holstein-Friesian cows. On 15 July, the average milking herd size was increased to 860 cows and then remained constant through the end of the study. Milk production is estimated to average 21,000 lb per cow-yr. The milking herd is housed in a naturally ventilated free-stall barn, which is connected to a milking center.

Manure is removed from the free-stall barn alleys daily by scraping with a skid-steer loader to a sump. From this sump, the accumulated manure flows by a combination of gravity and fluming with milking center wastewater to an influent holding tank containing a chopper type pump. The chopper-pump mixes the influent in the holding tank and transfers the manure into the anaerobic digester. After digestion, the coarse solids in the digester effluent are removed mechanically using a FAN screw press separator. The remaining liquid is discharged to a holding tank for short-term storage before land application to cropland.

The separated solids are stacked for partial drying before use as bedding. An estimated 55 tons of separated solids are used for bedding each week. The excess solids, approximately 22 tons per week, are sold to another dairy farm at $15 per ton for use as bedding. Gordondale Farms estimates that the on-site use of separated solids for bedding results in a $60,000 per year increase in gross farm income due to the avoided cost for bedding, and the sale of excess separated solids adds an additional $8,580 per year.

The anaerobic digester, which has been in operation since March 2002, was designed and constructed by GHD, Inc. of Chilton, Wisconsin for a milking herd of 750 cows. The digester dimensions are 91 ft long by 62.3 ft wide with an operating depth of 12.5 ft. The estimated operating volume is 70,866 ft^3. The design hydraulic retention time (HRT) for the digester based on the assumption of a 750 cow milking herd was 22 days with a predicted electricity generation potential of 3.7 kW per cow-day or 2,775 kWh per day.

The digester is described by the designer, GHD, Inc., as a two-stage modified plug-flow mesophilic digester with vertical gas mixing. Unlike a conventional plug-flow digester, the influent channel is separated into two compartments to allow, at least theoretically, acidogenesis to occur separately from methane formation. Hence, the use by the designer of the term two-stage to describe the digester. However, the relatively high density of methanogens in dairy cattle manure makes the separation of acidogenesis and methanogenesis unlikely. In addition, the Gordondale Farms' digester has two parallel channels connected at one end resulting in a U-shaped flow pattern. Thus, influent enters and effluent exits at the same end of the digester at adjacent locations. This configuration is not common but is being used where space or desirability of locating influent and effluent in adjacent locations are more effective for the project.

The Gordondale Farms' anaerobic digester is a poured in-place, reinforced concrete tank covered and sealed with reinforced concrete panels. The digester is partially below grade and is insulated to enable maintenance of mesophilic conditions during cold weather. It has been in continuous operation since March 2002.

Captured biogas is used to fuel a 150 kW engine-generator set. The engine, a Caterpillar 3406 is a diesel engine modified by the addition of spark ignition system to use low pressure/low energy biogas as a fuel. The unit is rated at 140 kW when fueled with biogas. The generator is an induction type unit with the following specifications: three phase, 480 volts, and 312 amps at 1,835 rpm. The engine-generator set is owned and operated by Alliant Energy Corporation, Madison, Wisconsin and all electricity generated is delivered directly to the Alliant transmission system. Alliant energy pays Gordondale Farms at the rate of $0.015 per kWh delivered and all electricity used by Gordondale Farms is purchased from Alliant Energy at retail rates. Waste heat from the engine-generator set cooling and exhaust system is recovered and used at no cost by Gordondale Farms for digester and milking center space and water heating. Biogas produced during periods when the engine-generator set is out of service for maintenance and repairs is flared to prevent an excessive increase in digester biogas pressure.

Data Collection

The performance of the anaerobic digester and liquid-solids separation unit was characterized using materials balances. The material balances were developed based on measured concentrations of selected parameters in the digester influent and effluent and the liquid and solid phase effluents from the liquid-solids separation unit and mass flow estimates. Grab samples from each waste stream were collected semi-monthly for analysis from January through December 2004. Each sample collected was a composite of several sub-samples collected over a 15 to 20 minute period of flow to insure that the samples analyzed were representative.

The influent flow rates for the digester and the liquid-solids separation unit were estimated by recording the time of chopper pump operation. The chopper pump transfers manure from an influent holding tank into the Gordondale digester. A float switch controls this pump, which transfers a constant volume of manure into the digester during each operating cycle. Based on the dimensions of the influent holding tank, it was determined that the average flow rate for this pump is approximately 521 gallons per minute. The liquid and solid fraction volumes after separation were estimated based the partitioning of total solids between the two fractions assuming conservation of mass through the separation process.

During each sampling episode, data also were collected for volume of biogas utilized, biogas methane and carbon dioxide content, electricity generation, and hours of engine-generator set and digester influent pump operation between sample collection events. In addition, measurements were recorded of cooling and exhaust system waste heat-used for digester and milking center space and water heating.

Sample Analyses

Physical and Chemical Parameters—All digester influent and effluent samples collected were analyzed on an "as received" basis to determine concentrations of the following: total solids (TS), total volatile solids (TVS), chemical oxygen demand (COD), soluble chemical oxygen demand (SCOD), total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_4-N), total phosphorus (TP), soluble orthophosphate phosphorus (SPO_4-P), and pH. Each FAN screw press separator liquid and solid phase effluent sample was analyzed to determine concentrations of TS, TVS, TKN, NH_4-N, and TP also on an "as received" basis.

U.S. Environmental Protection Agency (1983) methods were used for TS, TVS, TKN, TP, SPO_4 -P, and pH determinations. American Public Health Association (1995) methods were used to determine COD, SCOD, and NH_4-N concentrations. All analyses were performed by Northern Lake Service, Inc. of Crandon, Wisconsin, an analytical laboratory certified by the Wisconsin Department of Natural Resources for water and waste analysis.

Biodegradability—A 55-day batch study was conducted to estimate the biodegradable and refractory fractions of TVS in a random sample of as-excreted manure from Gordondale Farms. The study was a laboratory scale study in which two liters of manure was maintained at 95 °F (35 °C) in a glass reactor. A water trap was used to vent the biogas produced and maintain anaerobic conditions in the reactor. The contents of the reactor were sampled and analyzed to determine TVS concentration on days 0, 15, 20, 30, 45, and 55.

Microbial Parameters—Two microbial parameters were used to characterize the potential fate of pathogenic microorganisms in the Gordondale Farms waste management system. One parameter was the fecal coliform group of bacteria (fecal coliforms), a group of bacteria that includes *Escherichia coli*, *Klebsiella pneumoniae*, and other species that-are common inhabitants of the gastro-intestinal tract of all warm-blooded animals. The second parameter was the fecal streptococcus (fecal strep) group of bacteria, a group of bacteria that includes *S. faecalis*, *S. faecium*, and other species that also are common inhabitants of the gastro-intestinal tract of all warm-blooded animals. The presence of fecal coliforms and fecal streptococci are a commonly used indicator of fecal contamination and the possible presence of pathogenic microorganisms. In addition, a reduction in fecal coliform and fecal streptococci densities serves as an indicator of reductions in the densities of pathogenic microorganisms that also may be present. Densities of both groups of indicator organisms were estimated using the multiple tube fermentation technique (American Public Health Association, 1995) also by Northern Lakes Service, Inc.

Biogas Composition—On the days that digester and screw press separator influent and effluent samples were collected for analysis, biogas samples also were collected for determination of methane and carbon dioxide content using a CES-Landtec Gem™ 500 Landfill Gas Monitor. These determinations were performed at the Hickory Meadows Landfill in Hilbert, Wisconsin. In addition, a random sample of the Gordondale Farms' biogas was analyzed by Badger Laboratories and Engineering, Inc., Neehah, Wisconsin to determine concentrations of hydrogen sulfide (H_2S) and ammonia (NH_3). The determination of the H_2S content was performed using ASTM Method D-5504 (ASTM International, 1990). The same sample was analyzed to determine NH_3 content using EPA Method 350.1.

Data Analysis

Each data set generated in this study was analyzed statistically for the possible presence of extreme observations or outliers using Dixon's criteria for testing extreme observations in a single sample (Snedecor and Cochran, 1980). If the probability of the occurrence of a suspect observation based on order statistics was less than five percent ($P<0.05$), the suspect observation was considered an outlier and not included in subsequent statistical analyses.

With the exception of bacterial densities, all data sets were found to be approximately normally distributed and the null hypothesis that two means do not differ significantly ($P<0.01$) was tested using the Student's *t* test. For multiple comparisons, one-way analysis of variance (ANOVA) was used. If the null hypothesis that the means do not differ significantly ($P<0.01$) was rejected, Tukey's Honest Significance Test for pair-wise comparisons of means (Steel and Torrie, 1980) was used. To equalize variances, densities of fecal coliform and fecal streptococcus bacteria transformed logarithmically before calculation of means and standard deviations and comparisons of means to determine the statistical significance of differences.

The refractory fraction of TVS in the as excreted manure was estimated using the results of the batch biodegradability study. The estimate was based on the assumption that the biodegradable fraction of TVS approaches zero as the solids retention time (SRT) approaches infinity. Therefore, the refractory fraction of TVS can be determined graphically by plotting a time series of ratios of TVS concentrations to the initial TVS concentration versus the inverse products of the initial TVS concentration and the corresponding unit of time. The resulting relationship theoretically should be linear with the ordinate axis intercept representing the refractory fraction of TVS.

SECTION 4

RESULTS

Manure Production and Characteristics

As shown in Table 4-1, the volume of manure generated per cow-day at Gordondale Farms based on the volume of influent entering the digester, is significantly higher than the standard reference value published by USDA (1992). However, the influent to this digester includes milking center wastewater, which is used to flume the manure scraped from the free-stall barn into the digester influent holding tank. The USDA estimate does not include any water used for cleaning or accidental spillage from drinkers. If it is assumed that the USDA estimate of manure production is valid for Gordondale Farms, it appears that the rate of process water generation (milking center wastewater, spillage from drinkers, and other water used for cleaning) on this farm is about 1.22 ft^3 (9.1 gal) per cow-day, which is a reasonable value.

While the excretion rates for TS, TVS, and FS for Gordondale Farms also are somewhat higher than USDA (1992) values, it appears that the liberal use of separated solids for bedding in combination with unpaved free-stalls may be responsible, at least partially, for these differentials. The FS content of these separated solids, 31 percent, is approximately double the USDA value of-15.6 percent for typical dairy cattle manure. The separated solids used for bedding also may be a factor contributing to the significantly higher total phosphorus excretion rates although feeding practices usually are the primary factor.

Digester Operating Conditions

As noted earlier, the Gordondale Farms herd size increased from 750 to 860 cows on 15 July 2004. Before this increase, the average digester influent flow rate was 23.0±1.3 gal per cow-day, which translates into an HRT of 30.8±1.8 days. After the herd size increased, the average digester influent flow rate decreased slightly to 22.2±1.0 gal per cow-day. This decreased flow rate moderated the reduction in HRT due to the addition of 110 cows to 27.9±1.2 days. Presumably, this reduction in influent flow rate per cow-day was due to a reduction in water use per cow in the milking center. Because the difference in HRT between these two periods was not found to be statistically significant ($P<0.01$), the 12-month average influent flow rate of 29.1±2.1 gal per cow-day was used. This flow rate translates into an average HRT of 29.1±2.1 days. This HRT is seven days longer than the original design value for this digester (an HRT of 22 days).

Waste Stabilization

Table 4-2 summarizes the performance of the Gordondale Farms' plug-flow anaerobic digester by comparing mean influent and effluent concentrations. The results show substantial and statistically significant ($P<0.01$) reductions in TS, TVS, COD, SCOD, and TVA concentrations, as would be expected. In addition as expected was the statistically significant decease in the concentration of ON and concurrent increase in NH_4-N concentration, which reflects the mineralization of ON during digestion. The absence of statistically significant differences in influent and effluent TKN and TP concentrations suggest that this digester is operating in an ideal plug flow mode with no settling and accumulation of solids occurring. However, the statistically significant difference between influent and effluent FS concentrations contradicts this conclusion. While the reason for the difference between influent and effluent FS concentrations is unclear, it may be that the first compartment in the influent channel is functioning as a grit chamber and trapping FS, such as soil particles from the unpaved free-stalls. However, GHD, Inc. has indicated that no accumulation of settled solids in this chamber has been detected by periodic probing. The absence of a statistically significant difference between influent and effluent TKN concentrations suggests that any NH_3 desorption during the mesophilic anaerobic digestion of dairy cattle manure is, at most, nominal.

The differences between influent and effluent concentrations of TS, TVS, COD, and SCOD (Table 4-2) translate into the mass reductions presented in Table 4-3. The difference between the mass reductions of TS and TVS is a reflection of the difference between influent and effluent FS concentrations.

Biodegradability

The results of the batch biodegradability study indicate that 47 percent of the TVS are readily biodegradable and 53 percent are refractory. This suggests, in an engineering context, that 84 percent of the biogas production potential of the Gordondale Farms dairy manure is being realized at an HRT of approximately 29 days.

Indicator Organism and Pathogen Reduction

As shown in Table 4-4, the $\log_{10}$ densities of both the fecal coliform and fecal streptococcus groups of bacteria were reduced substantially in the Gordondale Farms' anaerobic digester. On a colony-forming unit (CFU) per 100 ml of manure basis, the reduction in the density of fecal coliforms was over 99 percent while the reduction in fecal streptococcus density was somewhat greater than 90 percent.

Biogas Production and Characteristics

Production—The biogas produced at Gordondale Farms is used by Alliant Energy to generate electricity and the waste heat from the engine-generator set is used for digester and milking center water and space heating. When the engine-generator set is out of service, biogas is flared. Only the biogas utilized to fuel the engine-generator set is metered.

At the beginning of this studying January 2004, a Roots gas meter was reinstalled after removal in the previous year due to the mistaken belief that it was restricting gas flow to the engine-generator set and the amount of electricity generated. However, Gordondale Farms removed the meter again in mid-February for the same reason. Due to funding considerations, it was not possible to install a new, non-flow restricting type gas meter, a FCI FlexMASSter thermal mass flow meter, until August 2004. When this new meter was installed, it was established that the Roots gas meter was not restricting biogas flow or electrical output.

Biogas production was estimated to be 93,501 ft^3 per day. Because of the circumstances described above, biogas production before July (when the herd size was increased to 860 cows) was determined based on gas meter readings during two January and one February sampling episodes. During this period, biogas production averaged 99,762±7,826 ft^3 per day, which translates into 133±10.4 ft^3 per cow-day. After the herd size was increased, biogas production decreased slightly to an average of 93,501±4,011 ft^3 per day or 109±5 ft^3 per cow-day. The reason for the reduction in biogas production is unclear given the nominal reduction in HRT that occurred when the herd size increased. However, the estimate of 133 ft^3 per cow-day is based on only three observations whereas the estimate of 109 ft^3 per cow-day is based on 11 observations and appears to be a more reliable estimate.

Composition—As shown in Table 4-5, there was little variation in the composition of the biogas produced during the course of this study. Methane and carbon dioxide contents averaged 55.9±2.1 and 43.8±2.1 percent by volume, respectively. The low NH_3 concentration of 0.000347 percent by volume confirms the conclusion, based on mass balance results, that NH_3 desorption during anaerobic digestion of dairy manure is nominal. However, the concentration of hydrogen sulfide found in the Gordondale Farms biogas, 0.310 percent by volume, indicates that emissions of oxides of sulfur during biogas combustion are potentially significant._

Based on a methane content of 55.9 percent (Table 4-5) and biogas production rate of 93,501 ft^3 per day, the rate of methane production from the Gordondale Farms anaerobic digester was 52,267 ft^3 per day. Thus, the rates of biogas and methane production are 24.22 and 13.54 ft^3 per lb TVS destroyed, respectively. Anaerobic digestion of municipal wastewater treatment sludges (biosolids) typically yields between 12 and 18 ft^3 of biogas per lb TVS destroyed (Metcalf and Eddy, Inc., 1991).

Theoretically, the destruction of one pound of ultimate biochemical oxygen demand (BOD_u) under anaerobic conditions should result in the generation of 5.62 ft^3 of methane (Metcalf and Eddy, 1991). Although not all COD is biodegradable, it can be assumed that a microbially mediated reduction of COD is equal to a reduction of the same magnitude in BOD_u. Thus, the 38.5 percent reduction in COD in the Gordondale Farms anaerobic digester (Table 4-2) is equivalent to a 4,107 lb per day (Table 4-3) reduction in BOD_u and the production of 23,081 ft^3 of methane per day. However, the observed rate of methane production from the Gordondale digester was 12.73 ft^3 per lb COD destroyed with no apparent explanation for this inconsistency.

Biogas Utilization

During this 12-month study, Alliant Energy generated and delivered to their transmission system 2,438±583 kWh per day of electricity, which translates into 3.25±0.78 kWh per cow-day with an on-line efficiency of 97.3 percent. This rate of electricity generation is about 88 percent of the design value estimate by the system designer, GHD, Inc. of 3.7 kWh per cow-day and translates into the use of only 73 percent of the rated capacity of the generator set (140 kWh). Because of the low capacity utilization, only 29.8 kWh were generated per 1,000 ft^3 of biogas utilized, which translates into a thermal conversion efficiency of only 18 percent. At full load, conversion of biogas energy to electrical energy should approach 30 percent with the added potential of recovering up to 60 percent of biogas energy as heat energy (Koelsch and Walker, 1981).

After this study was started, it was learned that the performance of the engine-generator set also had been below expectations during the previous year (2003), with electricity generation averaging 2,499±858 kWh per day. Although several attempts to identify the cause of the substandard performance (including the removal of the Roots gas meter), none were successful until spark plugs were replaced on 12 October 2004. When replacement occurred, the electrical output immediately increased to near its rated capacity of 140 kW. From 12 October through the end of the study, the engine-generator set operated at an average of 3.86±0.15 kWh per cow-day with thermal efficiency of approximately 21 percent.

Waste Heat Recovery

One of the objectives of this study was to determine the quantity of waste heat being recovered from the engine-generator set that is being beneficially used for milking center water and space heating. However, physical constraints precluded this determination. It was possible, however, to determine the total quantity of waste heat available from the engine-generator set cooling system and exhaust gases and the fraction being used for digester heating and in milking center. Two Onicon, Inc. Model F-1100 BTU meters were used.

During the 12 months of this study, 680,416 x 10^4 BTUs, which translates into 2.309 x 10^4 BTUs per cow-day (assuming an average herd size of 805 cows), were recovered. Of this total, 574,934 x 10^4 BTUs were used beneficially for digester and milking center space and water heating with the remainder discharged to the atmosphere. The total BTUs recovered represent approximately 34 percent of the biogas energy being produced at Gordondale Farms.

Solids Separation

As mentioned earlier, Gordondale Farms uses a screw press separator to recover coarse solids from the digester effluent for on-farm use and sale as bedding. On a wet weight basis, an average of 14,415 lb per day of course solids is recovered before drainage of free moisture, and they contain an average of 4,123 lb of dry matter. Table 4-7 compares the characteristics of the digester effluent and the separated liquid and solid fractions.

As indicated in Table 4-7, the concentrations of TS and TVS in the separated liquid and solid fractions are similar. Conversely, the liquid fraction contains over 75 percent of the TKN and NH_4-N and almost two-thirds of the phosphorus and FS originally present in the digester effluent. Although the removal of nitrogen and phosphorus by solids separation at Gordondale Farms is significant, over 70 percent of these nutrients remain on the farm because the separated solids are used as bedding.

Although the separated solids at Gordondale Farms are not being composted-prior to on-farm use or sale, composting could provide an opportunity for sale as a mulch material or soil amendment. The organic carbon content of the separated solids can be estimated as approximately 55.5 percent of TVS (Haug, 1980 and Rynk *et al*., 1992), the carbon to nitrogen (C:N) ratio of the separated solids at Gordondale Farms is approximately 17.5:1. At this C:N ratio, nitrogen availability will not limit the rate of stabilization but some ammonia will be emitted by volatilization. A C:N ratio of 30 to 35:1 generally is considered optimal for minimizing nitrogen loss without limiting the rate of stabilization.

SECTION 5

DISCUSSION

In a previous AgSTAR study, (Martin 2003) evaluated the performance two manure management systems in a cold climate (central New York): one system with anaerobic digestion (AA Dairy) and one without (Patterson Farms). The AA Dairy anaerobic digester is a conventional plug-flow digester. Where feasible, this discussion compares the performance and operating parameters of the modified plug-flow digester at Gordondale Farms with the more conventional plug-flow design at AA Dairy.

Manure Production and Characteristics

As shown in Table 5-1, there are both similarities and significant differences the production rate and composition of manure among Gordondale Farms, AA Dairy, and Patterson Farms. Probably the most important similarity is in the TVS excretion rates and the most important difference is in COD excretion rates, with the rate for Gordondale Farms being approximately two-thirds of the rates for AA Dairy and Patterson Farms. The reason for this difference is not apparent. It does, however, at least partially explain the previously discussed inability to relate COD destruction with methane production based on the previously discussed theoretical ratio of 5.62 ft^3 of methane generated per lb of COD destroyed. Conversely, the TVS:COD ratio for the Gordondale Farms manure closely agrees with the ratio based on the USDA (1992) standard reference value (See Table 4-1), whereas the ratios for the AA Dairy and Patterson Farms manures are substantially higher. The other difference of significance is the higher phosphorus excretion rate for Gordondale Farms, which is statistically significant and probably is a reflection of a difference in feeding practices. The higher volume of manure produced per cow-day at Gordondale Farms is due to the inclusion of milking center wastewater, which is not co-mingled with manure at AA Dairy or Patterson Farms before storage.

Anaerobic Digester Performance and Biogas Utilization

Waste Stabilization—The Gordondale Farms plug-flow digester was designed to operate at a HRT of 22 days but operated at an average HRT of 29 days during this study. At this HRT, TVS and COD reductions averaged 39.6 and 38.5 percent, respectively (Table 4-2). As shown in Table 5-2, the TVS reduction at Gordondale Farms was substantially higher than that observed in a conventional plug flow digester at AA Dairy, whereas the COD and TVA reductions were-similar (Martin, 2003). This is a reflection of the difference in the readily biodegradable fraction of TVS as discussed below.

The results of the batch biodegradability study indicated that 47 percent of Gordondale Farms manure TVS are readily biodegradable in an engineering context with the remaining 53 percent being refractory. Thus, it appears that 84 percent of the biodegradable volatile solids (BVS) in Gordondale manure are being degraded at the digester HRT of 29 days. The linear regression relationship developed from the batch biodegradability data (Equation 1) also suggests that reducing digester HRT to the design value of 22 days would reduce TVS reduction from 39.6 to 33.7 percent, a decrease of 15 percent. Therefore, it appears any significant increase in herd size beyond 860 cows could begin to measurably reduce the degree of waste stabilization. It should be noted that the biodegradable fraction of Gordondale Farms TVS is substantially higher than the previously reported value of 30 percent for AA Dairy TVS (Martin, 2003).

$$\mathrm{TVS}_t/\mathrm{TVS}_0 = 0.31\ (1/\mathrm{TVS}_0{*}\ t) + 0.53 \qquad (1)$$

where: TVS_t = total volatile solids concentration at time t,
TVS_0 = total volatile solids concentration at time 0,
t = time (HRT).

The 39.6 percent reduction in TVS observed in this study is comparable to the 37.6 percent reduction reported by Morris (1976) at a HRT of 30 days in a bench-scale anaerobic digester. The 41.9 percent reduction in COD is essentially the same as the 40.6 percent reduction also reported by Morris. The reduction in TVS observed in this study also is similar to the 40.6 percent reduction reported by Jewell *et al*. (1991) for a 65-cow plug-flow digester at a HRT of 30 days.

Pathogen Reduction—As also shown in Table 5-2, the reduction in the density of the fecal coliform group of indicator organisms at Gordondale Farms was somewhat less than the reduction observed at AA Dairy. However, the reduction still exceeded 99 percent with over a 90 percent reduction in the density of the fecal streptococcus group of indicator organisms. Thus, it seems reasonable to conclude that a significant reduction of any pathogens present including *M. avium paratuberculosis*, the pathogen responsible for chronic, contagious enteritis in cattle and possibly Crohn's disease in humans, also is occurring (Merck and Company, Inc., 1998).

Biogas Production—The mean rate of biogas production observed in this study was 109 ft^3 per cow-day. This is significantly higher than the biogas production rate of 78 ft^3 per cow-day observed in the evaluation of the conventional plug-flow digester at AA Dairy (Martin, 2003) and is consistent with the higher reduction in TVS observed in this study (Table 5-2). In addition, the rates of biogas and methane production per lb of TVS destroyed at Gordondale are somewhat higher than those observed at AA Dairy (Table 5-3), suggesting some difference in TVS composition. However, the AA Dairy biogas had a higher methane content, 59.1 percent versus 55.9 percent in the Gordondale Farms biogas.

If a future increases in herd size at Gordondale Farms reduce the digester HRT to the design value of 22 days, the estimated reduction in TVS destruction-also would reduce the biogas production rate by 15 percent to approximately 93 ft^3 per cow-day. However, total biogas production would increase to 98,766 ft^3 per day. This is based on an assumed increase in herd size to approximately 1,060 cows with no change in digester influent volume per cow-day.

Biogas Utilization—The full potential for generating electricity from the biogas produced at Gordondale Farms was not being realized during this study. Even at the peak output, which was observed during the last two months of this study, the 21 percent thermal efficiency for converting biogas to electricity is relatively low. Therefore, a greater potential for generating electricity at Gordondale Farms exists. If the thermal efficiency of converting biogas to electricity could be increased to 30 percent, which Koelsch and Walker (1981) suggested to be feasible, electrical output could be increased to 5.59 kWh per cow-day, which is close to output of 6.25 kWh per cow-day anticipated by the system designer, GHD, Inc. Achieving this potential, however, would require an increase in generating capacity to 200 kW.

Methane Emissions—Gordondale Dairy is estimated to be reducing methane emissions by 221 lb per cow-year through biogas production, capture, and utilization. This estimate was made using the methodology currently employed by the U.S. Environmental Protection Agency for developing the annual inventory of U.S. greenhouse gas emissions and sinks (U.S. Environmental Protection Agency, 2005) and the following assumptions. Based on the results obtained in this study, maximum methane producing capacity (B_0) was assumed to be 0.32 m^3 per kg of TVS excreted. This is significantly higher than the standard reference value for dairy cattle of 0.24 m^3 per kg of TVS excreted (U.S. Environmental Protection Agency, 2005 and Intergovernmental Panel on Climate Change, 2000). In addition, the methane conversion factor (MCF) for liquid/slurry manure storage facilities in Wisconsin of 22.4 percent was assumed. This translates into a total reduction of approximately 95 tons per year for the current 860-cow milking herd. Because methane has 21 times the heat trapping capacity of carbon dioxide (U.S. Environmental Protection Agency, 2005), the reduction in methane emission is equivalent to an emission reduction of 1,996 tons of carbon dioxide per year or 3.03 tons per cow-year.

However, the reduction in greenhouse gas emissions due to biogas production and utilization at Gordondale Farms is not limited to the reduction in methane emissions. The use of the biogas produced and captured to generate electricity reduces the demand for electricity generated using fossil fuels. Thus, carbon dioxide emissions resulting from the use of fossil fuels to generate electricity also are reduced. About 2,249 lbs of carbon dioxide are emitted per megawatt-hour (MWh) of electricity generated from coal (Spath *et al.*, 1999). Accordingly, the estimated 957,655 kWh of electricity generated by Gordondale Farms using biogas potentially reduces fossil fuel derived carbon dioxide emissions by an additional 1,077 tons per year or 1.33 tons per cow-year. With operation of the engine-generator set at its rated capacity of 140 kW and an on-line efficiency of 97 percent, these potential reductions would increase to 1,338 tons per year or 1.56 tons per cow-year. In addition, even greater reductions would be realized if the thermal efficiency of the conversion of biogas to electricity could be improved. In this analysis, the carbon dioxide emissions from biogas combustion are not considered to contribute to a buildup of greenhouse gases since the carbon dioxide emissions are not derived from a sequestered carbon source. Rather, this emission is part of the natural short-term carbon cycle where carbon dioxide is fixed by photosynthesis and then is regenerated as the plant matter produced is degraded microbially and by higher animals.

Separator Performance

Gordondale Farms uses a screw press separator to separate coarse solids from the anaerobic digester effluent for on-farm use and sale as a bedding material. As shown in Table 5-4, separation of coarse solids from the Gordondale the AA Dairy anaerobic digester effluents removed generally similar fractions of all of the parameters listed except total phosphorus. The percentage of phosphorus removed at Gordondale was substantially higher. This suggests that the Gordondale manure contained less soluble phosphorus as a percentage of total phosphorus.

Economic Analysis

One of the objectives of this study was to quantify the impact of anaerobic digestion with biogas capture and utilization to generate electricity on the cost of dairy cattle manure management.

<u>Capital Cost</u>—Gordondale Farms estimates that they have invested $550,000 in their anaerobic digestion/biogas production system. This investment includes the digester and all associated equipment and structures. However, the system was partially constructed by the farm owners. Based on an estimate of $650,000 for a turnkey system provided by the project designer and builder, GHD, Inc., the partial construction by farm owners reduced the capital cost by $100,000. These cost estimates exclude the cost of the engine-generator set, which is owned and operated by Alliant Energy. The installed cost of the engine-generator set was $198,000 of which $160,000 was for the engine-generator set and interconnection. The remaining $38,000 was the cost of installation, which included labor and materials. Based on the design herd size of 750 cows and including the cost of the engine-generator set, the capital cost of the Gordondale Farms system was $997 per cow and would have been $1,131 per cow for a turnkey system. However, based on the current herd size of 860 cows, these cost have been reduced to $870 and $986 per cow, respectively.

<u>Value of Electricity Generated</u>—Alliant Energy pays Gordondale Farms flat rate of $0.015 per kWh of electricity generated. If the engine-generator set operates at its rated capacity of 140 kW, the potential income from biogas production is $18,396 per year. Although Alliant's engine-generator set has not operated at its rated capacity except during the last two and one-half months of 2004, Gordondale Farms has not been penalized for the reduced generator output and has received payment for the biogas delivered based on the 140 kW rated capacity of the engine-generator set. If Gordondale Farms owned the engine-generator set, they would be paid $0.06 per kWh delivered to Alliant Energy, which would increase

income to $73,584 per year. To maintain the viability of agriculture in their service area, Alliant Energy pays farmers delivering electricity produced from biogas to their grid $0.06 per kWh. -

Annual Operation and Maintenance Costs—Because the digester system at Gordondale Farms has been in operation only since March 2002, there is no long-term record on which to base an estimate of annual operating and maintenance costs. Previously, Wright and Perschke (1998) and Nelson and Lamb (2002) have estimated operation and maintenance costs for the anaerobic digestion of dairy cattle manure with biogas utilization to generate electricity to be $0.015 per kWh of electricity generated. Because of the simplicity of the anaerobic digestion/biogas production component of these systems, essentially all of the operation and maintenance costs are associated with engine-generator set operation. Since Gordondale Farms does not own the engine-generator set, current operation and maintenance costs most likely are not reducing farm income significantly. -

Economic Viability—The attractiveness of any investment generally depends on the ability to generate income sufficient to recover capital at a rate of return that is competitive with other investment opportunities. If, however, odor control or some other benefit provided by anaerobic digestion is necessary to continue farm operation, an acceptable rate of return would be somewhat less than other investment alternatives if the general farm operation remains profitable.

As the system was operated during this study, the income produced from the sale of biogas to Alliant Energy was $18,396 per year with insignificant operation and maintenance costs. With income of only $0.015 per kWhr, the digester would not be economically viable without considering the other income generated by the manure management system. The additional income-includes an estimated $60,000 per year in avoided bedding costs and an estimated income of $8,600 per year from the sale of excess separated solids. With this overall income of $86,996, the simple payback period for recovering the invested capital is 6.3 years.

While owning and operating the engine-generator set would have increased Gordondale Farms capital investment to $748,000, the additional net income from the sale of electricity would reduce the time to recover the capital invested without consideration of the value of the separated solids to 13.6 years. When the value of these solids is included, the simple payback period decreases to six years.

If the Gordondale Farms system was financed over a 20-year period at an interest rate of seven percent, the net income generated would be somewhat less, but there would be a steady stream of net income over the life of the system. Under current conditions, the net income would be $35,082 per year or a total of $701,640 over the estimated 20-year life of the system. Purchasing and operating the engine-generator set would increase net income to $53,184 per year or a total of $1,063,680 over the life of the system assuming a reliable output of 140 kW could be realized.

Because the fraction of recovered waste heat that was being used for milking center space and water heating in place of a conventional fuel such as propane could not be determined, the monetary value of this source of heat energy could not be estimated. However, it appears to be significant. If only five percent of the total amount waste heat that is being used for digester heating and in the milking center is being used in the milking center, the avoided cost for propane at $1.70 per gal is approximately $5,600 per year.

The results of these cost analyses clearly demonstrate that anaerobic digestion of dairy cattle manure with biogas collection and utilization can provide significant environmental quality benefits while concurrently producing a significant source of income. It should be noted, however, that the economic attractiveness of anaerobic digestion with biogas utilization at Gordondale Farms is due, at least partially, to the relatively high fraction of total volatile solids (47 percent) that are readily biodegradable. Although the alternative of aerobic digestion can provide some of the same environmental quality benefits, no income is produced to offset capital and operating costs. Thus, total farm income would be decreased rather than enhanced.

Under both the short-term and long-term financing scenarios described above, it appears that there would be considerable merit in replacing the current engine-generator set with unit sized for the current rate of biogas production assuming the efficiency of converting biogas to electricity can be increased to about 30 percent. This system modification would increase electricity generated by about 43 percent with a somewhat lower but still significant increase in net income.

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Table 4-1. Comparison of Gordondale Farms manure production and characteristics with standard reference values assuming a live weight of 1,400 lb per cow.

Parameter	Gordondale Farms	USDA (1992)
Volume, ft^3/cow-day	3.04	1.82
Total solids, kg/cow-day	7.6	6.4
Total volatile solids, kg/cow-day	5.8	5.4
Fixed solids, kg/cow-day	1.8	1.0
Chemical oxygen demand, kg/cow-day	6.0	5.7
Total Kjeldahl nitrogen, kg/cow-day	0.30	0.29
Total phosphorus, kg/cow-day	0.067	0.044

Table 4-2. Gordondale Farms anaerobic digester performance summary, mg/L[*].

Parameter	Influent	Effluent	Reduction, %
Total solids	88,100^{a}±17,200	56,900^{b}±7,800	35.4
Total volatile solids	67,200^{a}±11,100	40,600^{b}±8,500	39.6
Fixed solids	20,900^{a}±7,300	14,400^{b}±4,400	31.1
Chemical oxygen demand	69,923^{a}±19,229	43,000^{b}±8,333	38.5
Soluble chemical oxygen demand	7,998^{a}±5,187	3,298^{b}±2,222	58.8
Total volatile acids	5,725^{a}±1,314	700^{b}±1,238	87.8
Total Kjeldahl nitrogen	3,478^{a}±719	3,254^{a}±663	—
Organic nitrogen	1,782^{a}±621	1,135^{b}±557	36.3
Ammonia nitrogen	1,696^{a}±243	2,119^{b}±231	+24.9[†]
Total phosphorus	783^{a}±228	715^{a}±178	—
Soluble orthophosphate phosphorus	7.3^{a}±4.3	4.7^{b}±2.1	64.4
pH	7.6^{a}±0.3	8.2^{b}±0.2	—

[*] Means in arrow with a common superscript are not significantly different ($P<0.01$, $n=24$).

[†] Increase in concentration.

Table 4-3. Gordondale Farms anaerobic digester reductions of total solids, total volatile solids, chemical oxygen demand, and soluble chemical oxygen demand.

Parameter	**Reduction, lb/day**
Total solids	4,760
Total volatile solids	3,860
Chemical oxygen demand	4,107
Soluble chemical oxygen demand	717

Table 4-4. Comparison of Gordondale Farms anaerobic digester $\log_{10}$ influent and effluent densities of the fecal coliform and fecal streptococcus groups of bacteria.

Parameter	**Influent**	**Effluent**	**Reduction**
Fecal coliforms, $\log_{10}$ CFU/100 ml	$8.9^{a}\pm1.4$	$6.6^{b}\pm1.1$	2.3
Fecal streptococcus, $\log_{10}$ CFU/100 ml	$8.6^{a}\pm1.2$	$7.3^{b}\pm1.2$	1.3

Table 4-5. Gordondale Farms biogas composition.

Parameter	**% by volme**
Methane	55.9[*] ±2.1
Carbon dioxide	43.8[*] ±2.1
Hydrogen sulfide	0.310[†]
Ammonia	0.000347[†]

[*] n=24

[†] n=1

Table 4-6. Methane and total biogas production as functions of total volatile solids and chemical oxygen demand destruction.

Parameter	**Biogas**	**Methane**
$ft^3/lb\ TVS_D$	24.22	13.54
$ft^3/lb\ COD_D$	22.77	12.73

Table 4-7. Comparison of the characteristics of the Gordondale Farms anaerobic digester effluent (separator influent) with the separated liquid and solid fractions.

Parameter	Digester effluent	Separated liquid	Separated solids
Total solids, g/L	56.9	33	286
Total volatile solids, g/L	41.9	23	210
Fixed solids, g/L	15	10	76
Total Kjeldahl nitrogen, mg/L	3,254	3,300	6,900
Organic nitrogen, mg/L	1,135	1,287	4,462
Ammonia nitrogen, mg/L	2,119	2,046	2,402
Total phosphorus, mg/L	715	495	2,888

Table 4-8. Distributions of the constituents of Gordondale Farms anaerobic digester effluent following separation, % by weight.

Parameter	Liquid fraction	Solid fraction
Total solids	52.5	47.5
Total volatile solids	51.0	49.0
Fixed solids	62.3	37.7
Total Kjeldahl nitrogen	82.3	17.7
Organic nitrogen	73.4	26.6
Ammonia nitrogen	89.1	10.9
Total phosphorus	62.2	37.8

Table 5-1. Comparison of the Gordondale Farms rates of production of manure and its various constituents with those of two upstate New York dairy farms.

Parameter	**Gordondale Farms**	**AA Dairy**[*]	**Patterson Farms**[*]
Volume, ft^3/cow-day	3.04	2.10	2.35
Total solids, kg/cow-day	7.6	6.7	7.1
Total volatile solids, kg/cow-day	5.8	5.7	5.8
Fixed solids, kg/cow-day	1.8	1.0	1.3
Chemical oxygen demand, kg/cow-day	6.0	9.1	9.4
Total Kjeldahl nitrogen, kg/cow-day	0.30	0.28	0.28
Total phosphorus, kg/cow-day	0.067	0.048	0.045

[*] Martin, 2003.

Table 5-2. Comparison of the performance of the Gordondale Farms and the AA Dairy anaerobic digesters with respect to waste stabilization and indicator organism reduction.

Parameter	**Gordondale Farms**	**AA Dairy**[*]
Total solids, %	35.4	25.1
Total volatile solids, %	39.6[†]	29.7
Chemical oxygen demand, %	38.5	41.9
Soluble chemical oxygen demand, %	58.8	30.0
Total volatile acids, %	87.8	86.1
Fecal coliforms, $\log_{10}$	2.3	2.8
Fecal streptococcus, $\log_{10}$	1.3	—

[*] Martin, 2003.

[†] A result of the higher total volatile solids biodegradability.

Table 5-3. Comparison of rates of biogas and methane production and biogas methane content observed at Gordondale Farms and AA Dairy.

Parameter	**Gordondale Farms**	**AA Dairy**[*]
Biogas, ft^3/lb TVS destroyed	24.22	20.81
Methane, ft^3/lb TVS destroyed	13.54	12.30
Methane, % by volume	55.9	59.1

[*] Martin, 2003.

Table 5-4. Comparison of percentages of anaerobic digester effluent constituents recovered in the solid fraction of screw press separator effluent at Gordondale Farms with percentages recovered at AA Dairy, % by weight.

Parameter	Gordondale Farms	AA Dairy*
Total solids	47.5	50
Total volatile solids	49.0	56.1
Fixed solids	37.7	26.3
Total Kjeldahl nitrogen	17.7	19.1
Organic nitrogen	26.6	22.8
Ammonia nitrogen	10.9	15.6
Total phosphorus	37.8	22.1

*Martin, 2003.

Exhibit 3

MONTROSE
AIR QUALITY SERVICES

Memo

To: California Bioenergy, LLC
From: Paul Wade, Montrose Air Quality Services, LLC
Date: June 12, 2020
Re: AERSCREEN Analysis for Hydrogen Sulfide Venting

Montrose Air Quality Services, LLC was contracted by California Bioenergy, LLC to determine worst-case ambient concentrations from emergency venting of hydrogen sulfide (H_2S) from digester systems. Given permit restrictions on flaring biogas in the San Joaquin Valley of California, Montrose was asked to confirm the safety of venting such biogas in a powered or unpowered vertical vent. The intent was to determine the impacts to workers in the area during emergency venting and provide guidance for future venting designs. Table 1 summarizes regulatory limits with the most stringent being California OSHA with an 8-hour Time Weighted Average (TWA) of 10 part per million (ppm).

To determine the worst-case ambient concentrations, EPA's AERSCREEN screening model (version 16216) was used along with what is considered as the worst-case meteorological conditions. Worse-case meteorological conditions consist of a 0.5 meters per second wind speed at an anemometer height of 10 meters, "Grassland" as the dominant surface profile, "Dry" as the dominant climate type, an albedo of 0.18 (the measure of the diffuse reflection of solar radiation out of the total solar radiation), Bowen ratio of 1.00 (the ratio of sensible to latent heat fluxes from the earth's surface up into the air), and roughness length of 0.050 meters (the height at which the wind speed theoretically becomes zero).

AERSCREEN modeling was performed using the fixed and variable model inputs based on direction from California Bioenergy and other interested parties and is summarized in Tables 2 and 3. Fixed model inputs include stack diameters of 10 inches and 12 inches and seasonal temperatures of 110 ºF for summer months and 77 ºF for winter, spring and fall months. Variable model inputs include: exhaust flow rates at 24 cubic feet per minute (CFM), 600 CFM, 800 CFM, and 1000 CFM; stack heights of 15, 20, 25, and 30 feet; and a H_2S exhaust concentration of 6000 ppm.

TABLE 1: Worker Hydrogen Sulfide Ambient Concentration Limits

Regulatory Limits				
OSHA PELs				CAL/OSHA PEL (*as of 10/2/2019*)
		Acceptable maximum peak above the acceptable ceiling concentration or an 8-hr shift		
Substance	**Acceptable Ceiling Concentration**	**Concentration**	**Maximum Duration**	**8-hour TWA (ST) STEL (C) Ceiling**
Hydrogen sulfide	20 ppm	50 ppm	10 min once only if no other measurable exposure occurs.	10 ppm (ST) 15 ppm (C) 50 ppm

OSHA	Occupational Safety and Health Administration
CAL/OSHA	California Division of Occupational Safety and Health
PELs	Permissible Exposure Limits
TWA	Time Weighted Average
STEL (ST)	Short Term Exposure Limit
C	Ceiling Limit

TABLE 2: AERSCREEN Fixed Model Inputs

Fixed Inputs		
Stack Diameter	10	inches
	12	inches
Stack Area	0.545	sq. ft (10 in die)
	0.785	sq. ft (12 in die)
Exhaust Temperature	Summer	110º F (Maximum)
	Spring	77º F (Ambient Average)
	Fall	77º F (Ambient Average)
	Winter	77º F (Ambient Average)

TABLE 3: AERSCREEN Variable Model Inputs

Variable Inputs					
Stack Height	15-foot, 20-foot, 25-foot, and 30-foot				
Exhaust Concentration Rates					
H_2S ppm	6000				
			H_2S		
			ppm	**lbs./hr.**	**Exhaust Temperature**
Exhaust Flowrate	24	CFM	6000	0.764	Ambient (77º F)
	24	CFM	6000	0.764	110º F
	600	CFM	6000	18.47	Ambient (77º F)
	600	CFM	6000	17.05	110º F
	800	CFM	6000	24.63	Ambient (77º F)
	800	CFM	6000	22.73	110º F
	1000	CFM	6000	30.79	Ambient (77º F)
	1000	CFM	6000	28.42	110º F
Exhaust Velocity	0.73	fps	24	CFM	10 Inch Diameter Stack
	18.33	fps	600	CFM	
	24.45	fps	800	CFM	
	30.56	fps	1000	CFM	
	0.51	fps	24	CFM	12 Inch Diameter Stack
	12.73	fps	600	CFM	
	16.98	fps	800	CFM	
	21.22	fps	1000	CFM	

The stack flow parameters were provided as actual cubic feet per minute (ACFM). In order to calculate mass emission rates for the model, ACFM was converted to dry standard cubic feet per minute (DSCFM) as reflected in Table 4. The conversion reflects an assumed elevation of 300 feet and saturated volumetric fraction water vapor content for 77° F (ambient) and 110° F (summer time value).

TABLE 4: Conversion of Actual Cubic Feet to Dry Standard Cubic Feet

ACFM	Absolute Pressure (PSI)	Station Elevation (Feet)	Station Pressure (PSI)	Ambient Temperature (°F)	Ambient Temperature (R)	Standard Temperature (R)	Volumetric Fraction Water Vapor *	DSCFM
24	14.696	300	14.505	77	537	530	0.02	22.91
600	14.696	300	14.505	77	537	530	0.02	572.80
800	14.696	300	14.505	77	537	530	0.02	763.74
1000	14.696	300	14.505	77	537	530	0.02	954.67
24	14.696	300	14.505	110	570	530	0.04	21.15
600	14.696	300	14.505	110	570	530	0.04	528.63
800	14.696	300	14.505	110	570	530	0.04	704.84
1000	14.696	300	14.505	110	570	530	0.04	881.05

*Based on saturated air weight of 0.0032 lbs./cf @ 110° F and 0.0011 lbs./cf @ 77° F

Table 5 includes a summary of hourly emission rates (lbs.) for hydrogen sulfide were calculated using EPA's accepted equation for converting ppm concentrations to pounds per hour emission rate.

H_2S lbs./hr. = (Conc of H_2S PPM) * (10^-6) * (Exhaust flow rate DSCFM) * (60 min/hr.) * (Molecular Weight of H_2S) / (Specific Molar Weight of Ideal Gas, 379.5 ft3/lb./lb.-mole)

TABLE 5: H_2S Emission Rate Convert PPM to Pounds per Hour

H_2S - 77 degree (Ambient)						
lbs./hr.	**ppm**	**DSCFM**	**min/hr.**	**Mw**	**Ideal Gas (ft^3/lb-mole)**	**ACFM**
0.764	6000	24.00	60	34	379.5	24
18.47	6000	572.80	60	34	379.5	600
24.63	6000	763.74	60	34	379.5	800
30.79	6000	954.67	60	34	379.5	100
H_2S - 110 degree						
lbs./hr.	**ppm**	**DSCFM**	**min/hr.**	**Mw**	**Ideal Gas (ft^3/lb-mole)**	**ACFM**
0.764	6000	24.00	60	34	379.5	24
17.05	6000	528.63	60	34	379.5	600
22.73	6000	704.84	60	34	379.5	800
28.42	6000	881.05	60	34	379.5	100

Using the model inputs defined in Tables 4 and 5, the AERSCREEN model was run to determine ambient concentrations downwind of the emergency venting stack. Tables 6 and 7 summarize the results of this modeling. A total of 60 model runs were performed. Table 6 summarizes the worst-case Winter, Spring and Fall results for an exhaust at ambient temperature (77º F). Table 7 summarizes the results of the worst-case summer months temperature of 110º F. For both tables, the results are sorted by stack height in column 1, stack diameter in column 3, exhaust flow rate in column 4, exhaust H_2S ppm concentration in column 5, and exhaust H_2S pounds per hour emission rate in column 6. Column 7 show the distance from the exhaust stack to the highest 1-hour ambient concentration in micrograms per cubic meter ($\mu g/m^3$) and column 8 presents the highest 1-hour $\mu g/m^3$ determined by the AERSCREEN model for each scenario. Column 9 presents the 1-hour $\mu g/m^3$ concentration converted to 1-hour ppm concentration by using a multiplying factor of 0.00139 ppm/$\mu g/m^3$ and Column 10 calculates the 8-hour ppm concentration by converting the 1-hour to an 8-hour average using an AERSCREEN multiplying factor of 0.9. Column 11 lists the lowest standard from Table 1, based on the California OSHA 8-hour Time Weighted Average (TWA) of 10 part per million (ppm).

TABLE 6: AERSCREEN Model Results for Ambient Temperature (Winter, Spring, and Fall Months)

Study #	Stack Height (ft)	Stack Temp. (°F)[1]	Stack Dia. (inches)	Exhaust Flow Rate (CFM)	H_2S Conc. (ppm)	H_2S Emission Rate (lbs./hr.)	Distance to Highest Conc. (m)	Highest Conc. 1-Hour Ave. ($\mu g/m^3$)	Highest Conc. 1-Hour Ave. (ppm)	Highest Conc. 8-Hour Ave. (ppm)[2]	Lowest Standard 8-Hour Ave. (ppm)
Study #41	15	Ambient	10	600	6000	18.475	38	12827.0	9.23	8.31	10
Study #65	15	Ambient	10	800	6000	24.633	38	17100.0	12.30	11.07	10
Study #81	15	Ambient	10	1000	6000	30.791	38	21372.0	15.38	13.84	10
Study #1	15	Ambient	12	24	6000	0.764	12	900.8	0.65	0.58	10
Study #42	15	Ambient	12	600	6000	18.475	38	12824.0	9.23	8.30	10
Study #66	15	Ambient	12	800	6000	24.633	38	17100.0	12.30	11.07	10
Study #82	15	Ambient	12	1000	6000	30.791	38	21372.0	15.38	13.84	10
Study #45	20	Ambient	10	600	6000	18.475	56	6721.9	4.84	4.35	10
Study #69	20	Ambient	10	800	6000	24.633	53	9063.8	6.52	5.87	10
Study #85	20	Ambient	10	1000	6000	30.791	42	13748.0	9.89	8.90	10
Study #3	20	Ambient	12	24	6000	0.764	14	770.3	0.55	0.50	10
Study #46	20	Ambient	12	600	6000	18.475	56	6721.9	4.84	4.35	10
Study #70	20	Ambient	12	800	6000	24.633	56	8961.2	6.45	5.80	10
Study #86	20	Ambient	12	1000	6000	30.791	51	11622.0	8.36	7.53	10
Study #57	25	Ambient	10	24	6000	0.739	21	453.0	0.33	0.29	10
Study #49	25	Ambient	10	600	6000	18.475	59	6074.0	4.37	3.93	10
Study #73	25	Ambient	10	800	6000	24.633	44	9887.7	7.11	6.40	10
Study #89	25	Ambient	10	1000	6000	30.791	36	16169.0	11.63	10.47	10
Study #58	25	Ambient	12	24	6000	0.739	20	484.7	0.35	0.31	10
Study #50	25	Ambient	12	600	6000	18.475	49	6736.3	4.85	4.36	10
Study #74	25	Ambient	12	800	6000	24.633	53	8506.6	6.12	5.51	10
Study #90	25	Ambient	12	1000	6000	30.791	42	12892.0	9.27	8.35	10
Study #61	30	Ambient	10	24	6000	0.739	21	328.5	0.24	0.21	10
Study #53	30	Ambient	10	600	6000	18.475	46	6573.0	4.73	4.26	10
Study #77	30	Ambient	10	800	6000	24.633	37	11956.0	8.60	7.74	10
Study #93	30	Ambient	10	1000	6000	30.791	31	20336.0	14.63	13.17	10
Study #62	30	Ambient	12	24	6000	0.739	20	348.3	0.25	0.23	10
Study #54	30	Ambient	12	600	6000	18.475	40	7895.1	5.68	5.11	10
Study #78	30	Ambient	12	800	6000	24.633	42	9668.9	6.96	6.26	10
Study #94	30	Ambient	12	1000	6000	30.791	36	15732.0	11.32	10.19	10

[1] "Ambient" Stack Temperature is equal to 77° F.

[2] Used AERSCREEN 1-hour to 8-hour conversion factor of 0.9.

TABLE 7: AERSCREEN Model Results for Worst-Case Ambient Temperature of 110° F

Study #	Stack Height (ft)	Stack Temp. (°F)	Stack Dia. (inches)	Exhaust Flow Rate (CFM)	H2S Conc. (ppm)	H2S Emission Rate (lbs./hr.)	Distance to Highest Conc. (m)	Highest Conc. 1-Hour Ave. ($\mu g/m^3$)	Highest Conc. 1-Hour Ave. (ppm)	Highest Conc. 8-Hour Ave. (ppm)(1)	Lowest Standard 8-Hour Ave. (ppm)
Study #43	15	110	10	600	6000	17.050	51	5265.4	3.79	3.41	10
Study #67	15	110	10	800	6000	22.733	46	5404.9	3.89	3.50	10
Study #83	15	110	10	1000	6000	28.416	49	6232.2	4.48	4.04	10
Study #2	15	110	12	24	6000	0.764	29	669.3	0.48	0.43	10
Study #44	15	110	12	600	6000	17.050	55	4631.8	3.33	3.00	10
Study #68	15	110	12	800	6000	22.733	46	5404.7	3.89	3.50	10
Study #84	15	110	12	1000	6000	28.416	49	6232.0	4.48	4.04	10
Study #47	20	110	10	600	6000	17.050	76	2715.7	1.95	1.76	10
Study #71	20	110	10	800	6000	22.733	64	3140.3	2.26	2.03	10
Study #87	20	110	10	1000	6000	28.416	66	3669.7	2.64	2.38	10
Study #4	20	110	12	24	6000	0.764	15	553.1	0.40	0.36	10
Study #48	20	110	12	600	6000	17.050	37	3008.6	2.16	1.95	10
Study #72	20	110	12	800	6000	22.733	80	3333.2	2.40	2.16	10
Study #88	20	110	12	1000	6000	28.416	66	3669.6	2.64	2.38	10
Study #59	25	110	10	24	6000	0.682	19	320.7	0.23	0.21	10
Study #51	25	110	10	600	6000	17.050	33	2151.6	1.55	1.39	10
Study #75	25	110	10	800	6000	22.733	49	2290.2	1.65	1.48	10
Study #91	25	110	10	1000	6000	28.416	53	2415.1	1.74	1.56	10
Study #60	25	110	12	24	6000	0.682	19	335.2	0.24	0.22	10
Study #52	25	110	12	600	6000	17.050	48	1788.1	1.29	1.16	10
Study #76	25	110	12	800	6000	22.733	47	2512.4	1.81	1.63	10
Study #92	25	110	12	1000	6000	28.416	50	2688.5	1.93	1.74	10
Study #63	30	110	10	24	6000	0.682	22	231.7	0.17	0.15	10
Study #55	30	110	10	600	6000	17.050	37	1740.7	1.25	1.13	10
Study #79	30	110	10	800	6000	22.733	41	1877.5	1.35	1.22	10
Study #95	30	110	10	1000	6000	28.416	44	1949.2	1.40	1.26	10
Study #64	30	110	12	24	6000	0.682	22	241.0	0.17	0.16	10
Study #56	30	110	12	600	6000	17.050	40	1447.4	1.04	0.94	10
Study #80	30	110	12	800	6000	22.733	39	2045.1	1.47	1.32	10
Study #96	30	110	12	1000	6000	28.416	42	2153.5	1.55	1.39	10

[1] Used AERSCREEN 1-hour to 8-hour conversion factor of 0.9.

Model results show exhaust temperature at ambient air (77º F) produces the highest concentration results for each individual operating scenarios. This is due to the lower thermal buoyancy of the plume from the exhaust gas temperatures of 77° F to 110º F. The higher temperature lifts the exhaust plume to higher elevations before bending allowing more plume depletion downwind from the vent stack.

All model results in Table 7, for an exhaust temperature of 110º F, are below the California OSHA 8-hour Time Weighted Average (TWA) of 10 part per million (ppm).

For model runs with exhaust temperatures at ambient (77º F), there are 7 out of 30 model scenarios where the 10 ppm standard was exceeded. These are highlighted in yellow in Table 6. Four of the exceedances involve stack height at 15 feet with high exhaust flow rates (800 and 1000 cfm), two are stack heights of 30 feet with a flow rate of 1000 cfm exhaust flow rate, and one is a stack height of 25 feet with a stack diameter of 10 inches at the 1000 cfm exhaust flow rate. Extending the stack to 20 feet reduces the downwind exhaust concentration by 30 percent and below the standard of 10 ppm. Increasing the stack diameter from 10 inches to 12 inches reduces the downwind exhaust concentration by 25 percent and below the standard of 10 ppm.

For future vent stack installations, from the model results, a stack height of 20 feet with a stack diameter of 10 or 12 inches suitably ensures adequate compliance with exposure limits for any expected flow rate and concentration configuration. In the case of California Bioenergy operations, stack extensions above 20 ft do not appear to provide notable benefits relative to worker exposure to potential ambient H_2S above California OSHA 8-hour TWA of 10 ppm.

In conclusion, if California Bioenergy installs emergency vents on its digesters that are built to a height of 20 feet with a 10” to 12” diameter, and operates these vents to expel biogas at California Bioenergy’s highest expected H_2S concentration of 6,000 ppm, or less, with a unpowered minimal flow rate of 24 cfm through a maximum powered blower flow rate of 1000 cfm, then the AERSCREEN model shows vented biogas containing H_2S will not violate any regulatory worker safety limits under all expected operating conditions.

Respectfully,
Paul Wade, Montrose Air Quality Services, LLC