Lessons Learned About Anaerobic Digestion

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Introduction

The Climate Friendly Farming (CFF) Project helped establish that anaerobic digestion (AD) technology could in fact be the center-piece of a more climate-friendly dairy farming system in the future. While it was well established that AD technology could reduce CH_4 emissions from stored liquid manure and be utilized to produce renewable energy, it was clear that a major research, development and education initiative was needed to overcome barriers to the widespread application of the technology in the Pacific Northwest (PNW). The CFF Project team, in collaboration with industry, non-governmental organization, and governmental agency partners launched a comprehensive program to evaluate existing and develop new AD technology, better understand the economic drivers for AD, improve the management of AD systems (including improved understanding of the benefits of co-digesting manure and food processing wastes), research and develop co-product technology for recovering nutrient and fiber-based products, explore options for better utilization of biogas, provide education and commercial demonstrations of technology, and developing effective public policy to support rapid deployment of AD technology to meet organic waste reduction, greenhouse gas (GHG) mitigation and renewable energy generation goals.

Our assessment (Bishop, et.al. in review) and communication with dairy industry leaders in the PNW made it clear that successful deployment of AD technology would depend on whether the AD technology became a “next generation” manure management platform that effectively resolved nutrient management, air quality and financial performance concerns for the dairy as well as meeting GHG mitigation and renewable energy generation expectations. As it was most eloquently stated by a Washington dairy farmer, “We don’t *necessarily* want to be energy producers. We want to milk cows. But to milk cows, we have to deal with manure. If an anaerobic digester can help us solve our manure problems and keep us in the business of producing milk, then producing energy and mitigating GHG emissions will be welcome side benefits.” Therefore, to achieve our goal of widespread deployment of AD technology, we needed to create a package that:

1. Ensure cost-effective, simple, reliable AD projects that could be managed “on-farm”.

2. Improve the economic performance of AD through improvements in design to reduce capital costs, increased understanding of the AD process to improve performance efficiency, and the development of value-added revenue generating products, including higher value uses for fuel than electricity.

3. Integrate nutrient recovery technologies and decision support to ensure that on-farm nutrient management goals are met.

4. Ensure that deployed technology performs as expected and meets GHG mitigation and waste management goals.

5. Support the development of effective public policy (e.g. incentives, regulations) that would enable rapid adoption of AD.

Specific Accomplishments of the CFF Anaerobic Digestion Effort

CFF AD accomplishments can be categorized into: (1) quantity of scientific and engineering knowledge that advances the fields of AD, manure management and renewable energy; (2) examples of new technology development; (3) role research/outreach has on AD adoption; and (4) quantifiable effects on capital/operating costs, air and water quality, and GHG mitigation.

Advancing knowledge in AD science, engineering and management

This section summarizes our most important scientific and engineering advancements. In the order presented in chapters 2 – 11 of this report, these include:

- Improved understanding of the effect of co-digestion on technical and economic performance and nutrient management in commercial AD systems. Data and summaries developed across the long-term testing represent a wealth of data available at commercial scale that simply did not exist for US digesters and was incomplete in European studies.
- Improved and updated understanding of economic viability of AD in the US, exploring a variety of alternative investment and management scenarios.
- Generated modeling processes capable of converting simple wastewater parameters and flow rates into outputs on co-digestion capable of informing project developers on design and management of AD projects, including the impact of feedstocks, feed mixes, and loading rates on system performance, reactor and generator sizing, and biogas generation.
- Improved understanding of the characteristics and variability of digested dairy fiber, leading to refined processing standards that enable use of treated fiber as a horticultural grade potting substrate.
- Improve the understanding of the fate of phosphorous during AD of dairy cow manure and how this impacts the technologies used to remove and recover phosphorous from the waste effluent, specifically the role of Ca and Mg ions and their relationship in binding inorganic phosphorous within the manure effluent was more completely understood.
- Improved understanding of the complexities of the CO_2/bicarbonate equilibrium within manure and how this is affected by methanogenic enzymes, mixing patterns, and aeration. Understanding and informed

manipulation of this relationship has led to improved capabilities in cost-effective solids and phosphorous removal.
- Manipulation of mathematical models in fluid transfer related to ammonia stripping and recovery, has led to new engineering designs for a next generation ammonia recovery and biogas purification technology.
- Production of both field-sampled and model-simulated data regarding the impact of storage and application of manures to fields, greatly enhancing our understanding of the GHG consequences *after* AD.
- Linked rumen hydraulics and microbiology to the fate of micro-organisms in manure, leading to the development of a new class of AD reactors focused on using natural fibrous biomass carriers for improved biomass retention and improved reactor kinetics.

New Technology Development

Important and distinctly new technologies have resulted from the AD research. In the order presented in chapters 2 – 11 of this report, these include:

- A *beta*-version of a co-digestion software tool, GISCOD, for AD project developers.
- A patented and commercial-ready process for the conversion of mechanically-separated AD fiber into a horticultural grade potting substrate.
- A commercialized process for de-gassing and recovery of super-saturated CH_4 prior to release from the gas-tight AD vessel
- A patented process for modifying a fluidized-bed struvite crystallizer for recovering phosphorous from AD dairy manure.
- A preliminary patent and new industrial process for simplified P-solids settling and recovery using aeration, pH control and CHP heat in a constructed settling channel.
- A patented, integrated P-recovery and ammonia stripping/ammonia salt recovery process which also scrubs H_2S and CO_2 from biogas.
- A sequential and commercialized approach to reducing AD H_2S concentration from ~2000 parts per million to below 50 parts per million, making biogas fueled CHP generators capable of meeting California's stringent air quality emission standards.
- Preliminary testing on two novel processes for biogas purification and conversion to compressed biomethane
- A preliminary patent on a new high-rate reactor for dilute manure wastewaters using natural manure fibers as support media for bacterial growth
- A preliminary patent on a new high solids anaerobic digester for more stable and efficient digestion of high strength, municipal and industrial solids

Role of Research and Outreach on AD Adoption

Only two AD projects existed in the PNW prior to the CFF Project supporting the establishment of the first dairy AD project in Washington State on the Vander Haak Dairy in Lynden in 2004 (only one of the previous two is still in operation at the Port of Tillamook, OR). Using the Vander Haak Digester as a evaluation, demonstration and outreach platform enabled CFF to provide a unique “kick the tires” tool for enabling industry, government, and non-governmental organizations ready access to a wealth of empirical information and experience to support further deployment in the region. This opportunity has supported development, construction and operation of numerous additional facilities. As of publication, the following 11 PNW projects are either operating or soon to come on line, treating manure from more than 40,000 WCE and installed CHP generating capacity of more than 15 MW:

- Lynden WA: 700 cow co-digestion, approximately 650 KW
- Sunnyside WA: 3,500 cow co-digestion, approximately 2.25 MW
- Rexville WA: 1,200 cows co-digestion, approximately 750 KW
- Qualco, WA: 2,000 cows, approximately 450 KW
- Lynden, WA: Under construction, 2,000 cows, approximately 1.5 MW
- Calgon, OR: 350 cows, approximately 100 KW
- Port of Tilamook, OR: 3,000 cows, approximately 450 KW
- Linn County, OR: 150 tons/day food processing, approximately 1.6 MW
- Dry Creek, ID: 10, 000 cows, approximately 2.25 MW
- Big Sky, ID: 4,700 cows, approximately 1.42 MW
- Double AA, ID: 15,000 cows, approximately 4.26 MW

Direct educational programming was also instrumental in supporting extensive public policy development in favor of AD, including enabling legislation and policy guidance for on-farm co-digestion, enabling legislation for distributed CHP generation, and recommendations and guidance for incentivizing the deployment of AD as a GHG mitigation technology. Outreach activities have directly addressed pressing questions and challenges faced by industry and government in the operation and management of dairy AD projects.

Quantifiable Effects on Capital and Operating Costs, Air and Water quality, and Climate Change

GHG emissions from a typical dairy were summarized in chapter 2 of this report, totaling 10.90 MT CO_2e/cow yr, 45% of which is the result of current manure management strategies. Subsequent chapters have described the GHG mitigation capabilities resulting from use of AD and associated technologies being developed through the project. Table 11.1 summarizes the potential GHG benefit of deployment of the full CFF AD package. The total potential mitigation of 15.76 MT CO_2e / cow / year clearly exceeds the assumed total emissions of the typical Washington dairy, indicating that AD can, in fact, turn a dairy from a net source to a net sink for GHG emissions.

Table 11.1: Summary of greenhouse gas savings from AD co-digestion with nutrient recovery (assumed 70,000 cows, across 40 AD projects, each co-digesting at 20% v/v)

	Total MMt CO_2 e/yr	Total Mt CO_2 e/cow yr
AD methane capture	0.342	4.89
Co-digestion methane capture	0.611	8.73
Electrical offset	0.114	1.63
Peat Replacement using separated fiber	0.019	0.27
Bio-phosphorous from P-solids recovery	0.0031	0.04
Bio-nitrogen from ammonia stripping	0.014	0.20
Total	*1.103*	*15.76*

References

Bishop, C.P., C.R. Shumway and P.R. Wandschneider (in review). Heterogeneity in the Adoption of Anaerobic Digestion Technology: Integrating Economic and Behavioral Theories of Conservation Adoption. Submitted to Land Economics. (Preliminary publication as Agent Heterogeneity in Adoption of Anaerobic Digestion Technology: Integrating Economic, Diffusion and Behavioral Innovation Theory. WSU School of Economic Sciences Working Paper 2008-8).