CONSIDERATIONS FOR INCORPORATING CO-DIGESTION ON DAIRY FARMS

Anaerobic Digestion Systems Series

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Abstract

This publication discusses the impacts of incorporating co-digestion at dairy-based anaerobic digesters. That is, mixing manure with non-manure waste in anaerobic digesters. This information is based on stakeholder perspectives and a literature review of infrastructure, operational upgrades, and related costs and revenues when non-manure wastes are added to dairy digesters.

The Anaerobic Digestion Systems Series provides research-based information to improve decision-making for incorporating, augmenting, and maintaining anaerobic digestion systems for manures and food byproducts.

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Considerations for Incorporating Co-Digestion on Dairy Farms

List of Abbreviations

AD	anaerobic digestion
ATA	anaerobic toxicity assay
BMP	biochemical methane potential
CH_4	methane
CHP	combined heat and power
CSTR	continuous stirred tank reactors
DAF	dissolved air flotation
FOG	fats, oils, and grease
K	potassium
N	nitrogen
NMP	nutrient management plan
P	phosphorus
REC	renewable energy credits
RIN	renewable identification numbers
RNG	renewable natural gas

Introduction

Many dairy digesters currently operating in the United States practice co-digestion. During co-digestion, off-farm organics (also called substrates), are added to anaerobic digesters along with dairy manure to produce renewable energy and other products. The primary motivation for co-digestion is usually increased biogas production, though tipping fees, tax credits, and fiber sales are also generated in many cases (Atandi and Rahman 2012). Because of the potential for increased revenues (Innovation Center for U.S. Dairy 2013), many anaerobic digestion (AD) facilities are considering utilizing co?digestion. These benefits are especially important when received electricity rates for AD are notably low across the nation.

Along with potential revenue increases, costs associated with practicing co-digestion must also be considered by farmers, project developers, regulatory agencies, and others who are evaluating whether co-digestion is a viable option for dairy digesters. The main objective of this manual is to aid decision-making by providing an overview of the engineering design and management issues associated with co-digestion at dairy AD facilities.

To provide an insider's look at design and management considerations, five individuals with extensive experience in co-digestion at dairy digesters were interviewed. The sample size is relatively small because few individuals have technical expertise with co-digestion in the United States, and some of those candidates were not willing to be interviewed. Several of the sources work primarily in the Pacific Northwest where the authors are located; however, to the extent possible, individuals with broader experience throughout the United States were included.

Interviewees included:

[A] a scientist with in-depth knowledge of AD and co-digestion;

[B], [C] two systems engineers who have designed numerous digesters that incorporate substrates;

[D] a dairy farmer who owns and operates a co-digestion facility; and

[E] a project developer who has successfully implemented co-digestion at a number of dairy digesters.

To preserve anonymity, interviewees are labeled as A, B, C, D, and E. Tips from these industry experts are included throughout the manual, cited by the letters denoted above.

This manual assumes a working knowledge of AD, co-digestion, and nutrient recovery. Readers interested in an overview of AD can refer to *Anaerobic Digestion Effluents and Processes: The Basics* (Mitchell et al. 2015). Readers will also likely be interested in a companion publication that discusses considerations relating to choice of substrate, *On-Farm Co-Digestion of Dairy Manure with High Energy Organics* (Kennedy et al. 2015a). More detailed information on permitting and nutrient considerations are covered in *Anaerobic Co-Digestion on Dairies in Washington State: The Solid Waste Handling Permit Exemption* (Yorgey et al. 2011) and *The Rationale for Recovery of Phosphorus and Nitrogen from Dairy Manure* (Yorgey et al. 2014).

Comparing manure-only AD with co-digestion

For co-digestion to be viable, increased revenues must be greater than the added capital and operating costs incurred by co-digestion. To help determine viability, Figure 1 illustrates how the main factors typically associated with co-digestion compare financially to a manure-only baseline scenario. Figure 1 presents the most common co-digestion scenario described during interviews with industry experts. Refer to Table 1 for the accompanying assumptions and related factors that affect the costs and revenues.

To go with Figure 1, Table 2 summarizes the major costs that should be considered when implementing co-digestion. Project developers and others should use Figure 1 and Tables 1 and 2 together, along with the accompanying text, to deepen their understanding of the factors they will need to take into account for feasibility studies or other project-specific analyses.

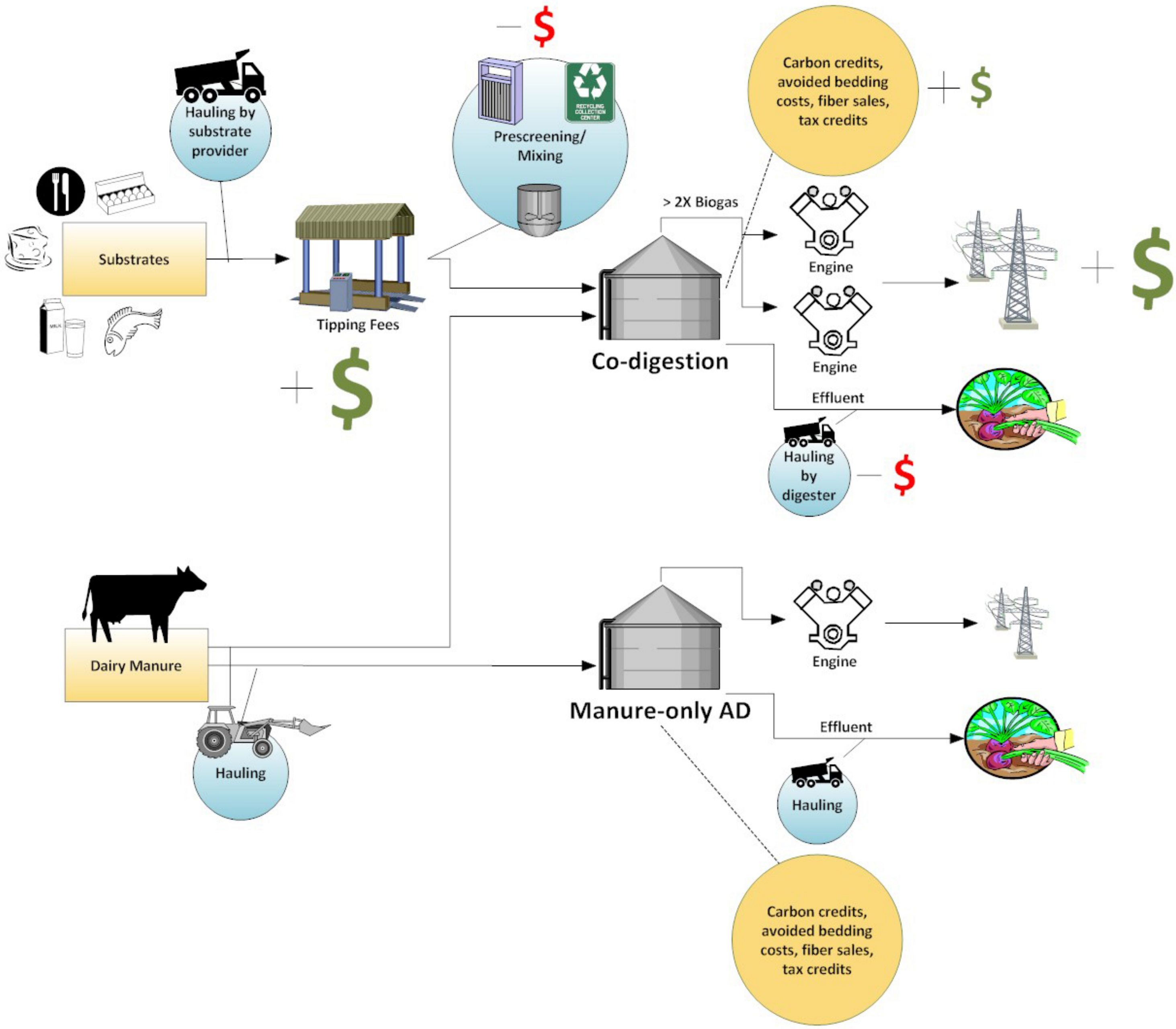

Figure 1. Comparing a typical co-digestion operation (top) with a manure-only AD baseline (bottom) demonstrates differences in both costs and revenues. Increases in costs are noted in red (negative dollar signs), while increases in revenues are noted in green (positive dollar signs). Note the assumptions and related factors (Table 1) that affect the magnitudes of costs and revenues. (Graphic by Nicholas Kennedy.)

Table 1. Assumptions and Related Factors that Affect Costs and Revenues

Assumption	Related Influencing Factor
• Combined heat and power (CHP; currently the main use of biogas at United States dairy digesters) will be produced under both the baseline and co-digestion scenario.	Upgrading CHP to renewable natural gas (RNG) is increasingly of interest.
• Tipping fees are paid by the waste generator to the AD operator for the disposal of organic wastes [E].	Some co-digestion operations do not receive tipping fees, and others pay a small fee for off-farm organics received.
• Nutrient management costs will increase after adding co-digesting substrates [A, D, C].	This could represent additional hauling costs for land application of AD effluent or implementation of nutrient recovery technology (not shown).

Table 2. Capital and operation costs typically encountered when co-digestion is added to a dairy manure AD project

Capital Costs	Operating Costs
• Screening and pre-treating wastes • Mixers and macerators • Buffer tanks • Receiving pits and metering systems • Modifications to generator sets • Infrastructure for safety • Nutrient management • Biogas purification	• Laboratory testing • Contract costs for managing substrate acquisition • Monitoring • Labor related to addressing any substrate co-digestion issues that arise • Hauling • Regulatory compliance

Capital costs

Whether co-digestion is planned from the outset at a new anaerobic digestion facility or added to an existing manure-only digester, co-digestion will likely require many or all of the following additional one-time expenditures to upgrade or install infrastructure or equipment compared to a manure-only baseline.

Screening and pre-treating wastes

Pre-consumer food scraps and food processing wastes are excellent substrates for AD because they generally result in high energy and good synergies when co-digested with dairy manure (e.g., carbon-to-nitrogen ratio, micro- and macronutrient content).

Unfortunately, some pre-consumer materials may be contained within packaging or mixed with inorganic material and are thus inappropriate for direct mixing with manure. One way to ensure that unwanted materials are removed prior to arriving at a digester is via off-farm source separation (Figure 2; [A]). Crushers, shredders, oscillating augers, magnetic separators, bio-separators, screw presses, pulpers, and hydrocyclones are some common technologies used to separate out unwanted material (Sullivan 2012). Technologies like these are used in series to shred packaging (feed hopper), remove inorganics (bio-separator), and blend the leftover material into homogenized, predominately organic, slurries for easy hauling and introduction into digester receiving pits.

Figure 2. Substrates can contain unwanted material such as plastics and bottles (left); prescreening facilities (right) use separation equipment to remove inorganics from organics prior to AD. (Photos courtesy of American Biogas Council.)

It is generally most cost-efficient for dairy-based co-digestion facilities to utilize a third party source separation company or waste hauler for pre-processing [D]. If this is not an option, adding substrates to dairy digesters is usually not recommended because of the high capital and operating costs of on-site source separation and pre-treatment [E].

Industry Tip: The amount of pre-processing (e.g., source separation and pre-treatment) and post-processing (managing nutrients) required for each co-digestion substrate should be carefully considered to adequately predict the costs of co-digestion.

Mixers and macerators

Whether the substrates will be liquids or solids also has important cost implications. Liquid materials have physical characteristics similar to dairy manure, and thus can be dumped into an existing manure receiving pit or pumped directly into a slurry digester, with minimal upgrades needed to the digester or receiving pit [C]. On the other hand, organic wastes with high solids content (e.g., pre-consumer food scraps) typically need to be reduced in size by macerators and then sent to mixers or agitators prior to entering a slurry digester [A, C]. Mechanical mixers are usually added to receiving pits to maintain substrate consistency; augers combine on- and off-farm substrates (Figure 3).

Macerators are all-purpose grinding machines that can reduce the size of substrates, allowing for easier introduction to the digester.

Mechanical agitators are stirring devices often used in continuous stirred tank reactors (CSTR) to maintain mixing and ensure that AD proceeds efficiently. Agitators can also be added to receiving pits to homogenize substrates into slurry prior to introduction to the digester.

Buffer tanks

If the pH of the substrate is 2 or more units above or below the preferred level of 7–8 for anaerobic microorganisms, a buffer tank may be used prior to the receiving pit to increase or decrease the pH of a substrate as needed [C]. (Substrates are typically neutral or on the acidic range, sometimes as low as pH 4.) Examples of acidic substrates include beets, potatoes, corn, maize, straw, grass, wood, and wastes from milk processing, slaughterhouses, and rendering (Steffen et al. 1998).

Receiving pits and metering systems

Because substrates are highly degradable, large spikes in biogas production can occur if they are introduced to the digester all at once. If these spikes are above the accepted flow rates of installed engine and generator sets, biogas flaring may be necessary, causing a loss of potential revenue [A, C].

Figure 3. Mechanical mixers installed in this receiving pit homogenize the slurry (left), while an auger mixes food wastes with dairy manure (right). (Photos courtesy of Jim Jensen and WSU Energy Program.)

Figure 4. Automated covers, placed on top of receiving pits, can be opened for substrate addition (left) and closed to minimize odor release (right). (Photos courtesy of Andgar Corporation.)

To avoid this, most project developers have installed a separate receiving pit for high strength substrates, particularly liquids (Figure 4; [D]). The receiving pit can act as a holding tank and substrates can be introduced using a metering system (e.g., pump on a timer, vibrating conveyor belt on an auger), though with added capital and operation costs [B]. In many cases, particularly for solids, timing substrate delivery so that loads are received over the course of the day can accomplish adequate metering [D, E].

Receiving pits can be fitted with automatic covers to reduce odor and fly production, thus reducing nuisance for neighbors (Figure 4). When high solid substrates are brought to the digester, the cover is lifted. For liquid substrates, the cover can be left partially down and the substrate can flow through the bottom opening into the receiving pit [A]. After substrates have been dumped into the receiving pit, the cover can be lowered to reduce odors. Dedicated tanks, negative air processing buildings, or a combination can also serve as odor and vector controls in lieu of receiving pits.

Modifications to generator sets

Even with appropriate metering, engine and generator sets may need to be added or altered to convert the higher biogas output to energy and capture higher revenues (Figure 5; [A]). Each facility is unique, so careful planning is needed to accurately determine how much biogas production will increase and how many engines and generators will be required.

Most manure-only AD developers factor in extra digester volume and capacity for engine and generator sets so they can handle any unforeseen increase in manure volume. This often means current engine and generator sets can handle the boost in biogas output with only slight modifications.

Figure 5. Three engine and generator sets were added at a co-digestion facility to handle additional biogas production from substrates; the new total output doubled to 6.3 megawatts. (Photo courtesy of DVO, Inc.)

Industry Tip: A buffer tank with a pumping system works best when introducing high-energy liquid substrates, while direct dumping from the hauling truck is a better option when bringing in high-energy solid substrates.

Infrastructure for safety

Infrastructure upgrades for safety at and around receiving pits help protect workers hauling organic wastes to the digester [A, D, E]. The safety measures shown in Figure 6 include fencing, an access road, and protective rails for trucks at the substrate receiving pit.

Both a project developer and a project operator stressed that the most significant safety concern associated with incorporating substrates into an AD operation is increased traffic flow from the hauling trucks [D, E]. Adequate road construction to and from the receiving pit, suitable sight lines, and effective turn-around areas can, together, ensure easy access and minimize congestion and safety issues (Figure 7).

Nutrient management

Especially in the many parts of the United States where dairies are required to have a nutrient management plan (NMP), it is critical to determine how substrates fit into the plan [A, B, C, D, E]. Substrates contain nitrogen (N), phosphorus (P), and potassium (K).

Figure 6. Added safety measures for waste haulers near receiving pits are another capital cost consideration associated with co-digestion. (Photo courtesy of Jim Jensen and WSU Energy Program.)

Figure 7. Trucks hauling substrates to receiving pits should be provided enough space to avoid congestion between haulers. (Photo courtesy of DVO, Inc.)

Thus, when co-digested with dairy manure, the total nutrient flows leaving the digester may increase. Refer to Kennedy et al. (2015a) for more information on substrates.

Increasing nutrient loads may not only increase effluent hauling costs (discussed further, below), but also create regulatory, political, or other significant consequences for dairies in areas where nutrient overloading is a concern. In some cases, it is beneficial to add nutrient recovery technology at the back end of the digester to recover nutrients from AD effluent prior to land application or other disposal (Figure 8). Refer to Yorgey et al. (2014) for more information on nutrient issues at dairy operations and Mitchell et al. (2015) for how to test substrates for nutrient content.

Figure 8. This nutrient recovery system, installed at a dairy anaerobic digester in Lynden, WA, produces ammonium sulfate, P-rich manure fines, and reduced-nutrient effluent. (Photo courtesy of Andgar Corporation.)

Industry Tip: Careful consideration of the potentially significant costs associated with modifying nutrient management plans and hauling additional nutrients off-site is critical to determining whether or not co-digestion will be profitable.

Biogas purification

Biogas produced from the AD of dairy manure consists of methane (CH_4) (55–70%), carbon dioxide (30–45%), water vapor (4–7%), and hydrogen sulfide (300–4,500 ppm) (Liebrand and Ling 2009). Depending on their composition, substrates may increase the amounts of unwanted gases such as carbon dioxide and hydrogen sulfide. In some cases, contaminants are increased to levels that require biogas purification or other strategies to reduce engine and generator set issues [A, B, D, E].

Some substrates release sudden and large amounts of carbon dioxide when they biologically degrade. If this occurs along with a drop in methane content to below 50%, engine and generator sets may set off an alarm or shut down. To minimize this risk and eliminate the need for carbon dioxide removal, substrates should be introduced to the digester at a steady rate or in smaller amounts throughout the day. AD operators can determine the specific changes needed by making gradual adjustments and periodically checking biogas levels or conducting online monitoring of the methane percentages entering the engine and generator sets [D].

A number of substrates can increase hydrogen sulfide production above acceptable limits, leading to corrosion of engine and generator sets when the hydrogen sulfide is combusted. For example, at one digester, the AD of whey, a liquid byproduct of the dairy industry, increased hydrogen sulfide production above the acceptable limit of the engine and generator sets [E]. The digester operator addressed the problem by running a secondary treatment system.

In contrast to whey, some substrates have been shown to reduce the production of hydrogen sulfide, and thus can help ensure that levels stay low. When milk dissolved air flotation (DAF; for thickening) was introduced at one dairy digester, iron contained within the DAF caused the hydrogen sulfide concentration in the biogas to drop markedly [E].

Operating costs

Maintenance for the core AD operation may increase under co-digestion because substrates tend to cause problems with mixers and agitators, and sometimes the digester itself (e.g., clogging, inorganic accumulations, scum formation). In addition, any technologies or infrastructure discussed above that is added to the operation to accommodate co-digestion will require both short- and long-term management (Figure 9).

Monitoring

Although all AD operations require ongoing monitoring to ensure that bacterial populations are being maintained, co-digestion requires a higher level of monitoring because it introduces more highly degradable substrates that are often more variable than manure. These needs are most significant when new substrates are introduced to digesters.

Laboratory testing

Understanding the composition of the substrate prior to its introduction to a dairy digester can help accurately predict how co-digestion will impact the AD process as well as costs and revenues.

Figure 9. Operating costs include maintaining and monitoring equipment to minimize digester failures and inefficiencies. Color-coding of piping helps workers quickly distinguish biogas (yellow) from water (orange, red, and blue). (Photo courtesy of DVO, Inc.)

Important parameters to test include total solids, volatile solids, biochemical methane potential (BMP), total phosphorus, and total ammonia nitrogen. In many cases, an anaerobic toxicity assay (ATA) should be used to reduce the chance of introducing contaminants or bactericides.

Even if no toxic material is present when the substrate is first introduced to the digester, food-processing plants frequently change processes, and compounds may be added that could lead to inhibition. For example, different polymers or wash-down agents in wastes from food or milk processing, DAF, distilleries, and breweries can harm anaerobic bacteria and cause digester upset [E]. If used judiciously, periodic ATAs can help reduce the chance of introducing contaminants or bactericides, saving on overall costs [A, E].

Industry Tip: Inconsistent substrates should be avoided because they can have dramatic effects on a digester over time.

Contract costs

Third party contractors are often utilized to locate and acquire substrates, perform necessary laboratory tests, and work directly with the substrate provider to ensure all substrates are clear of unwanted materials. Third party contractors generally negotiate an ongoing fee with the digester owner, such as a percentage of power sales [A].

Industry Tip: When evaluating the involvement of a third party contractor, consider price as well as the ability to provide reliable services that meet regulatory and legal obligations.

Hauling

One of the largest operating costs associated with co-digestion is truck hauling [D, E]. Hauling costs are incurred to get substrates to the digester and, in many cases, to haul treated or untreated effluent away from the digester for land application.

Although substrate hauling costs to the digester are usually borne by the waste producer, they are often at least partially passed along to the digester operator in the form of reduced tipping fees received by the digester.

Because substrate hauling costs are related to the distance between the substrate source and the digester, one strategy for minimizing these costs is to acquire substrates in close proximity to the digester. Similarly, one of the driving forces for entering agreements to co-digest wastes at farm-based digesters is the potential for reducing hauling costs to far-away landfills [A]. Efficient logistics can also help minimize labor and fuel costs for hauling.

Depending on the existing nutrient management constraints, increases in nutrient levels from substrate addition can significantly increase hauling costs to remove effluent [A, D]. Such cases can help justify investing in nutrient recovery technologies [A, D, E].

Regulatory compliance

Federal law does not require solid waste permits for dairy manure, but when outside organics are brought to a farm for co-digestion, some state regulatory agencies consider the operation to be a waste processing facility and may require a solid waste handling permit. See Yorgey et al. (2011) for details relevant to a permit exemption for co-digestion under specific circumstances in Washington State.

Even when a solid waste handling permit is not required, regulatory oversight may increase, requiring an ongoing investment of time from the digester operator [D]. Fees for permitting, legal advice, or other similar items may also increase.

Revenue potential

Improved and new revenue streams from co-digestion can include tipping fees, extra biogas and electricity generation, increases in fiber that can either offset existing farm costs (e.g., animal bedding) or be sold, and a variety of environmental credits (e.g., carbon credits, tax credits, renewable energy credits [RECs], and renewable identification numbers [RINs]). A recently developed enterprise budget calculator may be helpful for those wishing to explore the revenue potential of co-digestion scenarios (Astill et al. 2015).

Industry Tip: Incorporating even a small amount of high-energy substrates into a manure-only digester can substantially shorten the payback period for the AD facility and increase the return on investment.

Tipping fees

In most cases, tipping fees paid by the waste producer help offset capital and operating expenses associated with co-digestion (Environmental Science Associates 2011). While these fees can have a significant positive financial impact on the digester, the amount received can vary greatly depending on the quality, quantity, location, and transportation costs of the waste material, as well as other disposal options available (Bishop and Shumway 2009; Mallon and Weersink 2007; Coppedge et al. 2012a; Coppedge et al. 2012b).

Numerous states and cities now ban various types and levels of organics from landfills (U.S. Composting Council 2015). Meanwhile, tipping fees for accepted materials at landfills continue to rise, with fees for urban areas often well above $100 per ton (Washington State Department of Ecology 2012). Within this context, it has, in some cases, been possible for farm-based digesters to negotiate tipping fees that are more competitive and attractive to organic waste producers. This has the potential to create a win-win for local economies, while also recycling organics and recovering their embedded energy [A].

Although some co-digestion operations in the United States have been able to rely on consistently-priced tipping fees for substrates [A, D], this source of revenue has commonly been reduced over time and, in some cases, eliminated as a result of competition from other co-digestion operations or end-users (e.g., livestock owners who may use organic wastes as feed for young livestock) [E].

In some cases, a co-digestion facility may even have to pay a fee to obtain substrates [E]. In the Pacific Northwest, industry leaders indicate that tipping fees have disappeared in some areas and never existed at all in others [B, E].

Independent of these overall trends, tipping fees can be more stable for certain organics wastes if there is little competition from other types of potential consumers. For example, targeting DAF wastes (which cannot be used as animal feed because they contain chemicals and polymers) may be a useful strategy [E]. As long as the substrate is clear of any toxicity, a digester could process this type of substrate.

Digester operations also generally represent more reliable partners for receiving organic wastes than livestock-only operations or entities that directly apply wastes to land [E] because the higher level of processing involved with AD allows year-round operation and multiple loads of substrate per day [D, E].

Industry Tip: Given the potential for tipping fees to change over time, the best approach is to view this revenue source as supplemental rather than core income from co-digestion.

Electricity and renewable natural gas

If tipping fees are not available, the main boost in revenue from co-digestion will come from an increase in biogas output, resulting in higher electricity or RNG production. Studies have shown that co-digestion can increase biogas production by 25 to 400% compared to manure-only AD (Alatriste-Mondragón et al. 2006; Braun et al. 2003). Among the project developers interviewed for this publication, revenue from electricity sales increased significantly at their co-digestion plants despite comparatively low prices [D, E].

As of 2014, there were only a small handful of RNG operations on dairy AD operations in the United States, and none in the Pacific Northwest. However, benefits from substrate addition for facilities that produce RNG are likely to be similar to those seen at facilities that produce electricity, in the form of increased production. In addition, RNG economics will likely benefit from more price-effective scaling of gas scrubbing and compression units [A].

More detail on biogas purification approaches for RNG production is available in [Biogas Upgrading on Dairy Digesters](#) (Kennedy et al. 2015b).

Fiber and other coproducts

Fiber is an important product stream for both manure-only AD and co-digestion facilities. Fiber is typically extracted using solid–liquid separators and is most commonly used as animal bedding (Figure 10).

Figure 10. Separated fiber (top) from co-digestion can be used as animal bedding (bottom). (Images courtesy of Andgar Corporation.)

Co-digesting substrates generally increases fiber and bedding production, which yields higher fiber sales and lower bedding costs. Also, if nutrient recovery is utilized, a higher production of N and P can occur when adding substrates, resulting in higher revenue from soil amendment sales. Most substrates will have little to no effect on fiber quality. However, co-digesting fats, oils, and grease (FOG) and food wastes contaminated with plastics can leave an oily residue on the fiber coproduct unless the digester processing time is adjusted to compensate [A, E].

Environmental credits

AD operations can receive tax credits if biogas is used to produce renewable energy. For example, in Washington State, equipment, labor, and associated services from power production of at least 1 kW from the AD of dairy manure and substrates are exempt from 75% of retail sale and use taxes until January 1, 2020, when the exemption expires (RCW 82.08.962.12.962). Other tax breaks include AD exemption from retail sales and use taxes for the construction and operation, and thus related services and components of digesters if more than half the feedstock utilized in the digester is from dairy manure (RCW 82.08.900 and RCW 82.12.900). In addition, AD facilities in Washington State may be eligible for payments of $0.15/kWh (up to $5,000/year) from their partnering utility until June 30, 2020 (RCW 82.16.120). When these incentives apply to co-digestion, they may enhance the revenues and offset some of the costs.

Dairy AD operations also have the opportunity to sell carbon credits for the digester's avoided CH_4 emissions, with credits sold and traded at various different exchanges such as the Climate Action Reserve and California Cap and Trade Program. However, there may be limitations on the credits that can be obtained for substrates. For example, current carbon credit protocols at the Climate Action Reserve only allow credits to be bought for substrates derived from post-consumer organic food wastes or agro-industrial wastes (Coppedge et al. 2012a).

Another option is to sell RECs that ensure compliance with the state's renewable portfolio standard (Coppedge et al. 2012a). If biogas is upgraded and sold as transportation fuel, RINs can be generated and sold, and will be enhanced if co-digestion results in increased biogas production.

Because they can expire or be changed over time by political action, environmental credits may be somewhat less stable than other forms of revenue. Thus, like tipping fees, credits can be a significant revenue boost to a digester operation but should not be relied on as a primary source of income.

Conclusion

Several trends are likely to make co-digestion an increasingly important feature of dairy AD facilities. Historically low received electricity sale prices across much of the United States are negatively impacting the financial viability of manure-only AD facilities. Meanwhile, some states are enacting more stringent policies to encourage organics diversion from landfills, which may create opportunities for dairies near municipalities.

However, successful co-digestion depends on multiple factors, including the type of substrate, hauling costs, location of the digester compared to the substrate, local substrate competition, tipping fees, and nutrients. Each of these factors, and many others, will impact the magnitude of additional revenues compared to capital and operating costs. Before beginning co-digestion, developers need to first determine whether it makes economic sense at a particular dairy operation. If a sound business plan is developed and implemented, and if nutrient concerns relating to the effluent are addressed, co-digestion can provide economic and social benefits.

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