Fiber Recovery from Waste Paper: A Breakthrough in Re-Pulping Technology

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ABSTRACT

Paper mills and converters produce large quantities of waste paper. Paper trim from the process, roll ends, off-quality product and overruns are all sources of waste. Where feasible, process scraps are re-pulped and blended back into the feedstock. Converting paper to its final product sometimes produces wastes that are difficult if not impossible to re-pulp with conventional technology. For example, many paper products are laminated with plastic. Many mills either process laminated waste paper into pellets for boiler fuel or pay to have the wastes land filled. This paper describes a new technology that cost-effectively recovers quality fiber from papers currently being sent to landfill.

Fiber Recycling Technologies, Inc. (FRT) has developed a low-energy, mechanical re-pulping method that gently separates fibers while leaving contaminants largely whole, so that fiber can be readily screened from contaminants. Trials were run on a range of recovered papers and landfill waste, including poly-laminated paper trimmings, multi-laminated food packaging, and unsorted municipal solid waste. Success from the trials encouraged FRT to start a commercial re-pulping operation using their own technology. This expanding new business re-pulps high-grade landfill waste papers, creating 18 new jobs.

Recovered papers can use considerably less energy in pulping than wood-based pulp, so making secondary fibers competitive with virgin ones can save significant energy. A 20-ton per day FRT pulper now operating commercially annually saves about 7,000 tons of waste fiber from being land filled, and requires 11 to 30 kWh per ton for pulping. By comparison, refiner-mechanical pulping of virgin wood requires about 1,972 kWh per ton (Martin, N., et al 2000). Other mechanical and kraft pulping processes have similar or greater energy intensities.

Background

The pulp and paper industry converts fibrous raw materials into pulp, paper, and paperboard. The processes involved in papermaking include raw materials preparation, pulping (chemical, semi-chemical, mechanical, or waste paper), bleaching, chemical recovery, pulp drying, and paper forming and drying. The most significant energy consuming processes are pulping and the drying section of papermaking. The pulp and paper industry accounts for over 12% of total manufacturing energy use in the U.S, making it the nation's third largest consumer of energy in manufacturing. Total energy costs for the Wisconsin pulp and paper industry topped \$335 million in 1997, the highest of any Wisconsin industry (Wisconsin Paper Council 2003).

The U.S. pulp and paper industry is made up of three primary types of producers: 1) pulp mills, which manufacture pulp from solid wood or other materials, primarily wastepaper; 2) paper mills, which manufacture paper from wood pulp and other fiber pulp; and 3) paperboard mills, which manufacture paperboard products from wood pulp and other fiber pulp. In 1994, virgin wood pulps accounted for 68% of paper production by weight, with used paper covering the remaining 32%, when 82.46 million tons of paper were produced in the U.S. (Martin, N., et al 2000). More than 5.3 million tons of paper and over one million tons of paperboard are produced annually in Wisconsin (Wisconsin Paper Council 2003). Since recovered papers can use considerably less energy in pulping than wood-based pulp, making secondary fibers competitive with virgin ones can save significant energy in the mill (Martin, N., et al 2000).

As the United States paper industry approaches its 50% recovered paper target, getting that last couple of percent has gotten difficult. While there is potentially significant additional recovered paper tonnage, the paper industry faces a difficult challenge to collect and process much of this material in an economically attractive fashion. Among the obstacles to increasing the recovered paper percentage are: (1) papers with difficult to remove and separate contaminants and (2) quantities of particular recovered paper grades that are too small to justify separating and/or marketing.

Difficult to process recovered papers include those with coatings and laminations (such as plastic or foil) that are easily fragmented and difficult to remove in conventional cleaning and screening operations. Some contaminants, such as stickies, become well dispersed, but accumulate in the system and cause problems when they agglomerate. Other recovered papers require significant degradation (fiber damage, fines generation, freeness reduction and fiber shortening) to dislodge and disperse the contaminants.

Commonly used re-pulping methods combine high shear-factor mechanical stress, steam injection, and chemicals to re-pulp the waste paper. A conventional vertical pulper uses a high-horsepower motor driving a blender-like apparatus to shear the material into small pieces to allow rewetting and fiber separation. For example, a conventional vertical pulper of this type may be driven by a 300 hp motor and produce 150 tons per day of pulp. Waste paper is dumped into the top of the pulper, and blended into a slurry. Pulp exits the bottom of the machine, while contaminants exit out the side. The method is effective for ledger papers and other scrap with limited amounts of contaminants.

When used with laminated paper waste, a conventional blender-like pulper causes plastic and other layers to be ripped into fine pieces and dispersed throughout the re-pulp mixture as a contaminant. Large cleaners and fine screens are required to remove these contaminants before sending to the paper machine. These screens quickly become plugged with fine laminate pieces and become difficult to clean. For this reason, many mills and converters either have laminated waste paper converted into pellets for boiler fuel or pay to have the wastes land filled.

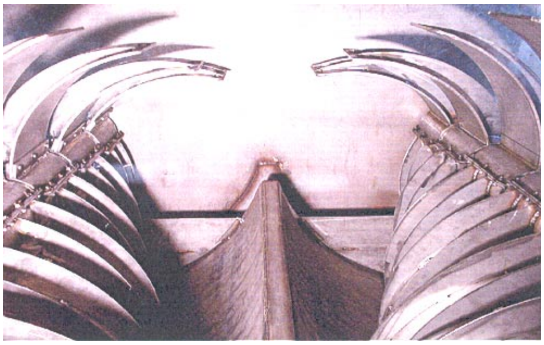
Drum pulpers have shown that slower, lower shear pulping processes can economically recover fiber from many of these difficult to process papers (Patrick, K. 2001). Drum pulpers are, however, typically quite large with a large footprint and high capital cost.

A New Re-Pulping Technology

Fiber Recycling Technologies, Inc. (FRT) of Neenah, Wisconsin has developed a much smaller modular pulping unit based on low shear. The Airborne Fiber-to-Fiber (AF2F) pulper, shown in Figure 1, has a unique twin rotor design with low connected horsepower. The twin horizontal rotors (see Figure 2.) turn in opposing directions to provide a simple lifting action and create gentle fiber-to-fiber action for low attrition on both fibers and contaminants. The AF2F pulper rotors, each 10 foot long, are powered by 20 hp motors and operate at 40 rpm. This low energy re-pulping method separates fibers while leaving contaminants largely whole, so that fiber can be readily screened from contaminants.

Figure 1. AF2F Pulper (Drive End)

Figure 2. AF2F Pulper Interior Showing Rotors



As part of a bale-to-pulp waste paper processing system developed by FRT, the "10 foot" AF2F pulper shown in Figure 1 can produce 25 tons of pulp per day. The 10 foot model was built as a pilot unit. The AF2F pulper can be extended to 20 feet to increase capacity. The AF2F pulper can be operated in either batch or continuous mode, however, experience to date has been in batch mode.

The baled recovered paper is automatically de-wired, de-densified and metered onto a belt conveyor by the "ABD Debaler" shown in Figure 3. The ABD Debaler was developed by FRT, leveraging experience from Val-Fab Inc, their metal fabricating sister company. In fact, FRT was formed by Val-Fab to expand their fabricating business.[1]

The loosened waste enters the drive end of the AF2F pulper from a belt conveyor immediately above the unit. Process water heated to 100°F to 110°F is also added in this area. Depending upon the furnish, small quantities of caustic soda, bleach, or surfactants may be added to speed the re-pulping process, for example, one gallon per half-ton batch of pulp. In current batch operations of the 10 foot pulper, about one-half ton of paper is being loaded, pulped, and emptied in 30 minutes. Pulping time

Figure 3. ABD Debaler (Bale Feed Side)

[1] Pulper technology based on patents by Mark Spencer, Inventor.

can require from 10 minutes to 20 minutes, depending on the furnish. The sight and sound of the pulping process is reminiscent of a commercial horizontal-axis washing machine.

Once the fiber has separated from the contaminant, the AF2F pulper empties the entire mixture to a tank. From there, the pulp mixture is fed into the "C-Screen", a large, horizontal rotating drum screen that separates the large contaminants from the fiber. FRT developed the C-Screen especially to handle the large contaminants that can be processed in the AF2F pulper. The fiber washes through coarse slits in the drum, while larger contaminants are channeled out the far end of the drum via internal dividers that rotate with a screw action.

Pulping Trials

This section of the paper presents the results from three of the many trials run on a wide range of recovered papers tested in the AF2F Pulper. The financial assistance for six of these trials was provided by the Wisconsin Industries of the Future program. These trials were primarily exploratory and, therefore, no steps were taken to optimize the AF2F Pulper performance on these trial papers. The three recovered papers were: (1) a pre-consumer coated paper plate stock, (2) poly-coated paper trimmings, and (3) unsorted municipal solid waste (MSW) from Chicago.

Trial One – Mill Comparison Trial Using Pre-consumer Coated Plate Stock

Trial number one was run to compare the performance of the AF2F Pulper to an existing conventional production pulper currently processing pre-consumer paper plate stock. This stock consists trim waste (to get a round plate from square paper) and quality control rejects. The coating that protects the plate from food moisture also makes pulping difficult.

Conventional production pulper. The existing production pulper was a medium consistency pulper operating in a continuous mode. The pulper was a 14 ft. Black & Clawson vertical pulper with a Vokes rotor and a 3/8" extraction plate. The rotor motor was a 300 hp Reliance operating at 4160 volts and 39 amps. An industrial fork lift retrieved the bales from inventory and set them at the top of the pulper. After the baling wires were cut, they were pushed, two at a time, into the pulper. Bale weight was about 1800 pounds each.

The production trial was set up to measure the energy used in pulping the coated plate stock (kWh per ton). The bales were weighed and the consistency was checked throughout the trial. The trial was scheduled to run for one hour of normal recycled pulp production at a rate of approximately 175 t/day of recovered paper. Due to the mill having its second pulper out of service, the trial was actually run at twice the normal production rate to meet the needs of the paper machines. Instead of running 8 bales, as planned, 16 bales (13.9 tons) were processed in one hour. The mill's standard chemistry and pulping temperature of 175°F were maintained during the trial.

AF2F pulper. Approximately half (855 lbs) of a bale representative of the coated paper plate stock was loaded into the AF2F pilot pulper along with sufficient heated water to bring the pulper consistency to 10% and temperature to 100°F. (maximum possible in the pilot plant).

Chemicals were added to the pulper to match the production unit standard conditions. The pulp was checked for defibering after 10 and 15 minutes (no change from 10 minutes).

Energy usage data and pulp samples were collected for both trials. The pulp samples were tested for fiber morphology, and standard TAPPI handsheets were prepared and tested[2]. Trial conditions are presented in Table 1.

Trial number one results. The results of pulping the pre-consumer coated plate are presented in Table 2. Key aspects of the results are reasonably similar between the conventional vertical pulper operated continuously and the AF2F twin rotor pulper run in the batch mode. The conventional pulper appears to require less pulping time and specific energy than the AF2F unit. The specific electric energy use levels for both units are nearly as low or lower than the lowest literature value of 10 kWh/t (Gottsching, L., Pakarinen, H. 2000). Overall, the AF2F pulper results may be slightly better considering that it was operating at a much lower temperature than the conventional pulper (100°F. versus 175°F.). It's also likely that the coated plate stock was defibered in less than 10 minutes in the AF2F pulper.

Table 1. Pulper Trial Number One: Operating Conditions

Experimental Conditions		
Variables:	**Conventional**	**AF2F**
Mode of Operation	Continuous	Batch
Motor Horsepower	300	40
Consistency, %	6.5	10
Temperature, ^{o} F.	175	100
Chemicals:		
Caustic	yes	yes
Surfactant	yes	yes

Table 2. Pulper Trial Number One: Results

Pulping Results		
Variables:	**Conventional**	**AF2F**
Pulping Time, min	~7.5	</= 10
Specific Electric Energy, kWh/t	9.2	</= 11.2
Nominal Pulping Rate, t/d	333	62
Pulp Properties		
Fiber Morphology:		
Length (Avg., Arithmetic), mm	0.419	0.429
Length (Avg., Length-wt'd), mm	1.15	1.05
Coarseness, mg/m	0.145	0.142
Pulp & Handsheet Properties:		
Freeness (C.S), ml	664	652
Density, g/cm3	0.372	0.39
Porosity (Gurley), ml/s	184	176
Tensile Index, J/g	26	30.2
Burst, kN/g	1.54	1.36
Tear Index, mN*m2/g	7.28	7.57
Brightness (ISO), %	70	70.1

The fiber length and coarseness values measured on the two pulps were nearly the same. Comparison of the two sets of handsheet tests didn't produce evidence of any major differences. While the AF2F pulp handsheets had significantly higher tensiles, the burst value was lower than the production pulp. As a consequence, there wasn't clear evidence of significant difference between the two pulps.

Trial Two – Recovered Poly-coated Paper Trimmings

Trial number two was run on waste paper currently being land filled. The poly-coated trimmings raw material, shown in Figure 4., is difficult to process conventionally because it produces thin strings of a very stretchy poly film. Approximately 800 lbs. of poly-coated waste paper was run in the AF2F pulper under the conditions shown in Table 3.

[2] A handsheet (or test sheet) is a single piece of paper made in a laboratory setting by draining water from a pulp suspension on a screen-covered sheet mold. This test sheet is used to evaluate paper properties.

Figure 4. Poly-Coated Paper Trimmings

Table 3. Pulper Trial Number Two: Operating Conditions

Experimental Conditions	
Variables:	**AF2F**
Mode of Operation	Batch
Motor Horsepower	40
Consistency, %	10
Temperature, degree F.	100
Chemicals:	
Hypo,%	0.03

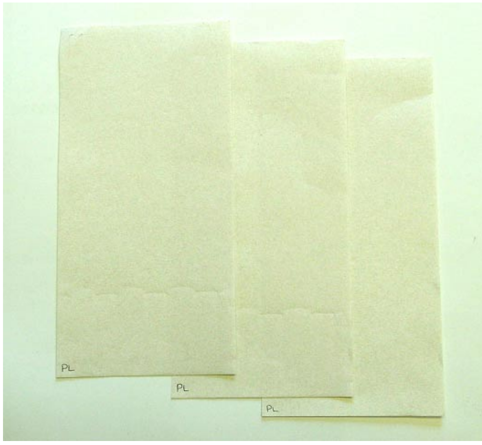
Trial Number two results. The trial material was pulped very easily in 10 minutes and the poly film didn't aggregate into balls or stringers in the pulper. Although it removed the poly film, the pilot plant C screen was not able to separate the poly and fiber materials completely and a significant percentage of the fiber slurry got entrained in the poly film. This resulted in a yield of recovered fiber of 65% (the "accepts level"), which was lower than expected. Two types of handsheets were prepared from the pulp that was collected from the coarse screen. Paper made on the automatic sheet former is shown in Figure 5. Table 4 contains the results of testing performed on standard TAPPI handsheets.

The fiber recovered from the poly-coated trimmings produced handsheet test results that indicated a high quality fiber is available from this raw material. The tensile and tear strengths were reasonably high for an unrefined recycled fiber pulp. The relatively low brightness came from the presence of black fibers that appear to have originated from the small quantity of printed trimmings.

Table 4. Pulper Trial Number Two: Results

Pulping Results	
Variables:	**AF2F**
Pulping Time, min	</= 10
Accepts (yield), %	65
Pulp Properties	
Handsheet Properties:	
Density, g/cm3	0.423
Porosity (Gurley), ml/s	143
Tensile Index, J/g	49.5
Burst, kN/g	2.88
Tear Index, mN-m2/g	13.2
Brightness (ISO), %	59.4

Figure 5. Handsheets from Screened Accepts



Trial Three - Recovered Paper from Unsorted Municipal Solid Waste

Trial number three was run on unsorted municipal solid waste (MSW) from Chicago. As can be seen in Figure 6., the bale of recovered paper contained many non-paper materials. These materials included wood, stones, plastics and metal items. A significant portion of MSW is paper and, therefore, potentially a source of fiber for paper products. The gentle twin rotor action and low shear design of the AF2F pulper should be well suited for pulping MSW.

A 700 lb batch of the Chicago MSW material was processed through the ABD debaling unit and conveyed to the AF2F pulper where it was pulped in hot water (100°F.) for 21 minutes to defiber the paper. The trial conditions are given in Table 5.

Figure 6. Bale of Unsorted Chicago Municipal Waste

Trial number three results. The AF2F pulper processed the MSW without any problems. Glass, rags, plastic jugs and bags emerged largely intact and were easy to remove via the coarse C-screen. The accepts level was 73.4%, which was higher than expected. At least part of the explanation for the high accepts measured is that Chicago municipal solid waste (MSW) is unsorted. The nominal pulping rate and pulp production rates for this trial are presented in Table 6. As in trial number two, two types of handsheets were prepared from the pulp that was collected from the coarse screen. Paper made on the automatic sheet former is shown in Figure 7. Table 6 contains the results of testing performed on standard TAPPI handsheets.

As the handsheet brightness and the appearance of handsheets in Figure 7. suggest, the pulp from the coarse screen had a significant amount of contaminants. The contaminants include fine grit and heavies that would be removed in the screening and cleaning processes of a typical secondary fiber pulping system. Considering the extremely low density of these handsheets and the contamination levels, this fiber source would be worth further evaluation.

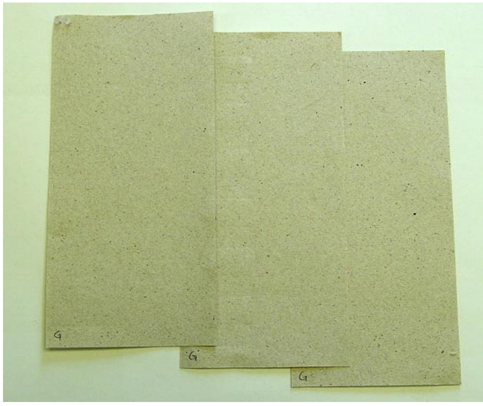
Table 5. Pulper Trial Number Three: Operating Conditions

Experimental Conditions	
Variables:	**AF2F**
Mode of Operation	Batch
Motor Horsepower	40
Consistency, %	10
Temperature, degree F.	100
Chemicals:	None

Table 6. Pulper Trial Number Three: Results

Pulping Results	
Variables:	**AF2F**
Pulping Time, min	21
Accepts (yield), %	73.4
Nominal Pulping Rate, t/d	24
Nominal Pulp Production Rate, t/d	17.6
Specific Energy, kWh/t	30.4
Pulp Properties	
Handsheet Properties:	
Density, g/cm3	0.25
Porosity (Gurley), ml/s	5000
Tensile Index, J/g	14.2
Burst, kN/g	0.73
Tear Index, mN-m2/g	4.41
Brightness (ISO), %	43.8

Figure 7. Handsheets from MSW



Conclusions from Trials

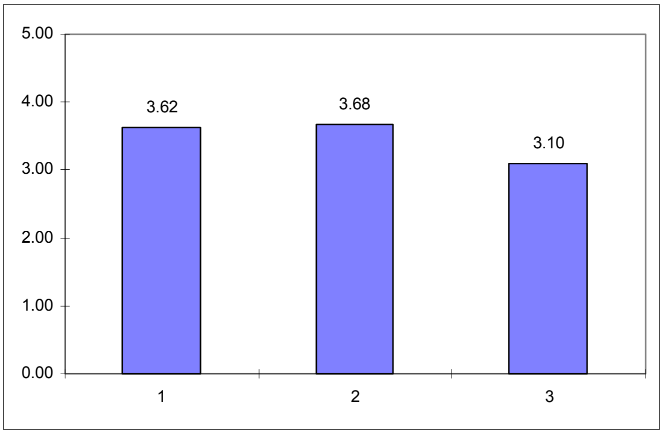
1. The AF2F Pulper was able to pulp pre-consumer coated plate recovered paper rapidly with low specific energy usage. Pulp properties were comparable to a highly efficient conventional vertical production pulper operating in a continuous mode.
2. High quality fiber was readily and efficiently recovered by the AF2F pulper from a difficult-to-process poly-coated trimmings wastepaper currently sent to landfill.
3. Unsorted MSW (Chicago) was successfully defibered in the AF2F pulper in 100°F. water. Limited pre-sorting to separate the light fraction (paper, plastics, etc.) from the heavy fraction (dirt, glass, metal, wood, etc.) would substantially increase yield and fiber quality. Further development of the technology for recovering good fiber currently going to landfills will be explored.

Promoting The FRT System To The Paper Industry

Through a State Energy Program Grant from the U.S. Department of Energy[3], the Energy Center of Wisconsin coordinated a demonstration event to promote the FRT technology to the sizable Wisconsin paper industry. The event took place on May 23, 2002, at the Fiber Recycling Technologies facility and the Valley Inn in Neenah, Wisconsin. The half-day event demonstrated this innovative paper equipment for 35 paper industry professionals. The group was split in two – one group viewed a live demonstration of the pulper, while the other group received information on the technology and had a question and answer opportunity. The group then switched locations.

A survey completed by 23 of the attendees indicated a very positive response, as illustrated in Figure 8 (Bensch, Ingo 2002). The event received a prominent article in the business section of the local regional newspaper (Appleton Post Crescent, June 5, 2002). The Energy Center of Wisconsin placed an article on the FRT pulper on the front page of its quarterly newsletter, which is distributed to over 800 recipients (Nelson, E. 2002).

Figure 8. Potential Application of this Technology
(Average scores on a scale of 1 to 5, where 1 = none and 5 = A lot)



1) overall.
2) in the paper industry.
3) in your company.

[3] Contact for this grant: Preston Schutt, State of Wisconsin, Department of Administration, Energy Division.

The demonstration event led to several follow-up demonstration trials with attending paper industries. Paper companies sought evaluations of waste papers they were sending to landfill, including several samples of food packaging. Examples included a plastic-foil-fiber-plastic laminate and wax-coated package trimmings.

Creating a Profitable Business to Commercialize the Technology

Despite months of promotional effort, FRT was unable to sell its new technology. While nearly all of the trials ended with successful defibering of the waste papers, no paper or re-pulping companies were willing to commit to being the first commercial application of the new technology. FRT also promoted the pulper for recovering fiber from the tremendous amount of paper currently going to landfill in municipal waste. This too met with interest, but no sales.

Analysis of the local market demand for recycled pulp, a heavy papermaking region, was estimated at approximately 500,000 air dry short tons per year. Local supply was estimated to be falling short of meeting this demand by 20%. To establish the necessary fiber balance within the region, pulp is purchased from other regions. The trials uncovered the fact that significant quantities of very high quality fiber were going to landfill directly from paper mills and converters, mainly in the form of plastic laminated waste. This presented an opportunity for FRT to produce commercial quantities of recycled pulp from their pilot AF2F pulper while demonstrating to industry that the technology can operate reliably and profitably.

Originally, an $86,000 grant from the Wisconsin Industries of the Future program was to be combined with owner equity and bank loans to close-loop the FRT pilot pulper in the FRT test facility in Neenah to produce 500 tons per month of marketable “wet-lap” pulp. As these plans were going forward in May 2002, Stora Enso North America placed a recently “mothballed” re-pulping plant in Appleton Wisconsin up for sale or lease at a favorable price. The Stora Enso Appleton facility was much larger than the FRT facility, and was built with two conventional pulping lines for a capacity of about 120 tons of wet lap pulp per day. Starting the business in the Appleton plant would allow for production of 20 tons per day from the relocated AF2F pilot pulper to be combined with 60 tons per day from one of the conventional pulpers already in the plant.

In Fall 2002, Wisconsin Fiber Resources, Inc (WFR) was formed by FRT to manufacture a de-inked fiber pulp from 100% recycled wastepaper. WFR is strategically located within the region, with several major consumers within 10-35 miles from the facility. The customers using these products are tissue manufacturers and converters, as well as printing and writing paper manufacturers and converters. These customers, in-turn, are responding to market requirements where a “recycled content” product is required or using the recycled pulp to reduce the fiber cost.

The formation of Wisconsin Fiber Resources, Inc is a very unique approach to pulp manufacturing in combination with on-going technology development. While WFR objectives are to enhance and sustain profitable growth, the company management realize that the competitive environment will require on-going research and development in production methods and technology to meet this objective. Fiber Recycling Technologies being the technology and equipment development partnering company, will be able to research, develop and evaluate its technology, while WFR will benefit from its beneficial use in reduced operating cost. The goal is to have all new technology confirmed and verified in "full scale operation" by WFR. Val-Fab, Inc., the original company, will benefit from fabricating and installation of the new FRT line of pulping equipment.

Financing of the lease and plant start-up was accomplished with a combination of owner equity, bank loans, the $86,000 grant from the 2002 Wisconsin Industries of the Future program, and a $250,000 investment from the Center for Technology Transfer (CTT).

The CTT is a non-stock, non-profit Wisconsin corporation formed in September 2002 using a grant from the Wisconsin Industries of the Future program. The mission of the CTT is to accelerate the research, development and industry adoption of processes and practices that improve industry competitiveness and are more energy efficient and environmentally friendly. The CTT will work to become self-sustaining by taking loan and equity positions in start-up companies. The Center for Technology Transfer will oversee the $250,000 investment in WFR. As part of the loan, the CTT has performed a due diligence review of the business financial plan, analyze market supply and demand, and advise the WFR management team.

A Successful New Business

Although originally planning to simply sell hardware, FRT leveraged assistance from many sources to re-open a mothballed re-pulp mill and enter the waste re-pulping business with a subsidiary, Wisconsin Fiber Resources. This first commercial demonstration now produces about 20 tons per day of high-quality wet lap pulp from paper supplies previously destined mainly for landfill. The FRT pulper provides a cost-advantage when combining with pulp from the 60 ton per day conventional pulper, to produce a total of 80 tons per day of wet lap pulp.

Throughout its first 2 months of commercial operation beginning in January 2003, WFR has pushed itself to limits to keep up with demand for its pulp. By the third month, the facility produced pulp on a 24/7 schedule, creating jobs for 18 people, and was selling all production at competitive market prices.

Impacts and Implications

Recovered papers can use considerably less energy in pulping than wood-based pulp, so making secondary fibers competitive with virgin ones can save significant energy. A 20-ton per day FRT pulper now operating commercially annually saves about 7,000 tons of waste fiber from being land filled, and requires 11 to 30 kWh per ton for pulping. By comparison, refiner-mechanical pulping of virgin wood requires about 1,972 kWh per ton (Martin, N., 2000). Other mechanical and kraft pulping processes have similar or greater energy intensities.

An additional objective will be to research, evaluate and apply new technology to use Municipal Solid Waste (MSW) as a partial fiber source for the manufacturing of a lower cost pulp to be used by unbleached board and newsprint producers. Partners from the waste handling business working with WFR have modeled the feasibility of a waste recovery facility. They estimate about 30-40% of the material going to landfill today consists of fibrous material such as envelopes, junk mail, catalogs, paper, and food packaging. The objective is to maximize the use of this fiber source by pre-sorting light materials from heavy waste, and pulping the light fraction in the FRT pulper. FRT has received a $150,000 grant from the Wisconsin Department of Natural Resources to work with county municipal waste authorities in recovering this fiber.

Increasing the use of recycled fiber for papermaking reduces the need for virgin fiber sources and the large amounts of energy to convert that fiber resource to pulp. By opening up access to a huge source presently unrecovered fiber, the FRT pulper not only improves prospects for creating a sustainable forestry industry, but also a sustainable energy future.

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