IEA Bioenergy

Task 38

Greenhouse Gas Balances of Biomass and Bioenergy Systems

BIOMITRE

Greenhouse Gas Benefits of an Anaerobic Digester in the USA

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Summary

Greenhouse gas (GHG) emissions – carbon dioxide, methane, nitrous oxide – expressed in terms of their global warming potential were reduced by four-fifths (79 %) at a 400-cow dairy in Durham, California, by substituting anaerobic digestion for open storage of dairy manure. The digestion system also produces valuable byproducts, plus heat and electricity for the farm. This study recommends that livestock waste-management systems should include anaerobic digestion systems to reduce GHG emissions and thus help minimize global warming.

Corn field of 107 acres, fertilized with wastewater from digester, Courtesy of Jane H. Turnbull, Peninsula

Livestock waste produces large amounts of GHGs – those gases in the atmosphere that trap energy from the sun and from human activities, and whose increase is a major cause of global warming. Managing such waste has become an increasingly severe problem over the past two decades, as livestock operations have become more and more intensive. As a result, government restrictions are becoming increasingly stringent. And one significant result of this is that anaerobic digestion systems are being included in more and more waste management systems. Digestion systems convert most of the livestock waste into biogas which can be used to meet local energy demands. The residue is a stabilized material that can be separated into liquid and solid fractions. The liquid is a good source of plant nutrients, and the solids make good soil conditioner or animal bedding.

Scope

This study provides a 50-year, full-life-cycle analysis of GHG emissions at the 400-cow dairy farm operated by the Langerwerf family of Durham, California. It compares GHG emissions from the dairy's present anaerobic waste-management system (Anaerobic System) with those of the previous system, which did not use anaerobic digestion, and compares the Global Warming Potential (GWP) of the two systems. The previous system is here termed the Reference System. The full report of this study you find under: www.joanneum.at/iea-bioenergy-task38/projects/task38casestudies/usa-fullreport.pdf

The Anaerobic System uses a plug-flow digester, which not only reduces GHG emissions dramatically but also produces electricity and hot water by means of a biogas engine-generator equipped with a heat recovery unit. And there are further benefits. Effluent from the digester is separated into solid and liquid fractions: The solids are used as bedding in freestalls and calf barns, and as a soil conditioner; the wastewater fertilizes a field of corn. Hot water from the engine is used to maintain the desired temperature of 95° to 100 °F in the anaerobic digester, and also for farm and domestic applications.

The day begins at the Langerwerf dairy as a diesel-powered skid loader scrapes the manure from the freestalls into a collection/mixing tank. The manure is mixed with water and agitated, forming a slurry with a solids content between 11 and 14 percent. As this slurry is pumped into the plug-flow digester, it displaces an equal volume of older digester effluent, which flows into the effluent tank. We will follow the further journey of this effluent in a moment.

Meanwhile, the manure pumped into the digester over previous days has been broken down by naturally occurring bacteria to become a medium-Btu biogas which is collected beneath the digester cover. From here a blower delivers it continuously to an internal combustion engine, which uses it as fuel. This engine in turn drives an electric generator which more than meets all the electricity needs of the farm. The farm owners sell the surplus to the local power company. The heat of the exhaust from the engine is recovered in a heat exchanger that delivers hot water to a storage tank.

The effluent which was displaced from the digester as the new slurry was pumped in is delivered to a vibrating-screen separator. Separated wastewater flows into an earthen storage basin from where it is pumped into a field of corn. The nutrients this wastewater supplies to the soil significantly reduce the demand for chemical fertilizer. (There's a further bonus – the Langerwerfs report that they are getting better than 20 percent more corn.) Separated solids are dried on a concrete pad and used as bedding for the cows or sold as a soil amendment.

The daily operation of the Reference System was similar, with the very notable exception of all the operations associated with the digester system. In the manure collection/mixing tank, water was added to the manure to form slurry, which was pumped into the vibrating-screen separator. The separated wastewater was stored for use directly as irrigation water for corn, and the solids were dried and used for bedding or sold as soil amendment, which is still done with output from the anaerobic system. Notably missing were the production of electricity and hot water – and in particular, there was none of the significant reduction in GHG achieved by the anaerobic digester. Instead, dissolved solids in the separated wastewater underwent natural bacterial decomposition and released large amounts of methane and CO_2 directly to the atmosphere. Considerable amounts of ammonia were also released, producing the distinctive odor associated with dairy farms. Table 1 defines the distinctions between the two systems.

The Anaerobic System was installed in 1981 and refurbished in 1998. Over the years its average annual electricity output has been about 320 000 kWh and its average annual thermal energy output has been about 2.6×10^6 MJ. The Anaerobic system produces 872 kWh per day, while the Reference system is totally dependent on the grid. Since 400 cows produce 20 640 kg manure per day, one cow produces 51 kg manure per day. Thus, one cow is able to provide sufficient manure to generate 17 kWh of power per day.

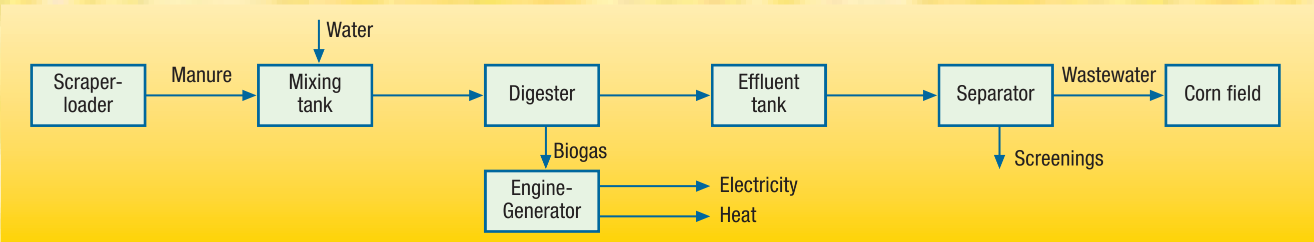
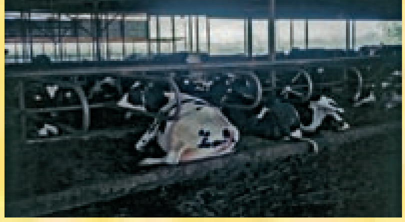


Figure 1. Schematic diagram of the Langerwerf dairy-waste management system

Figure 2. Schematic diagram of the Reference dairy-waste management system



Cows in the Langerverf Dairy,
Courtesy of Jane H. Turnbull, Peninsula

Method

The study considered four distinct life-cycle phases of the farm's waste management system: (1) acquisition of materials and energy, (2) construction, (3) operation, and (4) end-of-life.

For the materials acquisition phase (1) the study considered the materials used, energy consumed and the GHG emissions related to physically producing and transporting all the materials and energy required to build the digester system. For the construction phase (2) the study considered materials and energy required and GHG emitted for all the activities involved in fabricating the livestock waste management systems. Similarly, the operation phase (3) considered materials, energy and GHG for all the activities involved in running the systems over an assumed life of 50 years. This included manufacture and transportation of all materials required to maintain and refurbish the systems.

Table 1. Specifications for the Anaerobic and Reference systems

Item	Parameter		Anaerobic System	Reference System
1	Number of cows		400	400
2	Average weight of cow	[kg]	600	600
3	Total quantity of manure	[kg/d]	20 640	20 640
4	Total manure volatile solids	[kg/d]	2 400	2 400
5	Manure dilution water volume	[m^3/d]	20.8	20.8
6	Digester feed volume	[m3/d]	41.7	0
7	Volume of digester	[m3]	1 239	0
8	Hydraulic retention time	[days]	30	0
9	Biogas production	[m3/d]	576	0
10	Methane production	[m3/d]	346	0
11	Biogas heating value	[MJ/m3]	20.2	0
12	Grid electricity	[kWh/d]	0	652
13	Electricity generation	[kWh/d]	872	0
14	Heat production	[MJ/d]	7 000	0
15	Natural gas consumption	[m3/d]	0	23.2
16	Wastewater volume	[m^3/d]	34.4	34.4
17	Volatile solids in wastewater basin	[kg/d]	240	2 400
18	Applied nitrogen	[kg/d]	81	81
19	Nitrogen available to crops	[kg/d]	56.7	48.6
20	Dry screenings	[kg/d]	1 858	1 858

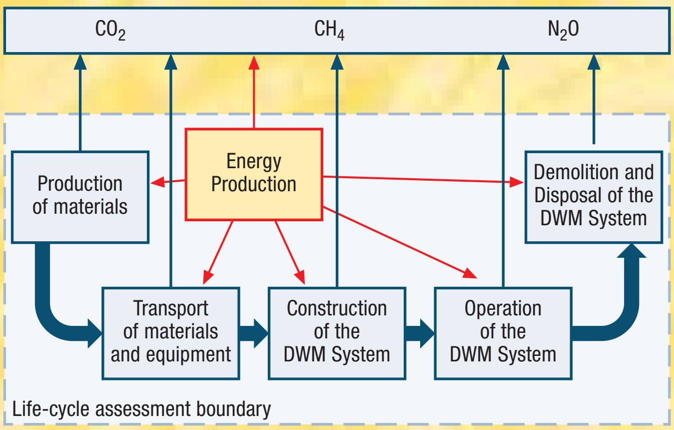


Figure 3.
Life-cycle Assessment boundary and system life-cycle phases

Finally, the end-of-life phase (4) looks ahead to inventory the eventual demolition of the systems, including the actual dismantling of the systems, transporting the waste materials to recycling operations and landfills, and restoring the land.

Creating an inventory of all the materials and energy consumption in the various processes of the system made it possible to estimate GHG emissions using known values of emission factors. Avoided emissions included those associated with producing commercial fertilizer, burning natural gas to heat water and generating electricity at the local utility power plant. For both systems, the field application of livestock wastewater and manure replaced an equivalent amount of chemical fertilizer and avoided the GHG emissions associated with producing that amount of fertilizer. Details regarding how the life-cycle emissions were calculated can be found in the original report (Turnbull and Kamthunzi) cited in the references.

Global warming potentials

The carbon dioxide, methane, and nitrous oxide emissions found in the study were converted into global warming potentials (GWP) with units of kg CO_2-equivalent (kg CO_2e) by using these conversions:

1 kg CO_2 = 1 kg CO_2e GWP;
1 kg CH_4 = 21 kg CO_2e GWP; and
1 kg N_2O = 310 kg CO_2e GWP (IPCC, 1996).

By summing the GWPs, the combined effect of the CO_2, CH_4, and N_2O emissions on the global environment was expressed as a single unit of measure.

GHG emissions during the materials acquisition phase

The GHG emissions from the production of materials were estimated by multiplying the mass of material by recognized emission factors. The methane and nitrous oxide emission factors for the production of the materials were very small and in some cases were not available.

GHG emissions during transportation of materials for fabrication

The materials needed to build the dairy's waste management systems were transported by road using heavy diesel trucks. Excavated soil from the construction site was trucked to a site 2 km away.

Disposal of waste materials was at a landfill 50 km away. Manure screenings not needed as bedding material are applied to a corn field 2 km away from the livestock farm.

GHG emissions associated with processes and activities

The GHG emissions processes, activities and operations are based on estimates of energy consumption. All excavation work at the construction site was done by diesel-powered excavators. Concrete was mixed and poured by diesel-powered mixers and pumps. Mixing and pumping of water, manure, effluent and wastewater is done by electric pumps. The baseline CO_2 emission factor for grid electricity was the current California state-wide electricity emission factor. The emission factors for electricity production from biogas engines is assumed to be comparable with grid electricity.

Hot water for the Reference System was produced by burning natural gas. Nitrous oxide emissions associated with land application of manure was estimated from the kilograms of N applied. The methane emissions from manure and wastewater storage basins were estimated from the methane production rate during anaerobic digestion. The actual quantity of GHG emissions from cow manure is determined by the value of the methane conversion factor, which is determined by the conditions in the storage basin. Under conditions of manure decomposition in an open storage basin, the amount of CO_2 produced is twice that of the CH_4 by weight.

End-of-life GHG emissions

The GHG emissions considered for the end-of-life phase were only those from demolition of the structures, final disposal of the manure and slurry, transportation of waste material to landfill and recycling centers, and the haulage of soil for backfilling the digester, the feed tank, the effluent tank, and the manure and wastewater storage basins. Emissions from the recycling processes and the landfill, or any other end-of-life management processes were assumed to be negligible.

Results

Tables 2 and 3 summarize the GHG emissions associated with both the Anaerobic Digester and the Reference Systems. It is clear that the bulk of the emissions occur as a result of the ongoing management of the livestock waste. Digestion of the waste reduces emissions by a factor of 4. In terms of annual reductions of GWP, anaerobic digestion at a dairy with 400 cows would decrease GWP by 54 858 kg CO_2e. This equates to a reduction of 137 kg CO_2e per cow annually.

The operation phase contributes the largest proportion (85 % for the digester system and 99 % for the Reference System) to the life cycle Global Warming Potential.

Table 2.
GHG emissions for Anaerobic System by life cycle phase

Phase	CO_2 [kg]	CH_4 [kg]	N_2O [kg]	GWP [kg CO_2e]
Material Acquisition	2 057 697	380	53	2 082 218
Construction	4 989	0	0	5 046
Operation	513 462	262 801	18 479	11 760 724
End of Life	43 623	2	1	44 115
TOTAL	**2 619 771**	**263 183**	**18 534**	**13 892 103**

Table 3.
GHG emissions for Reference System by life cycle phase

Phase	CO_2 [kg]	CH_4 [kg]	N_2O [kg]	GWP [kg CO_2e]
Material Acquisition	829 889	102	24	839 535
Construction	4 441	0	0	4 491
Operation	5 867 360	2 628 017	18 494	66 788 837
End of Life	38 895	2	1	39 333
TOTAL	**6 740 585**	**2 628 121**	**18 520**	**67 672 196**

Separator, with mound of separated solids,
Courtesy of Jane H. Turnbull, Peninsula

Manure slurry in collection tank,
Courtesy of Jane H. Turnbull, Peninsula

Table 4.
GHG emissions from operations of each waste management system

Daily Operation	Anaerobic System GWP [kg CO_2e]	Anaerobic System Percentage	Reference System GWP [kg CO_2e]	Reference System Percentage
Manure scraping	17 717	0.100	17 717	0.03
Electricity use	170 521	1.400	127 482	0.20
Wastewater basin emission	6 010 674	50.400	60 106 740	90.0
Soil N_2O emissions	5 728 219	48.000	5 728 219	8.60
Transport of used solid beddings	4 114	0.003	4 114	0.01
Natural gas use	0	0.000	804 566	1.20
TOTAL	**11 931 245**	**100.000**	**66 788 837**	**100.00**

Table 4 shows that the GWP of livestock waste management using the Reference system is nearly 6 times greater than when the Anaerobic Digester is included. Most of this difference is the result of wastewater storage in the open basin. If the slurry is digested, prior to being piped into the storage basin, the volatile organic materials no longer remain; they have become the biogas that now is providing power and heat to the farm and the grid. The Anaerobic system does require some additional electricity for mixing and pumping of both the slurry and the biogas. Nevertheless, the total electricity used on the farm is considerably less than that which is produced from the biogas.

Potential for Improvements

While the addition of an Anaerobic System markedly reduces GHG associated with livestock management, methane and CO_2 emissions still come from the wastewater storage basin and from the subsequent release of nitrous oxide from the nitrogen-containing effluents applied to the cornfield. It is possible that improvements in digestion technology could lead to more complete breakdown of volatile organic components during digestion. Furthermore, a better regime for fertilizer application might decrease the nitrous oxide emissions. It is unlikely that improvements in the efficiency of electric production would impact GHG emissions to any notable extent.

Conclusions

The overall result, shown in Table 5, is that use of Anaerobic Digestion in livestock waste management reduces the GWP by 79 %. Apart from the use of the biogas produced to generate power for use directly on the farm and displace fossil-generated power from the grid, there is excess power to be sold back to the utility that displaces a further amount of fossil-generated power. The boundary for this case study did not include the supplemental power provided to the utility, but if a program to reduce GHG emissions were developed in California, the Langerwerfs would additionally qualify for credits for the additional fossil power displaced. In the meantime, they are able to supply their own electricity and hot water while receiving payments from their local utility amounting to more than $20 000 (US) annually.

There are an estimated one million cows in California. The Langerwerf farm comprises 0.04 percent of that total. The potential for reducing GHG emissions using Anaerobic Digestion is truly extraordinary.

Table 5. Comparison of GWP (kg CO_2e) by type of GHG

Greenhouse Gas	Anaerobic GWP [kg CO_2e]	Reference GWP [kg CO_2e]	GWP Reduction [%]*
Carbon dioxide (CO_2)	2 619 771	6 740 585	61
Methane (CH_4)	5 526 852	55 190 548	90
Nitrous oxide (N_2O)	5 745 481	5 741 064	0
Total GWP	**13 892 103**	**67 672 196**	**79**

References

Turnbull, J. H. and Kamthunzi, W., 2004.
Full Report of the ‘Greenhouse Gas Emissions Reduction Associated with Livestock Waste Management Systems’. www.joanneum.at/iea-bioenergy-task38/projects/task38casestudies/usa-fullreport.pdf

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IEA Bioenergy (www.ieabioenergy.com) is an international collaborative agreement, set up in 1978 by the International Energy Agency (IEA) to improve international cooperation and information exchange between national bioenergy research, development and demonstration (RD & D) programs. IEA Bioenergy aims to realize the use of environmentally sound and cost-competitive bioenergy on a sustainable basis, thereby providing a substantial contribution to meeting future energy demands.

IEA Bioenergy Task 38 brings together the work of national programs in 13 participating countries on GHG Balances for a wide range of biomass systems, bioenergy technologies and terrestrial carbon sequestration. As one example of work, case studies have been conducted by applying the standard methodology developed by the Task 38. In the case studies GHG balances of different bioenergy and carbon sequestration projects in the participating countries have been assessed and compared, of which that of New Zealand is one example.

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