Glass Recovery Enhancement

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December 2013

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EXECUTIVE SUMMARY

Material recovery facilities sort glass from other recyclables primarily by size reduction. Common glass screening processes use rotating discs to shatter glass and allow pieces smaller than two inches wide to fall onto a conveyor belt. This process also allows non-glass materials to fall onto the same conveyor belt. The resultant glass mixture is called the fine waste stream, or, “fines,” for short. Methods exist to recycle the glass in the fine waste stream, but it is not cost-effective to recycle small quantities of junk materials such paper, plastic, and miscellaneous waste caught up in the stream. Before the glass in the fine waste stream can be recycled, it must be separated from these junk materials. Existing glass separation methods are often too costly for material recovery facilities, and the fine waste stream is often sold to sorting companies as-is. This can result on a low return for material recovery facilities, and sometimes in the landfilling of otherwise reclaimable glass. The Glass Recovery Enhancement team designed and built a demonstration-scale mechanism for material recovery facilities to increase the amount of recoverable glass in their fine waste stream.

The Glass Recovery Enhancement system uses high-velocity air to separate materials in the fine waste stream by weight. This is accomplished by feeding the fine waste stream into an angled chute and passing air through it. Two air sources are use to keep air flowing through the system. A centrifugal fan mounted at the base of the system blows air at high velocity perpendicular to the falling motion of the fines. The air from the centrifugal fan causes lighter materials in the fine waste stream to be blown to the end of the system while heavier glass is moved only a small distance before falling out of a hole in the chute. A second, low power fan draws a vacuum at the end of the system in order to collect dust and small waste particles.

The Glass Recovery Enhancement project successfully demonstrated a significant increase in the quality of glass recovered from a fine waste stream of known composition. Over 90% of the glass deposited in the system was recovered. Approximately 60% of this recovered glass was a high-grade fines mixture. The rest of the recovered glass was of significantly higher quality than the original fines composition. All remaining glass lost in the system was so small in size that it was unlikely to be recycled.

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NOMECLATURE

DEFINITIONS

Fines - Material that is sorted through a fines screen is known as the "fine waste stream," or "fines" for short. This material consists of any recyclable material that could fall through a 2"x2" hole in an MRF's sorting process. Fines include shredded paper, small plastics, broken glass, etc.

Glass Recovery Enhancement (GRE) – The name of the team responsible for the project described here.

Material Recovery Facility (MRF) - A specialized plant that receives, separates, and prepares recyclable materials for end-user recycling companies. Recycling is delivered directly from cities and communities to MRFs.

VARIABLES

F_d	Drag force
ρ_{air}	Density of air
v	Velocity
C_d	Drag force coefficient
A_p	Projected Area
F_N	Normal Force
m	Mass
g	Acceleration due to gravity
μ_S	Coefficient of static friction
CFM	Cubic feet per minute
lb_f	Pound force

1 PROBLEM STATEMENT & INTRODUCTION

In 1989, the California legislature passed Assembly Bill 939 (AB 939), the California Integrated Waste Management Act. AB 939 mandated that local jurisdictions meet solid waste diversion goals of 50% by the year 2000. According to CalRecycle, current legislation AB 341 seeks strategies and recommendations to increase future diversion rates to 75%.

In order to promote public participation in recycling efforts, most material recovery facilities (MRFs) have transitioned from using pre-sorted recycling bins to single stream recycling, which provides one large bin to collect paper, cardboard, plastic, glass, and metals. When single stream collections reach MRFs, glass is separated from the other recyclables by mechanically breaking it and letting it fall through a "fines screen." The fines screen allows all material less than two inches square to pass. Larger recyclables pass over the screen but the fines screen also captures small recyclables, such as paper shred, bottle caps, and small garbage.

If the glass is not separated thoroughly from these other small recyclables, it becomes too costly to recycle and is instead sent to landfills. By developing a process that better separates the glass from fine waste stream materials, higher diversion rates can be achieved and less recyclable material will be sent to landfills. Therefore, the GRE project directly benefits material recovery facilities, recycling companies, and cities by decreasing overhead due to extra sorting and reducing landfill waste.

2 FUNCTION & CONSTRAINTS

The function of the GRE project is to further separate glass from other recyclables and trash in the fine waste stream. The design will receive broken glass, plastic bottles and caps, metal caps, shredded paper, and trash and separate the broken glass into its own container. The design must integrate with existing power systems at material recovery facilities.

CONSTRAINTS

- Design must be resistant to abrasion from broken pieces of glass, metal, paper, trash, and plastics, sized less than 2 inches in diameter
- Design must be reasonably resistant to corrosion (rust, chemicals, etc.)
- Any air expelled from the system must be able to pass Air Board standards (Must include a dust collection system)
- Power Constraints (maximum 3 Phase or Single Phase, 480V, available at MRFs)
- Any equipment used must not project solids outside system or create projectiles
- Fed by high speed conveyor belt (30-60 feet per minute) with varying speeds depending on application
- Max Size - All pieces must fit on back of flatbed trailer (8ft x 6ft), and individual pieces must fit on Forklift pallet (48 in x 40 in)
- Max Weight - Forklift must be able to lift pieces (Capacity 4600 lb, 2080 kg)
- Ability to assemble on-site, if multiple pieces are used - Each piece limited to max weight and size of Flatbed Trailer (6 ft x 8 ft)
- Designed for onsite repair/ maintenance
- Fully automated system
- Must be able to process both dry and wet fines
- Design must not utilize open flames
- No water or corrosive fluids may be used as a primary sorting medium

3 DESIGN

PRELIMINARY DESIGN

The original GRE design consisted of a sloped chute through which air is passed upwards at high speed. The fine waste stream was to be fed in through a hopper at the bottom of the system. The high speed air would cause lighter materials to be blown into a dust collection system at the end of the chute. Lighter plastics would be carried to the end of the chute and deposited into a bin after falling through an opening at the end of the system. Due to its heavier nature, glass would travel the shortest distance and fall out of the system through a dropout hole situated just past the hopper inlet. An internal air deflection ramp angled at 30 degrees to the chute ensured that lighter particles would be carried over this first dropout hole.

The original design was selected due to its ease of fabrication, versatility, and the use of fluid separation. The fine waste feed system for the original system assumed the use of a magnetic roller at the end of the feed conveyor belt to remove ferrous metal from the fines before they entered the hopper. As use of magnetic rollers on fine waste conveyor belts is already widespread in the industry, metal separation was not factored into the original GRE design.

Ease of fabrication was a major consideration during the early stages of project design. The original design utilized ⅛” 1018 steel for construction of the chute. The use of 1/8” steel was to allow all joints to be cut and welded easily. The support system was to be fabricated from cut pieces of 2” 1018 steel angle iron. Angle iron was chosen for its low cost and weldability. Welding was determined to be the best joining method for the main chute assembly due to the team’s welding experience and ease of access to welding equipment.

The top of the chute was chosen to be clear Plexiglas so that the internal workings of the system could be seen and fine-tuned. The fan and dust collection system were initially left undesigned. The main fan was designed to push air through the system and through the dust collection system. An air flow of approximately 1300 CFM was calculated to be enough to move the air and fines through the system in this manner. Figure 1 is a CAD model of the original GRE system design.

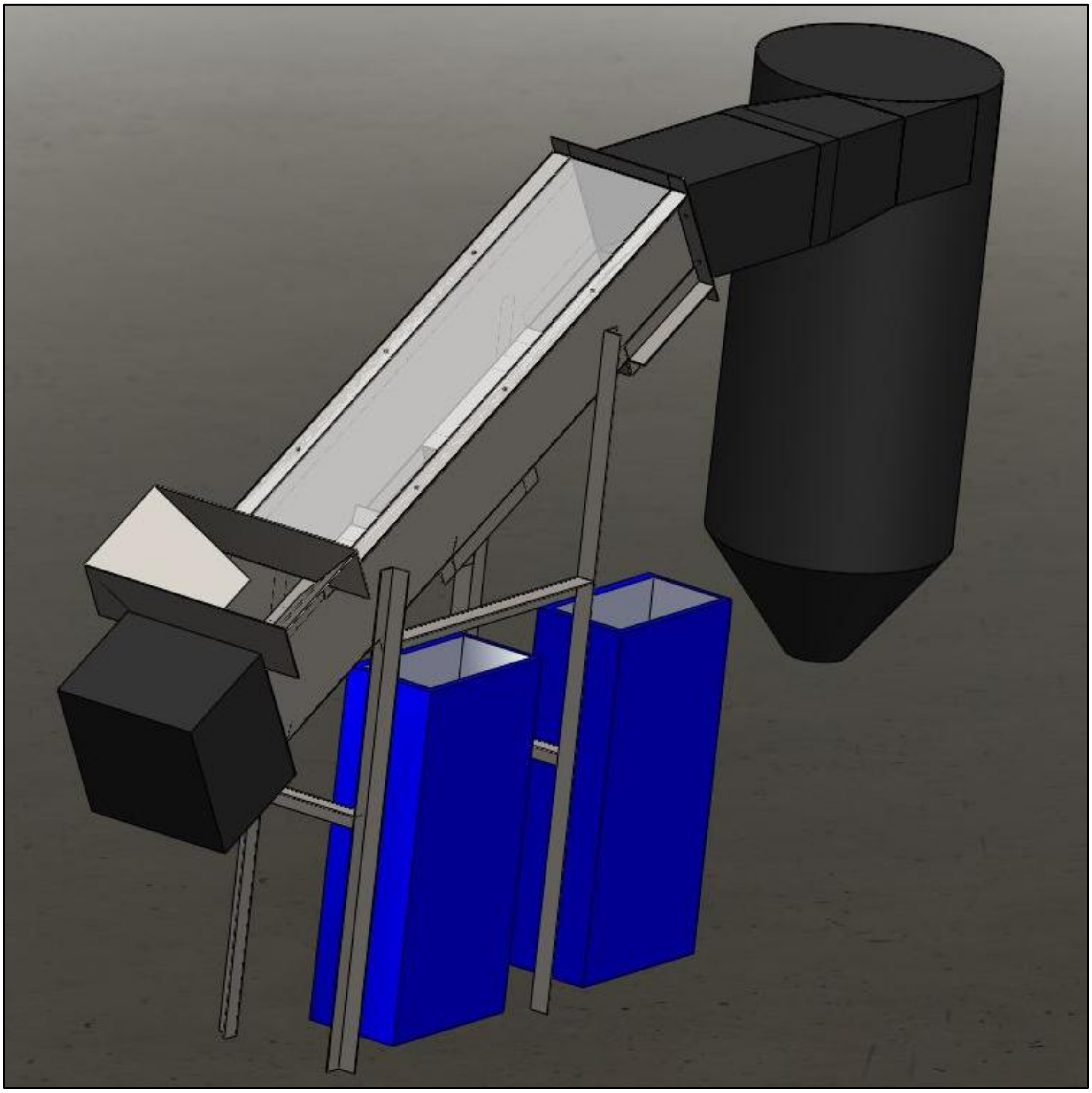

FIGURE 1: CAD Model of Original GRE Design

CHANGES TO PRELIMINARY DESIGN

Three major factors that changed the design of the original GRE system were on-site material recovery facility tours, fabrication, and the need to provide a variable testing platform. While each one of these factors changed the overall design, they also helped guide the manufacturing process to completion in a timely and organized matter.

Requirements that were not considered in the original GRE design were presented when the design team began touring material recovery facilities. For example, each MRF has a different consistency of dirt and moisture in its fine waste stream, depending on its geographical location. The design was altered to accommodate for this inconsistency by allowing facility managers to be able to adjust either the angle of the chute's incline or the size of the opening that the glass falls into. These design changes included a sliding air deflection plate and an adjustable support structure. This was accomplished by putting pins in the legs at the base that would allow the other end of the chute to pivot up and down. Figure 2 shows the redesigned pivot and air ramp slider. The rear two legs were made to be telescopic by using two different sized square tubing.

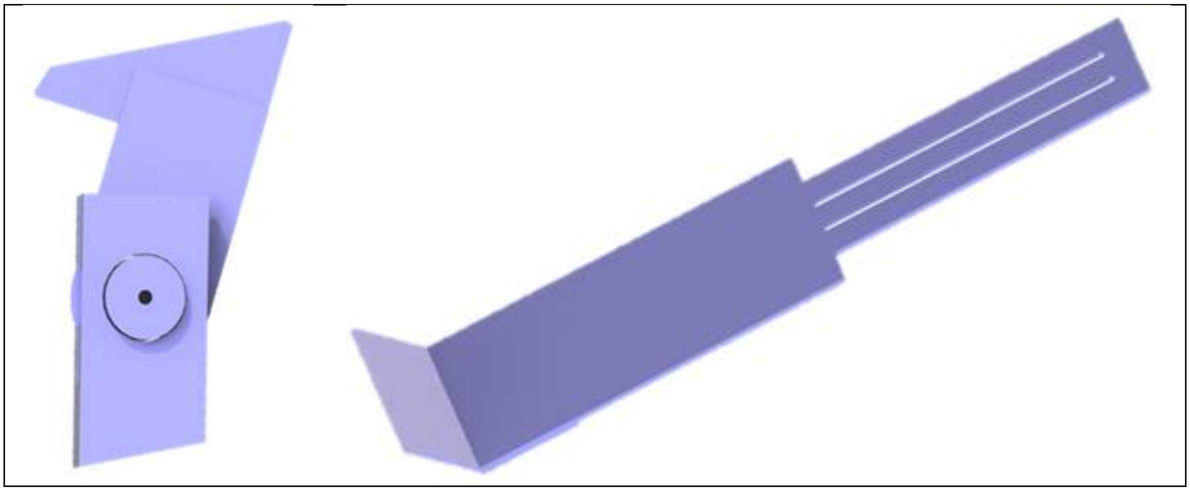

FIGURE 2: CAD Model of Modified Pivot and Air Ramp Slider

The fabrication process also greatly affected the overall design of the project. To outline and allocate time, the GRE team approached the fabrication process strategically. It was this planning that began to first alter the original design. For instance, upon welding the 4 major components of the chute, it was realized that more rigidity was necessary. The solution was simple, and the group added support ribs to the top of the chute, beneath the Plexiglas cover. Figure 3 shows the chute before and after the redesign. Redesigns for structural rigidity were a common occurrence throughout the entire build, due to the numerous welds involved. Another factor which affected the design was the need to simplify machining for some parts. If a part was difficult to machine, the design was modified so that it could be more easily accomplished.

Fortunately, the design was flexible due to its overall simplicity and the supply of 1018 steel the group had readily available.

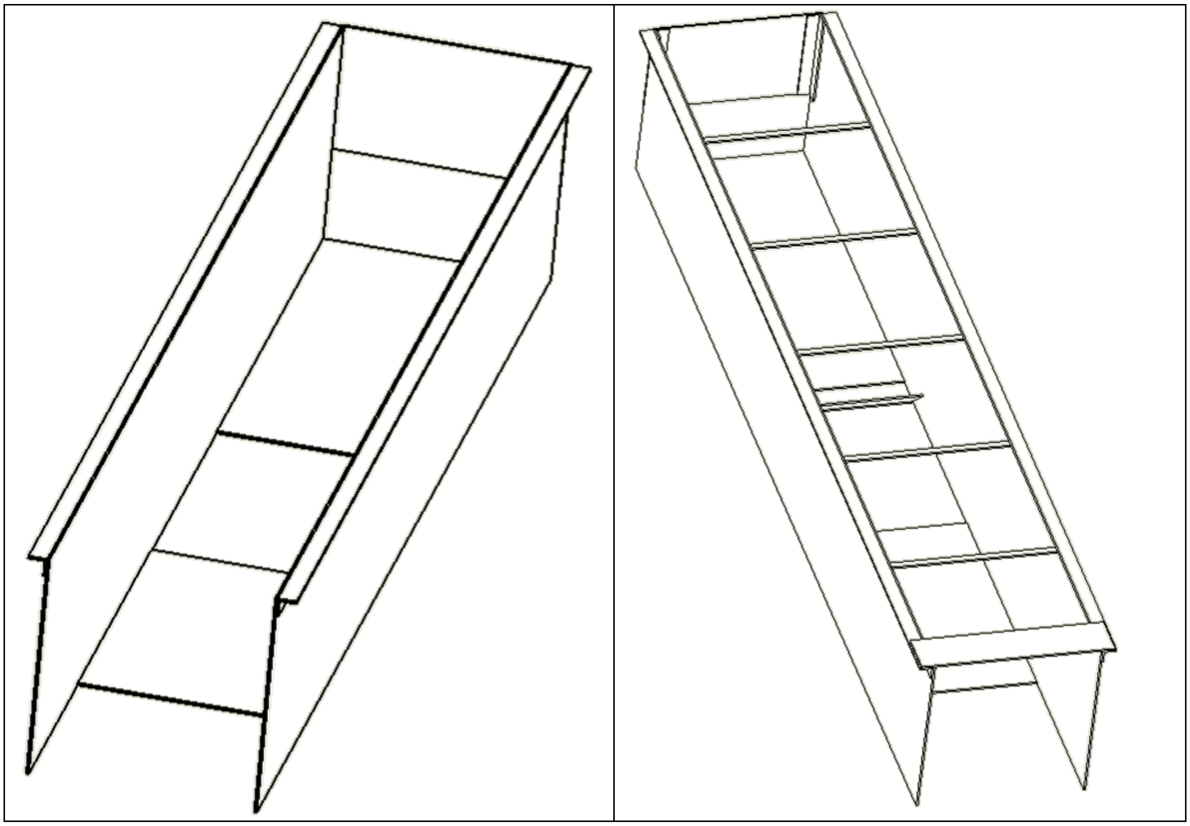

FIGURE 3: Original (Left) And Modified (Right) Chute Designs.

The need to obtain valuable testing results significantly affected the design of the original air ramp. This was facilitated by creating multiple air deflection ramps of different lengths and angles that would bolt on rather than be welded to the chute. This ensured that a sufficient amount of data could be collected to determine the best possible efficiency for the project. The group decided to try two three inch deflection ramps and two five inch deflections ramps with one of each length set at a 30 degree incline and a 45 degree incline. These four air ramps are depicted in Figure 4.

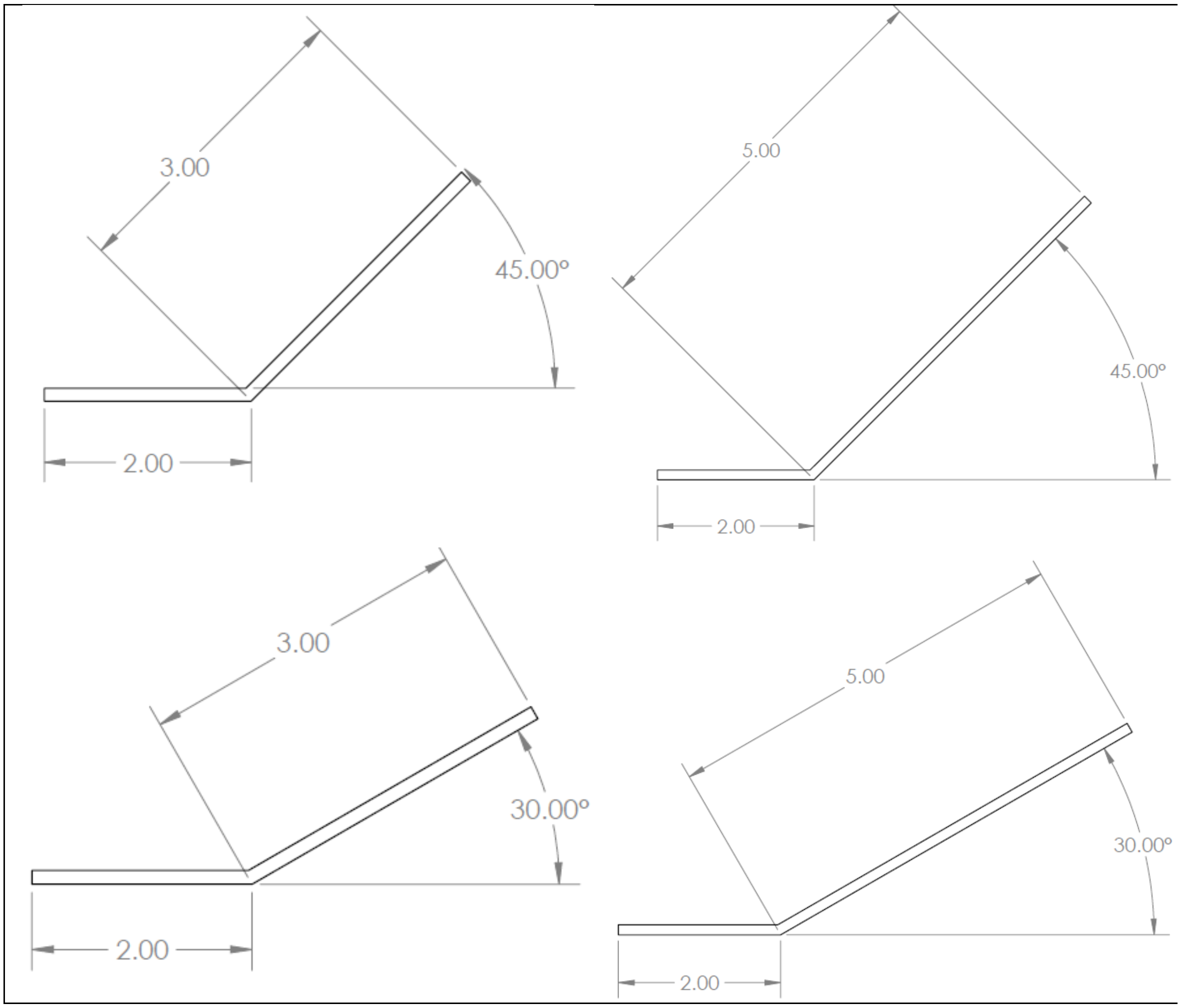

FIGURE 4: Deflection Ramps

Although these changes were incorporated throughout the design phase, there was uncertainty as to whether they would make a difference. The GRE team attempted to best prepare for these uncertainties by having enough adjustable variables to give alternative solutions. The best testing scenarios were found through iterative testing by adjusting all possible variables. Therefore these design changes were not only necessary, but advantageous.

FINAL DESIGN

The final GRE system design differed very little from the original in look and concept. However, the design changes described in the previous section significantly improved the structural integrity, variability, and ultimately the functionality of the system. A side by side comparison of the system designs is shown in Figure 5.

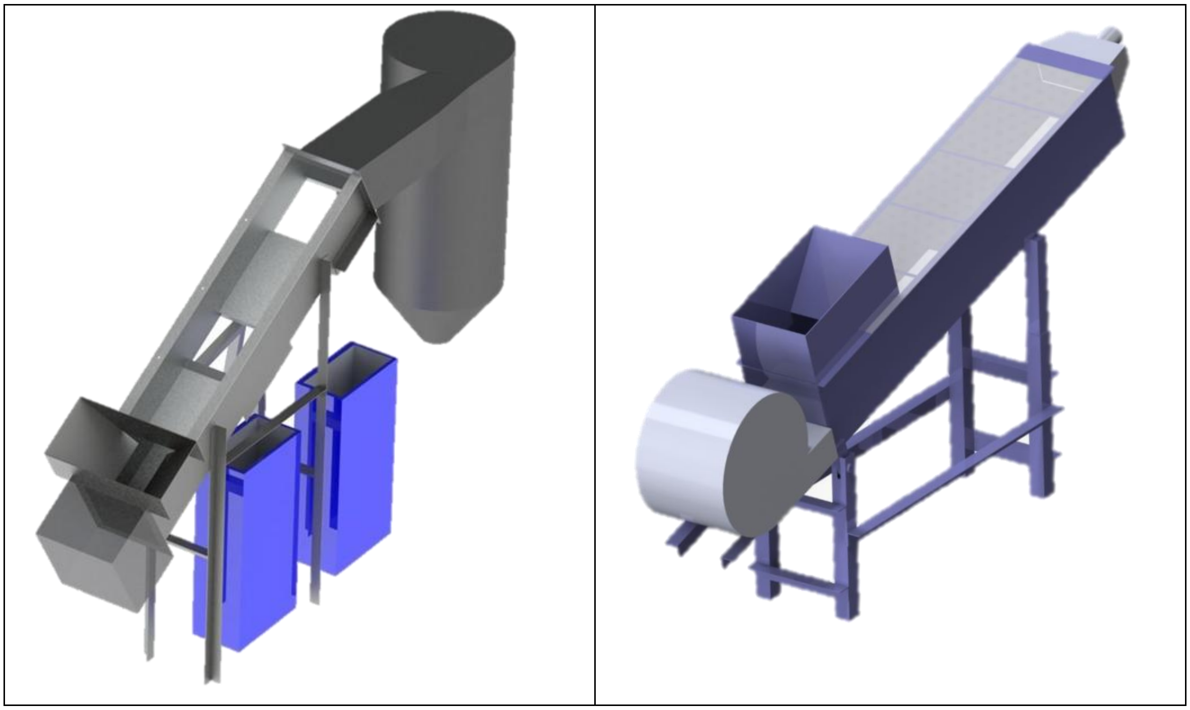

FIGURE 5: Original (Left) and Final (Right) GRE System

Whereas the original design called for tall angle iron supports, the final GRE design was lowered and used square tubing. The high center of gravity of the design was a concern in the case that the system overturned. Lowering the system also increased accessibility for testing and adjustment purposes. Square tubing was necessary for the sliding mechanism in the front section, which was used to prop up the chute at an angle.

The redesign of the system to allow for angling also required a reassessment of the dust collection system mounting. The redesigned dust collection system attaches to the system via a 6” diameter hose. The final dust collection system chosen also has its own air handling unit, as it was found that any base fan capable of pushing air all the way through the GRE system and the dust collection system would also move air too fast through the system for it to be effective.

A variable speed centrifugal fan (a modified carpet dryer) was attached at the base to provide the necessary air flow through the chute. This variability was important for testing purposes because the 1300 CFM originally calculated proved insufficient for proper system performance. The high flow of air and fine waste through and out of the system necessitated the addition of rubber flaps to control the disbursement of waste from the two main holes in the system. A picture of the final, operational system is shown in Figure 6

FIGURE 6: Final Working GRE System

4 MANUFACTURING SUMMARY

BILL OF MATERIALS

TABLE 1: BILL OF MATERIALS

Item #	Item Description	Predicted Cost Per Unit	Predicted Qty	Actual Qty	Actual Cost	Supplier	Model #
1	10 gauge steel plate 4'x8' Low Carbon Steel	$ 102.75	3	1	$ -	Western Baler & Conveyor	
2	16" x 60" x 1/2" Plexiglass	$ 95.00	1	1	$ -	ARTSS Security	
3	Heavy Duty Blower	$ 774.55	1	1	$ -	Western Baler & Conveyor	
4	1.25" x 10' Weather strip	$ 4.58	1	1	$ 7.67	Lowe's	R516WH
5	Angle Iron 1" x 1" x 6'	$ 10.00	2	2	$ 12.00	S & K Steel	Scrap
6	5/16" plate for dog ears	NA		1	$ 20.00	S & K Steel	Scrap
7	2" x 2" Angle Iron & Square Tubing for Support	$ 38.00	3	1	$ 96.00	S & K Steel	Scrap
8	Dust Collection System	$ 464.41	1	1	$ 168.00	Harbor Freight	97869
9	Ducting Fittings	NA		3	$ 52.00	Home Depot	RBF12X6X6 AF4X120
10	1/4" Hex Bolt 1.5" Length Bag of 25 pieces	$ 4.24	1 box	1 box	$ 4.24	Home Depot	9650
11	1/4" Hex Nuts Bag of 25 pieces	$ 1.47	1 bag	1 bag	$ 1.47	Home Depot	8424
12	1/4" Flat Washers Bag of 25 pieces	$ 2.46	1 bag	1 bag	$ 2.46	Home Depot	8034
		Projected Cost = $1788.96		Actual Cost = $479.84			

BUDGET

The original design budget was estimated at approximately $1800. The actual cost of completion for the project was approximately $900, or half of the expected cost. Project costs were kept low by redesigning to use less material, especially angle iron. Originally, materials were priced online and did not account for lower local business prices. Additionally, costs were reduced by using scrap metal rather than new or pre-fabricated in construction.

Thanks to donations from Western Baler & Conveyor and ARTSS Security, out of pocket costs were reduced to almost half of the total cost. Western Baler & Conveyor donated two 4’x8’ sheets of 10 gauge steel and the centrifugal fan. ARTSS Security donated the Plexiglas used for the top of the chute. Discounts were received from companies such as S&K Steel by mentioning that the project was for a Sacramento State University engineering senior project.

FABRICATION OF MAIN CHUTE

One 4'x8' sheet of 10 gauge steel was sheared into rectangular pieces which were then welded together to form the main chute with holes spaced along the bottom for glass and plastic to fall through. Small ribs were then added connecting the top sides of the chute to increase the rigidity of the chute, and reduce the load on the Plexiglas top. All welding on the chute was performed with the Miller 140 MIG welder in the school's metal shop. 1"x1" angle iron was then stitch welded to the top of both sides of the chute and holes were drilled in them. The Plexiglas top was affixed to the chute by bolting it through the holes in the angle iron. A small rectangular plate was also bolted onto the front entrance of the chute in order to fill in space that the centrifugal fan did not cover. Another small rectangular plate similar in size was welded onto the back exit of the chute to mount the dust collection attachment. A work order was submitted to have a 5/16" plate cut into two rounded "dog ear" pieces with a plasma cutter. A hole saw on the mill was used to drill holes in these pieces. These dog ears were then welded onto the bottom corners of the base of the chute to allow it to pivot.

Two 2"x2" pieces of angle iron were welded to the underside of the chute in a cantilever fashion. Holes were drilled in the top of these pieces to allow the centrifugal fan to be secured to the chute. A 12"-rectangle-to-6"-circle HVAC connector was drilled into the end of the chute. A 6" diameter hose leading to the dust collection system was secured to this with a standard hose clamp.

FABRICATION OF SUPPORT STRUCTURE

Four upright pieces of square tubing were used as the support legs of the system. The tubing was connected using 2"x2" angle iron arranged in a rectangular pattern. The front legs were not fixed to the chute, but were instead separated and secured by two pieces of angle iron in a double-H fashion. The front legs had smaller square tubing that fit inside of the tubing used for the legs. This sliding tubing was welded together by cross piece of the same size tubing. This assembly slid in and out of the front two legs, allowing the chute to rest on the crossbar at a desired height. A hole was drilled into each of the outer square tubes on the front legs and a nut was welded over the hole. A bolt was threaded through each hole to press the adjustable tubing against the inside walls of the legs, holding up the chute using friction. All welding done on the support stand was also done using the Miller 140 in the school's metal shop.

The legs at the base of the chute required holes to be cut into them for the pivot pins to slide through. Grooves were then cut into them so that the "dog ear" joints on the chute could pivot without interference. This work was performed on a mill. The pins were constructed from a piece of scrap 1-7/16" bar stock. Holes were drilled and tapped on both sides of each pin so that small plates could be bolted to the ends. These plates kept the pins secured in their holes.

FABRICATION OF AIR DEFLECTION RAMPS

Four different air deflection ramps were fabricated (Figure 4) as well as a sliding plate to mount the ramps on and an attachment plate to allow the bolting of different ramps to the system. The four deflection ramps consisted of two ramps with 30 degree inclines and another two ramps with an incline of 45 degrees. For both sets of ramps there was a ramp with a three in length and a ramp with a five inch length. Ten gauge steel plate was sheared to size and the plate bender was used to bend the ramps to their desired angles. Four holes were drilled into the 2 inch horizontal section on each ramp, and corresponding holes were drilled in the attachment plate. The attachment plate was welded to the slider to create an easily-interchangeable base to bolt the deflection ramps to.

The slider plate also allows the size of the first drop out hole to be adjustable, and was made from 10 gauge steel plate and completed via shop work orders. Notches were cut from the sides to clear the angle iron used to mount the blower to the chute. Elongated holes were put in between the notches to bolt the plate to the bottom of the chute and allow it to slide back and forth.

FABRICATION OF HOPPER

The hopper was assembled by welding rectangular pieces of 10 gauge steel together using the Miller 140 MIG welder on campus. Holes were drilled into the main chute as well as the hopper and used to bolt the hopper to the main chute.

MANUFACTURING SCHEDULE

The project was originally scheduled to be completed in eight weeks- four weeks before the actual project deadline. The project was fabricated on campus, so conflicts were introduced that had not been accounted for when planning for fabricating at a private shop in Lincoln, California. For example, time was lost waiting for other senior project groups to finish using the only working welder or waiting in line to use other machines. Another schedule issue was waiting for parts to be completed by the on-campus shop after work orders were submitted. This was mostly due to the large amount of work orders submitted by all the senior project groups throughout the semester. Despite these setbacks, the project was finished by the week 12 deadline and even allowed for a little bit of extra time to paint. Table 2 summarizes the project schedule, showing planned and. actual progress. Other than taking an extra four weeks to complete, the only change to the schedule was finishing the support stand before the hopper.

TABLE 2: PLANNED AND ACTUAL MANUFACTURING SCHEDULE

Week	Planned Progress	Actual Progress
1	Have all materials acquired and transported to Lincoln, CA	Acquired two 4x8' 10 gauge steel sheets, brought to CSU Sacramento
2	All Parts to be cut from sheets and angle iron to be cut to length	All parts for Chute cut to size, begin fabricating Chute
3	Fabricate and assemble Main Chute	Fabricate Chute
4	Fabricate and assemble Main Chute	Fabricate Chute
5	Fabricate and assemble Hopper	Complete Chute
6	Fabricate and assemble Hopper	Fabricate support stand
7	Fabricate angle iron and assemble support stands	Fabricate support stand
8	Attach fan & dust collector/Acquire fines for testing	Fabricate Hopper
9	Test	Mount Blower
10	Test	Mount Dust Collector
11	Test	Paint
12	Test	Mid-Semester Presentation
13	Test	Test
14	Test	Test
15	Test	Test
16	Test	Test

The GRE team learned quickly that the availability of tools and materials significantly impacts the length and scheduling of a project. Another manufacturing lesson learned was that parts requiring outsourcing for completion should be identified early in the design process. Any outsourced parts should be allocated additional time for completion in the schedule to allow for unforeseen problems with manufacturing or delivery.

5 TESTING

THEORETICAL ANALYSIS

The key physical and engineering concepts that governed the Glass Recovery Enhancement senior project design were drag, gravitational force, friction, and density to surface area ratios. The system was designed such that the air flow from the fan creates a drag force on objects in the fine waste stream that displaces the material according to its weight. Figure 7 illustrates the forces acting on an object in the fine waste stream. The dominating force on any particular piece is dependent on its density to surface area ratio.

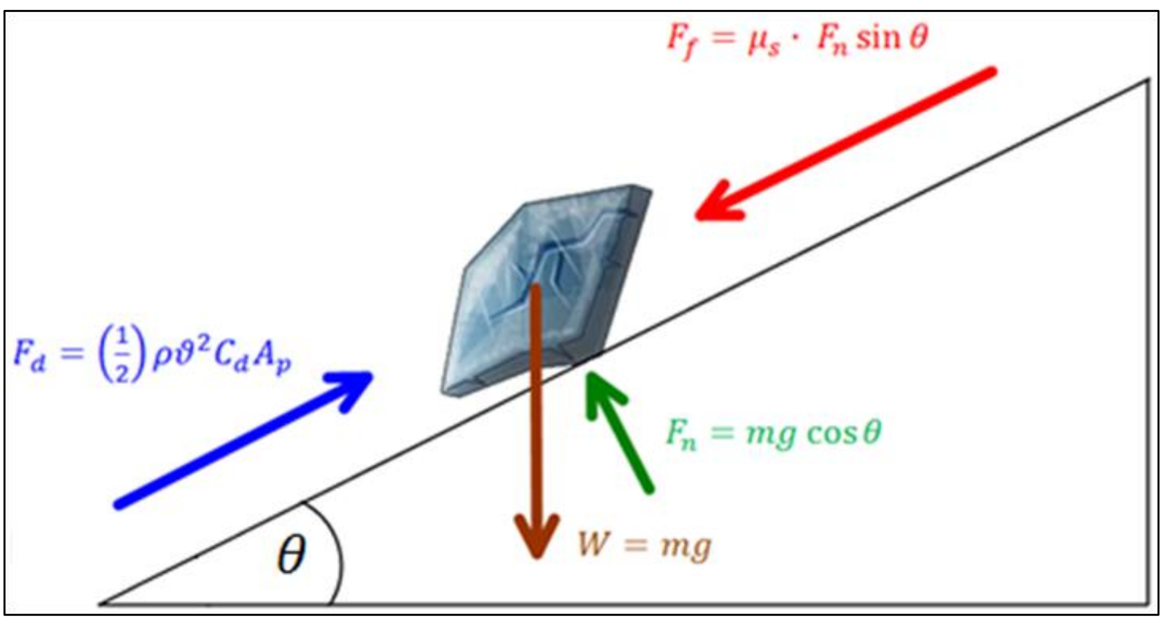

FIGURE 7: Free Body Diagram of Forces Acting on an Object in the Fine Waste Stream

Lighter fines tend to have a lower density to surface area ratio, resulting in drag force being the major factor in the object's movement. Due to the high velocity of the air in the chute creating this drag force, the lighter fines tend to remain airborne and move quickly to end of the chute. Glass pieces typically have a much higher density to surface area ratio than the lighter fines, and therefore friction and gravitational forces play an important role in their movement. An appropriate air flow was selected to ensure that lighter fines remained airborne while allowing gravitational forces and friction to slow the glass particles so they fell out of the system sooner. Increased friction, gravitational, and drag forces on glass created a much smaller resultant force. As glass moved up and over the deflection ramp, it lost energy to friction with the chute and was slowed enough to fall out of the system at the first dropout hole. The variation between dominant forces on each object in the fine waste stream is central to the theoretical working of the GRE system. These theoretical forces were calculated using Equations 1-3. Sample calculations are summarized in Table 3.

Drag Force

$$F_d = \frac{1}{2}\rho_{air}\, v^{\,2} C_d A_p \tag{1}$$

Normal/ Friction Force

$$F_N = mg\mu_s \sin(\theta) \tag{2}$$

Solving for minimum flow rate

$$CFM = \frac{9in\ x\ 12in}{12in^3}\frac{60sec}{1\ min}\sqrt{\frac{2mg\mu_s \sin(50)}{\rho_{air}\, C_d A_p}} \tag{3}$$

TABLE 3: SAMPLE VALUES USED IN CALCULATIONS

Density of Air	$1.34 \times 10^{-6}\ \frac{lbf}{in^3}$
Density of Glass	$0.0868\,\frac{lbf}{in^3}$
Drag Coefficient	1
Projected Area	$0.25\ in^2$
Angle of Slope	50 degrees
Volume of Glass Piece	$0.5\ in^3$
Static Frictional Coefficient Glass on Steel	0.6

AIR FLOW CHARACTERIZATION

During the initial design process assumptions were made about the predicted air flow in the chute. A constant air flow rate was assumed to ensure that the test material was displaced across the chute in a predictable matter. Additionally, a small decline in air flow needed to occur immediately after the deflection ramp in order to allow heavier materials to drop out.

An anemometer was used to record air flow characteristics at variable design settings. Air flow values were recorded at six locations: The hose entrance of the vacuum collection system (Position 0), the chute entrance (Position 1), the location directly after the ramp (Position 2), the air flow at the first drop out (Position 3), the airflow at the second drop out (Position 4), and the airflow out of the system into the dust collection system (Position 5). Figure 8 shows the locations of the anemometer testing locations on the system. Anemometer readings were taken at a central and side position for each location and air speed values were averaged. For the locations situated after the ramps, two tests were run for the ramp displacement variable. Finally, air flow values were recorded for the three speed settings of the blower.

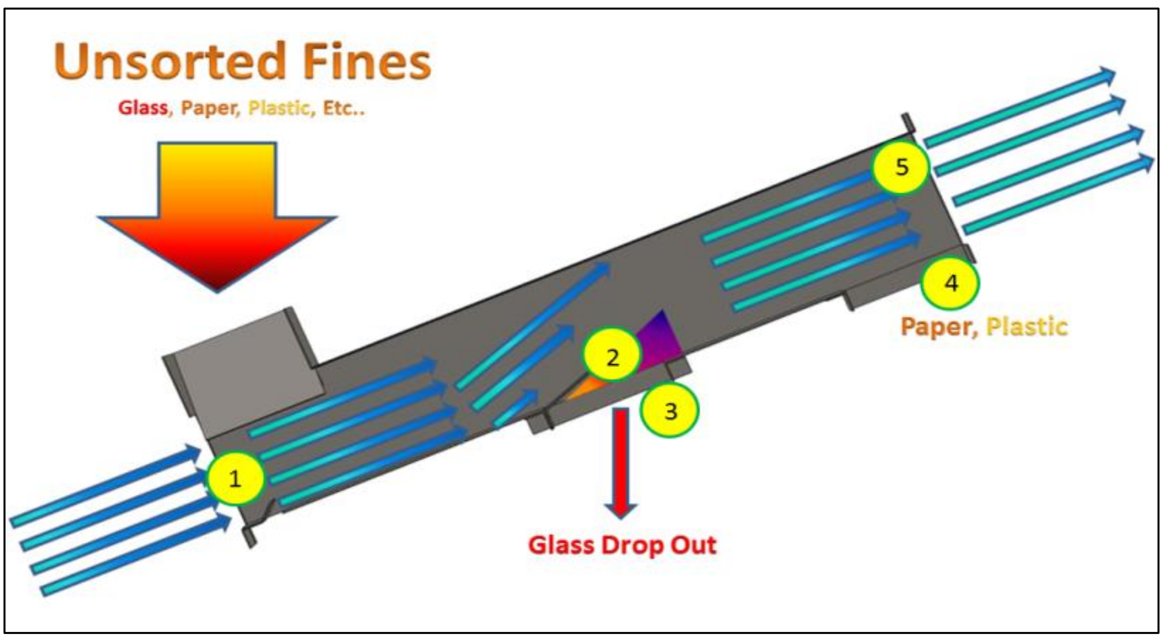

FIGURE 8: Side View of System, Showing Air Flow and Anemometer Testing Locations

After anemometer testing, results were gathered and organized to determine where, if any, discrepancies existed. Overall, air flow in the upper region of the chute remained constant. Interestingly, air flow increased at the outer edges of the chute, indicating that a standard laminar velocity gradient did not accurately model the system. Also, with the presence of the deflection ramps in the system a slight vacuum was created at the first dropout hole, drawing air into the chute rather than expelling it.

Constant Air Flow Readings (Positions 0 and 1)

During testing, two scenarios where measured that established a baseline for air flow values. The first test, at position 0, measured the air flow directly into the dust collection system. This value was found to be 32 ft/s, a higher value than any other test. This implies that the vacuum is always applying a negative pressure at the far end of the chute. The second test measured the air flow applied by the centrifugal fan. At this location, the values where highest for measured air flow speed, focusing, on average, 15.6% more air flow toward the center of the chute compared to the side edges. Figure 9 shows the variation between readings at the sides and center of the chute at positions 0 and 1 at different fan settings.

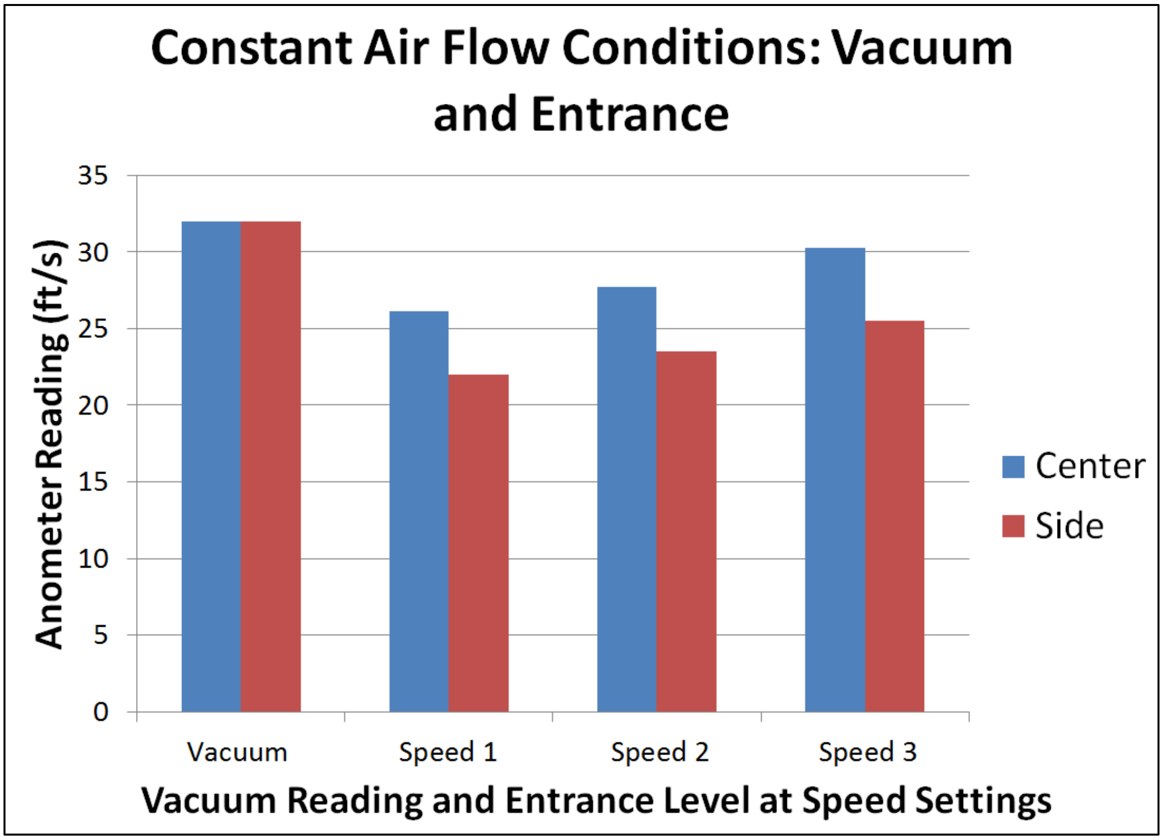

FIGURE 9: Anemometer Readings at Positions 0 and 1

Glass Gate (Position 2)

At position 2, the air stream was subjected to changes by the slope of the air deflection ramp and slider extension length. There was a noticeable shift of air flow to the outer edge of the chute after the deflector ramp. Values measure at the sides where on average 11.3- 13.8% higher than those measured at the center depending on the extension of adjuster plate. Values measured where higher when the ramp plate adjuster was in its minimum position (i.e., when the hole was opened all the way). On average, values decreased by 7.4% when the plate was set in maximum position, with the hole mostly closed. There was minor change caused by different ramps. This indicates that, as predicted, friction is the main force at work on glass particles at constant air speed conditions. Figure 10 summarizes anemometer testing data for position 2 at various conditions.

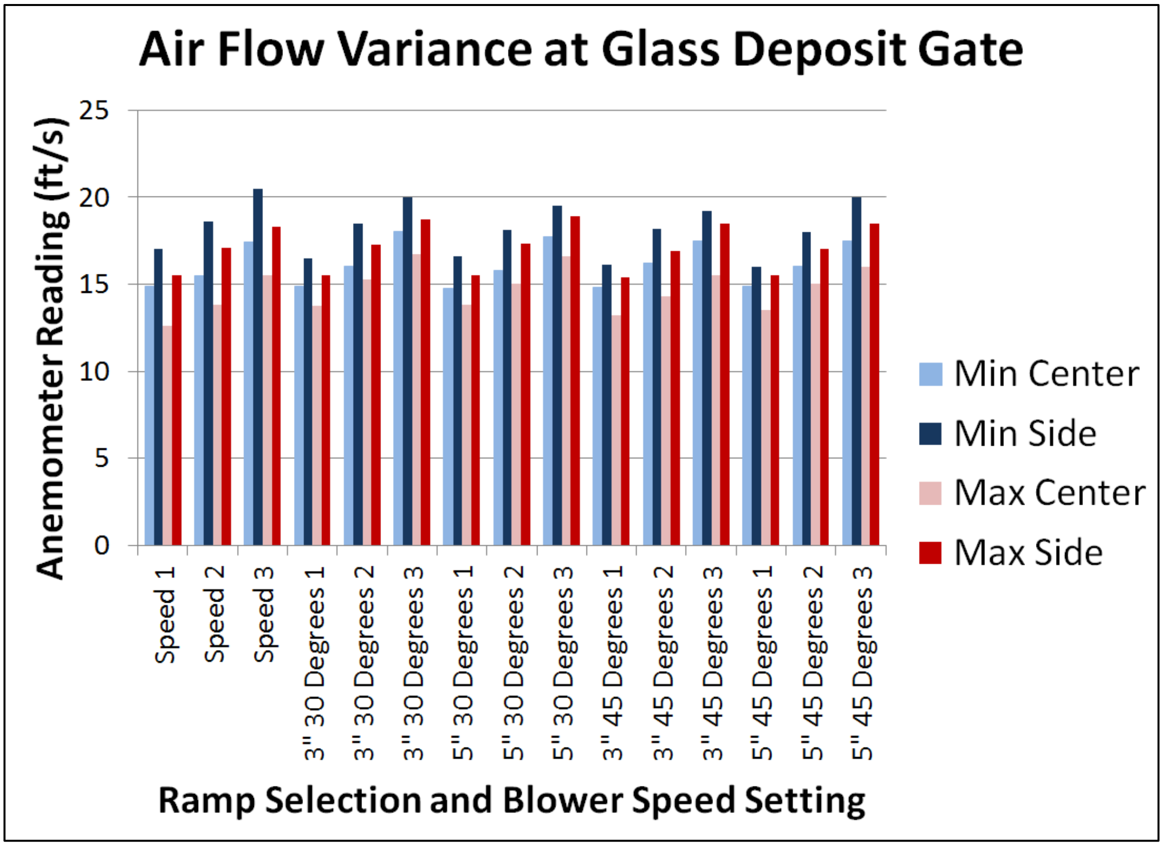

FIGURE 10: Summary of Air Speed in Chute at Various Locations and Conditions

Position 3: Glass Gate Exit Behavior

For the system to work correctly, the design required that there be no air flow lost through the first hole, thus minimizing the amount of plastic and paper escaping through it. When no air deflection ramp was used, air velocity out of this hole was on average 56.3% lower than conditions just past position 2. When the ramp slider was at minimum (largest opening), the air flow was 34.8% higher, with the air flow faster on the side of the chute. By using the air deflection ramps, the flow direction through the first hole reversed, creating a slight vacuum which drew air into the chute. The average vacuum air flow through this gate due to the addition of the ramps was 3.65 ft/s. The ramps pulled a 26% larger vacuum when the ramp slide was adjusted to maximum position, decreasing the inlet hole. Also, the air flow shifted back to a slightly higher value over the edge value for the vacuum induced scenarios. Figure 11 summarizes the results of anemometer tests at position 3.

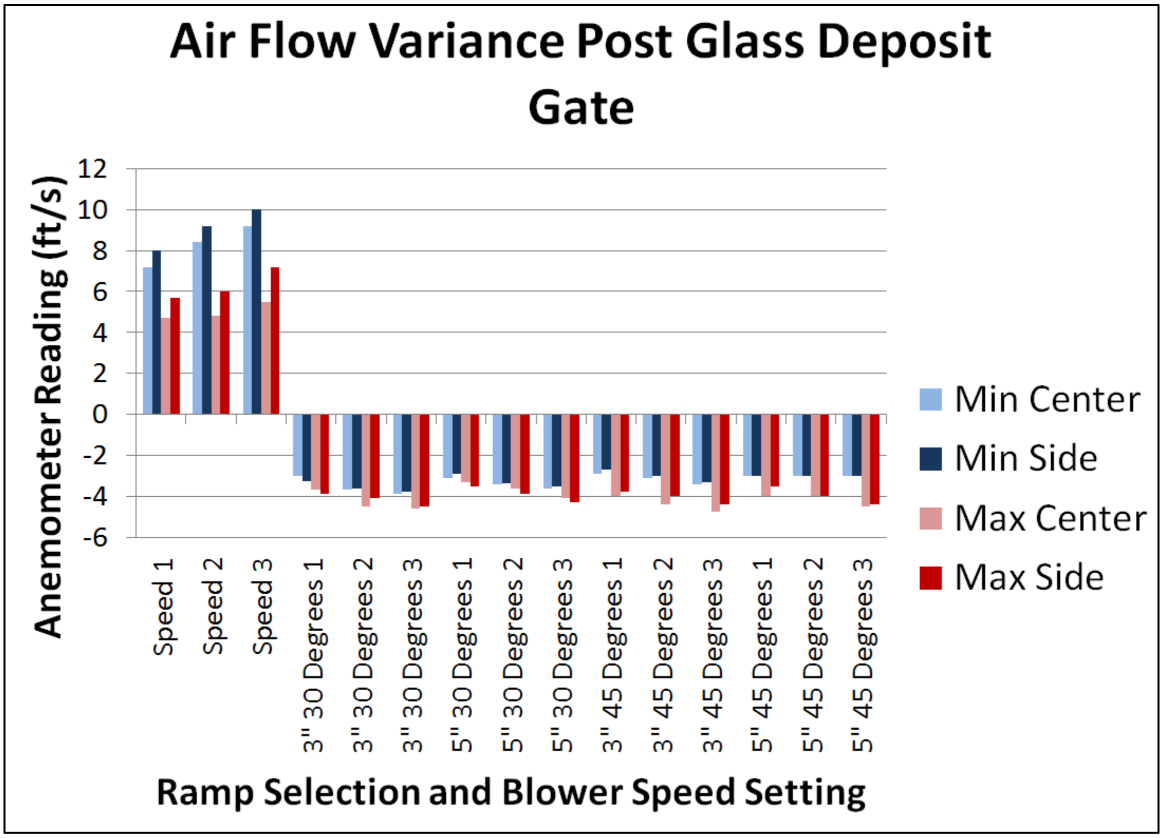

FIGURE 11: Summary of Air Speeds through Glass Deposit Hole at Various Settings

Paper & Plastic (Positions 4 and 5)

When readings were taken at the end of the chute, the accuracy of the anemometer began to decrease. At position 5, values were too erratic to determine a baseline assumption for values. At position 4, the exit hole for plastic and paper, values where averaged with an error of ±2 ft/s. With no deflection ramp installed upstream and minimal ramp slide placement, the center value for air flow was 31.5% lower than the side value. However, with the deflection ramp in place and minimal slide position, the center reading was the highest. The maximum air flow value measured at position 4 was 12 ft/s.

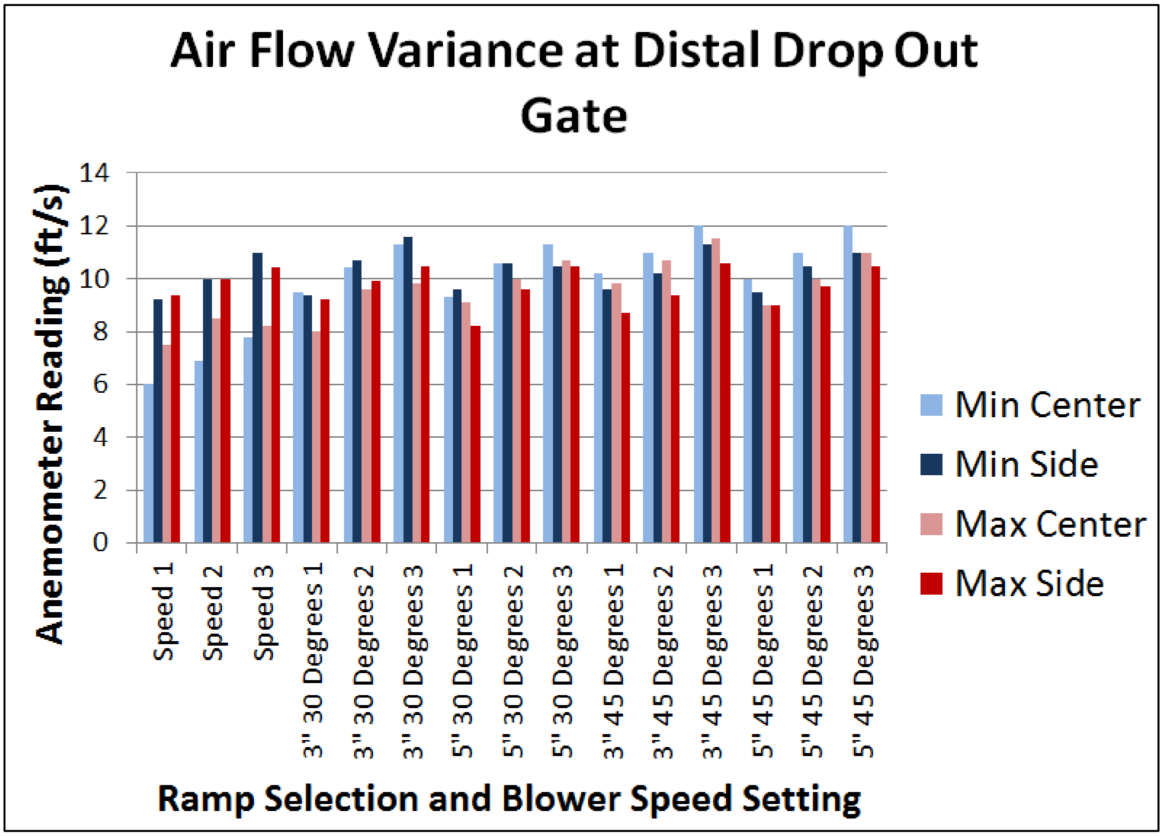

FIGURE 12: Summary of Air Flows at Paper and Plastic Hole at Various Conditions

MATERIAL SORTING TEST

The next stage of testing analyzed a realistic simulation of the operational system and compared results for all variable settings of the design. Testing was performed by feeding a known composition of mixed materials (glass, paper, and plastic) into the system. After these test fines were run through the system, measurements were taken for the glass and paper/plastic composition at each location: Hole 1, Hole 2, and not collected (NC). This was done by sorting and weighing the materials deposited at each location.

GLASS CHARACTERISTICS

Actual testing and observation of the process helped to reveal trends and confirm data. It must be noted that at no point was the design requirement met that, “90% of glass entering the system must exit through Hole 1”. In the best scenario 58.4% glass drop out at Hole 1 was achieved. However, the system did manage to collect 90% of the glass deposited in the system between both Holes 1 and 2 for all scenarios (except one test in which only 86.3% was collected). The majority of the glass lost in the system (approximately 10% for each test) was comprised of small, sand-like particles. Glass this size is generally too small to recycle and is therefore not considered in system performance. Glass dropped out of Hole 1 more often when a 45˚ air deflection ramp was used. Glass collection was also maximized when Hole 1 was all the way open. Figure 13 shows the percentage of glass collected from a known fines composition at various system conditions.

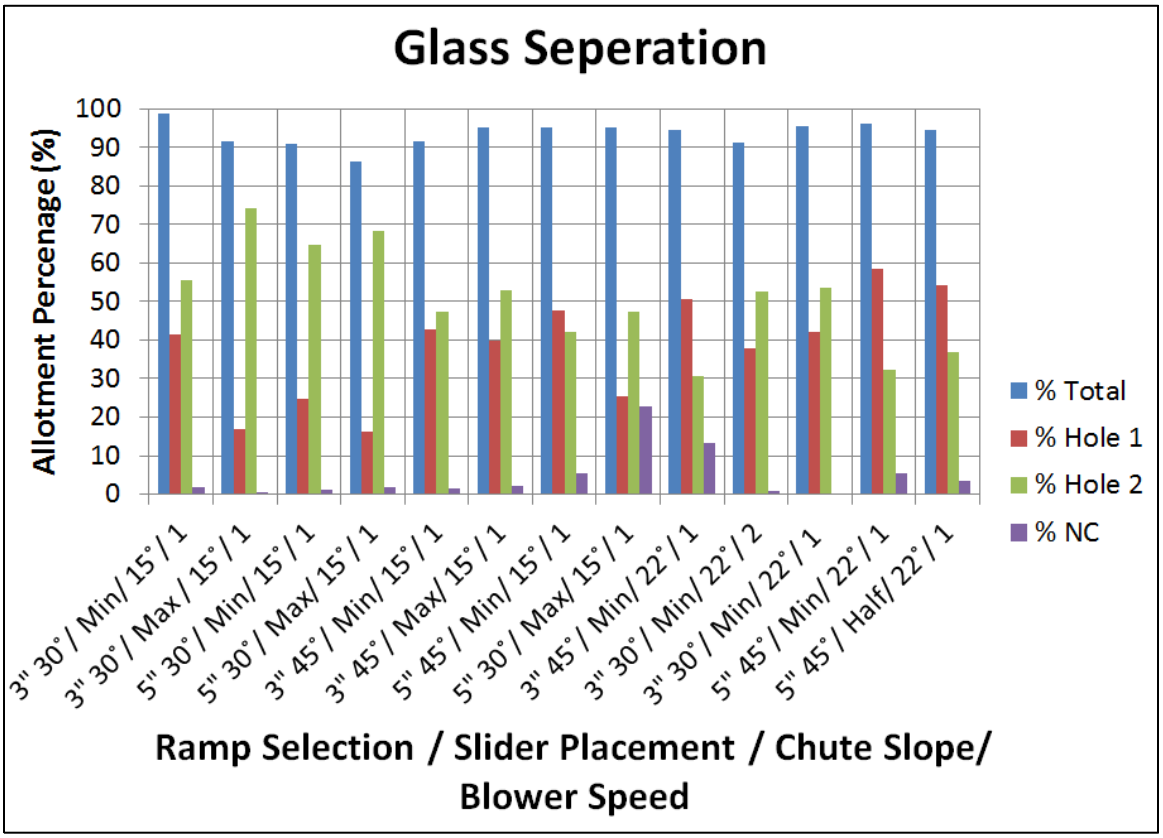

FIGURE 13: Summary of Glass Collected from System Using Known Fines Composition

PLASTIC/PAPER CHARACTERISTICS

Analysis was performed on the plastic and paper fines in order to determine the scenarios in which the mixture would best separate as designed. The highest dust collection used a 3" x 30 degree air deflection ramp with the chute at 15 degrees. This resulted in 33.3% of paper/plastic fines disposed with. However, the best scenario only allowed 6.2% in Hole 1 and used of a 5" x 30 degree ramp at max length with the chute at 15 degrees. More paper and plastic was deposited in Hole 2 when the air ramps were set at their max positions. Figure 14 summarizes the final location of paper and plastic at various system conditions.

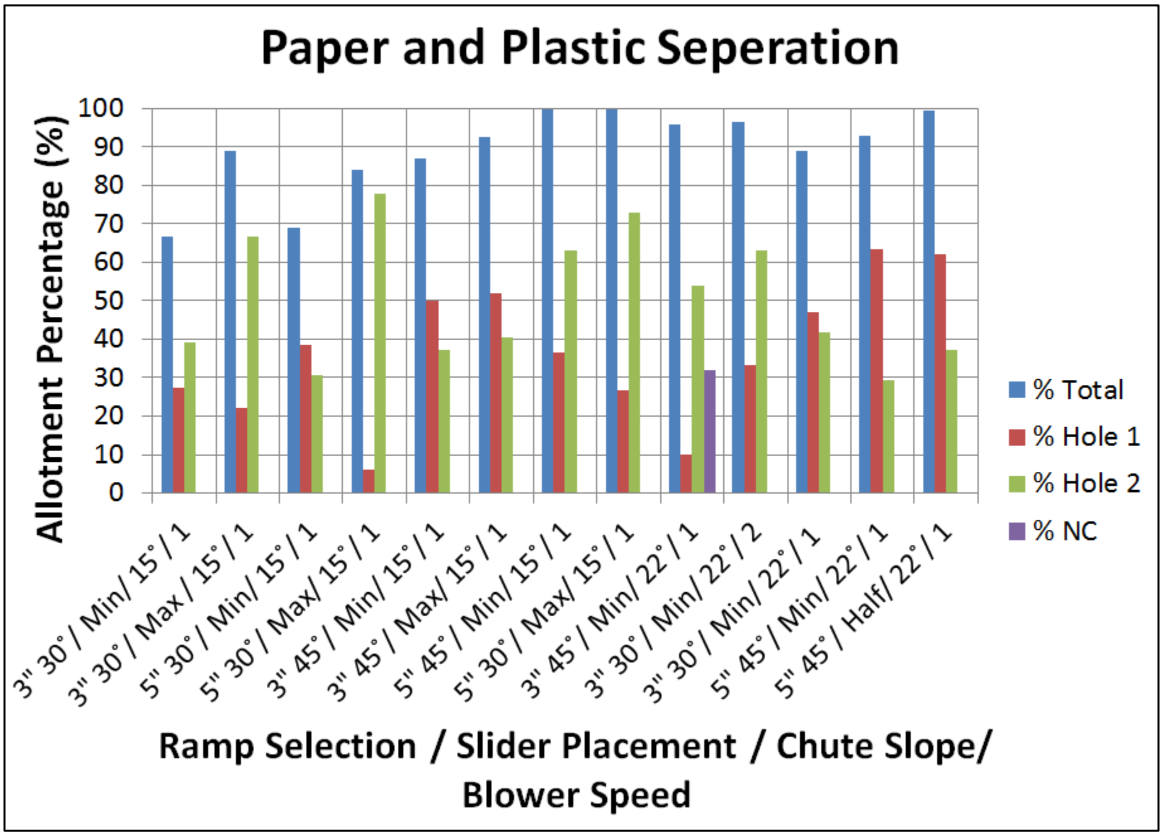

FIGURE 14: Summary of Final Collection Points for Paper and Plastic

GLASS BY WEIGHT IMPROVEMENT

Analysis was performed to determine which variables provided the best increase in percentage of glass by weight collected, compared to the initial composition. Shown in Figure 15 is the percentage improvement of glass at various system operating conditions. Positive values indicated an improvement of glass by weight percentage over initial conditions. Desirable results are displayed when the blue line is positive and the red line is negative as seen when the 3"/45 degree air ramp at minimum position with the chute sloped at 22 degrees and the fan speed set to 1. It is at this setting that glass in Hole 1 has the highest purity rating while decreasing its amount in Hole 2.

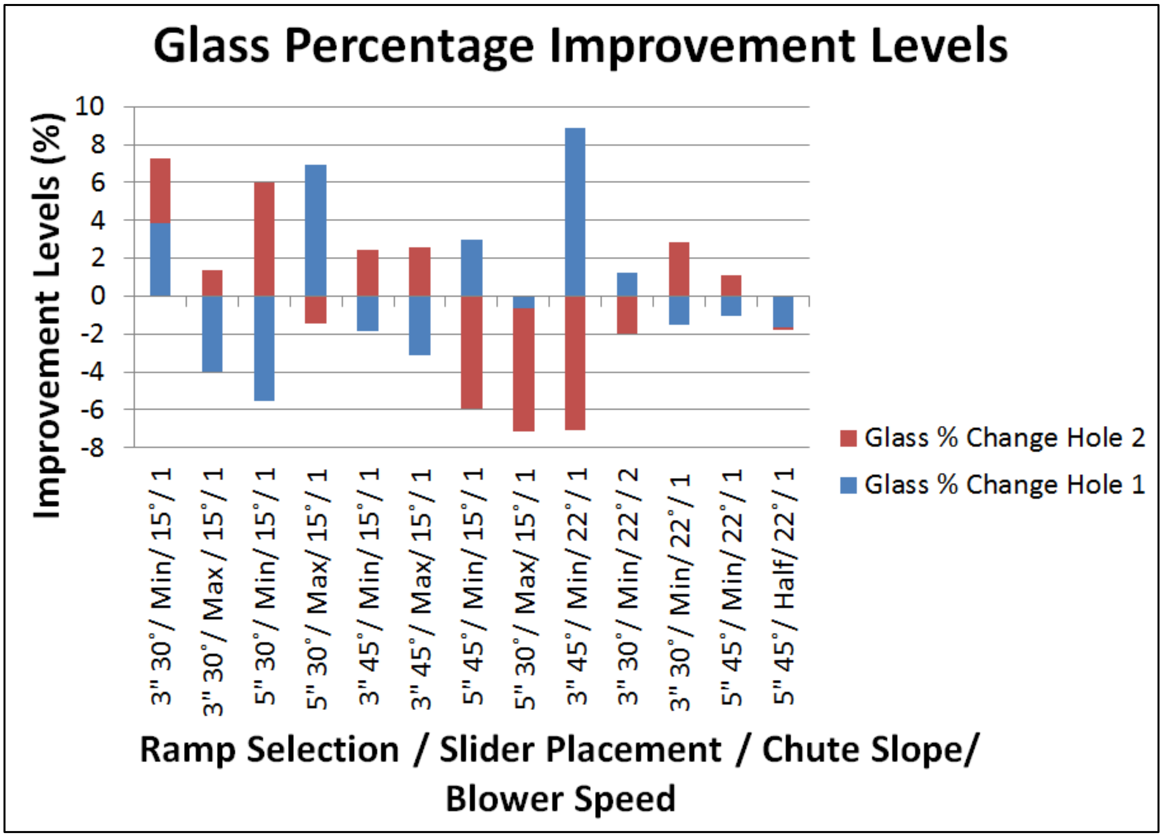

FIGURE 15: Improvement of Glass Recovery by Percent Glass by Weight

6 DISCUSSION, CONCLUSION, AND RECOMMENDATIONS

Over the course of two semesters, the Glass Recovery Enhancement team was able to design and build a system for sorting a material recovery facility's fine waste stream. Testing a fines mixture of known composition revealed that the initial goal of having 90% of the glass deposited in the system collected in one place (Hole 1) was unrealistic, or infeasible with the current design. However, 90% or more of the glass in the system is collected when the material in Hole 2 is considered. In this way, the project can be considered successful.

Assuming the best-case scenario in testing, approximately 60% of the glass deposited in the system is removed through Hole 1. An additional 30% or more in this case is also removed through Hole 2. By expanding the definition for what constitutes recovery to include the material in Hole 2, the system can be said to be extremely effective at separating glass from other materials in the fine waste stream. In order to fully justify this expanded definition of, "recovery" the quality of the glass exiting Hole 2 must be of a high enough quality that it can be sold to a recycling facility for more than the original fines mixture. Put simply, the glass by weight percentage must be increased to a level beyond normal fines. Results from testing show that indeed, fines collected from Hole 2 are an industry Grade 2 mixture (70-90% glass by weight). By comparison, the quality of the fines in Hole 1 are 90% or more glass by weight, or Grade 1. This improvement to glass recovery is significant, considering that many material recovery facilities sell their fines unsorted at lower grades. If the grade becomes too low, the glass in their fines may be landfilled rather than recycled.

The GRE system demonstrates a low-cost way for material recovery facilities to improve the quality of their fines. Rather than having a giant pile of low-grade fines, they have instead two piles: one large pile of high quality fines, and a somewhat smaller pile of medium-quality fines. While the 10% or less of glass lost using the GRE system would technically contribute to the quality of these piles, the glass itself would still not be recycled. Glass particles small enough to be lost in the GRE dust collection system are in general too small to be optically sorted, and thus too small to be properly recycled. Therefore these small particles do not represent a significant loss to overall system performance.

Despite the successful demonstration and performance of the final GRE system, there is room for improvement before actual implementation in a material recovery facility. The GRE system was designed with a clear top panel so the team could monitor material flow through the system. This panel would be unsuitable for actual material recovery facility conditions due to wear and tear from excessive and continued use. However, by viewing the system through this panel it became clear that about half of the glass destined for Hole 1 was overshooting the hole, hitting the top of the chute, and sliding back down the ramp. Some of it also bounced off the top and into Hole 2. By adjusting the overall length or height of the chute, it may be possible to curb this system behavior. Also, by increasing the size or position of Hole 1, it may be possible to collect more glass in it.

The GRE system was designed as a demonstration-scale project, and as such would require some modification for use in an actual material recovery facility. The system would require a change in air-handling systems before full-scale implementation. The GRE project used a variable speed centrifugal fan (carpet blower) for its main air source. Material recovery facilities would require a more rugged, commercial scale blower unit to handle the expected uptime of the system. The GRE project also features a shop-scale dust collection system at the end of the chute, connected by a hose. This was well-suited to the demonstration project, but the large volume of paper and small debris generated in a full-scale GRE implementation would require a much larger dust collection system.

It is the GRE team's recommendation that the project be continued with additional testing and refinement. Further variable testing would be beneficial, and on-site calibration in a material recovery facility would increase the likelihood of widespread system adoption. While the GRE system would most likely be adopted if refined and scaled up to industry caliber, it could potentially prove to be expensive in terms of up-front costs. Serious consideration would need to be given to material and construction costs on a scaled-up GRE system. However, the long term benefits of such a system would likely outweigh fabrication and installation costs.

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