DIGESTED FIBER SOLIDS: METHODS FOR ADDING VALUE

Anaerobic Digestion Series

By
Jim Jensen, Senior Bioenergy and Alternative Fuels Specialist, WSU Extension Energy Program, Washington State University. **Craig Frear**, Assistant Professor, Center for Sustaining Agriculture and Natural Resources, Washington State University. **Jingwei Ma**, Associate in Research, Center for Sustaining Agriculture and Natural Resources, Washington State University. **Chad Kruger**, Director, Center for Sustaining Agriculture and Natural Resources, Washington State University. **Rita Hummel**, Associate Professor, WSU Puyallup Research and Extension Center, Washington State University. **Georgine Yorgey**, Assistant Director, Center for Sustaining Agriculture and Natural Resources, Washington State University

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Introduction

Anaerobic digestion (AD) of dairy manure and other organic residuals produces biogas, a source of renewable power and fuel, while also benefitting the environment by capturing and converting methane, destroying pathogens and odors, and stabilizing organic matter (Informa Economics 2013; EPA 2008). Unfortunately, costs can be sizable, with capital costs estimated to be $2,000 per cow in 2011 for combined heat and power (CHP) projects in Washington State (David Paul Rosen and Associates 2011). While revenue generated from the sale of electricity from biogas can offset these costs, the value of electricity has decreased in many parts of the US. In some places, it has been valued so low that electricity sales do not even cover operation and maintenance costs (Costa and Voell 2012). These lower electrical revenues have threatened profitability for both existing and planned dairy digester projects (Novak 2012; Coppedge et al. 2012), leading AD project developers to focus on increasing value from all of the other digester revenue streams (Gorrie 2014). These can include tipping fees (as well as increased biogas or power) from accepting off-farm organics to be digested, various environmental credits, and sales from the digested fibrous solids or its value-added products (Figure 1).

This publication describes the composition and separation process for fibrous solids that result from the digestion of dairy manures. It also reviews both current and future potential uses of fiber.

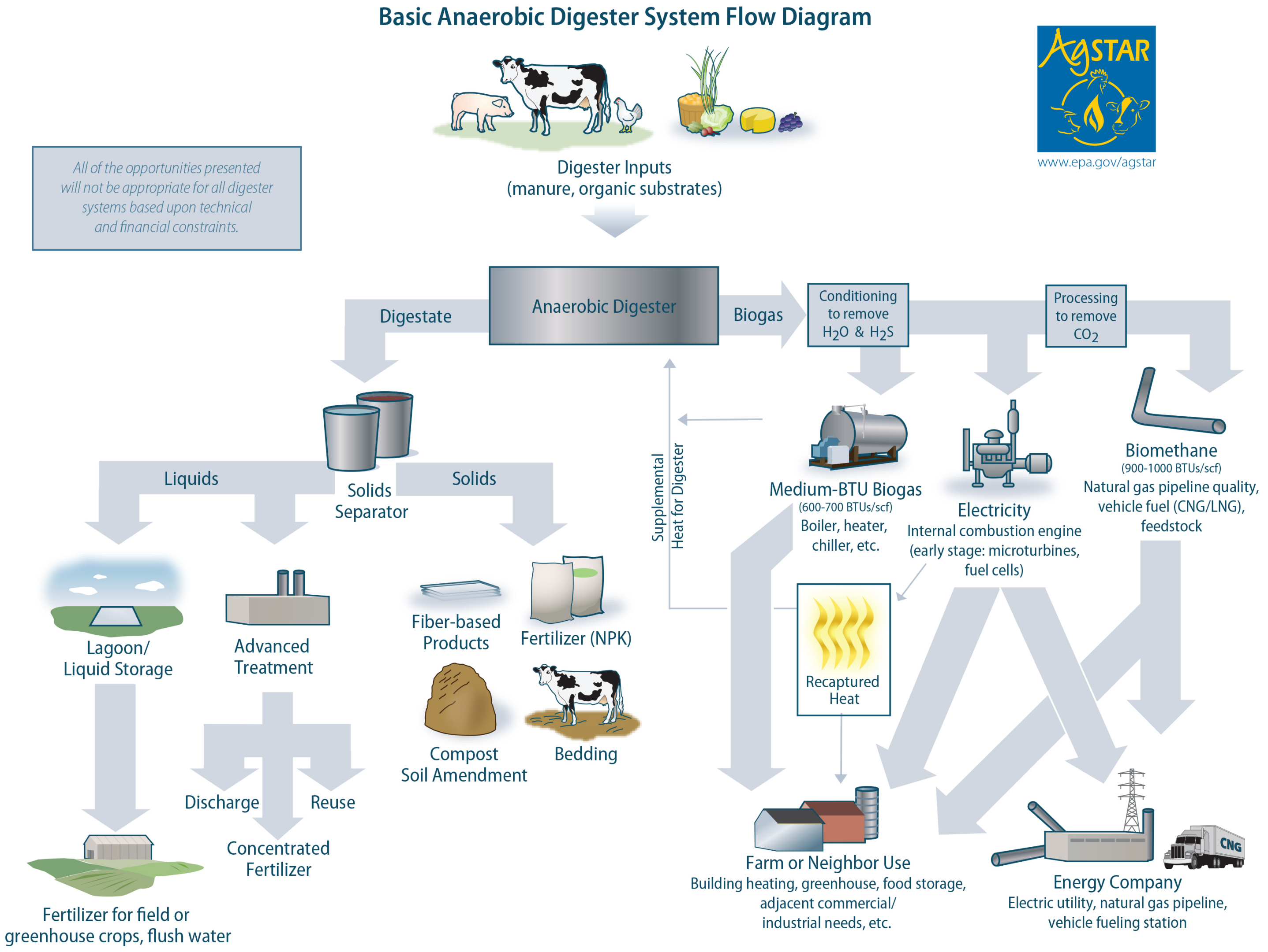

Figure 1. The focus on solids separated from digestate after anaerobic digestion. (Image courtesy of EPA AgSTAR.)

Fibrous Fraction of Dairy Manure and AD Effluent

Up to 40–50% of excreted dairy manure solids consist of fibrous matter that has been only partially digested by the cow (Liao et al. 2010; MacConnell et al. 2010). During manure management, dairy manure is typically diluted. Afterwards, prior to storage and field application, it is frequently separated into liquid and solid fractions. Unfortunately, the undigested or untreated separated solids are coated with organics that readily putrify, decompose, and can host pathogens and other disease vectors. Thus, additional downstream treatments, such as composting, are normally needed before the solids can be utilized as animal bedding or as a soil amendment (Terre-Source 2003).

Effluent from dairy AD projects also contains a considerable fraction of fibrous material, and AD effluent is also separated into liquid and solid fractions prior to storage and field application using the same approaches and technologies as those used for undigested manure. However, unlike undigested manure, the separated fibrous solids contain very few readily biodegradable organics because attached carbohydrates, proteins, lipids, and even pathogens have been biodegraded and removed by microorganisms during the AD process. The result is a quite stable, largely pathogen-reduced (EPA 2008) fibrous product that can be used to create numerous value-added products (Figure 2).

Approaches for Separating Fiber

Fiber separation methods may involve one or more sequential technologies (Katers 2008). The most common approaches use screens or presses (i.e., stationary-inclined, vibrating, rotary, screw) of varying pore size or pressures to separate and dewater the bulk of coarse fibrous solids from the liquid stream. Many digesters will use a single screen or press; however, if demand for separation or fiber warrants and costs allow, a sequence of screens and presses in a series can remove smaller particles and accomplish greater total solids recovery (Figure 3).


Figure 2. Screened and pressed fibrous solid from AD effluent. (Photo courtesy of Craig Frear.)

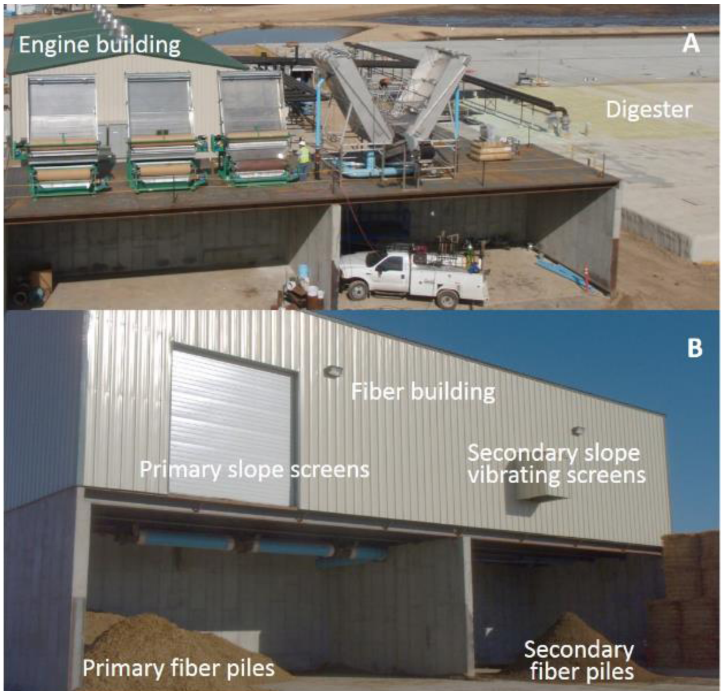

Figure 3. (A) AD fiber processing facility under construction (AA Dairy, Jerome ID) and (B) the same facility after construction of building cover and beginning of operation. (Photos courtesy of Regenis.)

The separated solids leaving these systems contain up to 90% moisture, so additional dewatering systems, such as roller or additional screw presses, are frequently used to reduce moisture to levels of approximately 70–75% (Frear and Ma 2015). This allows for a stackable material that is easy and more cost effective to transport and meets the needs of dairymen wishing to use the product as a bedding material, a primary use for the product (The Minnesota Project 2010; Alexander 2012).

A typical Holstein cow, often described as a wet cow equivalent (WCE), produces approximately 9–12 cubic yards per year of screened and pressed wet digested fiber with primary screening (Frear and Ma 2015). Approximate fiber separation costs as of late 2015 were on the order of $45–80 per cow in capital costs, with $8–16 per cow, per year in operating and maintenance costs (Regenis, personal communication). Capital costs vary based on scale, the degree of screening and dewatering achieved, and whether and how additional factors are incorporated—for example, covered buildings, automatic washers on timers, or vibrating stands (Regenis, personal communication). Meanwhile, operating and maintenance costs, which vary primarily based on scale, are incurred from transportation of product, replacement parts, and regular wash downs and periodic acid scrubs to remove accumulated salts and precipitates.

These separation processes reduce the solids content of AD dairy effluent by approximately 25–40%, and its water content by 7–10%, depending upon the degree of screening used (Frear and Ma 2015). The resulting effluent thus still has a considerable fraction of suspended solids. Approaches for recovery of these smaller-sized particles produce solids that are clay-like in form rather than fibrous (Ma et al. 2013), and are thus not covered in this publication. Those interested in additional information on these nutrient-rich products can refer to The Rationale for Recovery of Phosphorus and Nitrogen from Dairy Manure (Yorgey et al. 2014).

Physical and Chemical Properties of the AD Fiber

Screened and pressed AD dairy fiber has physical and chemical properties that differ from undigested dairy fiber and allow for its use within multiple value-added markets. Researchers have measured a wide range of characteristics of the AD fiber material (Figure 4 and Tables 1–4).

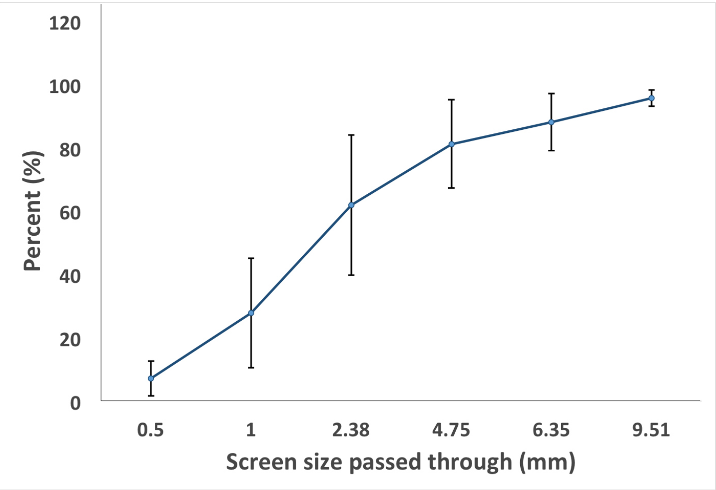

Figure 4. Size distribution of AD fiber particles after separation with 1/2-inch screen. (Source: MacConnell and Collins, unpublished data.)

Values reported in Tables 1–4 can inform assessments of potential uses and whether additional processing is needed to achieve desired markets.

In interpreting these values, it is important to understand that the nutrient content and other characteristics can be influenced by the makeup of an animal's feed, as well as the makeup of any co-digestion feedstock. For additional discussion of the impact of co-digestion on fiber and other products, see On-Farm Co-Digestion of Dairy Manure with High Energy Organics (Kennedy et al. 2015a).

Table 1. Elemental composition of AD fiber. Source: MacConnell and Collins, unpublished data.

	Measurement (average and standard deviation)	Units
Carbon (C)	52.1 ± 4.6	% Dry Matter (DM)
Nitrogen (N)	1.42 ± 0.21	% DM
Phosphorus (P)	0.28 ± 0.04	% DM
Potassium (K)	0.68 ± 0.16	% DM
Calcium (Ca)	1.44 ± 0.39	% DM
Magnesium (Mg)	0.28 ± 0.04	% DM
Sodium (Na)	0.27 ± 0.05	% DM
Sulfur (S)	0.50 ± 0.08	% DM
Copper (Cu)	99.3 ± 35.7	parts per million (ppm)
Zinc (Zn)	98.7 ± 15.2	ppm
Manganese (Mn)	98.7 ± 23.0	ppm
Iron (Fe)	929 ± 207	ppm
Boron (B)	27.8 ± 8.6	ppm

Table 2. Soil characteristics of AD fiber. Sources: MacConnell and Collins, unpublished data, and Liao and Frear, unpublished data. *A meq is the number of ions which total a specific quantity of electrical charges.

	Measurement (average and standard deviation)	Units
Moisture	74.2 ± 4.49	%
Dry Matter	25.8 ± 1.82	%
Organic Matter	92.0 ± 1.40	% volatile solids
Density	675.2 ± 72.3	lb per cubic yd
Air Space	37.3	%
Water Volume	19.4	%
Total Porosity	97.0	%
Electrical Conductivity (EC)	3.62 ± 1.11	deciSiemens per m (dS m^{-1})
pH	8.65 ± 0.29	
C:N Ratio	36.7 ± 5.4	
Cation Exchange Capacity	122.8	*milliequivalent of hydrogen per 100 g of dry soil (meq 100 g^{-1})
Percolation Rate	65.1 ± 37.2	inches per hour

Table 3. Structural composition of AD fiber. Source: Liao and Frear, unpublished data.

	% (average and standard deviation)
Fiber	74.3 ± 1.0
Cellulose	37.5 ± 0.31
Hemicellulose	9.17 ± 1.0
Lignin	27.7 ± 0.69
Ash	5.1 ± 0.24

Table 4. Fecal coliform numbers and total solids of AD fiber and post-AD heat treated fibers from a dairy near Lynden, WA. Source: Hummel and Mitchell (2016).

	Post-AD heat treated fiber		AD fiber	
Replication number	Fecal Coliform (MPN/g)^z	Total Solids (%)	Fecal Coliform (MPN/g)	Total Solids (%)
1	<0.791	22.78	140	24.82
2	<0.760	23.74	71.9	23.98
3	<0.692	26.05	127	21.84
4	0.859	23.29	247	21.97

^{z}MPN/g is the most probable number of fecal coliform bacteria per gram determined using the EPA_1681dw method.

Value-Added Uses for the AD Fiber

Once separated, fiber can be minimally processed through drying, or further processed to add more value. With additional processing, product development, and marketing there is the potential to add profit, as long as the additional revenue exceeds the additional costs. The discussion below covers some of the key uses for AD fiber, with those that are currently more common and commercially viable discussed first.

Animal Bedding

Until recently, livestock-based digesters focused on generating products that could be used directly on the farm. Thus, separated AD fiber has long been used as bedding for cows (Figure 5). This remained the most common use in 2015, when it was used for approximately 300,000 WCE in the US (DVO Incorporated, personal communication). When used in this way, AD fiber replaces other bedding materials, such as sand, sawdust, or straw. While sand is often favored as bedding

Figure 5. AD fiber as bedding in animal barn. (Photo courtesy of DVO Inc.)

material for cows, AD fiber is also considered quite acceptable (The Minnesota Project 2010; Alexander 2012). Depending on the type of AD system utilized, fiber is sometimes composted before being used as bedding.

When fiber is used on farm as bedding, it has financial value in the form of reduced or eliminated costs for purchasing sand, sawdust, straw, or other bedding materials. This value is reduced by the cost of the separation equipment and labor—though also often augmented by increased efficiencies in land-applying the remaining liquid effluent (which has a smaller volume once the fiber is removed). Typical revenues calculated from offset savings are on the order of $8–10 per wet cubic yard or $24–30 per wet ton, which amounts to a range of $72–120 per cow, per year. In some areas with high bedding costs, this range is considerably higher (Regenis, personal communication; Informa Economics 2013). Farms generally can use about 50% of the produced fiber internally, while the remainder can be sold as bedding to nearby dairies without a digester or processed into other value-added products (Frear and Ma 2015).

Some companies add value to the fiber through extra processing. For example, Boote (personal communication) describes a process for drying and pelletizing the AD fiber, allowing for use in horse stables as well as among rabbit breeders.

Compost and Soil Amendments

Composting AD fiber and utilizing it as a soil amendment is another common end use. Separated solids are relatively easy to stack and have adequate moisture and acceptable carbon-to-nitrogen (C:N) ratios for composting (Alexander 2012; Terre-Source 2003). Thus, they will generally compost readily if aerated. Composting can be accomplished through standard industry approaches, such as:

- Aerated static piles, in which the composting materials remain in place and air is piped through the piles using blowers;
- Turned windrows, in which the elongated piles are turned regularly with a front-end loader or compost turner; or
- Rotating drum composter, in which the feedstock is tumbled from one end of a horizontal, turning drum to the other.

Each of these methods has different comparative advantages and disadvantages, and the most appropriate approach will depend on the volume of material, space available, project assets and limitations, labor and management, climate and location, and other factors (Stentiford 1993). The On-Farm Composting Handbook (Rynk 1992) remains an excellent starter guide for those who would like more detail. Publications in the Dairy Compost Production and Use in Idaho Extension Series, including The Composting Process (Chen et al. 2011) and On-Farm Composting Management (Chen et al. 2012) are also likely to be of interest.

The composted fiber product is different than separated AD fiber and may have higher value (though not always). Carbon and other nutrients in the fiber material are more stable after composting. Volume is reduced and some of the moisture may be driven off, making the product lighter and easier to handle. The fiber is also darkened, making it look more like soil. While AD fiber may already have reduced pathogen numbers, hot composting practices (Figure 6) can give additional assurance of pathogen reduction and prevent regrowth of pathogens during storage (Terre-Source 2003).

The composted AD fiber can be used either as a standalone soil amendment or as a desirable ingredient in blended nursery and garden soil mixes (MacConnell et al. 2010; Martel 2013;

Figure 6. Turned windrow composting operation with dairy solids. (Photo courtesy of M.E. de Haro-Marti, University of Idaho Extension.)

Terre-Source 2003). In either case, the composted AD fiber can be sold either in bulk (by the truckload) or retail. Retail entails packaging (generally in bags) and marketing in smaller quantities. The compost can then be sold to either wholesale buyers or to retail customers.

Selling all of the product in bulk as a wholesale material generally has the lowest labor requirements and may be the easiest default method to move all the AD fiber produced. It also generates less revenue. Typical price points for bulk sales of composted dairy manure or fiber containing appreciable concentrations of nitrogen (~30 lb N per ton) are around $22 per ton with an additional $11 per ton charge for large-scale field application (PacifiClean, personal communication). Interestingly, prices received for bulk composted AD fiber are roughly equivalent to prices received for AD fiber with no further processing. Thus, many AD project operators currently choose not to compost, as long as fiber quality and pathogen reductions are acceptable.

Organic Products

One potential method for increasing the value of composted AD fiber is by having the product approved for use in the organic production process. Though certification may take some time, it can add value because organic growers have fewer options for adding nutrients than other growers. The added value may be captured through higher revenues per unit or by opening up additional markets (Baier 2012; Coleman 2012). In Washington State, the Department of Agriculture provides certification to approve products for use in organic production. Nationally, certification can be obtained from the Organic Materials Research Institute (OMRI). To meet certification guidelines, soil amendments or compost must:

- Use approved feedstocks
- Be composted with air for prescribed periods of time at minimum temperatures
- Be tested regularly
- Have proper recordkeeping
- Follow specific labeling requirements

Vermicompost

Another option that can add value is vermicomposting (Edwards et al. 2010; Edwards 1998). In vermicomposting, specific earthworms are grown in organic residuals (in this case, AD fiber) using a system such as low-cost floor beds, containers or boxes, or raised gantry-fed beds. Production parameters can be adjusted to emphasize production of a greater population of earthworms (e.g., as protein to feed animals or fish) or for production of earthworm castings or vermicompost (Edwards 1998).

Earthworms can effectively process cattle or dairy manure solids, as well as biosolids resulting from AD of wastewater (Edwards 1998). The earthworms fragment and consume the fibrous organic matter, obtaining nutrition from the microorganisms that grow on the feedstock (Edwards et al. 2010). Vermicomposts have unique physical, chemical, and biological properties including the presence of plant growth hormones and increased humates, which have produced positive effects in a number of controlled greenhouse experiments, leading to a rapid increase in the use of vermicomposts by commercial growers (Arancon 2010). The experiments that Arancon (2010) describes have shown benefits from even low vermicompost substitution rates in greenhouse crops, including faster germination rates, seedling growth, increase leaf areas and plant heights, increased numbers of flowers, more fruits, and greater overall yields.

Edwards et al. (2010) reports vermicompost values in the range of $55–550 per ton, which is roughly consistent with a separate report that vermicompost (including but not limited to that produced from AD fiber) has a value that is 4 to 14 times greater than regular compost (Manaugh 2012).

Peat Moss Replacement Product

Nearly 80% of greenhouse and nursery plants are grown in containers. These containers are filled with growing media composed of 70–80% organic materials, typically peat or bark (Gouin 1995; Raviv 2011). Both peat and bark have become more expensive in recent years. Bark is becoming more scarce due to reduced timber harvests, alternate uses, and rising prices (Lu et al. 2006; Buamscha et al. 2007), while sphagnum peat has experienced price hikes due to increased production and transportation costs and reduced availability (Schmilewski 2009; Raviv 2011). Peat is also a non-renewable resource that releases significant amounts of carbon when it is mined from ancient bogs and subsequently decomposes. Increased consumer awareness about the impact of peat mining is leading to greater demand for more sustainable alternatives (Oakley 2006).

In a 2005 survey of horticulture industry members in Washington State, 96% of respondents expressed interest in peat moss alternatives (Oakley 2006). This demand has encouraged researchers to develop alternative substrates from properly treated organic wastes (Raviv 2011; Bilderback et al. 2013; Caron et al. 2015; Carlile et al. 2015).

AD fiber is a promising option because of its high fiber content and other similarities to peat, including key parameters of importance to soilless horticultural producers (Dettling 2013), such as:

- Long fiber length and good air porosity

- Spongy quality (in contrast to composted products)
- Nitrogen, phosphorus, and potassium (NPK) as well as valued trace elements for good root and plant development
- Retains three times its weight in water

A small but growing body of research indicates that AD fiber performs well as a component of high-quality growth substrates (Raviv et al. 1983; MacConnell and Collins 2009; Krucker et al. 2010; Crippa et al. 2013; Hummel et al. 2014). One recent experiment with ‘Shasta’ chrysanthemums found that dairy fiber used alone or mixed with bark produced plant shoot dry weight, shoot growth index, quality, and flower bud counts similar to a commercial peat-perlite mixture (Krucker et al. 2010). Plants representative of the 100% AD fiber, 50% AD fiber and 50% bark, and commercial peat-perlite substrates are shown in Figure 7.

Blending and additional treatment steps are currently being explored to bring desired properties more closely in line with industry needs. While these efforts may result in improved product over time, certain characteristics remain of concern, particularly high pH and high levels of electro-conductivity.

Meanwhile, commercialization efforts to date have yielded mixed results, although progress is being made. Product consistency, including reliably low concentrations of indicator pathogens and non-detectable levels of trace herbicides, has hindered commercialization efforts, though project developers continue to work with both dairies and end users to provide a consistent raw or blended product. The first company to market an AD fiber peat moss replacement began shipping product in 2007, and as of July 2015, a small handful of other companies were actively marketing their products (Goldstein 2014; Figure 8).

The market potential for replacing peat moss in horticulture applications is significant and emphasizes the need for continued development of these nascent markets and products. Estimates of peat usage by the US horticultural industry range from 6.8–8.7 million tons per year, mostly imported from Canada (Informa Economics 2013; Carlile et al. 2015). Environmental benefits of meeting this demand from dairy

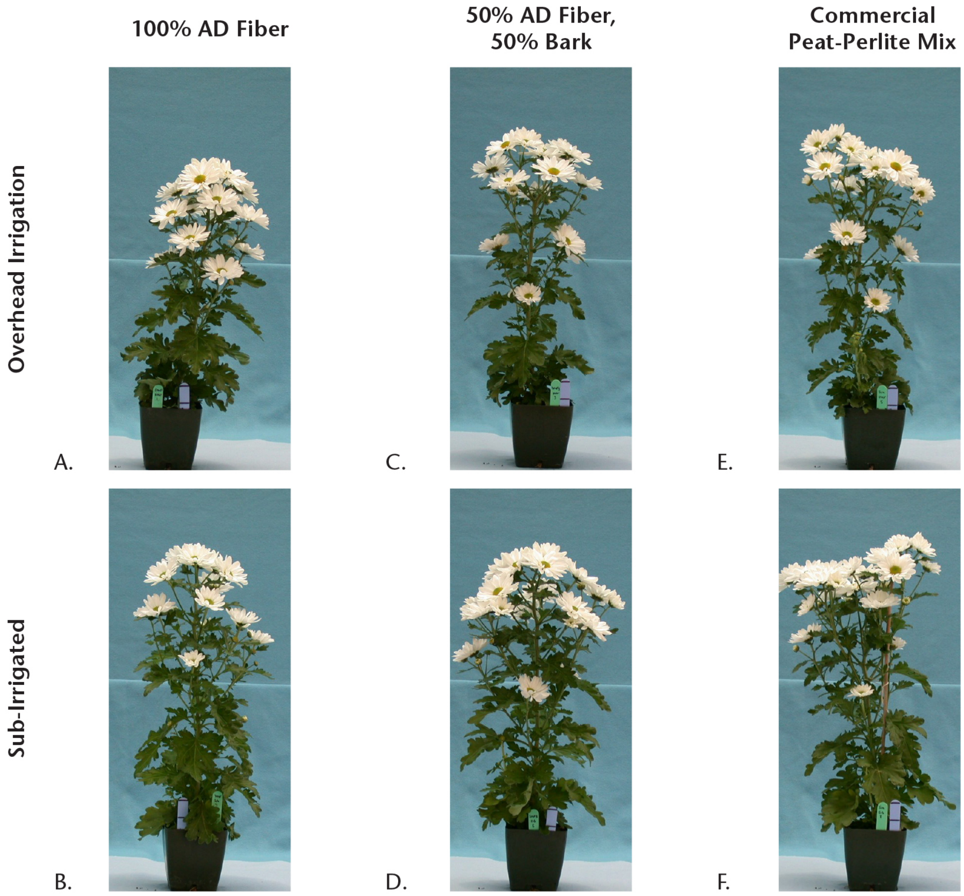

Figure 7. AD fiber growth trial with chrysanthemum (*Chrysanthemum ×morifolium Ramat*. ‘Shasta’). Plants were fertilized every other day with a 200 N-100 P-200 K milligram per liter solution. The plants in photos A and B were grown in AD fiber, C and D were grown in a mix of 50% dairy fiber and 50% bark, and E and F were grown in a commercial peat-perlite mixture. Plants A, C, and E were grown with overhead irrigation while B, D, and F were sub-irrigated. (Photos courtesy of Michele Krucker and Rita Hummel.)

Figure 8. Example of blended AD fiber product for sale as high-value soil amendment. (Photo courtesy of Biocycle.)

digesters could be significant; using AD fiber as a replacement for this mined peat moss could avoid the release of nearly 6 million metric tons of CO_2 equivalent per year, which is roughly the same output as one million cars (Dettling 2013).

From a revenue perspective, discussions with the nascent industry suggest that dairy AD operations can achieve approximately $10.50–17 per cubic yard for bulk quantities of AD fiber marketed as peat replacement, with wholesalers covering transportation costs (Promus Energy, personal communication) and then selling to the retail market for considerably higher prices. Prices for Washington State nursery and greenhouse growers in spring of 2015 were $101 per cubic yard for Canadian sphagnum peat and $30 per cubic yard for fine-grade Douglas fir bark, though these prices vary based on the amount purchased (Rita Hummel, personal communication). The sizeable difference in prices between fiber and these other products suggests that with increased market penetration, higher revenues may be achievable by dairy AD projects.

Engineered Materials

Specialty products engineered from AD fiber have also been studied, though there has been limited commercial success to date. To give a sense of the potential and barriers, two alternatives are discussed here: structural products, such as particleboard and wood-plastic composites, and plant pots.

Particleboard and Wood-Plastic Composites

Researchers have suggested that the size, geometry, and other characteristics of AD fiber make it a suitable substitute for fiber in medium-density fiberboard or for wood particles in particleboard (Winandy and Cai 2008). Experimental production indicated that particleboard panels produced with AD fiber, either alone or combined with wood particles, satisfied the requirements for medium-density fiberboard (ANSI A201.2-2004) or for H-1 grade commercial particleboard (ANSI A208.1-1999; Winandy and Cai 2008). One drawback was that water sorption was high, which was attributed to the absence of wax in the formulations used for producing the composites.

A more significant barrier was economics, as analyses at that time indicated that low-cost material such as sawdust or wood shavings could still undercut AD fiber for use in these products, and that diversion of the AD fiber to wood composite production was of lower value than using AD fiber as a replacement animal bedding (Spelter 2008). Potential consumer perception issues were also noted for a manure-derived building product (Goodman 2007). Since that time, others have patented a method for producing composites from AD biomass, including AD dairy manure fiber, without adding resins, waxes, or sizing components (Dvorak and Hunt 2013). Commercialization potential therefore still exists if economics change (Figure 9).

Figure 9. Particleboard samples made from AD fiber. (Photo courtesy of DVO Inc.)

Plant Pots for Retail Garden Products

Although quite specialized, one dairy in East Cannan, CT, has developed a successful production process for converting AD fiber into biodegradable plant pots (Kittredge 2008; Figure 10). The pots, prepared using conventional equipment for biodegradable pots, hold together for more than 12 weeks in a greenhouse environment. Like other biodegradable pots, they allow moisture and root penetration and decompose rapidly after planting in the soil. As of April 2015, the operation was a full-time manufacturing, storage, and distribution enterprise, employing 30 people year-round and distributing products nationwide (Hirshey 2009; Kittredge 2011; Freund 2015). The

Figure 10. Biodegradable plant pots molded from dairy fiber (Photo courtesy of CowPots, LLC.)

company is exploring whether additional products can be made with the same fiber process, including packing forms, degradable golf tees, and landscape mulch paper.

Fuel Production

Multiple options have been explored for using AD fiber to produce fuel. These include treating and anaerobically digesting the fiber to produce additional biogas for compressed natural gas; hydrolyzing and fermenting the fiber as an ethanol ingredient to gasoline; and thermally treating the fiber through torrefaction, pyrolysis, or gasification, generating heat energy and biochar.

Compressed Natural Gas (CNG)

While most digesters in the US currently combust biogas in engine and generator sets to produce electricity, refining the biogas to meet renewable natural gas standards is of increasing interest. This topic is covered in more detail in the publication Biogas Upgrading on Dairy Digesters (Kennedy et al. 2015b). Within the CNG context, increasing biogas output is of particular interest, as CNG is generally a higher-value product than electricity, and because increased output contributes to efficiencies in scale that can contribute to economic viability. Without pre-treatment, the carbon in fiber is not accessible to the microorganisms that generate biogas during the AD process. However, AD fiber is 52% carbon, albeit embedded in recalcitrant fibrous matrices. Recognizing this, researchers have devised numerous processes to increase the degradation of dairy manure fiber (and other lignocellulosic materials) so as to more effectively convert the carbon to biogas (Angelidaki and Ahring 2000; Hartmann et al. 2000; Carrère et al. 2010).

In one process, already supported by large-scale data, Biswas et al. (2012) report on the digestion of dairy manure with subsequent separation and treatment of the fibrous solids with a patented wet explosion process. Treated solids are then re-digested for additional biogas production. Their data, in conjunction with known operational data from US AD systems (Frear and Ma 2015), indicate that the process could increase dairy manure AD methane production by as much as 41%, with pre-treated fiber accounting for nearly 30% of the total methane production. While this is an impressive increase in gas productivity, net revenues after considering pre-treatment costs are not currently greater than other value-added uses for the digested fiber. However, future increases in biogas value could lead to adoption of this approach.

Ethanol

Studies have demonstrated that AD alters the composition and structure of dairy manure fiber (Teater et al. 2011; Yue et al. 2010; Yue et al. 2011) in ways that allow for ready hydrolysis via processes similar to those used with switchgrass, corn stover, and other agricultural energy crops and residues. The AD fiber can thus be used for ethanol production (Teater et al. 2011; Yue et al. 2010; Yue et al. 2011; Zhong et al. 2015).

Illustrating the potential of such an approach, Liao et al. (2014) reported about an integrated farm-based biorefinery concept that integrates AD of manure (for biogas power generation) with AD fiber processing for ethanol fermentation. Fiber fermentation is integrated with yeast ethanol fermentation and algal cultivation to create a closed-loop system for agricultural residue treatment and utilization.

Thermal Processing for Heat and Biochar

Fiber could also be treated thermally to produce biochar and heat. Biochar, a form of charcoal, is produced through pyrolysis or other carbonization processes. Globally, biochar has gained popularity as a soil amendment that can improve soils for crop production and sequester atmospheric carbon (Fuchs 2012). The value of biochar as a soil amendment continues to be studied, though at present it appears to rely less on agronomic benefits and more on benefits for carbon sequestration (Galinato 2011). In the Pacific Northwest, economic analysis has suggested that profitable uses of biochar in crop production may be possible, but only if the biochar market price is low enough and the value of the carbon sequestration can be monetized.

More specialized (and potentially higher value) uses for biochar have also been investigated, including use as a filtering media for liquids or gases. Streubel et al. (2012) evaluated how well biochar produced from pelletized AD fiber could filter phosphorus from liquid digester effluent. The biochar sequestered an average of 381 milligrams per liter of inorganic phosphorus from the effluent, while 4 grams per liter of the fiber was captured as a coating on the biochar. These results suggest a possible beneficial role for biochar in future phosphorus recovery systems on dairies. Other research has considered the use of engineered AD fiber biochars to remove hydrogen sulfide or other problematic trace gases from AD biogas (Peláez-Samaniego et al. 2015).

In addition to engineered AD fiber-based biochar, these systems would also produce thermal (heat) energy. Within the AD system, this heat could be quite beneficial for drying value-added products, such as fertilizer products (Garcia-Perez et al. 2013).

Conclusion

AD processing of dairy manure yields a significant mass of AD fiber, an important revenue source for dairy AD projects. For example, AD fiber sales split between peat substitute production and fertilizer distribution accounted for 38% of the AD project revenue of a Washington State digester operation (Coppedge et al. 2012). Given low electricity values, these sources were largely responsible for generating a positive cash flow for the AD project, and were projected to account for more than half of the revenue stream in future projections.

The majority of AD fiber is currently utilized as animal bedding, while bulk soil applications after composting are also common. Numerous other value-added uses for fiber are presently being explored, with the potential to displace current uses. Two primary areas of current activity include market development for composted soil amendment bagged as retail products, and both technical and market development for peat-replacement products. Other options with potential include engineered products, pre-treatment and processing for energy production, and conversion to biochar for absorbing contaminants or nutrients.

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