ANAEROBICALLY DIGESTED BOVINE BIOFIBER AS A SOURCE OF FIBER FOR PARTICLEBOARD MANUFACTURING: AN ECONOMIC ANALYSIS

Henry Spelter,[a*] Jerrold Winandy,[a] and Timothy Zauche[b]

This paper explores the physical and economic potential to substitute anaerobically digested bovine biofiber (ADBF) for wood in the making of particleboard. Laboratory tests indicated that replacement of one-half the wood in particleboard with ADBF produced panels that compared favorably to the requirements for commercial particleboard performance (specified by ANSI Standard A208.1–1999). The economic question hinges on the opportunity costs of alternative uses for ADBF. The current use is primarily animal bedding, and prices appear to be greater than those paid by particleboard plants for sawdust and planer shavings but less than for chips. ADBF is most similar in size to, thus most likely to be substitutable for, sawdust and shavings. At current bedding values, use for particleboard appears a less favorable alternative. However, this could be overcome by large-volume, long-term contractual arrangements that provide a secure long-term outlet for excess ADBF fiber that may otherwise not have value. For a particleboard operation, the opportunity for fiber diversification and the incorporation of post-industrial waste in the process offer strategic advantages.

Keywords: Anaerobically digested bovine biofiber; Particleboard; Economics

*Contact information: a: U.S. Forest Service, Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53726;b: Dept. of Chemistry & Engineering Physics, University of Wisconsin–Platteville, Platteville, WI 53818; *Corresponding author: hspelter@fs.fed.us*

INTRODUCTION

Trends in modern farming have been to increase the size and specialization of farms. Dairy operations and other confined animal feedlots in Wisconsin have followed suit with more mega facilities that contain larger numbers of animals concentrated in one location. This has raised the challenge of managing manure at a scale heretofore rarely encountered but has also created opportunities to manage this waste to extract value from it.

Of Wisconsin's approximately 21,000 dairy farms, most are small, with 150 or fewer head per farm (Ag Environmental Solutions, LLC 2002). However, based on 2007 permit applications, at least 110 of these held 700 or more dairy cows, with associated large volumes of manure (WDNR 2008). The number of animals at these 110 facilities was 175,000 (~1,600 average), which, with planned expansions, was set to rise to 226,000 by 2009. At that time, the average number of animals per farm for this group will therefore be almost 2,100. Each such operation would generate about 105,000 L (28,000 gallons) of manure per day at an average rate of 3 kg (8 lb) per animal, or 0.3 million dried metric tons per year for the 110 units in aggregate (Burke 2001).

Such volumes have led to concerns over potential environmental problems, such as odor, catastrophic spills, or groundwater contamination, and regulations have been issued intending to control them. Such pressures have stimulated interest for ways to mitigate the concerns and possibly turn a business cost into a revenue stream. Anaerobic digesters to transform bio-wastes into usable products have received growing attention for their potential to accomplish this.

Anaerobic digestion is a natural process that uses bacteria to convert biomass (any organic matter derived from plants, animals, or their wastes) into methane gas in an oxygen-free environment. Anaerobic digestion has been used for over 100 years to stabilize municipal sewage and a wide variety of industrial wastes (Burke 2001). Transforming manure solids into methane gas, which can then be purified and fed into the natural gas pipeline distribution system or burned on site to generate heat or electricity, is a potential way for large farms to reduce odors and flies, improve nutrient management, and produce renewable energy, thus resulting in income to offset costs (Roos 1991).

Along with gas, anaerobic digestion also transforms the raw manure, yielding a nutrient rich liquid effluent that has applicability as fertilizer and a wet cellulosic-based fibrous residue that, when dewatered and dried, has utility as animal bedding, soil amendment, or potting soil. Because of the potentially huge volumes, however, these applications by themselves may not be enough to economically utilize all the supply. Other uses might be needed, and one such possibility may be using mixtures of the fiber in combination with wood for making particleboard or medium-density fiberboard (MDF).

An associated paper details the processing techniques and physical and mechanical properties of various mixtures of wood fiber and ADBF fiber for particleboard and fiberboard (Winandy and Cai 2008). The present paper explores the potential for savings in operating costs by using this processed fiber in composite panels manufacturing in general and within Wisconsin in particular. Two particleboard manufacturing plants in Wisconsin had a combined annual capacity of 221,000 m^3 (125 million square feet, 3/4-in. basis) (Composite Panel Association 2005). However, one of these closed in 2006. At an approximate average panel density of 600 kg/m^3 (45 lb/ft^3), the remaining plant requires approximately 92,000 metric tons (101,000 short tons) of fiber per year. This plant lies within a 200-km (125-mile) radius of most large dairy operations, thus making the transportation of fiber to it a potentially feasible proposition.

OVERVIEW OF ANAEROBIC DIGESTERS FOR ANIMAL MANURE

Although a widely used process with an extensive history, operating a digester requires some expertise. In the 1980s, federal tax credits spurred the construction of more than 100 digesters across the country, but many failed because of poor design, faulty construction, improper operation, and lack of service infrastructure (Nelson and Lamb 2002). The current wave of interest follows considerable subsequent experimentation and development by universities, government, and private entities.

Several different types of digesters are suited for specific methods of waste collection. Most farms collect their manure deposits either by flushing them with water down a sloped channel towards a central reception point or by using a front end loader to periodically “scrape” the material to the same destination. For operations that scrape, the least demanding type of digester is the “plug-flow” system in which the waste enters on one side of a reactor chamber and pushes older material toward the discharge end in the form of a semi-solid “plug.” To function as such, this requires a high solids concentration of about 10%, or manure in “as excreted,” undiluted condition, which is provided by the scraping collection method. This system requires few moving parts, has minimal maintenance requirements, and is intermediate in its gas conversion efficiency (Burke 2001). It is thus the most widespread digester in use. For that reason, we focus on the economics of this type of digester.

Once collected and fed into the reactor, the slurry undergoes chemical reactions caused by acid-forming bacteria (acetogens), which convert the soluble contents to carbon dioxide and a variety of short-chain organic acids, and methane-forming bacteria (methanogens), which use the acids to produce methane. These types of bacteria function best in a medium temperature range of 35–38°C (95–100°F).

A second key process variable is pH. If the slurry is too acidic, the methanogenic bacteria are inhibited. Likewise, in an environment that is too basic, growth of the acid-forming bacteria is retarded. Thus, the process operates within a relatively narrow pH window of 6.5 to 8.0. Further, because acid-forming bacteria operate faster than the methanogens, an appropriately larger population of methane-forming bacteria must be maintained. Controlling the amount of organic matter fed into the digester is also important because if the organic loading is too high, the acid-forming bacteria produce too much acid and overwhelm the methane producers, causing system failure.

The process of generating methane reaches the point of diminishing returns after about 20 days. The gas produced consists roughly of 58% methane; the rest is mostly carbon dioxide, with slight amounts of hydrogen sulfide. This produces a low-grade combustible gas that can be burned to produce electrical power or heat. Alternatively, it can be “scrubbed” by removing carbon dioxide and hydrogen sulfide to create a nearly pure methane gas stream that can be injected into the pipeline system for distribution.

The remaining processed material can be separated into an odorless liquid discharge effluent with highly concentrated nutrients and a wet lignocellulosic slurry. When dewatered, the slurry yields a relatively dry mass of lignocellulosic biofiber. This has a moisture content after separation but before drying of ~70% +/-10%. After drying the composition of the lignocellulosic biofiber is about 10-15% lignin and 25-30% cellulose. Other major components are ash (10-20%), non-cellulosic fibers (20-25%), starches (1%), proteins (1%), and fats (<1%). A variety of other carbon containing compounds (e.g. non cellulosic fibers) make up the remainder.

Overall, from the operational perspective, the demands of the process are fairly straightforward, requiring only periodic monitoring of temperature, pH, and organic content of the inflow to operate properly.

OVERVIEW OF THE PARTICLEBOARD PROCESS

Particleboard emerged in the United States after World War II as a lower cost substitute for lumber and plywood in furniture, millwork, cabinetry, and sub-flooring end

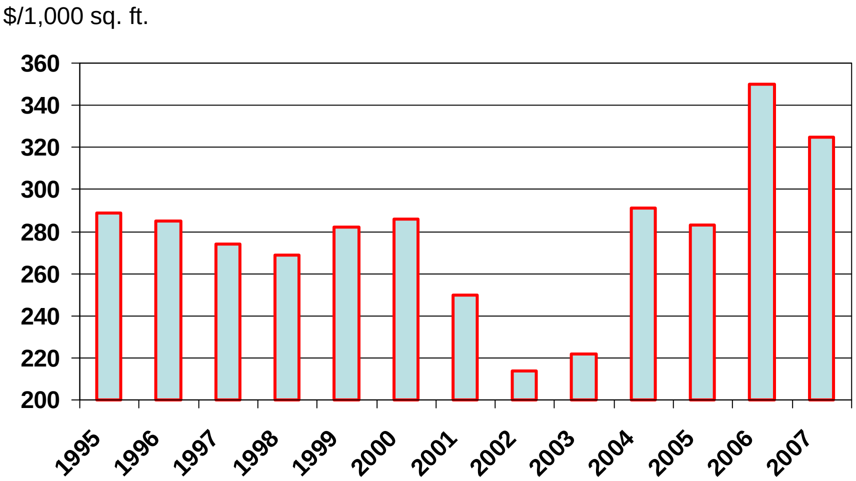

Figure 1. Price of ¾-in. industrial grade particleboard (eastern markets). From Random Lengths Publications, Inc.

uses. It is a largely standardized commodity whose price, and thus how much can be afforded for inputs, fluctuates with the forces of supply and demand (illustrated by its recent price history, Fig. 1).

Particleboard production is largely based on wood fiber residues—mostly planer shavings and sawdust—obtained as a byproduct of sawmilling or other wood processing activities. As such, the fiber must be admitted largely in the shape in which it is received, and the amount of further milling that can be performed is limited (Maloney 1977).

Wood residues brought to a particleboard plant are initially placed in storage. They may receive further processing in a hammermill or similar machinery to modify the size distribution. The residues are subsequently dried in a rotary dryer, screened, and separated by size, mixed with resin (usually urea formaldehyde) and wax, and formed into thick layered mats. The mats are conveyed into a multi- or single-opening platen press, where they are compressed and heated until the adhesive sets. At the end of the press cycle the pressure is slowly relaxed to allow any moisture buildup to escape, after which the press opens and the boards are discharged onto a rotating cooling rack. After cooling they are trimmed and cut to final size, stacked, strapped, and made ready for shipment.

Modern particleboard mills are capable of handling two or three fiber streams, such as sawdust, planer shavings, or chips. A possible viable substitute for sawdust used in the process would be non-clumped biofiber material screened between 12 and 16 mesh. Larger material could also be used, provided that it did not clump. However, much smaller material would result in increased resin use and lower physical properties and thus should be avoided.

WOOD–ADBF HYBRID PARTICLEBOARD PERFORMANCE

Particleboard mills are large users of woody biomass. Anaerobically digested bovine biofiber (ADBF) could potentially replace (or supplement) wood fiber (WF).

Recent work at the Forest Products Laboratory (FPL) evaluated the compatibility of woody fiber and ADBF for both traditional wet-formed fiberboard and dry-formed particleboard.

The dry-formed particleboard work was done in two stages. In the first stage, compatibility and requirements of ADBF with wood with and without mechanical separation (i.e., hammermilling) were evaluated. Using 50/50 mixes of dried WF and ADBF (~5% moisture), the following combinations were studied: (1) neither WF nor ADBF hammermilled; (2) both WF and ADBF hammermilled; and (3) only WF hammermilled.

In the second stage, these three variously processed fiber mixtures were made into a dry-formed particleboard using phenol formaldehyde resin at 3.5% and a hot-press temperature of 180°C. Results indicated that woody fiber and ADBF could be mixed in a 50/50 mixture either with or without hammermilling (Fig. 2). Results also indicated that the three variously processed 50/50 mixed-fiber types produced a particleboard that compared favorably to the requirements for commercial particleboard performance (specified by ANSI Standard A208.1–1999 (ANSI 1999)). To date our work at FPL has concentrated mostly on 50/50 mixtures, but virtually any combination is potentially feasible. Local economics will probably determine the optimal mixture at each plant. Such decisions will undoubtedly affect the critical price-point for ADBF in woody composites. To help in such determinations, a study now underway at FPL is focusing on five mixed fiber combinations from 0/100 to 100/0 using multiple resin systems and board densities.

The wet-formed hardboard work was done using a 50/50 mixture of WF and wet ADBF (~70% moisture). The wet-formed WF–ADBF hardboard was produced without resins or additives. Tensile strength perpendicular to panel surface (i.e., internal bond strength), thickness swell, and water absorption of WF–ADBF hardboard were evaluated using procedures of ASTM D 1037 (ASTM 2007). Tensile strength perpendicular to panel surface (i.e., internal bond strength), thickness swell, and bending strength of WF–ADBF hardboard were compared to performance specifications required for various grades of commercial hardboard (ANSI A135.4–1995 (ANSI 1995)) (Figs. 3–5).

From this comparison of wet-formed WF–ADBF hardboard with various commercial grades of hardboard made with WF alone, tensile strength perpendicular to panel surface was superior to all commercial grades of basic hardboard (Fig. 3). However, the WF–ADBF hardboard without additives or resins did not meet commercial requirements for thickness swell (Fig. 4). This result was generally expected, as no resin or additive oils were used in these laboratory trials. Because most commercial hardboard commonly uses various resins and additives to promote resistance to moisture, it is probable that the commercial requirements for resistance to thickness swelling and water absorption could be met with the additional use of resins/additives and with greater processing experience. Finally, we note that our wet-formed laboratory WF–ADBF hardboard compared favorably with 4 out of 5 commercial grades of hardboard made with WF alone.

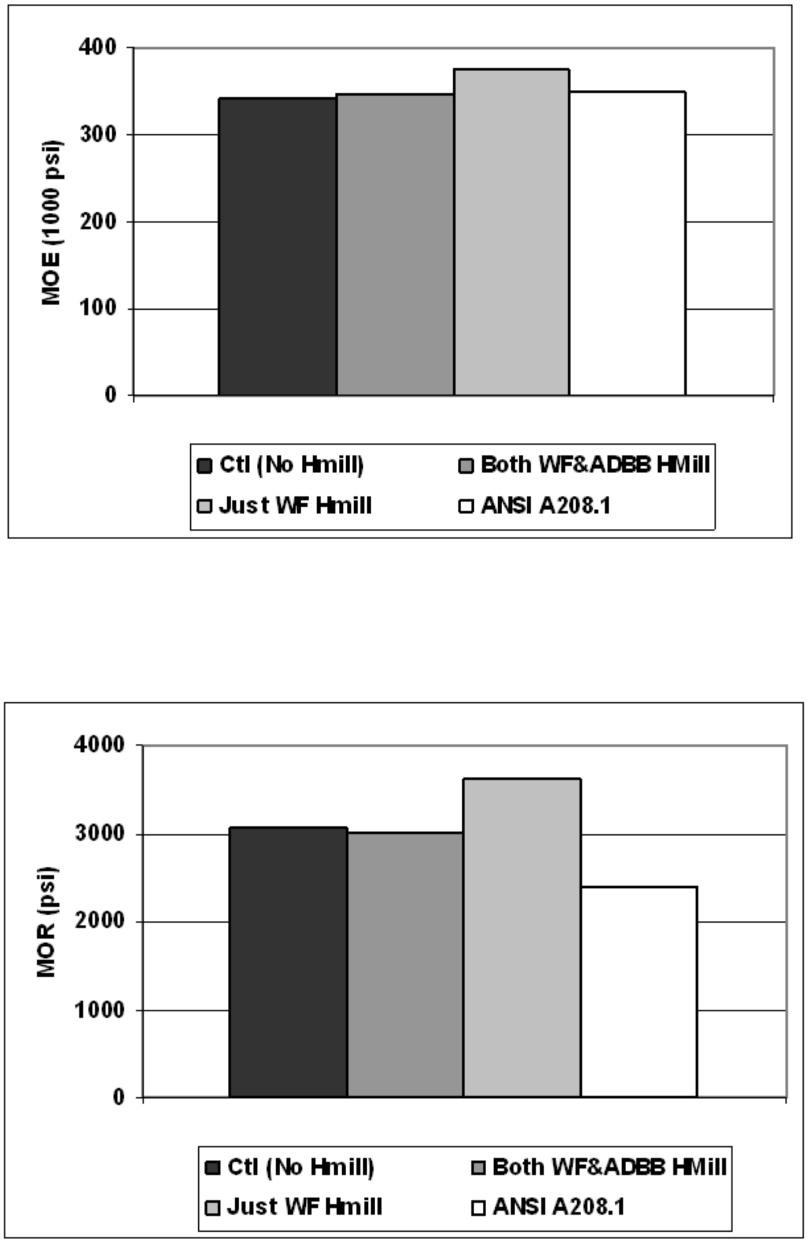

Figure 2. Effects of pre-process hammermilling of fiber on modulus of elasticity (MOE, top) and bending strength (modulus of rupture, MOR, bottom) of 50/50 hybrid wood–ADBF dry-formed particleboard compared with the commercial particleboard requirements in ANSI Standard A208.1 (1999).

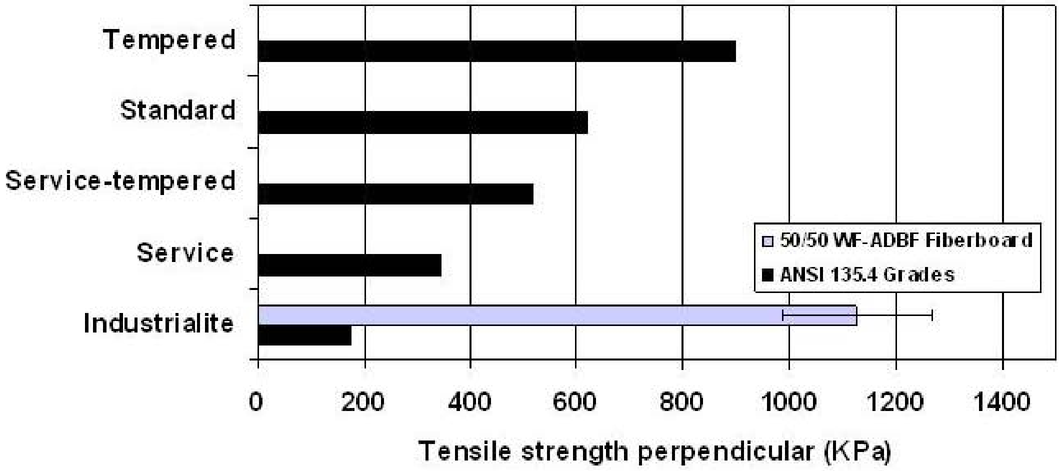

Figure 3. Comparison of tensile strength perpendicular to panel surface for 50/50 hybrid wood–ADBF wet-formed hardboard compared with commercial requirements of ANSI A135.4–2004.

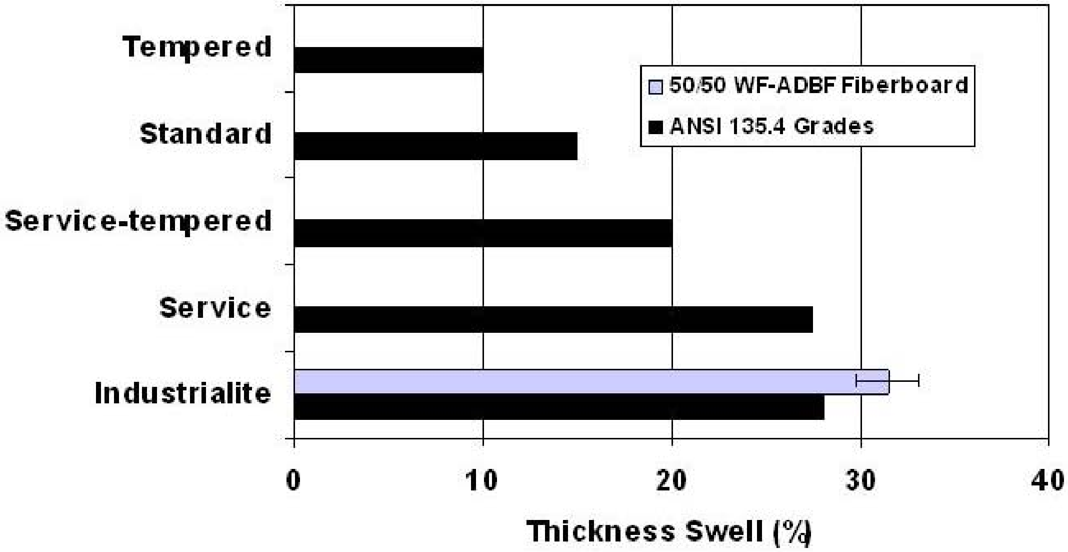

Figure 4. Comparison of 24-h thickness swell for 50/50 hybrid wood–ADBF wet-formed hardboard compared with commercial requirements of ANSI A135.4–2004.

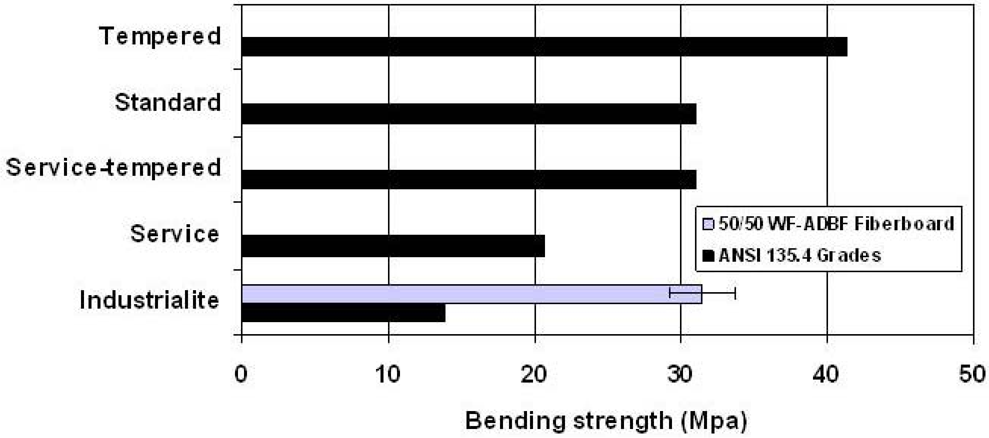

Figure 5. Comparison of bending strength for 50/50 hybrid wood–ADBF wet-formed hardboard compared to commercial requirements of ANSI A135.4–2004.

PARTICLEBOARD ECONOMICS

For the evaluation of ADBF's economic suitability for particleboard, we focus on a generic medium size plant whose salient operating parameters are depicted in Table 1.

Few residues or byproducts are normally generated in a particleboard plant, so the only outputs are the boards themselves. Unit prices and costs attached to the output and inputs used here were in the range generally experienced in 2007 and are shown in Table 2 along with the annual revenue streams derived by combining the unit values in Table 2 with the volume amounts in Table 1. Such a plant would essentially be at break even under the economic circumstances embedded in assumptions used for this study.

Table 1. Base Case Operating Parameters for a Medium-sized Particleboard Plant

	Amount	U.S. units	Amount	SI units
Output	80,000,000	ft^2 (3/4-in. basis)	141,600	m^3
Panel density	45	lb/ft^3	593	kg/m^3
Wood fiber, chips	78,066	odt	70,800	odmt
Wood fiber, dust	39,000	odt	35,400	odmt
ADBF	—	odt	—	odmt
Resin @ 7%	17.7	$\times 10^6$ lb	6.6	$\times 10^6$ kg
Wax @ 0.5%	1.3	$\times 10^6$ lb	0.5	$\times 10^6$ kg
Production labor	50	People		
Technical labor	20	People		
Electricity	260	$kWh/10^3\ ft^2$	147	kWh/m^3
Natural gas	2	$10^6\ Btu/10^3\ ft^2$	1.2	GJ/m^3
Propane	1.5	$gal/10^3\ ft^2$	3	L/m^3

Table 2. Base Case Prices and Revenue Streams Generated for a Medium-Sized Particleboard Plant in 2007.

Production item	Prices	Unit	Costs	Revenue
Particleboard	300	$\$/10^3$ ft^2 (3/4-in. basis)		$24,000,000
Wood chips	65	$/odt	$4,474,148	
Shavings/sawdust	32.50	$/odt	$1,124,137	
ADBF	55	$/odt		
Fiber waste (trim, etc.)	12	%	$671,794	
Urea formaldehyde	0.4	$/lb	$7,056,000	
Wax	0.56	$/lb	$708,750	
Labor, production[a]	21.25	$/h	$2,146,048	
Labor, technical[a]	32.00	$/h	$1,292,671	
Electricity	0.065	$/kWh	$1,300,000	
Gas	8.0	$\$/10^6$ Btu	$ 1,280,000	
Propane	2.5	$/gal	$300,000	
Administration and overhead			$3,272,795	
Total			$23,626,343	
Gain (loss)			$373,657	

[a] Consists of base salary, fringe benefits, and social insurance payments.

Of particular interest is the amount paid for the fiber. Wisconsin has relatively few sawmills, and the amounts of planer shavings and sawdust available are therefore more limited than in regions that are richer in wood-processing facilities. Accordingly, plants in this region need to source fiber from a wider and often more expensive range of sources. Even in regions with more sawmills, however, periodic cycles in the sawmilling industry cause residue supply interruptions that disrupt particleboard production. Thus, ADBF offers a chance to diversify fiber procurement from a less cyclical source.

The $65/bdt (bone dry ton) for virgin chips and $32.50/bdt for sawdust used above are based on prices for delivered material typical for Wisconsin in 2007. To the extent ADBF can substitute for chips, the potential price limits are therefore $65/bdt. If it is only feasible to substitute it for sawdust, then the upper limit is half that. As noted above, ADBF has current uses as animal bedding. Biomass sold for this purpose fetches about $25/wet ton at 70% moisture, which translate to over $80/dry ton (Wagner 2007). A separate report cites $50/dried ton as an expected price for such material (Energy Solutions 2002). Thus, the further use of this material depends on (1) what it can be technically substituted for (i.e., chips or sawdust) and (2) demand for the material as animal bedding and other uses in relation to its supply.

Our material property comparisons we present here provide a positive answer to the question of technical substitutability. The answer to the economic question appears more tentative. Adding in $5/dry ton for delivery to an expected price of $50/ton, a resulting mill cost of $55/dry ton offers an economic advantage for chips but not for sawdust or shavings. We simulated the impact of ADBF on particleboard economics by replacing 75% of the chip input with ADBF. This creates an input mix consistent with our physical tests of 50% ADBF and 50% wood fiber (of which 2/3rd is sawdust/shavings and 1/3rd is chips). The resulting change in the gross income statement is a gain of $551,000 per year (Table 3). Stated another way, $551,000 are available per year should the substitution require other changes, such as increased resin use.

Table 3. ADBF Case Prices and Revenue Streams Generated for a Medium-Sized Particleboard Plant in 2007.

Production item	Prices	Unit	Costs	Revenue
Particleboard	300	$\$/10^3$ ft^2 (3/4-in. basis)		$24,000,000
Wood chips	65	$/odt	$1,118,537	
Shavings/sawdust	32.50	$/odt	$1,124,137	
ADBF	55	$/odt	$2,863,150	
Fiber waste (trim, etc.)	12	%	$612,699	
Urea formaldehyde	0.4	$/lb	$7,056,000	
Wax	0.56	$/lb	$708,750	
Labor, production[a]	21.25	$/h	$2,146,048	
Labor, technical[a]	32.00	$/h	$1,292,671	
Electricity	0.065	$/ kWh	$1,300,000	
Gas	8.0	$\$/10^6$ Btu	$ 1,280,000	
Propane	2.5	$/gal	$300,000	
Administration and overhead			$3,272,795	
Total			$23,074,786	
Gain (loss)			$925,214	

[a] Consists of base salary, fringe benefits and social insurance payments.

CONCLUSIONS

1. Our comparisons of the physical and mechanical properties of particleboard indicated that a 50/50 mixture of wood fiber and ADBF compares favorably with commercial standards for wood-based particleboard. The economic analysis indicates that replacing 75% of the chip input to a particleboard plant in Wisconsin with ADBF results in an economic gain of over a half-million dollars at prices and costs for particleboard and ADBF typically prevailing in 2007.
2. However, we note that the quoted ADBF prices were typically for relatively small volume sales to local purchasers. To be of interest to particleboard producers, fiber supply arrangements for ADBF will require large volumes contracted to be delivered regularly over extended periods.
3. Our familiarity with industry practices indicates that high-volume, long-time-horizon contracts are likely to be negotiated at lower prices than those typical of small-volume transactions. Thus, the ultimate negotiated cost of this fiber will likely be lower than assumed here. Whether this would still be attractive to dairy operators depends on the amounts of fiber generated by the industry over and above their own needs for bedding. Because such long-term, high-volume contracts currently do not exist, we can only speculate on what such terms might be.
4. An additional factor for particleboard producers to consider is the prospect of diversifying supply fiber to less cyclical sources, thus reducing procurement risk. Another factor is the regulatory and environmental pressures on industry in general to engage in more “green manufacturing” practices. ADBF dovetails well into this because of its post-industrial waste classification.

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