

**BROWARD COUNTY BEACH DEMONSTRATION PROJECT**

**GEOTECHNICAL INVESTIGATION REPORT  
TECHNICAL MEMORANDUM**

**Submitted to:**

**Broward County Office of Integrated Waste Management  
Broward County Department of Planning & Environmental Protection**

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## EXECUTIVE SUMMARY

Broward County is implementing a demonstration project to determine the feasibility of using recycled glass as beach-compatible material. This material could supply, on an emergency basis, some of the volumetric needs of the County's shore protection program while providing another market for recycled glass.

This technical memorandum summarizes the results of geotechnical investigations conducted to determine grain-size distribution, Munsell color, carbonate content, grain angularity, and chemical analyses for potential contaminants in beach sand and glass cullet. Six samples of beach sand were collected from a back dune area at the southern end of the broad walk on Hollywood Beach (near Jackson Street). Subsamples of glass cullet were obtained from three manufacturers:

1. Andela Products Ltd., Richfield Springs, NY
2. Glass Aggregate Systems, Faribault, MN
3. Recycle America Alliance, New Haven, CT

The manufacturers were requested to provide pulverized glass samples that were similar to the grain size distribution of the natural sand along the Hollywood, Florida beaches. The results of the grain size analysis are summarized in the Table I below.

**Table I**  
**Summary of Sample Grain Size and Percent Fines**

<b>Source</b>	<b>Mean Grain Size (mm)</b>	<b>Percent Fines (%)</b>
Hollywood Beach (dune)	0.49	1
Andela Products Ltd.	0.89	4
Glass Aggregate Systems	0.40	3
Recycle America Alliance	0.33	8

The Florida Department of Environmental Protection (FDEP) requires that beach fill sediments contain no more than 5% fines (silt plus clay).

Public perception and FDEP requirements require that glass cullet looks like beach sand. The alphanumeric Munsell color system was used to determine the color (hue, value and chroma) of glass cullet, which ranged from pale yellow (2.5Y 8/3) to pale olive (5Y 6/4) to dark olive gray (5Y 5/2). The beach sand ranged from pale brown (10YR 6/3) to light brownish gray ((10YR 6/2) to light gray (10YR 6/2). The color of glass cullet can be controlled by admixture of source materials.

Beach sand in Broward County is compositionally dominated by carbonates. The average percent carbonate (bioclastic materials) in the native beach sand samples was

70%, while the remaining 30% was comprised by silica (quartz grains). The glass cullet was not tested for carbonate content because glass is 100% silica.

Contaminant tests were performed on beach sand and glass cullet for lead (Pb), mercury (Hg), total coliform, fecal coliform, enterococci bacteria, semi volatile organics, petroleum hydrocarbons (PHC), and total salt content. The contaminant levels of the beach sand and glass cullet samples were either undetectable or below the FDEP Reuse Target Levels for direct residential exposure (see Appendix B).

Therefore, based on the geotechnical and contaminant analysis performed for this study, glass cullet is viable as beach fill material.

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## 1 INTRODUCTION

Broward County has conducted numerous beach nourishment programs since the early 1960's because the County's beaches are in a chronic state of erosion. Significantly, 21 miles of the 24 miles of Broward beaches are defined as critically eroded (FDEP, 2000). Although a 1.3 million cubic yard nourishment project is currently underway that will dredge sand from offshore and place it on the beaches in Hollywood Beach, Hallandale Beach, and John U. Lloyd State Park in 2005 (CPE & Olsen, 2003), the County is examining the possibility of using alternative sources of sediment for areas with comparatively higher and localized erosion rates. If shoreline retreat in these erosional hotspots can be minimized, the lifetime of the beach fill can be extended.

Coordination with personnel in State and Federal regulatory agencies led to the recommendation that Broward County conduct a feasibility project to investigate potential geological and biological impacts of deploying recycled glass as a supplement to beach nourishment. The *Broward County Beach Demonstration Project* is thus investigating the potential of using recycled glass to control development and expansion of erosional hotspots. Glass cullet has grain size and color characteristics that are comparable to native beach sands.

The Broward County Solid Waste District processed 15,840 tons of recycled glass in 2004 at a cost of approximately \$145,000 (Austin, 2004). Due to limitations in the secondary materials market and increasing costs for recycling of glass, the Broward County Office of Integrated Waste Management (OIWM) conducted a Beach Nourishment Pre-Feasibility Project in January 2003 (Malcolm Pirnie, 2003). The results of this investigation indicated that recycled glass was a viable alternative material that could be used for beach nourishment because the cullet retained physical, chemical, mechanical, engineering properties, as well as geological characteristics, that were similar to beach sand. The glass cullet alternative can consistently supply a limited annual volume of material that supplements increasing demands for beach fill material while, at the same time, addressing some of the economic problems currently experienced with recycling glass.

The present investigation involved the collection and testing of processed recycled glass (glass cullet) and samples of beach sand for comparative purposes. Samples were tested for mean grain size, grain-size (frequency) distribution, Munsell color, carbonate content, particle angularity, and presence of contaminants. Chemical analyses were conducted to determine the presence of lead (Pb), mercury (Hg), total coliform, fecal coliform, enterococci bacteria, semi volatile organics, petroleum hydrocarbons (PHC), and total salt content. This technical memorandum summarizes the results and details the suitability of recycled glass as beach fill material.

## **2 SAMPLE COLLECTION**

Glass cullet samples were obtained from three manufacturers:

Andela Products Ltd.  
493 State Route 28  
Richfield Springs, NY 13439

Glass Aggregate Systems  
1100 Cannon Circle  
Faribault, MN 55021

Recycle America Alliance  
495 Blake Street  
New Haven, CT 06515

The samples were created using recycled glass from the manufacturer's local geographic-product area. The manufacturers were requested to provide samples that had a mean grain size of 0.55 mm and were provided with the grain-size distributions of natural sand, as presented in Appendix A.

Six beach samples were collected in the vicinity of Jackson Street, Hollywood Beach, near FDEP Monument R-116. This section of beach was nourished on two previous occasions (1979 and 1991) using sand dredged from offshore borrows. The samples were collected from two test pits dug into the back dune approximately 30 feet east of the board walk. Samples were collected at the surface and at 1.5 and 3 foot depths. The samples were collected using the standard operating procedures described in FS 3000 (Soil).

Surface samples were collected in May 1999 for the Broward County Shore Protection Project (CPE & Olsen, 2003). Geotechnical analyses for samples collected at FDEP monuments R-114 and R-117 (SEA, 1999) were compared in this analysis. Samples were collected at the dune and mid berm for R-114 while samples were collected at the dune, mid berm, mean high water line and mean tide line at R-117.

## **3 GRAIN SIZE ANALYSIS**

Grain size of the placed sediment (beach fill material) is an important factor because particle size affects beach stability. Larger sand grains require relatively greater energy to move in comparison to smaller grains, so coarser sands increase beach stability (USACE, 2001). The goal of this project is to selectively place glass cullet in erosional hotspots, which are spatiotemporally limited zones of accelerated erosion, to help stabilize the beach. The glass cullet can be ground to a specified grain size, preferably one that is coarser than existing beach sand. The adventitious supply of coarse cullet, when strategically placed, can thus theoretically help stabilize erosional hotspots on beaches.

Mechanical sieve analyses of the sediment samples were carried out in accordance with the American Society for Testing and Materials (ASTM), Standard Materials Designation D422-63 for particle size analysis of soils (ASTM, 1987). This method quantitatively determines the distribution of sediment size particles. A gradation analysis was performed, which calculated the mean, median sorting, and percentage of fines for each sample. The sediment characteristics were computed using the moment method of analysis, which utilizes the entire sample results to compute mean and sorting values. Grain-size distribution curves and granulometric reports are contained in Appendix A.

### Mean Grain Size

The average of mean grain sizes for beach samples was 0.49 mm, but ranged from 0.46 mm to 0.54 mm (Table 1). The beach sands collected in 1999 had an average grain size of 0.57 mm.

**Table 1  
Summary of Grain Size Analysis Results**

<b>Sample</b>	<b>Mean Grain Size (mm)</b>	<b>Sorting</b>	<b>Percent Fines <sup>(2)</sup></b>
<i>Beach Samples</i>			
Sample #1 (surface)	0.50	0.74	1.7
Sample #2 (-1.5 ft)	0.47	0.76	1.1
Sample #3 (-3ft)	0.46	0.86	0.7
Sample #4 (surface)	0.54	0.77	1.6
Sample #5 (-1.5ft)	0.48	0.67	1.1
Sample #6 (-3ft)	0.51	0.82	0.7
Average	0.49	0.77	1.2
<i>GRR Beach Samples <sup>(1)</sup></i>			
R-114 (dune)	0.65	0.97	0.0
R-114 (mid berm)	0.44	0.82	0.4
R-117 (dune)	0.38	0.61	0.3
R-117 (mid berm)	0.43	0.50	0.1
R-117 (mean high water)	0.71		0.0
R-117 (mean tide level)	0.83		0.0
<i>Glass Cullet Samples</i>			
Andela Products	0.89	1.12	3.7
Glass Aggregate Systems	0.40	0.84	2.7
Recycle America Alliance	0.33	0.95	7.5

1. SEA, Inc., 1999.

2. Percent material passing the #230 sieve.

The grain size of the glass cullet samples ranged from 0.33 mm to 0.89 mm. Andela Products provided a glass cullet sample (0.89 mm) that was coarser than the requested

grain size (0.55 mm). This coarse grain size is similar to that found along Broward County's beaches in the vicinity of the mean tide line where natural wave action has already sorted the sand. Sand that is coarser than the existing beach is preferable, from an engineering point of view, when attempting to stabilize a beach, especially in areas exhibiting higher erosion rates. However, this material may not be accepted as beach fill for Broward County's beaches due to environmental implications of increasing the composite grain size. This issue will require additional investigations.

The sample provided by Glass Aggregate Systems had a mean grain size (0.40 mm) that most closely matches the composite grain size of the existing beach sediment. Ideally, the grain size of the glass cullet should be coarser than the existing beach in order to stabilize hotspots. The 0.33 mm Recycle America Alliance glass cullet is not recommended as beach fill material because it will erode more quickly than the existing sand.

The range of glass cullet grain sizes supplied for testing highlights that it is possible to manufacture the glass cullet with various target grain sizes. Andela Products indicated that they would have had to alter their equipment setup to meet the requested grain size. This capability may prove to be an important benefit when analyzing the potential use of glass cullet as beach fill.

### Sorting Values

Sorting indicates the range of grain sizes found within a sample. Poorly sorted sediments (sorting values greater than 1.0) have a wide range of grain sizes whereas well sorted sediments (sorting values less than 0.35) have a narrow range of grain sizes (Folk, 1974). The degree of sorting can affect grain packing and compaction of the material, thus affecting the ability of sea turtles to nest. While the grain size of the beach-fill is typically viewed as more important than the sorting value, beach-compatible fill material should ideally have a sorting value similar to native beach sand.

Nearshore transport processes naturally sort material across the beach face and berm, with finer material often being transported offshore and coarser material tending to concentrate within the intertidal zone. Sorting of material can also occur during construction of beach nourishment projects, especially when hydraulic dredging is used. Since Hollywood Beach was nourished by hydraulic dredging on two different occasions, the beach sediments exhibit some sorting. Native beach sands are moderately sorted (sorting values averaging 0.77); sorting values for the 1999 sand samples ranged from 0.5 to 0.97.

In comparison, the glass cullet samples were poorly sorted (wider range of grain sizes) with sorting values between 0.84 and 1.12. The glass cullet provided by Andela Products has a higher sorting value than the existing beach (1.12) and is classified as poorly sorted. The Glass Aggregate Systems and Recycle America Alliance samples have sorting values similar to existing beach sands. Sorting values alone do not restrict or prohibit the use of

any of the glass cullet samples as beach fill material on Broward County's beaches under state or federal regulatory requirements for placement of compatible material.

#### Percent Fines

In order for fill material to be considered beach-compatible, according to FDEP requirements, less than 5% of the material may pass the #230 sieve (62B-41.007 (2)(j)(1) of the Florida Administrative Code).

The beach sediment samples averaged 1.2% fines with a maximum of 1.7%. The 1999 samples of beach sand had less than 0.4% fines. The Recycle America Alliance sample, which contained 7.5% fines, would thus need to be washed to remove the fines prior to placement on the beach. The percentage of fines in the Andela Products and Glass Aggregate Systems samples was less than the 5% threshold. Because the grinding of glass product to create glass cullet produces a fine fraction, the fines need to be monitored to meet the State of Florida's specification of less than 5% contained fines.

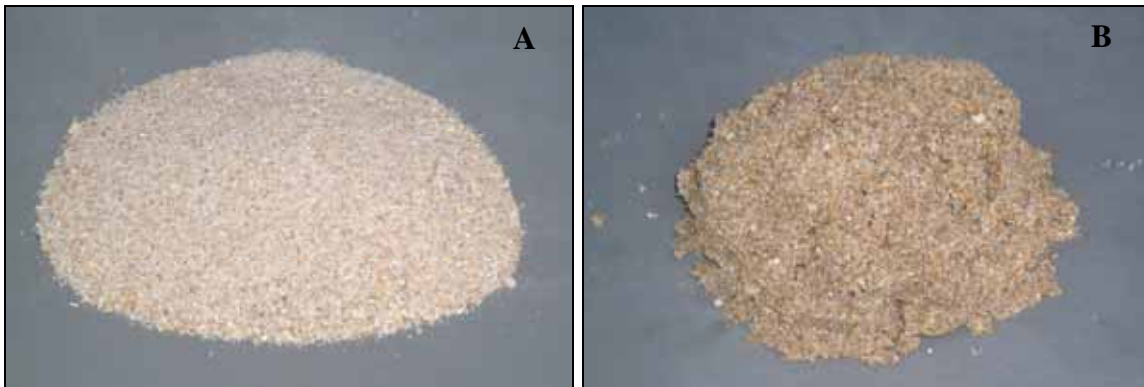
#### **4 MUNSELL COLOR**

Public perception and FDEP requirements will likely require that the glass cullet looks similar to the existing sand, as determined by color characteristics. Color may also affect the thermal properties of the glass cullet and thus has potential environmental implications. The Munsell color test was used to characterize the color of the samples analyzed during these investigations. The Munsell color test involves matching the color of the sediment to the Munsell chart (Macbeth Division of Kollmorgen Instruments Corporation, 1994). Table 2 summarizes the color results for the existing beach sample and glass cullet. Because color varies between wet and dry conditions, the Munsell color is provided for both conditions.

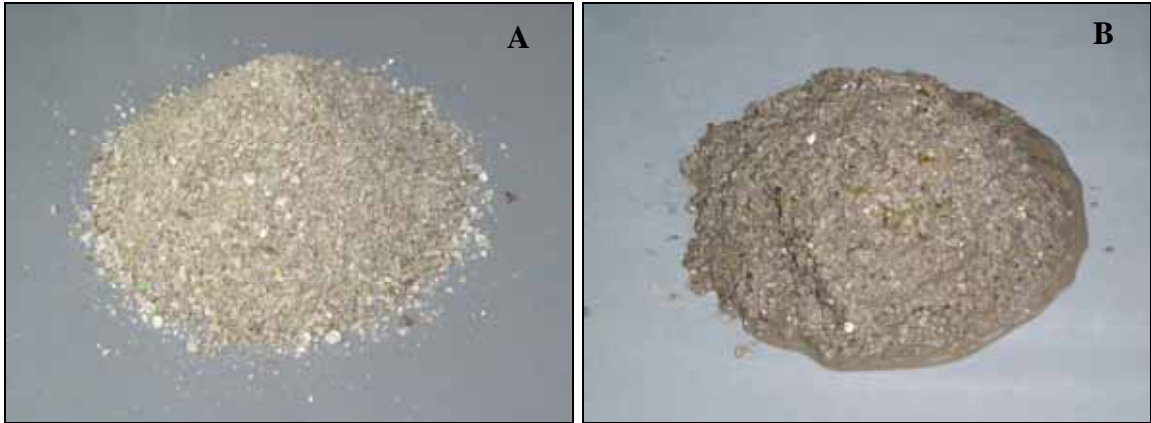
**Table 2  
Munsell Color Results**

Sample	Munsell Color Value		Munsell Color Description	
	Dry	Wet	Dry	Wet
<i>Beach Samples</i>				
Sample #1 (surface)	10YR 7/1	10YR 6/2	Light gray	Light brownish gray
Sample #2 (-1.5 ft)	10YR 7/2	10YR 6/3	Light gray	Pale brown
Sample #3 (-3ft)	10YR 7/2	10YR 6/3	Light gray	Pale brown
Sample #4 (surface)	10YR 7/1	10YR 6/2	Light gray	Light brownish gray
Sample #5 (-1.5ft)	10YR 7/2	10YR 6/2	Light gray	Light brownish gray
Sample #6 (-3ft)	10YR 7/2	10YR 6/3	Light gray	Pale brown
<i>Glass Cullet Samples</i>				
Andela Products	5Y 3/2	5Y 5/2	Olive gray	Dark olive gray
Glass Aggregate Systems	2.5Y 8/3	5Y 6/4	Pale yellow	Pale olive
Recycle America Alliance	10Y 8/1	5Y 6/3	Light greenish gray	Pale olive

The beach sample colors ranged from pale brown (10YR 6/3) through light brownish gray (10YR 6/2) to light gray (10YR 7/1) (Figure 1). The glass cullet samples ranged in color from pale yellow (2.5Y 8/3) through pale olive (5Y 6/4) to dark olive gray (5Y 5/2) (Figures 2 to 4). The bulk cullet sample from Glass Aggregate Systems most closely resembles the color of native beach sand, pale yellow (2.5Y 8/3), when dry. Since the color of cullet can be controlled by admixtures of glass product, color control should not become a major issue in the success of the project.



**Figure 1. Bulk Beach Sand from Hollywood Beach, Sample #4. (A) sample when dry (light gray 10YR 7/1), (B) sample when wet (Light brownish gray 10YR 6/2).**



**Figure 2.** Bulk Glass Cullet from Andela Products. (A) sample when dry (olive gray 5Y 3/2), (B) sample when wet (dark olive gray 5Y 5/2).



**Figure 3.** Bulk Glass Cullet from Glass Aggregate Systems. (A) sample when dry (pale yellow 2.5Y 8/3), (B) sample when wet (pale olive 5Y 6/4).



**Figure 4.** Bulk Glass Cullet from Recycle America Alliance. (A) sample when dry (light greenish gray 10Y 8/1), (B) sample when wet (pale olive 5Y 6/3).

## **5 CARBONATE CONTENT**

Beach sands can be broadly categorized by their chemical composition into either carbonate beaches ( $\text{CaCO}_3$ ) or siliciclastic/quartz ( $\text{SiO}_2$ ) beaches. The beaches in Broward County are a mixture of bioclastic carbonate sands (coquina shell fragments, reef fragments, and skeletal fragments of marine organisms) and silica sands in the form of quartz (CPE & Olsen, 2003). The carbonate content is important because carbonate sands perform differently than silica sands due to different intraparticle porosities, density, bulk density, and structural integrity of carbonate grains (Halley, 2000). In Miami-Dade County, weathering of carbonate sands produces sediments with higher concentrations of silt and clay sized material, which results in elevated turbidity levels in the nearshore zone (USFWS, 2002). Glass cullet avoids these issues because it is composed primarily of silica-based compounds and fines can be washed away prior to placement on the beach.

The average carbonate content of the beach samples was 70% (Appendix A), but ranged from 61% to 84%. The glass cullet samples were not tested for carbonate content because they are chemically 100% silica.

## **6 GRAIN ANGULARITY**

The angularity, or roundness, of individual grains effects sediment settling and motion initiation. It can also be important as a public perception issue. Sample grains of the beach sand and glass cullet were placed under a microscope and visually examined to determine grain angularity using Power's visual classification (Powers, 1953). The existing beach sand is rounded to sub-angular with both high and low sphericity values while the glass cullet was very angular with low sphericity. Edge (2002) showed that glass cullet abrades but that the rate of abrasion decreases and stabilizes with time. Therefore, the angularity of the glass cullet can be expected to decrease over time. Angularity is not expected to have a significant impact on the performance of the glass cullet as beach fill.

## **7 CONTAMINANT TESTING**

FDEP requires that for fill material to be beach-compatible, it must not contain toxic material, as specified in Section 62B-41.007 (2)(j)(4) of the Florida Administrative Code.

Glass cullet and beach sands were tested for contaminants as part of these investigations. Beach sands were used as a control or guide to general background contaminant levels to which the glass cullet would be compared. Tests were performed to detect the presence of lead (Pb), mercury (Hg), total coliform, fecal coliform, enterococci bacteria, semi volatile organics, petroleum hydrocarbons (PHC), and total salt content. The test results are summarized in Table 3. The semi-volatile organic results were limited to the five compounds detected (out of 85 that were investigated). The complete list of tests and test results are contained in Appendix B.

**Table 3  
Summary of Contaminant Exposure Limits and Test Results**

Parameter	Detection Limits & Units	Glass Cullet Samples			Existing Beach Samples			Limit for Direct Exposure Residential <sup>(1)</sup>
		Andela Products	Glass Aggregate Systems	Recycle America Alliance	Sample 1	Sample 2	Sample 3	
Lead	10 mg/kg	71	U <sup>(2)</sup>	U	U	U	U	400
Sodium	10mg/kg	1300	850	U	2700	3300	2500	N/A
Mercury	0.05 mg/kg	0.11	U	0.099	U	U	U	3.4
Chloride	20 mg/kg	480	U	160	U	U	200	7800
Enterococci Bacteria	1 CFU/1g	U	U	U	U	U	U	N/A
Fecal Coliform Bacteria	1 CFU/1g	U	U	U	U	U	U	N/A
Total Coliform Bacteria	1 CFU/1g	U	U	U	U	U	U	N/A
Benzyl butyl phthalate	100 g/kg	340	U	240	U	U	U	15,000,000
Bis(2-ethylhexyl) phthalate	100 g/kg	1800	U	680	U	U	U	76,000
Di-n-butyl phthalate	100 g/kg	250	U	250	U	U	U	7,300,000
Fluoranthene	100 g/kg	170	U	U	U	U	U	2,900,000
Pyrene	100 g/kg	130	U	U	U	U	U	2,200,000
Petroleum Range Organics	10 g/kg	280	190	350 <sup>(3)</sup>	U	U	U	340
Hydrocarbon Range	-	C <sub>18</sub> -C <sub>36</sub>	C <sub>18</sub> -C <sub>36</sub>	C <sub>18</sub> -C <sub>38</sub>	-	-	-	-

1. FDEP, 2001.

2. U=Analyte not detected.

3. Within the soil cleanup target level for the C<sub>18</sub>-C<sub>38</sub> carbon chain range.

The FDEP (2001) developed guidance for the maximum direct exposure to various compounds. Only sodium (Na) and chloride (Cl<sup>-</sup>) were detected in the beach sands. A direct exposure limit for sodium was not provided by FDEP and the chlorine level was 0.025% of the allowable limit.

Table 3 summarizes the contaminants that were detected and shows that all glass cullet samples were below the direct residential exposure limit, except one. The Recycle America Alliance glass cullet sample had 350 mg/kg of petroleum range organics (aromatic hydrocarbons), which is above the 340 mg/kg limit for direct residential exposure. However, the hydrocarbon range must be considered when interpreting this limit. The 340 mg/kg limit is specifically for hydrocarbons in a carbon chain range of C<sub>8</sub>-C<sub>10</sub> but the glass cullet samples contained hydrocarbons in the C<sub>18</sub>-C<sub>38</sub> range. The soil cleanup target level is 1,300 mg/kg for hydrocarbons in the C<sub>16</sub>-C<sub>21</sub> range and 2,200 mg/kg for hydrocarbons in the C<sub>21</sub>-C<sub>35</sub> range (Saranko *et al.*, 1999). Therefore, the glass cullet meets the contaminant standards required for placement of fill on a beach.

## 8 CONCLUSIONS

Based on geotechnical and contaminant analyses performed during this study, glass cullet is viable as an alternative beachfill, compared to sand dredged from offshore. It is possible to process recycled glass so that the glass cullet has a grain size that is similar to native beach sands, as shown by bulk cullet samples that had mean grain sizes both larger and smaller than beach sand. Contaminant levels for all glass cullet samples were within accepted limits.

Of the three samples tested, the cullet from Glass Aggregate Systems has the most similar geological characteristics compared to existing beach sand. The grain size (0.40 mm) is smaller than the average grain size of the existing beach (0.49 mm) but is still coarser than a beach dune sample collected in 1999. This sample is preferred as beach compatible material due to the grain size and sorting values most closely matching the existing beach values, low fine content, and pale yellow color (2.5Y 8/3).

The Andela Products glass cullet sample had a coarse grain size (0.89 mm), which would be favorable for constructing a stable beach. However, environmental implications of placing such coarse material on Broward County's beaches would have to be investigated. The color of this sample could also raise concerns during permitting and the source material would have to be manipulated.

The Recycle America Alliance sample has a smaller average grain size than the existing beach sand and would increase the current erosion rate. The content of fine-grained cullet is too high for placement on the beaches without further processing of the material.

While the three subsamples have been compared to each other and the existing beach sand, the glass cullet manufacturers indicated that they can alter the equipment to achieve a designated grain size, grain size distribution, and percent fines. The color of the glass cullet can also be controlled by selection of input materials. A great advantage of

manufacturing glass cullet is that physical characteristics of the beach fill material can be specified.

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