

# Small-Scale Recycled Glass-to-Fines Processing System

## Appendix A Protocol



# **Small-Scale Recycled Glass-to-Fines Processing System**

## **PROTOCOL**

*Prepared by:*

**The Clean Washington Center (CWC)**

Division of Pacific NorthWest Economic Region (PNWER)

2200 Alaskan Way, Suite 460

Seattle, WA 98121

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## Protocol

# SMALL-SCALE RECYCLED GLASS-TO-FINES PROCESSING SYSTEM

The value of substituting recycled glass for low-priced virgin raw materials in container manufacturing has always placed an upper limit on the value of collected recycled glass. Increasingly, however, research is being performed to assess the viability of processing glass to sand sizes and finer for marketing as a raw material in traditional industrial materials applications.

This protocol deals with equipment issues and economics of processing glass to sand sizes in small-scale facilities. For the purpose of this protocol, low-value is considered to be less than \$20 per ton aggregate markets, intermediate value is considered to be \$20-60 per ton, the approximate range of the value of collected recycled glass to container manufacturers, and high-value is considered to be greater than \$60 per ton.

The Recycling Technology Assistance Partnership (ReTAP) is an affiliate of the national Manufacturing Extension Partnership (MEP), a program of the Commerce Department's National Institute of Standards and Technology. The MEP is a growing nationwide network of extension services to help smaller U.S. manufacturers improve their performance and become more competitive. Other major support comes from the U.S. Environmental Protection Agency and the American Plastics Council.

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The special glass grain sizing requirements for some glass applications could create market opportunities for small-scale processing operations. A number of fine grade uses have been tested, including filtration media, fused glass, polymer fillers, paint additives, blasting abrasives, hybridized cement, and landscaping and roofing materials. Most of these applications can use mixed color glass. The reader should keep in mind that testing fitness for use is not the same as market development. Actually selling significant volumes of processed glass into any of these applications requires extensive local marketing.

Processing glass for these applications requires size reduction and contaminant removal. Physical specifications vary for each application.

This protocol describes some of the operational issues and economics of small-scale, post-consumer glass crushing and processing systems that remove debris and size glass "sand" suitable for various intermediate and high-value market applications. Field test results for one type of system are also presented. This protocol includes the following sections:

- Recommended Processing Methods
- A Cost Model
- Forms to record trial conditions
- Trial Data from a Prototype System
- Parameters for equipment evaluation



## **Introduction**

The most basic glass processing system includes only a feed hopper and crushing mechanism. However, for most applications, certain ancillary equipment is required. Ancillary equipment may include infeed conveyors with speed controls to regulate the amount of material flow into the crushing mechanism, discharge conveyors, dust control, and vibratory screens or trommel screens for control of particle size and debris removal. Other equipment may be included with more sophisticated beneficiation systems.

Equipment for large-scale glass processing operations may be found in existing industrial mineral or glass beneficiation operations. However, the purpose of this report is to describe potential small-scale glass operations. Small-scale glass processing can be established either by assembling individual components or through purchase of a system manufactured specifically for glass crushing. In either case, this report describes some important issues to consider and develops a model for cost estimating.

This report is intended to describe issues related to small-scale processing, rather than the details of glass processing equipment. For more detailed information on specific pieces of equipment, see individual reports in *Best Practices in Glass Recycling*, published by the Clean Washington Center.

In this report, “fines” refers to material passing through a standard 8 mesh screen. “Small scale” means under two tons per hour.

### **Equipment Availability**

Some equipment used for crushing rock or concrete has proven to work for crushing glass for use as a coarse construction aggregate. However, processing glass to fines in standard aggregate processing equipment can result in increased maintenance of

wearing surfaces because glass is both hard and has a relatively low specific gravity, reducing the effectiveness of most impact equipment.

In addition, equipment such as jaw crushers and cone crushers which rely on abrasion crushing perform poorly with glass because the hardness of the glass causes excessive wear of the crushing surfaces, while the type of crushing action can cause the glass to fracture into shards. Shardy shapes are less desirable than cubical particles in most applications.

When designing glass crushing systems, individual situations should be evaluated carefully in terms of potential supplies, demands, quality, and markets.

### **Dedicated Small-Scale Equipment**

There are a few small-scale systems now on the market manufactured specifically for pulverizing glass into sand. Such equipment offers the advantages of the knowledge and experience of the manufacturers in dealing with glass processing issues. These small scale crushers (one to two tons per hour) for producing glass sand may cost anywhere from \$10,000 to \$40,000, without any ancillary equipment.

## **Recommended Processing Methods**

When evaluating the feasibility of using a recycled material in a new application, it is important to first document baseline requirements for target markets. This baseline information can be compared to data obtained from tests performed on the recycled materials. It is critical to test recycled materials from known sources processed by known processing equipment, because the physical characteristics of the processed material may vary widely depending on the source and processing strategy.

Processing post-consumer or post-industrial recycled glass into high-grade, industrial quality glass sand generally consists of the following steps, described in detail below:

- *Feedstock Acquisition*
- *Feedstock Preparation*
- *Drying*
- *Pulverizing*
- *Debris Control*
- *Dust Removal*
- *Sizing*
- *Packaging/Storage*

### **Feedstock Acquisition**

It is important to first assess the characteristics and availability of recycled feedstock. Glass that is free of ferrous metal and other debris is preferable, to reduce both the wear on crushing mechanisms and the cost of debris removal. Suppliers of post-consumer and post-industrial glass should both be considered<sup>1</sup>. Any possible effects from chemical or physical differences between types of glass should be taken into account for each possible application. Feedstock may also be obtained directly from generators, such as local drop box sites, community recycling centers, local restaurants, company cafeterias, or other heavy users of glass.

### **Feedstock Preparation**

In this report, “breaking” refers to gross size reduction and “pulverization” refers to reduction to fine sizes.

Before any crushing, the glass may be run over a magnetic removal device to pull out any large pieces of ferrous metal. A picker station following the magnet is necessary for visual inspection and removal of other large contaminants.

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<sup>1</sup> Refer to CWC publication GL-95-6 for suppliers in Washington State.

The glass is then fed through a glass breaker and reduced to cullet. Most of the contaminants expected with recycled glass (e.g., paper, aluminum, and plastic), are less friable than glass. Therefore, they tend to remain in larger pieces than the glass during crushing. The cullet is then passed through a 3/4" screen to remove gross debris. Running the glass over a second magnetic head pulley after the glass is broken into cullet should remove any remaining ferrous metal that may have been attached to the glass.

More sophisticated debris removal techniques, such as nonferrous metal removal systems, are probably not economical at a small scale.

In conveyors, sealed ball bearing troughing idlers are preferred over grease-type idlers, since grease-type idlers can be damaged by glass dust contaminating the lubricants. If the cullet is wet or sticky, it may also be preferable to use a belt without cleats, so that a belt scraper may be installed on the underside of the return conveyor. The maximum incline of a cleatless conveyor is thought to be about 18 degrees.<sup>2</sup>

### **Drying**

Glass must be dried prior to pulverization if the sand is to be dry sized, especially if using mesh sizes smaller than 1/8". The glass is much easier to dry prior to the final pulverizer because it has a smaller surface area from which to evaporate the water before final crushing. Drying also helps to prevent the wet glass dust from plugging dust collection bags.

The most commonly used type of dryer is a tumbling rotary drier, fueled by natural gas or propane. Information on the appropriate flow rate and temperature is best obtained by performing trial runs

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<sup>2</sup> Schedel, Don. “How to Make Good Quality Cullet,” *Glass Industry*, February, 1990, pp. 10-13.

because most dryer manufacturers will not be familiar with the drying characteristics of crushed glass.

### **Pulverizing**

Multiple row hammermills, consisting of multiple hinged, free swinging bars or “hammers” attached to pivots fixed to a rotating shaft, seem to work well for producing glass sand, as the multiple impacts tend to produce grains that are relatively uniform in size and not shardy. The tip speed of the hammers and the retention time determine the product size. Conventional single-pass hammer mills have also been successfully used if the cullet is properly prepared and the hammer tip speed and flow are controlled properly.

If the multiple row hammermill is used, the angle at which the hammermill barrel sits should be adjusted in order to optimize the retention time in the mill and to spread wear evenly over the hammers, increasing the time between shutdowns for hammer replacement.

The distance between the hammers and the mill walls also affects system performance. Placing the hammers too close to the walls can cause excessive wear to both the hammers and the walls. If the hammer tips are too far from the walls, however, the impact efficiency is reduced.

It is advantageous to operate the hammermill at a rotor tip speed and feed rate that will pulverize the glass but leave any remaining debris intact, so that it may be screened out later. The optimal speed for this purpose, according to one professional, is 3,500 feet per minute.<sup>3</sup>

Some hammermills recirculate oversize material internally until it reduces to a size small enough to pass through a discharge screen or orifice. This

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<sup>3</sup> *ibid.*

configuration gives tighter gradation control than single-pass mills, but cannot tolerate as much contamination as systems that allow contaminants to exit the mill in larger pieces that are easier to screen out.

Further information on these and other small-scale glass-to-fines processors may be obtained by contacting the following manufacturers.<sup>4</sup>

- SMC Manufacturing, Vancouver, B.C.  
Contact: Geoff Brown, 604-266-0422
- Andela Tool & Machine, Richfield Springs, NY  
Cindy Andela, 315-858-0055
- Glass Aggregate Manufacturing & Engineering (G.A.M.E.), Faribault, MN  
Don Cook, 507-334-6437
- Glass Recycling Inc., Marietta, GA  
Don Lucas, 404-516-0816

Feed rate can be an important parameter in any of these systems. Feed rate effects the gradation of the final product and the load on the pulverizor motor. For both of these reasons it may be worth controlling the feed rate. When pulverizors are new, they tend to make more fine material. As impact surfaces wear and tolerances increase, slowing the feed rate may enable the processor to maintain consistent product gradation. In addition, overloading the pulverizor can cause the motor to stall or jam. To address both of these issues, some systems monitor the electrical current load on the pulverizor motor and regulate the speed of the infeed conveyor to maintain a constant load.

The most common pulverizers seen in large-scale glass processing facilities are vertical shaft impactors (Keu-Ken, Remco, Barnac, Canica, Spokane, etc.).

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<sup>4</sup> This is not intended to be a complete list of manufacturers. Others can be found in the Thomas Register.

These mills reduce the glass to fines by flinging it against the inside wall of a rotating casing. The rotating casing becomes lined with glass to be crushed. The advantage of this configuration is that glass functions as both the impact and the wearing surfaces. These impactors process upwards of 20 tph and start at about \$50,000.

### **“Powders” Processing**

Some potential markets for very fine (smaller than 200 mesh) glass are under investigation. In many of these potential markets, fine glass substitutes for other fine silicas or dry clays. The equipment used to process glass to that grade of fineness is not covered in this report. Ball mills and vibratory mills have been in use for many years for that sort of processing. The physics of reducing one hundred percent of the input of a glass processing machine to 200 mesh material differ markedly from those employed with the generation of the 1/8-inch material described in this report. For that reason, although some of the pulverizers described here may be adjusted to produce more or less very fine glass, the process is not an efficient one and results in extensive wear.

On the other hand, all pulverizers produce some dust, as described below. That dust, if properly captured and secondarily processed, can be marketed as a by-product of the main process outlined in this report.

### **Dust Control**

It is necessary to control glass dust generated by the pulverizer. Ambient dust can be controlled by pulling a negative pressure on the outlet of the pulverizer. The dust is pulled first across a drop-out box or through a cyclone, where the velocity slows down and the heavier pieces fall into a barrel. After the drop-out box, the fan draws the dust into a baghouse for collection.

If possible, the fan should be placed at the exit of the baghouse out of the stream of material, because glass flowing over the blades will wear them down very quickly. Bags should be porous enough to prevent plugging and to maintain a negative air pressure.

With additional processing, it may be possible to recover marketable fractions from the very fine glass collected in the dust control system.

### **Final Debris Removal**

Final debris removal is accomplished through a well-designed combination of dust control and screening. A correctly sized dust control fan pulls a negative pressure adequate to remove the finest mesh glass and light weight contaminants, including paper and plastic. After the dust control, a small rotating trommel screen with a carefully calibrated mesh size will remove heavier contaminants that have remained larger than the glass through the pulverizer.

### **Sizing**

Screening systems for fine aggregates have been developed over the decades and are available in every size and many configurations. Two basic types of screening systems for industrial aggregate applications are circular and tilted bed rectangular vibratory screens. Either type of screen can be built up to any number of layers for multiple size gradations. Material to be screened enters from the top and passes from deck to deck. The top screen has the largest opening size. At each deck, the aggregate larger than the screen size opening is removed from the flow.

In circular screens, the aggregate flows in a circular course around the screens, with the oversize exiting through an outlet hose at each level. In rectangular screens, the aggregate enters at the elevated end of the screen and flows across, with the finer aggregate dropping through the screen while the oversize flows

off the end. In general, rectangular, tilted bed screens have greater capacities, while flat circular screens do a better job of separating the material. Circular screens may be adequate for feed rates of up to two tons per hour. Above that rate, a multiple decked screen may be necessary.

Most manufacturers of screening systems will perform test runs in their laboratories to provide data on flow rate and efficiency of separation for a new material. A perspective system buyer can have a barrel of glass processed in the type of pulverizer he is considering sent to a screen manufacturer for test.

### **Packaging/Storage**

Provisions need to be made for both packing and weighing the final product. Bagging, palletizing, bulk-bagging and wrapping requirements will depend on product specifications and quantities required by the customer, as well as the customary packaging expected in a particular industry.

There are many manufacturers of packaging systems, many of which are listed in the *Thomas Register*. Research should be performed to determine the packaging requirements for the perspective markets, then finding packaging systems to fulfill those requirements. The processor must respond to market packaging expectations, rather than expecting the market to respond to the processor's convenience.

### **A Cost Model**

The following categories of costs should be considered when evaluating a prospective processing system.

### **Capitol Cost**

Capitol costs consist of the fixed costs of purchasing equipment and the costs of mechanical and electrical

installation. As with any commodity manufacturing process, return on investment is dependent upon economics of scale. Templates for estimating capitol costs and production costs are presented in Appendix A.

### **Production Cost**

Production costs include the costs of labor, building and equipment rental, utilities, gasoline, oil, maintenance and supplies, and the cost of dust and debris disposal.

Continuous labor is required to perform maintenance tasks and replace parts, line up feedstock, change the dust collector barrel, move bulk bags of product, and weigh the product. If the system is properly designed, however, one full-time operator is probably adequate in a small-scale operation.

Gasoline, oil, lubrication, and rental costs should be calculated for a forklift (for moving the product and bins) and bobcat (for loading feedstock onto the infeed conveyor).

Building rental costs should be based on the floor space required for equipment as well as the space required to stockpile materials.

Actual line item production costs for a pilot operation are summarized in appendix B.

### **Selling, General, & Administrative Costs**

Selling, general, and administrative costs include management, office expenses, insurance, taxes, and commissions. These line items are also summarized in appendix A.

Prototype or pilot processing can be used to generate material for end-use testing. This form tracks inventory so that end-use projects can be developed.

## **Forms to Record Trial Conditions**

Forms that have been developed to capture the pertinent data for evaluating prototype or pilot systems are presented at the end of Appendix A. The following forms are included:

### *Economic Evaluation - Recycled Glass Sand Processing System.*

This spreadsheet enumerates the costs detailed above, along with formulas for duplicating the spreadsheet.

### *Equipment List*

A listing of the principle equipment in a glass processing system.

### *Recycled Glass Feedstock Sourcing Report*

Sourcing quality material is a critical prerequisite to producing a quality product. This form helps to track incoming recycled glass and to link it to the production of final products.

### *Recycled Glass Daily Operations Report*

This form tracks the overall production rate and efficiency of the system.

### *Operational Data & Analysis*

This form tracks equipment performance data for comparison over time and can give an early indication of performance deterioration.

### *Recycled Glass Sand Production/Inventory/Shipping Report*

### *Production Cost Data*

This form is the first-cut for accumulating equipment operational data

## **Parameters for Equipment Evaluation**

Appendix C is a listing of parameters to be considered when evaluating a glass processing system. Many are quantitative factors that have been integrated into the economic evaluation above. Others are qualitative factors requiring consideration.

## **Acknowledgments**

The support of this project by Don Freas, of IMTEK, Inc. is gratefully acknowledged.

# APPENDIX A

## Economic Evaluation - Recycled Glass Sand Processing System Operating Parameters

Note: Adjust values for Q and h until the volume of production equals the available feedstock.

### Operating Parameters

Hours of operation, h	estimate hrs/yr	<input type="text"/>	hrs/yr
Available feedstock	estimate tons/yr	<input type="text"/>	tpy
Debris content, d <sub>1</sub>	estimate % debris	<input type="text"/>	
System capacity, Q	estimate tons/hr	<input type="text"/>	tph
Production efficiency, f	estimate %	<input type="text"/>	
Dust generation, d <sub>2</sub>	estimate %	<input type="text"/>	
System power use, e	estimate power rating	<input type="text"/>	kw
Gas consumption, g	estimate btu/hr	<input type="text"/>	btu/hr
Production, P	$(Q \times f) \times (1 - d_1 - d_2) \times h$	<input type="text"/>	tpy

### Utilities

Electricity	enter cost per kwh	<input type="text"/>	/kwh
Gas	enter unit cost	<input type="text"/>	/btu

## Economic Evaluation - Recycled Glass Sand Processing System Profit Calculation

### Product Sales

Product	enter price per ton	<input type="text"/>	/ton
Bag/pallet charges	enter charge per ton	<input type="text"/>	/ton
<b>Total revenue, TR</b>	<b>total per ton x P</b>	<input type="text"/> /yr	<input type="text"/> /ton

### Variable Costs

Managerial		<input type="text"/>	/mo	<input type="text"/>	/ton
Sales & admin.		<input type="text"/>	/mo	<input type="text"/>	/ton
Operator	estimate salary + benefits	<input type="text"/>	/hr	<input type="text"/>	/ton
Gasoline, oil, lube	bobcat, forklift	<input type="text"/>	/mo	<input type="text"/>	/ton
Materials/supplies	bags, pallets, etc.	<input type="text"/>	/mo	<input type="text"/>	/ton
Maintenance materials		<input type="text"/>	/mo	<input type="text"/>	/ton
Electricity	e x cost per kwh x h	<input type="text"/>	/yr	<input type="text"/>	/ton
Gas	g x cost per btu x h	<input type="text"/>	/yr	<input type="text"/>	/ton
Mobile equipment rental	bobcat, forklift	<input type="text"/>	/mo	<input type="text"/>	/ton
Debris removal	enter cost per ton	<input type="text"/>	/ton	<input type="text"/>	/ton
Dust removal	2nd cost per ton	<input type="text"/>	/ton	<input type="text"/>	/ton
Cost of glass delivery	enter cost per ton	<input type="text"/>	/ton	<input type="text"/>	/ton
<b>Total Variable Cost, VC</b>		<input type="text"/> /yr		<input type="text"/> /ton	

### Fixed Costs

Building Lease, L		<input type="text"/>	/mo	<input type="text"/>	
Equipment, EC	(from equip. list)	<input type="text"/>		<input type="text"/>	
Amortized Life, n		<input type="text"/>	years	<input type="text"/>	
Assumed Interest Rate, i		<input type="text"/>		<input type="text"/>	
Amortized Cost of Equip, AC	$EC \times i \times (1+i)^n / [(1+i)^n - 1]$	<input type="text"/>	/yr	<input type="text"/>	
<b>Total Fixed Cost, FC</b>	<b>AC + L</b>	<input type="text"/> /yr		<input type="text"/> /ton	

### Total Cost

<b>Total Cost, TC</b>	<b>VC + FC</b>	<input type="text"/> /yr		<input type="text"/> /ton	
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### Net Margin

<b>Net Margin</b>	<b>TR - TC</b>	<input type="text"/> /yr		<input type="text"/> /ton	
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## Equipment List (Fixed Capital)

<i><b>ITEM</b></i>	<i><b>COST</b></i>
Glass Hopper	
Initial Belt Conveyor (with or without cleats)	
Primary Crusher	
Rotary Dryer w/ Trommel Screen Section & Gas Burner	
Belt Conveyor with Magnetic Head Pulley	
Impactor or Hammermill	
Belt Conveyor with Magnetic Head Pulley & Dust Collection Hood	
Motor Control Center with Frequency Controller on Impactor & Feed Conveyors	
Sizing Apparatus	
Baghouse	
Bag Packer with Beam Balance	
Installation - Mechanical, Electrical	
<b>TOTAL</b>	

# Recycled Glass Feedstock Sourcing Report

Date: \_\_\_\_\_

Source Code:	
Type Available:	
Size Available:	
% Debris:	
Amount Ordered:	
Color Ordered:	
Size Ordered:	
Cost Ordered:	
Delivery Cost:	
Requested:	
Delivered:	
Comments:	
Prepared By:	

# Recycled Glass Daily Operations Report

Date: \_\_\_\_\_ Day: \_\_\_\_\_ Prepared By: \_\_\_\_\_

	<i>Units</i>	<i>Comments</i>
Feedstock Source Code		
Tons Processed		
Hours Operation		
Feed Rate (tph)		
Pulv Elec Load (ave amps)		
Stack Temp (°F)		
Dust Produced (est lbs)		
Debris (+6m - est lbs)		
Production:		
6 x 20 mesh (lbs)		
20 x 30 mesh (lbs)		
30x 40 mesh (lbs)		
40 x 50 mesh (lbs)		
50 x 100 mesh (lbs)		
< 50 mesh (lbs)		
< 100 mesh (lbs)		
Total lbs		
% Product Recovery		
Operator (hrs/name)		
Operator (hrs/name)		
Downtime (hrs/explanation)		
Operating Time Overall (%)		
<b>Notes</b>		

## Operational Data & Analysis

Date: \_\_\_\_\_ Period From: \_\_\_\_\_ To: \_\_\_\_\_

<i>Harris Dryer/Pulverizer</i>	<i>Date</i>	<i>Units (lbs/hrs/\$)</i>	<i>Tons Processed</i>	<i>Units/Ton Processed</i>	<i>Comments</i>
<i>Wear Data - Pulverizer:</i>					
Weight Hammers (start)					
Weight Hammers (end)					
Fuel Consumption:					
Weight Hammers (start)					
Weight Hammers (end)					
Electricity Cost (\$/kwh)					
Fuel Cost (\$/lb)					
Hammer Cost (\$/lb)					
Labor (rate/hrs) #1					
Labor (rate/hrs) #2					
Associated Payroll (%)					

# Recycled Glass Sand Production/Inventory/Shipping Report

Date: \_\_\_\_\_ Prepared By: \_\_\_\_\_ Period From: \_\_\_\_\_ To: \_\_\_\_\_

<i>Product</i>	<i>Color</i>	<i>Code</i>	<i>Begin Inv</i>	<i>Productn</i>	<i>Shpmnts</i>	<i>End Inv</i>
Mixed Container						
6 x 20 mesh (lbs)						
20 x 30 mesh (lbs)						
30x 40 mesh (lbs)						
40 x 50 mesh (lbs)						
50 x 100 mesh (lbs)						
< 50 mesh (lbs)						
< 100 mesh (lbs)						
Total lbs						
Plate						
6 x 20 mesh (lbs)						
20 x 30 mesh (lbs)						
30x 40 mesh (lbs)						
40 x 50 mesh (lbs)						
50 x 100 mesh (lbs)						
< 50 mesh (lbs)						
< 100 mesh (lbs)						
Total lbs						
Clear Container						
6 x 20 mesh (lbs)						
20 x 30 mesh (lbs)						
30x 40 mesh (lbs)						
40 x 50 mesh (lbs)						
50 x 100 mesh (lbs)						
< 50 mesh (lbs)						
< 100 mesh (lbs)						
Total lbs						

Recycled Glass Sand Production/Inventory/Shipping Report

Date: \_\_\_\_\_ Prepared By: \_\_\_\_\_ Period From: \_\_\_\_\_ To: \_\_\_\_\_

<i>Product</i>	<i>Color</i>	<i>Code</i>	<i>Begin Inv</i>	<i>Productn</i>	<i>Shpmnts</i>	<i>End Inv</i>
Green Container						
6 x 20 mesh (lbs)						
20 x 30 mesh (lbs)						
30x 40 mesh (lbs)						
40 x 50 mesh (lbs)						
50 x 100 mesh (lbs)						
< 50 mesh (lbs)						
< 100 mesh (lbs)						
Total lbs						
Amber Container						
6 x 20 mesh (lbs)						
20 x 30 mesh (lbs)						
30x 40 mesh (lbs)						
40 x 50 mesh (lbs)						
50 x 100 mesh (lbs)						
< 50 mesh (lbs)						
< 100 mesh (lbs)						
Total lbs						
Other:						
6 x 20 mesh (lbs)						
20 x 30 mesh (lbs)						
30x 40 mesh (lbs)						
40 x 50 mesh (lbs)						
50 x 100 mesh (lbs)						
< 50 mesh (lbs)						
< 100 mesh (lbs)						
Total lbs						

## Production Cost Data

<i>Item</i>	<i>Description</i>	<i>Units</i>	<i>\$/Unit</i>
Labor:		hour	
Operator #1		hour	
Operator #2		hour	
Operator #3		hour	
Manger/Supervisor		month	
Associated Payroll		%	
Building Rental		sq. ft./mo.	
Equipment Rental		month	
Electricity		kwh	
Gas/Propane		btu	
Gasoline, Diesel, Oil, Lube		month	
Maintenance Materials	Detail	month	
Packaging Materials	Detail	item	
Dust Disposal		ton	
Debris Disposal		ton	
Other Expenses	Detail	month	
Office Expenses		month	
Insurance		month	
Taxes, fees, permits, etc.	Detail	month	
Commissions, discounts	Detail	ton	
Other items	Detail	month	

# APPENDIX B

## Small-Scale Glass Sand Recycling Process Assessment Case Study

The Harris Dryer/Pulverizer system (tested by IMTEK in 1994 under a contract with The Clean Washington Center) was used to produce glass sand and generate initial data to evaluate the performance of various system components. Product was also distributed to local manufacturers to evaluate the local market potential of post-consumer glass sand.

The Harris Dryer/Pulverizer is a small one-tph horizontal dual rotor hammermill. Conventional systems process material in two stages, using a separate dryer and impactor or hammermill. The Harris Dryer/Pulverizer, however, is constructed so that the mill and dryer are both contained in the same unit. This configuration was initially believed to be economically advantageous for small scale processing operations. In the end, the Harris Dryer/Pulverizer prototype was found to be neither an efficient nor cost effective system for making sand from recycled glass.

### System Description

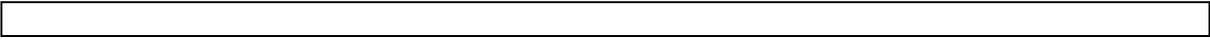
The system included a feedstock preparation unit, dryer/pulverizer, scalping screen, an initial conveyor with a magnetic head pulley, a second conveyor, and a 48-inch Sweco gyratory separator (see Figure 1 on the following page). Product was collected and shipped either in bulk or 100-pound bags.

The hammermill rotors are synchronous, with seven rows of 16 bar hammers attached to the central shaft. The dryer/pulverizer unit is powered by a 10 hp 440V three-phase motor. The mill is fed by a conveyor on which cullet is loaded and conveyed up to a feed hopper directly over the mill.

After pulverization, the product is dribbled onto a 6-mesh screen mounted on top of a Syntron vibratory feeder to scalp off most of the debris. The undersize is conveyed over a magnetic pulley to another conveyor which transports the product to a 48" Sweco gyratory vibrating screen. This screen has three or four decks, depending on the number of size fractions required. Most the time the Sweco was run with 3 decks, including 20, 30 and 50 mesh screens. The discharge from the screens was collected in pails and transferred by hand to bulk bags held up with hanger cages.

**Table 1. Feedstock Sources**

Source	Color	%Debris	Type	Availability	Cost	Comments
Recomp, Inc.	mixed	high	bottles	1000 tpy	< \$5/ton	dirty glass w/ metal
Northwest Recycling, Inc. (Bellingham)	mixed	moderate	bottles	1000 tpy	< \$5/ton	dirty glass w/ metal
Fibres International, Inc. (Seattle)	mixed	moderate	< 1/4" cullet	unknown	\$12/ton	shards from conveyor belt droppings
Environmental Technology, Ltd. (Surrey, BC)	amber	moderate	5/8" cullet	3000 tpy	\$50/ton	ferrous metal removed, clean, well sized
Bedrock Industries, Inc. (Seattle)	plate	low - none	broken	150 tpy	\$15/ton	clean, some large pieces; tempered/ untempered



**Table 2. Feedstock Preparation**

Equipment type	CP Glass Hopper/Break - no magnetic separator loaded into bulk bags
Capacity	tph 4 tph
Operating time - %	Continuous as required
Power rating - hp/voltage	3/4 hp
Equipment configuration - design/layout	Hopper/Cleated Conveyor Vertical Shaft Breaker- for bottles only
Cost of new equipment	Approx. \$6,000
Manning required	(safety equipment required) one w/ gloves/goggles/mask
Special maintenance requirements, if any	Regular cleaning of belt and pulleys; replacement of belt depending on use; replace breakers

**Feedstock Source**

Feedstock was obtained from various sources. Due to time and cost restraints, most of the feedstock sourced was already broken into cullet. As there was no magnetic separator on the feedstock circuit and metal in the glass caused excessive wear in the mill, it was decided to use only processed ferrous metal-free cullet. Both post-consumer and post-industrial plate glass were used. The sources of feedstock and preparation procedures are outlined in Tables 1 and 2.

**Dryer/Pulverizer Performance**

The operating results for the Harris Dryer/Pulverizer were disappointing when performance and wear were considered. The unit was originally designed to crush clay. Because the original chains could not withstand the abrasive nature of the glass, they were replaced with tungsten carbide-faced case hardened steel hammers approximately 1" x 1/2" x 3". Various combinations of hammers were tried, but swinging bars, mounted on four rows on each shaft, eventually proved to be the best configuration. These were mounted about 1/4-inch from the shell of the mill. Actual wear data was very difficult to obtain because of the varying conditions encountered when the mill did not operate properly and the introduction of metal into the mill. Actual weights on the hammers were

meaningless as a measure of wear as some hammers wore very rapidly while others did not. Instead a more meaningful measure of the wear is obtained when all the hammers were replaced at once. This was necessary after about 50 tons of material was processed. As it cost approximately \$750 for the complete set of hammers and labor to install them, the cost per ton of wear related to the hammers is \$15 per ton, a very excessive cost indeed.

This high rate of wear is was apparently due to the material staying in the chamber too long. This also lead to a product that contained too many fines. About 38% of the product was minus 50 mesh. The unit was designed to pull the pulverized material by suction from the fan via a drop-out box, cyclone and dust collector, but this mechanism did not perform satisfactorily in spite of numerous modifications made to improve the system. It was necessary to modify the mill a number of times, reconfigure the hammers, and replace the hammers that were worn. Various attempts were made to improve this situation. The best results were finally obtained when the machine was tilted about 10° to help material out of the mill and the discharge point was lowered at the back end. While this improved the wear rate somewhat, it was still too high. This wear rate in the Harris Dryer/Pulverizer by itself

obviates the advantage of having a combination dryer and pulverizer in a single unit.

The dryer system seems to work satisfactorily, however, it cannot adequately dry extremely wet cullet (during a heavy rainy day, for example). The burner input point is too low in the front of the mill and material is kicked back by the hammers into the burner manifold, requiring constant cleaning.

### **Dust Control System Performance**

Dust collection was imperative with a dry system but the pilot plant dust collector was not ideal. The fan was located in the stream of the glass to draw material through the pulverizer, which caused excessive wear on the fan blades. The cast aluminum blades had to be replaced three times.

### **Labor Requirements**

Two operators were used to run the system. At least one operator is required, and must be a good mechanic/welder to maintain the equipment. The dryer/pulverizer and the entire system was difficult to keep operating for any length of time. Due to the frequent breakdowns and modifications required, considerable mechanical work was required to maintain the system. This situation is typical of a prototype system where much work has to be done by hand instead of with machinery. Any such system would be doing well to achieve a 65% operating time with two operators, as there are other things, besides maintenance, that they must do, such as lining up feedstock, changing the dust collector barrel, moving bulk bags of product, and weighing the product.

### **Downtime**

Shutdowns were numerous with the prototype unit. Many of them were necessary to make modifications in the equipment. Others were simple breakdowns, such as the dust collector fan failing, or metal getting into the mill or a belt coming out of alignment. By the end of the program, however, most of these problems had been corrected and better operating time was achieved. Once the Sweco was set up properly and

adjusted, no operating problems were encountered other than the bands loosening occasionally.

### **Sizing System Performance**

It is apparent from the typical size analysis of the Harris Dryer/Pulverizer products that the pulverizer makes a large portion of fines. About 38% passes the 50 mesh screen which is an undesirable feature of the unit. Here again, the inefficient grinding action tends to make too many fines. This proportion of fine product could be difficult to market as the main markets are for coarser sized products. This is even more obvious in Figures 2 through 4, which show the product distribution.

The system evaluated here actually made a reasonably clean, debris-free product, even from the extremely dirty post-consumer containers from the local recyclers. This was achieved with the scalping screen, air separation after pulverizing, vacuuming the top deck of the Sweco, and a final screening when the sized product is put into the bulk bags. Various techniques were tried, but any final system will require some combination of screening, vacuuming, and air classifying. Dust collection is critical in any dry processing operation.

In conclusion, the design of the Harris Dryer/Pulverizer prototype is neither efficient nor cost effective for making sand from recycled glass. It clearly makes too many fines. The Sweco sizing system performed as expected and made satisfactory products. Most of the debris can be removed by simple methods, but the cleaner the feedstock, the easier it is to remove the debris. Other hammermills or impactors need to be considered for small systems, but all of these will require a separate dryer. All such systems will have relatively high operating costs on a small scale, but can be put together for slightly more than \$100,000.

### **Disposition of Glass Sand Produced**

Nearly all the product produced during the project has been disposed of with the exception of the -50 mesh and dust. The details of the product disposition are shown in Table 4. The product was distributed to 12 customers.

Generally the users found the glass to work well in their applications and to be cost effective. None of the markets were thoroughly tested, as insufficient product was generated. More than 50 tons were processed in the project and another 40 tons were processed with the same system during November by Olivine Corporation. This product was done on a tolling basis for Bedrock Industries, Inc. which supplied its own cullet.

### **Cost Analysis**

The cost of operation of the small prototype system, which has a capacity of about one tph, is \$120 per ton of product including bags and pallets. Aside from the excessive wear cost, the volume is too low at one tph to be cost effective. A two tph system with a small, separate dryer would be a more efficient system, and the cost could drop to about \$86 per ton of product (excluding amortized capital costs and depreciation). If the product could be sold for an average of \$125 per ton including bag and pallet charges, a small profit could be obtained. A summary of estimated costs for one and two tph systems are attached, along with a schematic flow sheet for a two-tph system.

**Table 3. Harris Dryer/Pulverizer Performance Factors**

<b>Pulverizer</b>	
Equipment configuration - type/design/wear materials type	Dual rotor chain or hammers mounted axially - Case hardened steel with WC facing; T-1 steel lining
Capacity-tph feed rate	1 tph
Operating time -%	50%
Power rating (if separate from pulverizer) - hp/voltage	10 hp/440 V
Wear rate of impactors/hammers - lb/ton processed	replaced after 50 tons processed
Size analysis of output - standard sieve analysis curve/bar graph	variable according to pulverizer settings
Manning required, if separate unit (safety equipment required)	2 operators; goggles, mask, gloves
Cost of new equipment	\$20,000
Special maintenance requirements, if any	prototype unit requires much maintenance
<b>Dryer</b>	
Equipment configuration/design	integrated with pulverizer
Capacity-tph feed rate	same as pulverizer
Operating time -%	same as pulverizer
Power rating (if separate from pulverizer) - hp/voltage	n/a
Type of fuel	propane
Fuel Price - per unit	\$1/lb.
Fuel consumption \$/ton processed	\$2/ton
Temperature in stack	140-180°F
Screenability of product output (Y or N)	yes
Manning required, if separate unit (safety equipment required)	n/a
Cost of new equipment	n/a
Special maintenance requirements, if any	manifold requires regular cleaning
<b>Debris Removal</b>	
Scalping screen @ 6 mesh	2 tph
Cost of new equipment	\$3,000
Continuous operation	
Magnetic Separator- Head pulley	very effective
Air Classifying Equipment	set up did not work as constructed
Modified Paper Removal w/ air stream over belt	worked OK
<b>Dust Collection</b>	
Cloth Bag mounted over barrel w/ fan discharge to bag; cyclone before fan	
Capacity	approximately 1000 scfm
Power rating	5 hp fan
Dust Removal	adequate
Special maintenance requirements, if any	repair fan; empty barrel
<b>Sizing System</b>	
Type/Design	2 hp 48" Sweco gyratory separator - 3/4 decks
Capacity - tph feed	2 tph
Mesh sizes	6, 20, 30, 50 mesh
Operating time -%	100%
Power rating - hp/voltage	2 hp 440V
Per cent above/below screen size separations	+/- 5 to 10% depending on mesh size
Manning (safety equipment required)	same operator as pulverizer; goggles, mask, gloves
Cost of new equipment	\$15,000 complete
Special maintenance requirements, if any	none
<b>Packaging</b>	
Type design/layout	Hand loading from Sweco to bulk bags
Supersaks	2500 lb bulk bags
Bagging Equipment - type/design (if any)	Simple hopper w/ gravity loading valve
Cost per unit - package	\$15.85 per bag
Capacity - tph	bulk bags as produced; paper bags 2-3 tph
Manning - bagging/palletizing/wrapping	one operator; goggles, mask, gloves
Storage - space required	Depends on shipments - approx 1000 sq. ft.

**Table 4. Disposition of Product**

Cust. No.	Application	Substitute Material	Value of Substitute	Quantity Sold	Color	Price Paid	Value to User	Satisfied
1	Flooring Additive	Silica Sand	\$85/ton	1500 lbs	clear	\$85/ton	\$85/ton	Yes
1	Flooring Additive	Silica Sand	\$85/ton	800 lbs	mixed	\$110/ton	\$110/ton	Yes
2	Fused Glass	None	n/a	1000 lbs	plate	\$120/ton	\$150/ton	Yes
2	Fused Glass	None	n/a	2500 lbs	various	\$100/ton	\$150/ton	Yes
3	Sandblast Medium	Silica Sand	\$85-\$110/ton	2000 lbs	mixed	\$85/ton	unknown	unknown
3	Sandblast Medium	Silica Sand	\$85-\$110/ton	2000 lbs	mixed	\$85/ton	unknown	Yes
3	Sandblast Medium	Silica Sand	\$85-\$110/ton	2000 lbs	mixed	\$85/ton	unknown	Yes
3	Sandblast Medium	Silica Sand	\$85-\$110/ton	5600 lbs	mixed	\$85/ton	unknown	Yes
3	Sandblast Medium	Silica Sand	\$85-\$110/ton	3800 lbs	mixed	\$85/ton	unknown	Yes
4	Sandblast Medium	Silica Sand	\$85-\$110/ton	100 lbs	mixed	sample	\$85-\$110/ton	Yes
5	Sandblast Medium	Silica Sand	\$85-\$110/ton	400 lbs	mixed	sample	unknown	unknown
6	Fusing	None	n/a	700 lbs	mixed	\$29/ton	market \$	Yes
7	Sandblast (booth)	Silica Sand	\$130	150 lbs	mixed	\$133/ton	unknown	No
8	Fusing and Art	New Glass	n/a	400 lbs	mixed	\$50/ton	unknown	unknown
9	Admixture in Fiberized Concrete Driveway	Colored Aggregate	\$100-\$250/ton	38,000 lbs	brown	\$150/ton	unknown	unknown
10	Sandblast Medium	Silica Sand	\$92/ton	1500 lbs	mixed	sample	unknown	unknown
11	Sandblast Medium	Garnet	\$300/ton	100 lbs	mixed	sample	unknown	No
12	Aquarium Sand	Silica Sand and other colored sands	\$980/ton retl; \$500/ton whl	50 lbs	various	sample	unknown	unknown

## Economic Evaluation - Recycled Glass Sand Processing System

### Operating Parameters

Hours of operation, h	estimate hrs/yr	1300	hrs/yr
Available feedstock	estimate tons/yr	1300	tpy
Debris content, d <sub>1</sub>	estimate % debris	5%	
System capacity, Q	estimate tons/hr	1	tph
Production efficiency, f	estimate %	90%	
Dust generation, d <sub>2</sub>	estimate %	5%	
System power use, e	estimate power rating	1	kw
Gas consumption, g	estimate btu/hr		btu/hr
Production, P	$(Q \times f) \times (1 - d_1 - d_2) \times h$	1053	tpy

### Utilities

Electricity	enter cost per kwh	\$0.08	/kwh
Gas	enter cost per btu		/btu

### Profit Calculation

#### Product Sales

Product	enter price per ton	\$100	/ton
Bag/pallet charges	enter charge per ton	\$25	/ton
Total per ton			\$125/ton
Total Revenue, TR	total per ton x P	\$131,625	/yr

#### Variable Costs

Managerial		\$2,083	/mo	\$23.74	/ton
Sales & admin.		\$2,083	/mo	\$23.74	/ton
Operator	estimate salary + benefits	\$23.08	/hour	\$28.49	/ton
Gasoline, oil, lube	bobcat, forklift	\$100	/mo	\$1.14	/ton
Materials/supplies	bags, pallets, etc.	\$1,755	/mo	\$20.00	/ton
Maintenance materials		\$293	/mo	\$3.33	/ton
Electricity	e x cost per kwh x h	\$104	/yr	\$0.00	/ton
Gas	g x cost per btu x h	\$0	/yr	\$0.00	/ton
Mobile equipment rental	bobcat, forklift	\$1,050	/mo	\$11.97	/ton

Debris removal	enter cost per ton	\$2/ton	\$2.00/ton
Dust removal	2nd cost per ton	\$0/ton	\$0.00/ton
Cost of glass delivery	enter cost per ton	\$5/ton	\$5.00/ton
<b>Total Variable Cost, VC</b>		<b>\$125,104/yr</b>	<b>\$119/ton</b>

**Fixed Costs**

Building Lease, L		\$1,000/mo	
Equipment, EC	(from equip. list)	\$87,000	
Amortized Life, n		7.00 years	
Assumed Interest Rate, i		10.00%	
Amortized Cost of Equip, AC	$EC \times i \times (1+i)^n / [(1+i)^n - 1]$	\$17,870/yr	
<b>Total Fixed Costs, FC</b>	<b>AC + L</b>	<b>\$18,870/yr</b>	<b>\$18/ton</b>

**Total Cost**

<b>Total Cost, TC</b>	<b>VC + FC</b>	<b>\$143,974/yr</b>	<b>\$137/ton</b>
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**Net Margin**

<b>Net Margin</b>	<b>TR - TC</b>	<b>-\$12,349/yr</b>	<b>-\$12/ton</b>
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## Economic Evaluation - Recycled Glass Sand Processing System

### Operating Parameters

Hours of operation, h	estimate hrs/yr	1400	hrs/yr
Available feedstock	estimate tons/yr	2800	tpy
Debris content, d <sub>1</sub>	estimate % debris	5%	
System capacity, Q	estimate tons/hr	2	tph
Production efficiency, f	estimate %	90%	
Dust generation, d <sub>2</sub>	estimate %	5%	
System power use, e	estimate power rating	1.5	kw
Gas consumption, g	estimate btu/hr		btu/hr
Production, P	$(Q \times f) \times (1 - d_1 - d_2) \times h$	2268	tpy

### Utilities

Electricity	enter cost per kwh	\$0.08	/kwh
Gas	enter cost per btu		/btu

### Profit Calculation

#### Product Sales

Product	enter price per ton	\$100	\$/ton
Bag/pallet charges	enter charge per ton	\$25	\$/ton
Total per ton			\$125/ton
<b>Total Revenue, TR</b>	total per ton x P	<b>\$283,500</b>	<b>/yr</b>

#### Variable Costs

Managerial		\$3,750	/mo	\$19.84	/ton
Sales & admin.		\$2,917	/mo	\$15.43	/ton
Operator	estimate salary + benefits	\$21.43	/hour	\$13.23	/ton
Gasoline, oil, lube	bobcat, forklift	\$167	/mo	\$0.88	/ton
Materials/supplies	bags, pallets, etc.	\$3,750	/mo	\$19.84	/ton
Maintenance materials		\$630	/mo	\$3.33	/ton
Electricity	e x cost per kwh x h	\$168	/yr	\$0.00	/ton
Gas	g x cost per btu x h	\$0	/yr	\$0.00	/ton
Mobile equipment rental	bobcat, forklift	\$1,050	/mo	\$5.56	/ton

Debris removal	enter cost per ton	\$2/ton	\$2.00/ton
Dust removal	2nd cost per ton	\$0/ton	\$0.00/ton
Cost of glass delivery	enter cost per ton	\$5/ton	\$5.00/ton
<b>Total variable cost, VC</b>		<b>\$191,608/yr</b>	<b>\$85/ton</b>

### Fixed Costs

Building Lease, L		\$1,667/mo	
Equipment, EC	(from equip. list)	\$120,000	
Amortized Life, n		7.00 years	
Assumed Interest Rate, i		10.00%	
Amortized Cost of Equip, AC	$EC \times i \times (1+i)^n / [(1+i)^n - 1]$	\$44,649/yr	
<b>Total Fixed Costs, FC</b>	<b>AC + L</b>	<b>\$46,315/yr</b>	<b>/ton</b>

### Total Cost

<b>Total cost, TC</b>	<b>VC + FC</b>	<b>\$237,923/yr</b>	<b>\$105/ton</b>
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### Net Margin

<b>Net Margin</b>	<b>TR - TC</b>	<b>\$45,577/yr</b>	<b>\$20/ton</b>
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# APPENDIX C

## Protocol for Operational & Economic Evaluation of Equipment for Processing Recycled Glass Into Industrial Sand Products

I. Scope - To evaluate recycled glass processing equipment which can be used as part of a system to produce industrial sand products  
Definition of Process Functions

### II. Definition of Process Functions

- A. Feedstock - Acquisition
- B. Feedstock - Preparation
- C. Drying
- D. Pulverizing
- E. Debris Removal
- F. Sizing
- G. Packaging/Storage
- H. Product Disposition

### III. Performance Factors

- A. Feedstock - Acquisition
  - 1. Source - Location or type code
  - 2. Specifications - Type/quality/sizing
  - 3. Quantity of Debris (visual estimate %)
  - 4. Cost (with or without delivery charges)
  - 5. Estimate of availability
- B. Feedstock - Preparation
  - 1. Equipment type/design/layout - storage, glass breakers, conveyors, magnetic separators, debris removal
  - 2. Capacity- tph
  - 3. Operating time - %
  - 4. Power rating - hp/voltage
  - 5. Equipment configuration - design/layout
  - 6. Cost of new equipment
  - 7. Manning required (safety equipment required)
  - 8. Special maintenance requirements, if any
- C. Drying
  - 1. Equipment configuration/design - separate or integrated with pulverizer
  - 2. Capacity -tph feed rate
  - 3. Operating time -%
  - 4. Power rating (if separate from pulverize) - hp/voltage

5. Type of fuel
6. Fuel Price - per unit
7. Fuel consumption S/ton processed
8. Temperature °F in stack
9. Screenability of product output (Y or N)
10. Manning required, if separate unit (safety equipment required)
11. Cost of new equipment
12. Special maintenance requirements, if any

D. Pulverizing

1. Equipment configuration - type/design/wear materials type
2. Capacity - tph feed rate
3. Operating time -%
4. Power rating - hp/voltage
5. Wear rate of impactors/hammers - lb./ton processed
6. Size analysis of output - standard sieve analysis curve/bar graph
7. Manning required (safety equipment required)
8. Cost of new equipment
9. Special maintenance requirements, if any

E. Debris Removal

1. Magnetic belt or separator to remove metal wear materials (estimate of effectiveness)
2. Scalping screens - type/design
  - a. Capacity - tph feed
  - b. Mesh size
  - c. Operating time -%
  - d. Power rating -hp/voltage
  - e. Cost of new equipment
  - f. Special maintenance requirements, if any
3. Air classifying to remove fine paper - type/design
  - a. Capacity - tph feed
  - b. Operating time -%
  - c. Air requirements - cfm/lbs
  - d. Effectiveness - estimate of retained paper
  - e. Special maintenance requirements, if any

F. Dust Collection - type/design

1. Capacity - cfm
2. Power rating
3. Dust removal
4. Special maintenance requirements, if any

G. Sizing Equipment - type/design

1. Capacity - tph feed
2. Mesh sizes
3. Operating time -%

4. Power rating - hp/voltage
5. Per cent above/below screen size separations
6. Manning (safety equipment required)
7. Cost of new equipment
8. Special maintenance requirements, if any

H. Packaging

1. Type design/layout
2. Bulk bags
3. Bagging Equipment - type/design (if any)
4. Cost per unit - package
5. Capacity- tph
6. Manning - bagging/palletizing/wrapping (safety equipment required)
7. Storage - space required

I. Product Disposition

1. Economic Evaluation
2. Customer (code)
3. Specifications
4. Application
5. Usage - tpm
6. Type material substitutedfor
7. Price (t.o.b., del.)
8. Packaging

IV. Economic Evaluation

A. Feedstock- Cost/Specifications

B. Processing System Capacity

1. Hours Operation (annual)
2. Capacity - Sizing/Packaging - tph
3. Operating Time - overall %
4. Recovery of Product - %

C. Cost Factors

1. Capital Cost - fixed + working capital
2. Production Cost
  - a. Labor (include associated payroll)
  - b. Supervision (include associated payroll)
  - c. Building rental
  - d. Equipment rental
  - e. Depreciation
  - f. Utilities
  - g. Gasoline, Oil, Lube
  - h. Maintenance materials & supplies
  - i. Packaging materials & supplies

- j. Dust/debris disposal
- k. Other expenses
- 3. Selling, General & Administrative Expenses
  - a. Management
  - b. Office Expenses
  - c. Insurance, taxes, fees, etc.
  - d. Commissions, discounts, etc

D. Sales - Sales Price by Product

E. Proforma P & L

V. Project Templates to be Used for Data Collection

- A. Feedstock Acquisition - for each supplier/order
- B. Feedstock Preparation - daily log for direct feed to process or storage
- C. Drying/Pulverizing/Sizing - daily log
- D. Packaging/Storage - Inventory Report
- E. Product Disposition - by Customer
- F. Cost Data Collection Sheet - items