Co-digestion of dairy cow manure and food waste creates a more efficient biogas cycle

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ABSTRACT

The AgSTAR project of the U.S. EPA analyzed the possibility of installing anaerobic digesters with energy generation and nutrient capture in all confined dairy operations in the US with 500+ cows, with a total potential capacity of more than 2,000 digesters nationwide. This study uses environmental life cycle assessment to identify the potential benefits of disposing locally accessible commercial food waste with manure at those digesters (via co-fermentation) in comparison to other disposal options. Anaerobic digesters show an advantage compared to compost or landfill for all impact indicators examined: human health, climate change, ecosystem quality and water withdrawal. For greenhouse gases, the installation of digesters could potentially reduce 20-25 million metric tons (MMT) CO_2e of fugitive methane emissions from manure compared to current manure management practices, 10 MMT CO_2e of fugitive methane emissions from landfilled food waste, and another 10 MMT of CO_2e from avoided electricity, fertilizer production and peat moss production by harvesting energy, nutrients, and fibers from digesters, respectively.

Keywords: Dairy, food waste, anaerobic digestion, compost, landfill, manure

1. Introduction

It is estimated that 13 percent of greenhouse gases in the United States are associated with growing, manufacturing, transporting, and disposing of food (US EPA 2009). This sector is therefore among the high priorities for achieving climate reduction goals. As part of the next phase of the 2013 Climate Action Plan, announced in March 2014, the US government has placed a heavy focus on cutting methane emissions to help meet a national goal of reducing U.S. greenhouse gas emissions by 17 percent below 2005 levels by 2020. Two key sources of methane reductions cited in the strategy are the reduction of landfill waste and a plan to manage biogases. The latter component mentions implementation of manure digesters on dairy farms as one key component.

Economic analysis has previously shown a large potential benefit for implementation of digesters on US dairy farms (Informa 2013), emphasizing in particular the potential economic benefits that might be gained through taking advantage of the excess capacity of these digesters to produce fuel from other organic matter, such as collected food waste. In addition, the financial potential to market the co-product of digesters as a landscaping material (replacement to peat moss) is also explored. In total, the potential economic benefits of implementing these systems on dairy farms are estimated to be in the range of $3 billion.

Complementary to the economic analysis, the objective of this research was to use environmental life cycle assessment to validate and to examine the effectiveness of the strategy of diverting food waste to co-digestion with dairy manure as a solution for reducing greenhouse gas emissions and other environmental impacts. The system analyzed forms an example of how a circular economy concept is possible within the food production chain, with wastes from food production re-entering the food production system in a way that supports the solution environmental problems at earlier stages of production. The system also provides linkages to other industrial systems, resulting in a potential for a type of Eco-industrial Park centered around an agricultural system. The quantification of the benefits of this system is based on a life cycle assessment (LCA) approach).

2. Methods

2.1. Scenarios under study

Worldwide, the dominant methods of waste disposal are landfills and open dumps. According to U.S. EPA 2012 MSW Characterization Reports (US EPA 2012a), food waste is the largest category of municipal solid waste (MSW) sent to landfills in the United States, accounting for approximately 21% of the waste stream. In

2012, over 30 million tons of food waste is sent to landfill in the US. Of the less than 5% of food waste currently being diverted from landfills, most of it is being composted to produce fertilizer. In this study, the following three systems are analyzed:

a. Landfilling (baseline)
b. Composting
c. Co-digestion of food waste with dairy manure.

In addition to these scenarios for the management of food waste, the benefit is also assessed of using the fiber derived from digesters as a replacement for peat moss in landscaping applications. The present scope does not include consideration of the impact in producing any of the treatment infrastructures for the various options.

2.2. Landfilling

Figure 1 illustrates the methane emissions from landfills based on data provided by US EPA (2012 b). Approximately, 38% of methane is directly emitted to atmosphere, 33% of methane is either flared or oxidized, and 29% of methane is recovered for energy, of which most (74%) is harnessed for electricity generation, 24% is used for heating, and 2% is used for alternative transport fuel (US EPA 2012c) LMOP database).

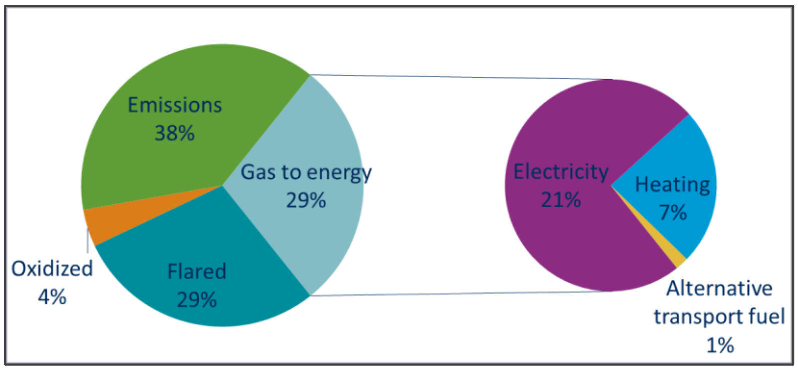

Figure 1. Fate of CH_4 generated by U.S. landfills in 2009

The environmental impact of landfilling food waste was modeled based on an LCA approach using the ecoinvent v2.2 database (processes "disposal, biowaste, 60% water to municipal landfill/CH U") with adaptations made to account for 84% degradation of the materials within a 100 year timespan, following the estimates made in the US EPA (2006) solid waste report. The direct methane emission factor is calculated to be 0.085 kg methane per kg of wet food waste mix treated. The avoided electricity generation, heating and transport fuel were also modeling with the ecoinvent 2.2 database with adaptation from US LCI database and GREET Model.

2.3. Composting

There are several types of composting technologies, including Backyard or Onsite Composting, Aerated (Turned) Windrow Composting, Aerated Static Pile Composting and In-Vessel Composting. ISWM-TINOS (2010) and Morris et al (2011) review recent LCA publications related to composting for more than 30 different sample sizes, results are found with large variability, especially for energy requirement and fugitive emissions. For energy requirement, Rob van Haaren, et al (2010) reported an estimate of 30kWh/ton of wet food waste mix, which is in line with the average energy requirements reported by Diaz et al. (1986, cited in US EPA 2000 report) that estimates 34.4 kWh is required per ton of waste in an MSW composting facility. For fugitive CH_4 and N_2O emissions, default factors from biological treatment for Tier 1 method given by IPCC (2006) were used that is 4 g CH_4/kg waste treated and 0.3 g N_2O/kg waste treated on a wet weight basis. In this study, life cycle inventory data is based on the Rob van Haaren, et al (2010) study for windrow composting technology with fugitive CH_4 and N_2O emission adjusted with data mentioned above.

2.4. Anaerobic digestion

The AgSTAR project (US EPA 2011) analyzed the possibility of installing anaerobic digesters in confined dairy operations of 500 cows or larger, which, at the time of their analysis, amounted to 2,647 dairy operations nationwide. The anaerobic digestion scenario here considers the primary electricity output and co-product (N, P, fiber) produced by disposing of food waste in dairy farm digesters that are also managing manure. The characterization of this system made here relies heavily on the Informa (2013) report National Market Value of Anaerobic Digester Products. This representation attempts to reflect a realistic implementation of the use of digesters for disposal of all accessible food waste within the U.S. on an annual basis. It is assumed that the food waste used in digesters will primarily be commercial food waste and food processing wastes, rather than residential food waste; also the food waste generated on farm (pre-harvest food waste) is not included. Table 1 below lists the potential products for a manure and food waste co-digestion system. Table 2 gives CH_4 emission factors of different feedstock inputs used for anaerobic digesters.

Table 1.Potential Production and Value of Products and Co-Products for co-digestion of manure and food waste in 2,647 Dairy Anaerobic Digesters.

Inputs and assumptions[a]	**Manure+ Food waste**	**Manure**	**Food waste**	**Unit**	**Avoided burden**
Number of cows	3,974,143	3,974,143		Number	
Manure	108,792,165	108,792,165		US tons/year	
Food waste	19,849,474		19,849,474	US tons/year	
Output					
Electricity production	11,701,222	6,375,637	5,325,585	MWh/year	Electricity production, US average
Recovered Nitrogen	331,163	176,337	154,826	US tons/year	Nitrogen production, US average
Recovered Phosphorus	108,782	57,174	51,608	US tons/year	Phosphorus production, US average
Nutrient enriched Fiber	30,111,422	30,111,422		US tons/year	Horticultural peat moss

[a] Data comes from Informa (2013) report.

Table 2.Methane emission factors for different composition of inputs for anaerobic digesters

Type of input	**Quantity**	**Unit**
Manure only (wet)	0.0101	kg CH_4/kg treated
Manure and food waste (wet)	0.0140	kg CH_4/kg treated
Food waste mix only (wet)	0.0353	kg CH_4/kg treated

The methane calculation follows the calculations done in the Ag STAR study (US EPA 2011). The calculation is based on volatile solids (VS) excretion by cattle. This calculation includes a weighted average methane conversion factor based on the manure management systems used on these dairies. EPA provided those estimates by state, but they effectively reduce the methane used in the calculation of the GHG credits by a factor ranging from 35% to 76%, with a national average of 58%.

2.5. Modelling impact of operating digesters and avoided burdens

2.5.1. Impact of operating digester systems and avoided burden from energy and nutrient products

The impact of operating digester systems are modelled based on the ecoinvent v2.2 dataset "electricity, at cogen with biogas engine, allocation exergy/kWh/CH" with adaptations to reflect the biogas generation from food waste.

Methane emissions from dairy manure are assumed to be 100% emitted to air if they are not managed by anaerobic digesters. The avoided burdens associated with energy and nutrient production are modeled with ecoinvent v2.2 datasets as described in Table 1.

2.5.2. Avoided burden from replacing peat moss with digester-derived fibers

There are three main uses for anaerobic digested fiber from dairies. Digested fiber is used for animal bedding, land application to provide plant nutrients, and as a peat moss replacement (Informa 2013). Here, we assume all digester fibers produced are used as peat moss replacement. The Informa report made state-by-state assumptions regarding the fiber that would be available as a peat moss replacement, estimating that of the 18,843,757 cubic yards of fiber produced by plug flow digesters, 16 million cubic yards could be used as peat moss replacement.

Table 3 provides the volume consumed for different types of horticultural peat moss consumption in US in 2011 based on USGS statistics. In total, nearly 6.8 million cubic yards of peat moss is consumed annually in US for horticulture. Most of this volume is imported from Canada. The fiber that goes to peat moss replacement will be 52.8% of the total digester fiber produced. In this study, the maximum benefits are estimated based on future scenario assuming the peat moss market will reach 16 million cubic yards.

Table 3. Different type of peat moss consumed in US in 2011 (USGS statistics)

Type of peat moss consumed in US 2011	**Quantity[a] (cubic yards)**
Canada Sphagnum moss	6,503,569
US Sphagnum moss	289,057
Other import	190,881
Peat moss total	6,792,626

[a] Source: USGS statistics http://minerals.usgs.gov/minerals/pubs/commodity/peat/

The peat life cycle includes harvest, packaging, transport, use, disposal, as well as the in-situ decomposition from the harvest site. For environmental impact of horticultural peat moss production and use, we compared both European (Quantis 2012a) and Canadian peat moss (CIRAIG 2006) studies. Both studies show that peat decomposition during use and disposal stages contributes the majority of climate change impact across the peat moss life cycle (175-180 kg CO_2e/ m^3 of black peat moss). Contributions from other life cycle stage are relatively small or negligible in the European peat moss study. However, in-situ decomposition contributes ~60 kg CO_2e/m^3 peat moss in Canadian horticultural sphagnum peat study, which accounts for peat oxidation from the opening of the harvesting site until its restoration, considering that 50% of the sites are restored after the product cycle and 50% are rehabilitated. Detailed study on peat moss replacement can be found in Quantis (2012b) report (URL: http://www.usdairy.com/~/media/usd/public/digesterfiberstudyquantis.pdf.pdf)

2.6. Impact assessment method

The impact assessment methodology used in this study is based on IMPACT 2002+ vQ2.21, adapted by Quantis to included Water Withdrawal indicator that is the sum fresh water (drinking water, irrigation and sea water. Our results will focus on climate change, water withdrawal and three areas of protection (human health, ecosystem quality and resource depletion). Although the presentation of results focusses on these endpoints, a complete interpretation should also consider the contributing results at the midpoint level and some discussion of midpoint results is included here where relevant to the interpretation. Further details are found at http://www.quantis-intl.com/pdf/IMPACT2002_UserGuide _for_vQ2.21.pdf

3. Results and Discussions

3.1. Detailed results for climate change

Figure summarizes the estimated climate change benefit (CO_2e) of co-digestion of food waste and dairy manures that could potentially be provided by 2,647 digesters, if they were installed in large US dairy operations nationwide and produced the products used in the ways described above. Each bar shows the contribution of a different aspect of the digester + avoided burdens system to the total net impact. Beneficial contributions appear on the positive y-axis, while detrimental contributions appear on the negative y-axis. Compared to landfill of food waste and direct methane emissions from manure, the potential benefit of co-digestion of 18 Million MT of food waste with manures in 2647 dairy farm digesters in US for a year equates to avoiding release of greenhouse gases equivalent to 50 million metric tons of CO_2e.

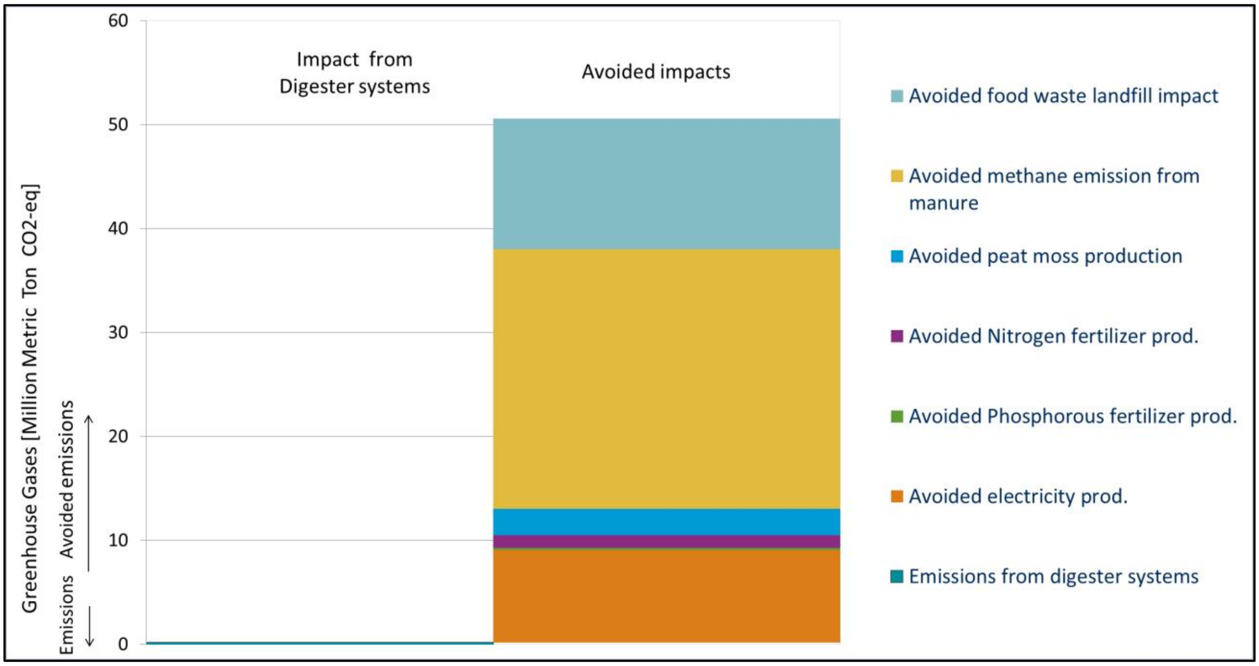

Figure 2. Contribution of different life cycle stages to climate change benefits for co-digestion of food waste with manures system vs. food waste landfill & direct methane emissions from manure (Positive value: beneficial/credits; Negative value: detrimental/impact)

For all scenarios, the avoided fugitive methane emissions from dairy manure management provide the largest climate change benefit (25 million metric ton CO_2e), by converting all biogenic methane that would otherwise be emitted into air to energy. Diversion of food waste from landfill provides the second largest climate change benefit (12 million metric ton CO_2e). US EPA (2012b) reports that 38% of landfill methane is emitted directly to air, and avoiding this release also provides substantial climate change benefit. The third largest climate change benefit (9 million metric ton CO_2e) is due to using the biogas harvested from digesters to replace electricity production.

The impacts of producing the biogas and then converting it to electricity are shown in Figure 2 as 'Emissions from digester systems'. It should be noted that landfill gas is harvested from landfills in the US at a rate of roughly 28%, and largely converted to electricity. When food waste is diverted from landfills, the beneficial use of the landfill gas is also lost. This loss of recovered landfill gas to energy has been subtracted from the food waste landfill benefits shown.

Finally, during the digestion process, nitrogen and phosphorous are recovered, and as a result the digester systems are credited with the avoided impact of average nitrogen and phosphorous fertilizer production in the US. Table Table 4 details the potential positive and negative (beneficial and detrimental) environmental impacts of food waste and manure disposal in landfills, compost and digesters, and the difference among these scenarios. Landfill and composting of food waste generates environmental impact for climate change and ecosystem quality but provides a net benefit for resources due to the harvested landfill gas for electricity and heat, which avoids the fossil fuel use associated with conventional sources for electricity and heat. Composting also shows a net impact in the category of human health effects of pollution, whereas landfilling shows a small net befit in this category. In contrast to landfilling and composting, digestion of food waste and manure causes benefits for all the impact categories examined here.

Table 4: Potential environmental profile of baseline landfill and compost relative to dairy farm co-digestion system (Positive value: beneficial/credits; Negative value: detrimental/impact)

Impact category	Unit[b]	Baseline: Landfill	Alternative: Compost	Alternative: Digester	Compost vs. landfill	Digester vs. Compost	Digester vs. Landfill
Climate Change[a]	MMT CO_2 e	-13	-3.4	37	9.1	41	50
Human Health	DALY	0.22	-4.3	7.2	-4.5	11	7
Ecosystem	Million PDF.m^2.yr	-140	-700	1400	560	2100	1500
Resources	Million MJ Primary	11	1.7	190	-9.7	190	180
Water Withdrawal	Million m^3	17	7.1	340	-10	330	320

a.Climate change result for digester systems also includes 21 MMT CO_2e. benefits from avoided methane emission from dairy manure management. By excluding this benefit, digester is still preferable to other options

b. Abbreviations: MMT= million metric tons

The results indicate that digester disposal is preferable to landfill and compost for all environmental impact categories when biogas is used for electricity generation.

3.2. Summary of results for endpoint impact categories

Figure 3 provides impact results for indicators in addition to climate change for all options under evaluation. The comparative advantage of anaerobic digesters also holds for all endpoint environmental impact categories examined.

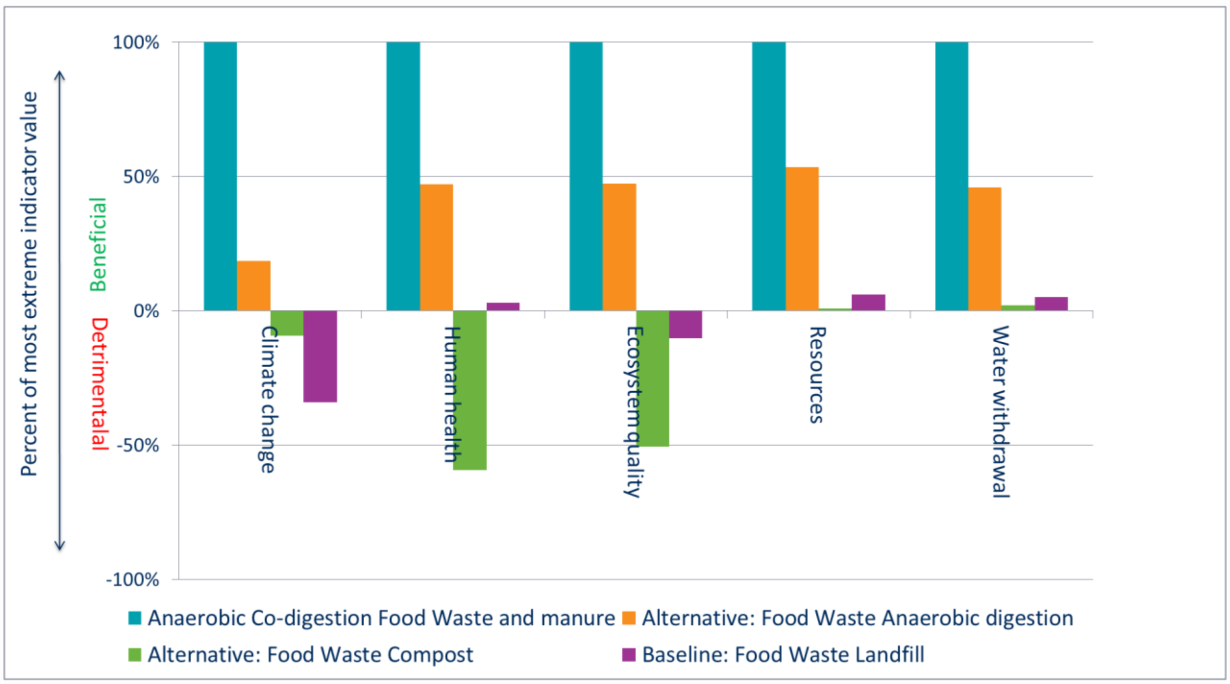

Figure 3. Multi-indicator environmental evaluation of routes of disposing food waste (and/or manure) (IMPACT 2002+ VQ2.2)

4. Conclusion

The findings indicate that for each impact category examined (including climate change, human health, ecosystems and resources), co-digestion of food waste with dairy manure is preferable to landfill disposal and composting for most environmental indicators. In terms of climate impacts particularly, diversion of this food waste from landfill to digesters could avoid the release of greenhouse gases equivalent to between 50 million metric tons of CO_2e. This equates to taking 10 million cars off of the road for a year or to reducing U.S. annual methane emissions by 7%.

Dairy farm digesters are proven to be not only a financially cost-effective but also environmentally favorable business model to provide opportunities for dairies, food processors and retailers. The digesters can play an important role to cultivate the circular industrial economy for food and agriculture industry and also an effective strategy to support achieving greenhouses gas reduction goals in this U.S.

5. References

Climate Action Plan - Strategy to Cut Methane Emissions (2014) http://www.whitehouse.gov/sites/default/files/strategy_to_reduce_methane_emissions_2014-03-28_final.pdf

ecoinvent v2.2 http://www.ecoinvent.ch/

GREET Model http://greet.es.anl.gov/

Humbert, S. et al (2012) IMPACT 2002+ vQ2.2: User Guide, available at http://www.quantis-intl.com/pdf/IMPACT2002_UserGuide_for_vQ2.2.pdf

Interuniversity Research Centre for the Life Cycle of Products, Processes and Services (CIRAIG) (2006) Quantitative environmental information on the life cycle of Canadian sphagnum peat in horticulture, available at http://www.tourbehorticole.com/en/pdf/cycle.pdf

Informa 2013, National market value of anaerobic digester products, prepared for the Innovation Center for U.S. Dairy, available at: http://www.usdairy.com/~/media/usd/public/nationalmarketvalueofanaerobicdigesterproducts.pdf.ashx

IPCC (2006) Guidelines for National Greenhouse Gas Inventories Chapter 4: Biological Treatment of Solid Waste http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_4_Ch4_Bio_Treat.pdf

ISWM-TINOS (2010) Deliverable 1-4: LCA studies for composting and anaerobic digestion units http://uest.ntua.gr/iswm-tinos/uploads/d1_4_ISWM_TINOS_english_report.pdf

Jeffrey Morris, H. Scott Matthews, et al. (2011) Review of LCAs on Organics Management Methods & Development of an Environmental Hierarchy. ISBN: 978-0-7785-9519-9 (On-line Edition) http://environment.gov.ab.ca/info/posting.asp?assetid=8350&categoryid=20

Niels Jungbluth, et al (2007) ecoinvent report No. 17 Life Cycle Inventories of bioenergy

Quantis (2012a) Comparative life cycle assessment of horticultural growing media based on peat and other growing media constituents, Prepared for EPAGMA, available at http://www.epagma.eu/default/home/news-publications/news/Files/MainBloc/EPAGMA_Growing-media-LCA_Final-report%20_2012-01-17_Quantis.pdf

Quantis (2012b) Preliminary assessment of the environmental advantages of disposal of food waste through co-fermentation with cow manure in the United States, Prepared for Innovation Center for U.S. Dairy, available at Informa (2013) National market value of anaerobic digester products, prepared for the Innovation Center for U.S. Dairy Appendix B: http://www.usdairy.com/~/media/usd/public/nationalmarketvalueofanaerobicdigesterproducts.pdf.ashx

Quantis (2012c) Preliminary assessment of the environmental advantages of replacing horticultural peat moss with dairy farm digester-derived fiber in the United States, available at http://www.usdairy.com/~/media/usd/public/digesterfiberstudyquantis.pdf.ashx

R. van Haaren, N.J. Themelis, M. Barlaz (2010) LCA comparison of windrow composting of yard wastes with use as alternative daily cover (ADC).Waste Management 30 (12): 2649-2656

U.S. Environmental Protection Agency (USEPA) (2000) Life Cycle Inventory and Cost Model for Mixed Municipal and Yard Waste Composting https://mswdst.rti.org/docs/Compost_Model_OCR.pdf

U.S. Environmental Protection Agency (USEPA) (2006) Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks. 3rd Edition. September 2006.

U.S. Environmental Protection Agency (USEPA) (2009) Opportunities to Reduce Greenhouse Gas Emissions through Materials and Land Management Practices, available at: http://www.epa.gov/oswer/docs/ghg_land_and_materials_management.pdf

U.S. Environmental Protection Agency (USEPA) (2010) Co-Digestion Economic Analysis Tool (CoEAT) http://www.epa.gov/region9/organics/coeat/index.html

U.S. Environmental Protection Agency (USEPA) (2011) Market Opportunities for STAR Biogas Recovery Systems at U.S. Livestock Facilities, available at: http://www.epa.gov/agstar/documents/biogas_recovery_systems_screenres.pdf

U.S. Environmental Protection Agency (USEPA) (2012a) MSW Characterization Reports http://www.epa.gov/epawaste/nonhaz/municipal/msw99.htm

U.S. Environmental Protection Agency (USEPA) (2012b) Chapter 8: Waste in Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010. Table 8-4. http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2012-Chapter-8-Waste.pdf

U.S. Environmental Protection Agency (USEPA) (2012c) Landfill Methane Outreach Program LMOP landfill and project database http://www.epa.gov/lmop/documents/xls/lmopdata.xls

US LCI database http://www.nrel.gov/lci/

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