

Introduction to Anaerobic Digestion

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Dairy formed a natural focus for the Climate Friendly Farming™ Project because of the industry's significance in Washington. As the second most valuable agricultural industry in the state, it generates nearly \$900 million in revenue annually from approximately 450 dairies and 275,000 wet cow equivalents (WSDA, 2006). As such, Washington State ranks 10th nationally in milk production, producing 3.2% of the nation's milk supply (USDA-NASS, 2006).

Beyond economic import, greenhouse-gas-related environmental concerns make dairy central to any effort to make farming more climate friendly. Within Washington State, 30% of dairy farms have more than 500 cows. Nationally, over 50% of dairy operations have more than 500 cows, and the number continues to increase at an annual rate of 20% (USDA-NASS, 2002). Although large dairies or concentrated animal feeding operations (CAFOs) provide economies of scale and milk production efficiencies, the growth of CAFOs elicits climate change and other environmental concerns, particularly in regard to manure management.

Climate Change Impacts from Dairy CAFOs

Dairy farming results in both direct and indirect emissions of greenhouse gases, at every step along the production process. Methane gas (CH₄), a greenhouse gas with 21 times the effect of carbon dioxide, is produced during enteric fermentation, the digestion process unique to cows and other ruminants. Methane is also released from manure when it is stored under conditions that enhance anaerobic decomposition, including wastewater lagoons. Because lagoons are a common manure management strategy for CAFOs, the U.S. EPA (2008) estimates that from 1990-2006, methane emissions from dairy operations rose 34% as the number of CAFOs increased.

Nitrous oxide (N₂O), a gas that causes 298 times as much global warming as carbon dioxide, and that also depletes ozone (Ravishankara et al., 2009), is released both directly and indirectly during storage and field application of the manure. Presently, an estimated 40% of all N₂O emissions are anthropogenic, primarily occurring from agriculture, with emissions rising at ¼ of percent per year (IPCC, 2007).

Finally, carbon dioxide (CO₂) emissions result from fertilizer synthesis, farm diesel use and transportation of feeds, etc. Table 2.1 below summarizes the total GHG emissions from CAFO dairies operating in cold climates such as Washington State, as estimated in the literature, to provide context for the possible reductions resulting from technologies and practices researched and demonstrated in this CFF Project.

Table 2.1: CAFO dairy GHG emissions (minus soil C, machinery and building construction)

Source	Washington Scrape Lagoon MT CO ₂ e/cow yr ^a
Enteric CH ₄	2.88 ^b
Manure Management CH ₄	4.89 ^b
N ₂ O (direct, indirect, grazing and manure management)	2.44 ^c
CO ₂ (fertilizer synthesis, diesel use, transportation)	0.70 ^c
<i>Total GHG CO₂ equivalents</i>	10.90

^a MT = metric tons (1 MT = 1 Mg)

^b (US-EPA, 2008)

^c (Olesen et al., 2006)

Manure Management, Climate Impacts, and Other Environmental Concerns

As these estimates show, current manure management strategies are a central cause of the negative climate impacts of dairies. At a production rate of 15 wet tons of manure/cow/yr (ASAE, 2005), Washington State dairies produce over 4 million wet tons of manure annually. In addition to the sheer volume, the manure's consistency (approximately 15% total solids) makes it difficult to pump or move around the farm, hampering manure management efforts. Currently, dairy producers typically collect the manure via flush or scrape diluting systems and store the resulting wastewater in liquid/slurry lagoons until specific regional regulations allow for their direct application to fields (Meyer et al., 1997). In Washington State, roughly 11,000 gallons of dairy manure wastewater are produced every minute, resulting in over 6 billion gallons of manure wastewater stored in lagoons each year.

Besides generating greenhouse gases through direct and indirect mechanisms, the dilution, long-term open-air storage, and field application of this immense volume of nutrient-rich manure contributes to non-climate environmental problems, including odor, air quality, water quality, pathogen transfer, and nutrient management issues (US-EPA, 1998). Table 2.2 below quantifies the production rates and mass quantities for some of the most problematic manure constituents and summarizes the concerns associated with their presence.

Table 2.2: Dairy manure constituents of concern

Parameter	Production Rate (lbs/cow day) ^a	Washington (tons/yr)	Concern
Total Nitrogen	0.36	18,000	climate, water quality, crops
Ammonia	0.17	8,500	climate, odor, water & air quality, crops
Phosphorous	0.048	2,500	climate, water quality, crops
Volatile Solids	8.1	400,000	climate, odor, air & water quality, crops

^a (ASAE, 2005)

Manure volatile solids (VS), the most copious of these constituents, contribute to a variety of problems. Through physical release and biological degradation, VS result in odorous emissions of chemicals including, among others, hydrogen sulfide (H₂S), volatile fatty acids (acetate, propionate, butyrate, etc.), and ammonia (NH₃). These gaseous chemicals create nuisance odors and result in severe air quality and health concerns. For example, ammonia emissions can harm farm workers and nearby residents but can also interact with other air constituents to produce particulate matter concentrations (US-EPA, 2004) known to be detrimental to human health. Animal operations are the major source of these emissions, contributing 81% of all ammonia emissions in the U.S. (Battye et al., 1994). Several CAFO dairy regions in the US, including the Yakima region of Washington State, presently exceed the 15 µg/m³ annual and/or 35 µg/m³ twenty-four hour PM 2.5 Standard (US-EPA, 2004).

The total amount of nitrogen and phosphorous in the manure is also problematic. Because these nutrients are expensive to economically transport to distant fields in their liquid state (Heathwaite et al., 2000), they are normally spread as close as reasonably possible, where they often cause localized nutrient overloading. Approximately 36% of all CAFO dairies are in a state of nitrogen overload, while even more, 55%, suffer from phosphorous overload (USDA-APHIS, 2004). In the meantime, much of the world's cropped farmland is nutrient-deficient, requiring fossil-fuel based inorganic fertilizers whose production results in negative impacts to the environment and climate. The climate impact is quite significant; the latest IPCC report estimates that fertilizer production is directly responsible for about 1.2% of global GHG emissions (Swaminathan and Sukalac, 2004, as cited by IPCC, 2007).¹

Excess nutrients from overloading negatively impact crop production and are more likely to be released to surface waters, where they threaten water quality. Specific water quality threats include ionic ammonia and its inorganic derivatives, nitrite and nitrate, which are harmful to both human and aquatic animals, with ammonia being toxic to fish, nitrite being a known carcinogen, and nitrate capable of causing blue baby syndrome and pregnant miscarriage (US-EPA, 1996). Meanwhile, phosphorous can lead to eutrophication, the leading cause of impaired water quality in the US (US-EPA, 1996). The consequences of eutrophication include algal blooms, low levels of dissolved oxygen, fish kills, turbidity, and shifts in plant and animal populations in surface waters.

Lastly, dairy manures often contain numerous human and animal pathogens such as *Salmonella* spp., *Escherichia coli* O157:H7, *Listeria monocytogenes*, *Mycobacterium avium* subsp. *paratuberculosis* (*Mycobacterium paratuberculosis*), *Cryptosporidium parvum*, and *Giardia* spp. which have been implicated as contaminants of agricultural products (Grewal et al., 2006).

¹ Except for fertilizer emissions resulting from fertilizer use on dairy farms, these impacts are not included in the calculation of Washington State CAFO dairy emissions presented above, as the emissions mostly occur on other farms.

Dairy CAFO Concerns in Relation to Global Environmental Stresses

Dairy CAFOs have multiple negative environmental and climate impacts, and in fact, are central causes of some of the most important environmental issues of our day. In a recent article in *Nature*, Rockstrom et al (2009) proposed safe operating boundaries for Earth regarding ten specific environmental threats facing the planet. Notably, CAFO dairies contribute to three of the top four areas of greatest threat including nitrogen and phosphorous cycle misuse and climate change. Although the primary purpose of the CFF Project has been to minimize the climate change impacts of agriculture, these impacts are inextricably linked with other issues such as nutrient management. By addressing these problems holistically, we aim to generate solutions that will help address producers' most pressing concerns, and make a variety of positive environmental impacts.

CFF™ Dairy Component – A Focus on AD Technology for Manure Management

Many of the environmental threats discussed above can be in part alleviated through new manure management technologies for CAFO dairies. Modern anaerobic digestion (AD) technology is a known wastewater treatment approach that converts complex organic material to biogas containing CH₄ under anaerobic conditions (Figure 2.1). In essence, the process biologically mineralizes a fraction of the organic carbon into inorganic carbon in the form of biogas, simultaneously diminishing odors, stabilizing waste, decreasing pathogen counts, and reducing GHG emissions (Martin and Roos, 2007; US-EPA, 2004; US-EPA, 2005; US-EPA, 2008). Besides the environmental benefits that the process provides, the CH₄-rich biogas that is produced is combustible and can be used to generate combined heat and power (CHP) (US-EPA, 2006).

As a result of these potential benefits, there has been increasing interest in AD on dairy farms. The number of new farms adopting AD has grown 60% annually since 2000, and there are now over 100 dairy digesters in operation in the U.S., servicing approximately 150,000 wet cow equivalents, providing an installed generating capacity of 21.5 MW, and reducing greenhouse gas emissions by 0.44 MMT of CO₂e/yr (US-EPA, 2007).² As impressive as this is, the present digesters service only 3.5% and 4.4% of potential farms and cows, respectively (based upon an assumption that AD installation is only economically advantageous for dairies with 500 cows or more) (US-EPA, 2006). Barriers to adoption include the intensive capital cost of the existing commercial systems, with typical heated and constructed cogeneration systems costing as much as \$1,500/cow for a 500-2,000 cow operation (Andgar, 2008). Clearly, scientific and engineering research and development still has much to contribute in terms of enhancing biological activity and performance in order to reduce the size and capital costs of installed systems.

² MT = metric tons (1 MT = 1 Mg); MMT = million metric tons (1 MMT = 1 Tg)

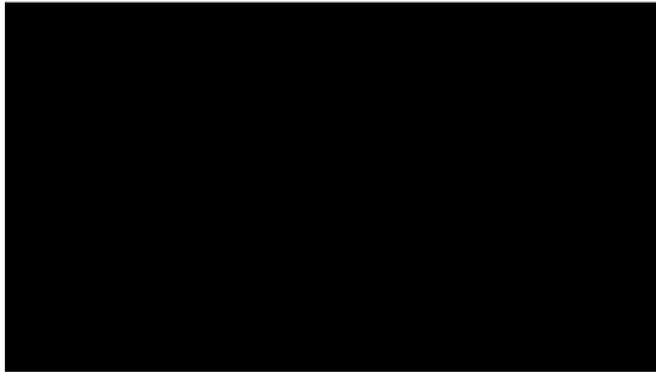


Figure 2.1: Anaerobic digestion process

Another factor contributing to relatively low adoption rates rests in the fact that current AD technology does little to control nutrient overloading, an issue that dairy owners generally identify as one of their more important environmental concerns, and one with potentially negative economic impacts on their business. If technologies could be developed to concentrate and recover the nutrients present in manure wastewater, then they could conceivably be sold to other locations, eliminating nutrient overload problems on farm. In addition, these products could replace fossil fuel-based inorganic fertilizer use in other locations, generating considerable climate benefits, and potential offsets that could be sold by dairy farms. Thus, the CFF vision for next generation manure management on CAFO dairies incorporates AD technology with nutrient recovery components, providing a package that is economically viable, thus improving adoption rates and providing enhanced social benefits (Figure 2.2).

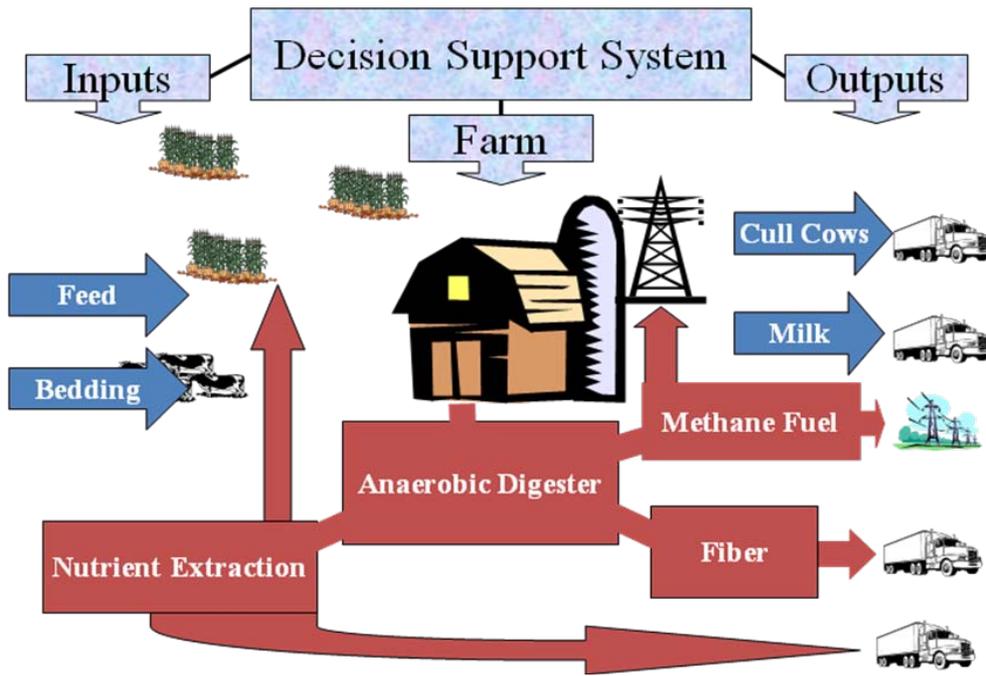


Figure 2.2: Next generation dairy farm and manure management system

A commercial-scale digester formed a key component of the CFF AD development strategy. This digester allowed for a solid understanding of existing technology capabilities and weaknesses, and provided the full-scale test-bed necessary to catalyze applied technology breakthroughs in engineering design, biological and nutrient chemistry, systems development and value-added product advancement at a commercial-ready scale. Lastly, the operational digester allowed for an extensive outreach program, thus catalyzing adoption by other farmers. Particular research agendas for the project included the following:

- Baseline performance monitoring and economic analysis of an initial commercial system;
- Laboratory and bench-scale testing of new technologies (enhanced digester performance, improved biogas quality, nutrient recovery, system integration, etc.) to improve upon deficiencies noted in baseline monitoring;
- Scaled testing of successful technologies within the commercial test-bed facility;
- Generation of individual and system models demonstrating the environmental and climate impacts of new technology adoption.

AD technology is only one of many biomass related renewable energy technologies that have received considerable commercial and scientific interest over the last ten years. Corn ethanol plants and virgin/waste-oil biodiesel refineries were one of the first technologies to emerge, with considerable early growth followed by numerous closures as global economic pressures played out. Meanwhile, second and third generation biofuel projects involving cellulosic and algal biomass continue at bench and near-commercial scale. Each of these technologies promises a combination of enhanced biomass or waste utilization, decreased dependence on fossil fuels, increased energy independence and economic development, but it remains to be seen whether they can fully deliver on that promise. The CFF incorporated work on a variety of bio-energy issues of relevance to the state and region, with results that are summarized in the Bioenergy Section.

AD has been placed at the center of CFF efforts because we feel it has perhaps the greatest chance among the various bioenergy alternatives to achieve long-term commercial viability at scale. AD technology is also distinguished by its potential for multiple beneficial climate impacts: reducing the emissions associated with manure management, displacing the emissions associated with GHG-intensive products such as peat moss and chemical fertilizers through byproducts including peat substitute and bio-fertilizers, and displacing energy emissions through biogas that can be used directly for combined heat and power or further refined into a vehicle fuel. The chapters within this section are a summary of the key findings and accomplishments regarding anaerobic digestion by a team of multi-disciplinary researchers and outreach specialists.

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