Glass Feedstock Evaluation Project

Testing Program Design

Clean Washington Center
ACKNOWLEDGEMENTS

Organizations most directly involved with the sponsoring of this study are:

Co-Sponsors / Direct Support

Arizona Department of Environmental Quality
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California Department of Conservation
New York Office of Recycling Market Development
Minnesota Office of Waste Management
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1.0 INTRODUCTION

Our country's long term success at recycling glass economically will rest on the development of new markets. Construction aggregates - materials like sand or stone, used in road beds, engineered fills, drainage fields, and other construction applications - look to be a viable market for recovered glass. The size of the construction aggregates market dwarfs the potentially available supply of recycled glass. However, without solid data on the engineering and environmental performance of glass in these applications, and information on how to process glass efficiently to construction aggregate specifications, wide spread acceptance of cullet in this market will not occur.

The purpose of the Glass Feedstock Evaluation project is to provide the necessary information on cullet properties and processing so that engineers can specify the use of cullet as a construction aggregate with confidence and recycled glass aggregate suppliers can invest in market development with minimal risk. The study will define the suitability of cullet as a construction aggregate in terms of its engineering performance, environmental impact, cost comparability to natural aggregates, and safety in handling.

This initial report covers the design of a program to test cullet as a construction aggregate and introduces an economic model for evaluating the market potential of the construction aggregates market. Further reports will document the study findings and interpret the data.

1.1 STUDY APPROACH

An important underlying assumption of the Glass Feedstock Evaluation project is that good technical information is crucial to speeding the development of new markets. Without such information engineers will be reluctant to specify recycled materials, because they have the responsibility for the final product performance. In effect, technical information on the material properties will enhance competitiveness of glass feedstocks. Information on processing to end use specifications, coupled with market data, will enable cullet suppliers to target those application which make the most economic sense.

The information developed, although aimed at the development of the construction aggregates market, will also have relevance to the use of cullet in higher value-added applications, such as terrazzo flooring and foamglass.

1.2 CURRENT MARKET CONDITIONS

At present there is only one well established market for glass cullet, the glass container industry. Currently this market is characterized by oversupply. The advent of community recycling programs in the late 80's and early 90's resulted in a tremendous surge in the supply of recovered glass. This growth in supply continues unabated as more communities join the ranks of recyclers and more people are drawn into existing recycling programs. On the demand side, many glass plants are limited to a low percentage of cullet in their batch for technical and economic reasons.

1 Recently, new markets have developed, such as the fiberglass market. However, these markets are highly localized in one or two geographic areas at this time.
This market also suffers supply/demand dislocations relative to cullet supply as historically the glass plants were located near reserves of the virgin materials used in glass making. This resulted in the geographic concentration of glass plants. Cullet, because of its relatively high density, is expensive to transport long distances. Transportation costs often outweigh the market price of cullet as container batch.

Construction aggregates have been identified as a high-volume market for the cullet. The construction aggregates market could easily absorb any excess cullet in the market, besides having the advantage of being a local market. In Washington State alone, the estimated demand for aggregates in non-paving applications on road construction projects is more than 20 times the state’s projected supply of cullet in 1995. Private sector and other public works projects create additional demand.

In the glass container market, cullet competes with virgin batch in the range of $60 per ton. Use of cullet also conserves energy in glass making for additional savings. However, the cost of supplying cullet to furnace-ready specifications is at least as high and often exceeds the cullet’s market price. Cost to color sort the glass containers is a substantial component of supply costs. For communities located at a distance from glass plants, transportation costs are another significant cost element.

In the aggregates market, cullet would compete with materials ranging from $5 to $10 per ton. However, because there is no need to color sort the glass and because contamination specifications are less stringent, the cost to supply to the construction aggregate market will be substantially less than that to supply to the container market. The construction aggregate market, then, may be as high a value-added market as the glass containers market. This conclusion is supported by the economic model developed in this report.

States and other organizations currently using or studying the use of cullet as a construction material include:

- The National Association of Plumbing-Heating-Cooling Contractors - at the urging of the New Jersey Department of Environmental Protection - changed its widely used National Standard Plumbing Code to include the use of 3/4-inch crushed glass as fill around perimeter wall french drains.

- Pennsylvania - Pennsylvania Department of Transportation has developed draft specifications for using waste glass as pipe backfill and embankment material, and has used glass as fill around two culverts beneath a state highway.

- North Carolina - North Carolina DOT is currently testing the practical limits of using recycled materials in highway work, and may use crushed glass as drainage aggregate beneath concrete highway slabs.

- Connecticut - The Connecticut Department of Transportation has recently revised their specifications to include the use of recycled glass in roadway embankment fill. These specifications include: no particles larger than one inch, glass content not greater than 25 percent by weight of the fill, and no glass mixture within five feet of the embankment slope.

- California - CalTrans has developed specifications for aggregate base and subbase which includes the use of recycled glass. The specifications preclude the use of glass for surfacing material.
City of Seattle - Seattle Drainage and Wastewater Utility has designed a filtration trench system for the Green Lake Storm Water project which includes the use of recycled glass as storm water filtration media. The glass was wrapped with a geotextile fabric, and subsequently covered with 6 inches of conventional aggregate.

Washington State Department of Transportation - Standard Specifications for Road, Bridge, and Municipal Construction, Section 9-03.21 (Amendments to Division 9 dated September 14, 1992) allows for aggregate to be made of up to 15% cullet. Additionally, the fraction of aggregate retained on 1/4 inch or larger sieves are limited to 10% cullet.

New Hampshire Department of Transportation - New Hampshire DOT has developed specifications for use of processed glass aggregate as a construction material. Some contracts will require the use of processed glass aggregate in base course applications.

City of Seattle, Solid Waste Utility - SWU authorized a study to evaluate the use of glass cullet in drainage and base course applications.

British Columbia Hydro - B.C. Hydro authorized a study to evaluate the use of green cullet as electrical trench backfill.

1.3 PROJECT SCOPE

The Glass Feedstock Evaluation project will provide the engineering data necessary to determine the acceptability of cullet as a construction aggregate in terms of:

- **Engineering Performance:** The testing program will determine the physical and engineering performance properties of cullet and cullet mixed with natural aggregates. Tests include those for specific gravity, gradation, grain shape, durability, compaction, permeability, thermal conductivity, and shear strength.

- **Environmental Suitability:** The testing program is designed to assess the organic and inorganic chemical composition, the potential for contaminant leachability, and the potential for bacteria growth.

- **Cost Comparability to Natural Aggregates:** An equipment evaluation will provide information on cullet processing costs and on the quality of feedstock produced relative to construction aggregate applications.

- **Safety in Handling:** The program will test cullet and cullet production for potential safety and health hazards, such as the respiration of glass dust.

In addition to the study objectives above, the study will also quantify physical debris levels typical of different collection/sorting techniques. The amount of physical debris influences both the engineering performance and the environmental effects of cullet feedstock.
The testing program controls for three major physical variables in the feedstocks: physical debris levels, aggregate size, and the percentage of glass content in the aggregate mix. The variable's significance is that cullet suppliers will process and mix glass with natural aggregates to end use specifications that denominate these variables.

As noted in the section above, several states and other utilities have initiated studies on use of cullet in construction aggregate applications. The difference between previous studies and the Glass Feedstock Evaluation project is in the depth and comprehensiveness of the information being generated. Previous studies on engineering performance have relied primarily on materials classification tests rather than engineering properties tests. The latter tests provide the information which will allow prediction of cullet behavior. It is then that the classification test data, correlated to engineering properties, becomes useful. No interpretive study has been done on the environmental suitability of the materials. No study has examined the range of variables undertaken in this study. Finally, most previous testing has been conducted with reference to specific state and localities specifications. The testing program and analysis has been designed to present information that should have universal application throughout the country.

This study does not address cullet as a feedstock for use in composites such as asphalt pavement (glassphalt) and concrete. A program that could account for all the variables in composites and still have universal application is beyond the scope of this study.

1.4 STUDY REPORTS

The Task 1 report, Testing Program Design, is the first of five. This report serves to document the study's overall design. Preliminary drafts of this report were reviewed by a Technical Advisory Committee which consisted of representation by the project's co-sponsors and participants, including review by the California Department of Transportation (CALTRANS), and the Washington State Department of Transportation (WSDOT).

Reports 2 through 4 will document the research findings for the environmental suitability determination, the equipment evaluation, and the engineering performance testing, respectively. It is anticipated that the contents of these reports will be highly technical.

The final report, the Task 5 report, will evaluate the uses for glass as a construction aggregate based on the laboratory testing program results and analysis of the operational constraints on both processors and users. The report will include model specifications for those applications where cullet meets performance specifications and where it is economical to use. The information in this report will be accessible to a general audience.

In addition, a brochure will be prepared highlighting the findings concerning the use of glass as an aggregate.
2.0 SAMPLE SELECTION AND TESTING

Figure 2.1 presents the sampling and analysis sequence of this project for both environmental and engineering testing.

2.1 BACKGROUND

Study co-sponsors are to provide samples from sources of cullet of up to four sources each. The total number of sources for the study equals 24. The sources were selected to represent typical materials recovery facility (MRF) collection-sorting systems. Also, a balance among the color feedstocks (green, amber, flint, and mixed color) was sought. The collection/sorting categorization is presented in Attachment A-1 in Appendix A, Sample Collection Procedures. Samples were collected by the co-sponsors as detailed in Appendix A.

The first step in the testing program will be to designate the debris levels in the samples according to a high/low classification and confirm these designations through physical contamination testing. The methods used to quantify debris level are described in the following section.

Following the physical contaminant testing, engineering property testing and environmental testing will be done in parallel.

Three high and three low debris level sources will be evaluated in the environmental testing program. In addition, testing for total lead content on samples from twenty three sources will be conducted by study co-sponsor, Browning-Ferris Industries.

In the engineering performance testing program, samples will be tested by investigating three independent variables. These include cullet content in the aggregate mix (15, 50, or 100% by weight), aggregate mix gradation (1/4" minus or 3/4" minus), and relative debris level (high or low). The lower bound of cullet content (15% by weight) was selected to correspond to the maximum use content for cullet specified in the Washington and California departments of transportation specifications. The mix gradations of 1/4" minus and 3/4" minus are intended to cover the majority of applications for cullet aggregates. By varying the relative debris levels, it will be possible to investigate the sensitivity of the chemical and engineering properties on this parameter.

2.2 PHYSICAL DEBRIS TESTING

Two methods for quantifying physical contamination level have been identified. One utilizes visual classification and the other requires physical separation. The debris level is significant for both the environmental and physical performance of the cullet.

A simple but easy method will be a semi-quantitative, visual method to obtain a percentage or index of contamination. This method is based on standard charts developed for estimating percentage composition for geologists (AGI, 1982) For example, 200 grams of cullet could be placed in a pan on a 10 cm square grid, the particles of contamination counted, and a number recorded. After several iterations with various samples of differing contamination levels, an index could be developed and correlated with other testing methods. This index could further be developed for field inspectors or crushing plant managers. An example of the proposed visual
classification is presented on Figure 2.2. Measuring contamination by weight, by volume and by physical separation will be used to correlate the visual methods.

The development and implementation of these procedures will be performed during physical and environmental testing, and equipment evaluation tasks. Our selected procedure will be used throughout the project. Contamination levels will be correlated to processing techniques.
Figure 2.1

**GLASS FEEDSTOCK SOURCE SAMPLING AND TESTING SCHEME**

*Percent cullet by weight in mixture of cullet and natural aggregate.*

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FIGURE 2.1
3.0 ENVIRONMENTAL SUITABILITY EVALUATION

Cullet from post-consumer recycling programs not only includes glass but debris such as labels, plastic and metal bottle caps, food residues, polystyrene labels, non-magnetic foil, and ceramics. Although the constituents of glass are relatively inert, the addition of common contaminants to cullet influences the chemical characteristics of the overall glass feedstock stream. In addition, the level of found in glass feedstocks varies due to differences in collection and sorting techniques. Types of organic and inorganic compounds associated with these contaminants may include metals, phthalates, organic acids, various hydrocarbons and waxes, resins, starches, glues, casein, asphalt emulsions, cellulose derivatives, and dyes.

If used as a construction aggregate, cullet will be in contact with native soils, and may be exposed to surface water and ground water. Contact with these elements may increase the potential for leaching and migration of organic and inorganic compounds. Leachable organic compounds such as sugars, starches or proteins from food residue may also induce bacterial growth in soil or water. The proposed chemical testing program is designed to assess the:

- Organic and inorganic chemical composition,
- Potential for contaminant leachability,
- Potential for bacterial growth.

The results of this testing program will be used to demonstrate the environmental suitability of the material for use as construction aggregate to federal, state and local regulatory communities.

3.1 PREVIOUS TEST DATA

Only limited chemical test data is available for recycled glass feedstocks. Clean Washington Center has provided Dames & Moore analytical results from cullet collected from various sources in the state of Washington. These sources included mixed-color (screen and unscreened), green, flint, and amber cullets. Test results are summarized in Table 3.1.

Toxicity characterization leaching procedure (TCLP) for metals was performed on all samples. TCLP indicates the potential leachability of constituents from a material. The results are generally used to determine if the material can be disposed of in a landfill with or without pretreatment. Test results are compared to a constituent's regulatory limit (based on 40 CFR Part 261). Although the TCLP tests have specific application in landfills, the conditions of the test are most likely not representative of those found in other soil structures such as embankments.

The TCLP results for all samples indicate that all metals, except lead, occurred at concentrations below the regulatory limit. Lead concentrations for several samples were near or above the regulatory limit of 5 parts per million (ppm or mg/l) in the unscreened mixed-color and green samples. TCLP lead levels in the screened mixed-color and the flint samples were detected but were below the regulatory limit. No lead was detected in the amber samples. These preliminary results indicate that lead is positively associated with green, flint, and mixed-color cullets.
TABLE 3.1
PREVIOUS ANALYTICAL DATA
FROM GLASS FEEDSTOCK SOURCES

<table>
<thead>
<tr>
<th>GLASS SOURCE</th>
<th>GLASS CULLET TYPE*</th>
<th>ANALYSIS</th>
<th>No.</th>
<th>RESULTS**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seattle</td>
<td>Mixed Color</td>
<td>TCLP Metals</td>
<td>12</td>
<td>TCLP lead concentrations in 2 samples: 18 ppm and 11 ppm.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TCLP Metals</td>
<td>10</td>
<td>TCLP lead concentrations in 10 samples: 0.07 to 0.36 ppm.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TCLP Organics</td>
<td>2</td>
<td>None detected.</td>
</tr>
<tr>
<td>Bellingham</td>
<td>Mixed Color-Screened</td>
<td>TCLP Metals</td>
<td>10</td>
<td>TCLP lead concentrations ranged from 0.13 ppm to 3.7 ppm.</td>
</tr>
<tr>
<td>Burlington</td>
<td>Green</td>
<td>TCLP Metals</td>
<td>1</td>
<td>TCLP lead concentration: 14.7 ppm.</td>
</tr>
<tr>
<td>Bellingham</td>
<td>Flint</td>
<td>TCLP Metals</td>
<td>1</td>
<td>TCLP lead concentration: 10.5 ppm.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Semi-Volatile</td>
<td>1</td>
<td>Phthalates: 1.2 ppm to 4.2 ppm.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organics</td>
<td></td>
<td>All metals concentrations below regulatory limits.</td>
</tr>
<tr>
<td>Burlington</td>
<td></td>
<td>Semi-Volatile</td>
<td>1</td>
<td>Phthalates 91 ppm to 199 ppm.</td>
</tr>
<tr>
<td></td>
<td>Amber</td>
<td>TCLP Metals</td>
<td>1</td>
<td>All metals concentrations below regulatory limits.</td>
</tr>
</tbody>
</table>

* Cullet samples were not screened before analysis.
** Regulatory TCLP limit for lead is 5 ppm.

The results also indicate variability in the frequency and concentration of TCLP lead. For example, the TCLP lead content of 12 unscreened mixed-color samples varied from 0.07 to 18 ppm. In addition, only one out of two flint samples had detectable lead (4.6 ppm). The TCLP lead concentration was most consistent in the two green cullet samples.

At this time, it is believed that the presence of lead in cullet is associated with the lead foil wrappers on wine bottles in various cullet feedstocks - principally in green cullet and to a lesser degree in flint cullet. This accords with the experience of bottle manufacturers who see high levels of lead in green furnaces and moderate levels in flint furnaces.

An analysis of TCLP organic compounds was conducted on two mixed-color samples. None of these compounds were detected, suggesting that organic compounds in cullet have a low leachability potential.
The semi-volatile organic results of two flint samples indicate the presence of phthalate compounds - the biodegradation products of plastics. Phthalate concentrations ranged from 1.2 ppm to 199 ppm, suggesting that phthalate levels are variable and are a function of the plastic debris level in the cullet feedstock.

In summary, the results suggest that variability exists in both the incidence and concentration of lead and phthalates in the cullet samples. This variability is thought to be attributed to whether the sample is screened for debris prior to analysis, the color of the cullet, and the sorting and collection procedure for each source. The results suggest that lead contamination may be of primary concern in the evaluation of potential glass cullet applications.

3.2 ENVIRONMENTAL TESTING

The environmental testing program includes two components that will be conducted simultaneously. The first component includes evaluating the incidence of lead contamination in different feedstocks, and the identification of potential lead source(s). The second component includes an assessment of the organic and inorganic chemical characterization and the potential for contaminant leachability over time. The chemical testing program includes an assessment of the potential for bacterial growth. A description of both components follows.

3.2.1 Lead Evaluation

The incidence of lead will be evaluated by analyzing a statistically representative number of samples to provide a mean, standard deviation, and 90th percentile upper confidence level for total lead. Prior to sample preparation for analysis, each feedstock will be crushed using a jaw crusher to a specified gradation. This gradation will be further described in the Task 2 report.

Browning-Ferris Industries (BFI), a study co-sponsor, will analyze ten discrete samples from each source (250 analyses) for total lead using EPA Method 3010/6010 plus samples from bottle plant scrap. BFI will then select twenty percent of the feedstock sources which contain total lead levels greater than 100 ppm, and also twenty percent of the feedstock sources containing total lead levels less than 100 ppm. BFI will analyze these samples for leachable, TCLP lead using EPA Method 1311/6010. The intent of TCLP analysis on these sample types is to determine the correlation between total and leachable (TCLP) lead concentrations.

The rationale for selecting 100 ppm as the action criteria is based on the theoretical assumption that at 100 ppm total lead, the TCLP lead concentration will exceed the regulatory limit of 5 ppm (for TCLP lead). Conversely, a sample having a total lead concentration less than 100 ppm would be expected to be below the TCLP lead regulatory limit.

BFI will submit the total and TCLP lead results to Dames & Moore for evaluation. These results will be evaluated in conjunction with the physical contaminant testing results to identify potential sources of lead contamination. Since TCLP analysis is designed for determining leachability associated with landfill disposal, TCLP lead results will be subject to interpretation for the evaluation of the environmental suitability of the cullet samples for use in engineering applications.
3.2.2 Chemical Characterization

The physical debris testing program will identify three feedstocks each that contain "high" and "low" debris levels. The six sources will be evaluated in the environmental testing program. Duplicate analysis will be performed on each feedstock source. The rationale for selecting "high" and "low" sources assumes that inorganic and organic compound concentration levels are directly related to the amount of debris present in the glass feedstock source. We assume that a "high" debris source will correlate to elevated inorganic and inorganic sample concentrations, and a "low" debris source will correlate to low concentrations of organic and inorganics.

The analyses include pH, total metals (antimony, arsenic, beryllium, cadmium, chromium, copper, mercury, nickel, selenium, thallium, zinc, and cobalt), semi-volatile organics, total organic carbon, and loss of ignition. The results will be used to assess the organic and inorganic chemical composition, and the potential for bacterial growth. Volatile compound analyses were not included in the testing program because we have assumed that these compounds would be removed during handling and crushing activities. Previous TCLP volatile organic analysis of mixed-color cullet supports this assumption. The proposed testing program and number of sample analyses are listed in Table 3.2.

<table>
<thead>
<tr>
<th>Chemical Analysis</th>
<th>EPA Test Method</th>
<th>&quot;High&quot; Debris Level(1)</th>
<th>&quot;Low&quot; Debris Level(2)</th>
<th>Total Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>9045</td>
<td>6</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Priority Pollutant Total Metals (and Cobalt)</td>
<td>6000 and 7000 Series</td>
<td>6</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Semi-Volatile Organics</td>
<td>8270</td>
<td>6</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Total Organic Carbon</td>
<td>ASA 90.3</td>
<td>6</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Loss of Ignition</td>
<td>ASTM 2974</td>
<td>6</td>
<td>6</td>
<td>12</td>
</tr>
</tbody>
</table>

(1) Three feedstocks with highest physical debris level (2 samples/feedstock)
(2) Three feedstocks with lowest physical debris level (2 samples/feedstock)

The analyses will be performed using Environmental Protection Agency (EPA) and Society of Agronomy methodologies. The acid or basic nature of the cullet and the potential to promote contaminant leachability will be determined by pH analysis. Total metals analysis will provide information regarding the inorganic chemical composition of the feedstock. Semi-volatile analysis will be performed using gas chromatography/mass spectrometry methods. This analysis was chosen because it encompasses the identification of a wide variety of organic compounds that may be present in the cullet contaminant. Approximately 233 organic compounds will be analyzed by the gas chromatograph, with the identification of approximately 20 additional organic compounds using the mass spectra library matching technique.
The potential for bacterial growth or regrowth from food residues or other biological contaminants present in the cullet may result in viable bacteria surviving the collection, sorting, crushing, and screening processes and utilizing existing nutrients in the cullet to sustain growth. Total organic carbon analysis will be performed to determine the potential for bacterial growth. The ash content and organic matter content will be evaluated using a loss of ignition analysis.

3.2.3 Contaminant Leaching Over Time

A sequential batch extraction of cullet with water will also be conducted on one "high" and one "low" contaminant feedstock source in accordance with ASTM D 4793 to assess the potential for contaminant leaching over time. This method involves the shaking of a known weight of sample with water and the separation of the aqueous phase. The procedure is conducted ten times in sequence over a ten-day period on the same sample and generates ten aqueous solutions. The composition of the aqueous solutions may be used to estimate the release of certain constituents of the glass feedstock source under laboratory conditions. This method is not intended to provide analytical results that are representative of actual leachate produced from glass cullet in the field under engineering design applications; however, the results will provide a general indication of potential waste constituents that may be generated sequentially over time from the cullet. The analytical program for the sequential batch extraction aqueous samples is listed in Table 3.3. The analyses will be performed using EPA and "Standard Methods for the Examination of Water and Wastewater" methodologies.

<table>
<thead>
<tr>
<th>Chemical Analysis</th>
<th>Test Method</th>
<th>Number of Samples High*</th>
<th>Total Number of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>SM 9040</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Specific Conductivity</td>
<td>EPA 9050</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Priority Pollutant Total Metals</td>
<td>EPA Methods 6000/7000</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Total Organic Carbon</td>
<td>SM 5310C</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Biological Oxygen Demand</td>
<td>SM 5210B</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Chemical Oxygen Demand</td>
<td>SM 5220D</td>
<td>20</td>
<td>30</td>
</tr>
</tbody>
</table>

* Includes a duplicate analysis

SM - Standard Methods, 18th Edition.

ASTM D 4793 method has been evaluated to determine its applicability to certain inorganic compounds; however, it has not been evaluated for its applicability to organic substances and volatile matter. The agitation rate
specified in the test method may significantly influence the dissolution and volatilization of some organic compounds which may skew the results for organic wastes; therefore, only a limited number of organic analyses were included in the leachate analysis. Although it is recognized that phthalates have been identified as the primary organic substance identified in cullet based on information provided by Clean Washington Center, the analyses for phthalates and other volatile and semi-volatile organic compounds (EPA Methods 8240 and 8270) were not included in the test due to the high degree of uncertainty associated with the analytical results. A duplicate sample of the high contaminant level source will be analyzed to evaluate potential variability of the testing procedure.

**pH**

The acidic or basic nature of the leachate over time will be evaluated using pH analysis. We anticipate that the pH of the leachate will be influenced by cullet size and agitation of the cullet sample over time, and may increase the potential leachability of metals over time.

**Specific Conductivity**

Specific conductivity analysis will be used to determine the electrical conductivity of the leachate over time. Electrical conductivity may be used as an indicator of the concentration of dissolved metals and/or other inorganic ionic species present in the leachate.

**Total Metals**

Total metals analysis will provide information regarding the inorganic chemical composition of the sequential leachate solution over time with different contaminant levels.

**Bacterial Growth**

The potential for bacterial growth in the leachate produced from the cullet will be evaluated using biological oxygen demand (BOD), chemical oxygen demand (COD) and total organic carbon analysis.

### 3.3 EVALUATION OF ANALYTICAL RESULTS

A statistical evaluation of the lead analysis will be presented in the Task 2 report, and will include the mean, standard deviation, and 90th percentile upper confidence limit. The results of the total lead and TCLP lead will be evaluated to determine the correlation between total lead and leachable lead concentrations.

The results of the physical contaminant testing program will be evaluated with the chemical test results of the cullet samples to correlate physical contaminants (such as bottle caps and foil wrappers) with the chemical test results. The collection and storing procedures associated with the cullet samples analyzed will also be evaluated to determine if correlation exists between the collection and sorting procedures, types of physical contaminants, and the chemical test results.

The results of the chemical testing program for each feedstock will be compared to federal regulatory contaminant limits to determine if the material contains chemical compounds of regulatory concern. The results
of each feedstock will also be evaluated and compared to determine the presence of organic and inorganic compounds and concentrations, variability and similarities.

The results of the sequential batch extraction will be evaluated to compare the chemical constituents of the leachate from a "high" and "low" contaminant level feedstock source. The results will also be used to assess the potential concentrations of these chemical constituents in the leachate over time.
4.0 ENGINEERING SUITABILITY EVALUATION

A major barrier limiting the use of cullet as a construction aggregate is the lack of test data on its physical and engineering performance properties. The proposed engineering suitability test program identifies the properties relevant to construction aggregate applications and the standard test methods that will be used to obtain these properties.

4.1 CONSTRUCTION AGGREGATE APPLICATIONS

Table 4.1 relates potential applications to the properties relevant to the performance of aggregate in these applications. Potential aggregate applications can be categorized as follows:

- General Construction - Such as foundation or retaining wall backfill.
- Roadway Construction - Pavement sections, shoulders and embankments.
- Utility Construction - Pipe bedding and trench backfill.
- Drainage - Such as drainage blankets, french drains, septic fields and leachate treatment.
- Miscellaneous - Such as daily landfill cover, sand blasting, underground storage tank fill, and lightweight aggregate.

Classification properties are those properties which help identify a material and include specific gravity, relative density, grain size (gradation), grain shape (workability), and durability. Engineering properties are those used for engineering design. These are dependent properties, that is, properties that change according to the material state of the cullet, and include compaction, permeability, filtration capacity, thermal conductivity, and shear strength. Table 4.1 indicates that specific gravity, gradation, workability, and compaction are relevant for most applications. These properties, their relevance to specific applications, and the test methods by which they are measured are described more fully below.

Specifications

There are many aggregate specifications which have national rather than local character. For example, ASTM and AASHTO have standard specifications for road materials. Such specifications must necessarily be broad. Hence they should be regarded primarily as guides rather than as absolute standards. We have included the available national specifications for this purpose (Appendix B). Individual state specifications are based on variations such as aggregate source and climate. Therefore cullet may be acceptable for applications in some states while not in others. We have included a summary of pertinent state specifications from co-sponsor states which may apply to potential cullet applications (Appendix B). We are preparing a matrix showing state specification based on application. We are also conducting an analysis of these specifications to determine the property limits on which to base the test results. For example, WSDOT specification 9-03.9(3), Crushed surfacing, has a L.A. wear specification (35% max. at 500 rev.) as well as a gradation specification.
<table>
<thead>
<tr>
<th>APPLICATIONS</th>
<th>CLASSIFICATION PROPERTIES</th>
<th>ENGINEERING PROPERTIES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Specific Gravity</td>
<td>Gradation</td>
</tr>
<tr>
<td>GENERAL BACKFILL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-loaded Conditions</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Fluctuating Loads</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Heavy, stationary loads</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>ROADWAYS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base, Subbase, Subgrade</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Embankments</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>UTILITIES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pipe Trench Bedding &amp; Backfill</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Conduit Bedding and Backfill</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Fiber Optic Cable Bedding &amp; Backfill</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>DRAINAGE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foundation Drainage</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Drainage Blanket</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>French Drains</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Septic Fields</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Leachate Treatment</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>MISCELLANEOUS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landfill Cover</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Sandblasting</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Underground Tank Fill</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Lightweight Aggregate</td>
<td>●</td>
<td></td>
</tr>
</tbody>
</table>

DAMES & MOORE
## TABLE 4.2
**Test Matrix by Contamination Level***

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>TEST TYPE</th>
<th>TEST METHODS &amp; SPECIAL CONDITIONS</th>
<th>Contamination Level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>Specific Gravity</td>
<td>ASTM D 854 (fine aggregate). ASTM C 127 (coarse aggregate).</td>
<td><img src="" alt=" " /></td>
</tr>
<tr>
<td>Relative Density</td>
<td>Maximum-Minimum Index</td>
<td>ASTM D 4253 (maximum density). ASTM D 4254 (minimum density).</td>
<td><img src="" alt=" " /></td>
</tr>
<tr>
<td>Grain Size Distribution</td>
<td>Sieve Analysis</td>
<td>ASTM D 422. Test all noted samples; also test samples after compaction and triaxial shear testing.</td>
<td><img src="" alt=" " /></td>
</tr>
<tr>
<td>Workability</td>
<td>Angularity Particle Shape</td>
<td>ASTM D 2488 Samples are classified by visual methods.</td>
<td><img src="" alt=" " /></td>
</tr>
<tr>
<td>Durability</td>
<td>L.A. Abrasion</td>
<td>ASTM C 131.</td>
<td><img src="" alt=" " /></td>
</tr>
<tr>
<td>Compaction</td>
<td>Light Impact</td>
<td>Standard Proctor ASTM D 698.</td>
<td><img src="" alt=" " /></td>
</tr>
<tr>
<td></td>
<td>Heavy Impact</td>
<td>Modified Proctor ASTM D 1557.</td>
<td><img src="" alt=" " /></td>
</tr>
<tr>
<td></td>
<td>Semi-Vibratory</td>
<td>WSDOT 606.</td>
<td><img src="" alt=" " /></td>
</tr>
<tr>
<td></td>
<td>Nuclear Density Gage</td>
<td>Manufacturer’s recommended procedure. Test samples placed in a 18 x 12 x 12 inch-plywood box.</td>
<td><img src="" alt=" " /></td>
</tr>
<tr>
<td>Permeability</td>
<td>Constant Head Permeability</td>
<td>ASTM D 2434. One sample each compacted to 90% and 95% of ASTM D 698 maximum density.</td>
<td><img src="" alt=" " /></td>
</tr>
<tr>
<td>Filtration Capacity</td>
<td>None (see § 4.4.3)</td>
<td>AWWA Standard B100.</td>
<td><img src="" alt=" " /></td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>Thermal Conductivity</td>
<td>ASTM C 518 Aggregate mix %: 50 &amp; 100, Cullet size: %-inch minus, Contamination level: <em>low</em> &amp; <em>high</em>.</td>
<td><img src="" alt=" " /></td>
</tr>
<tr>
<td>Shear Strength</td>
<td>Direct Shear</td>
<td>ASTM D 3080 Normal loads = 500, 1,000, 2,000 psf. Samples compacted to 90% of ASTM D 1557 maximum density. Samples compacted to 95% of WSDOT 606 maximum density.</td>
<td><img src="" alt=" " /></td>
</tr>
<tr>
<td></td>
<td>Triaxial Shear</td>
<td>Consolidated, drained with volume change measurements; Confining Pressures = 500, 1,000, 2,000 psf; Samples compacted to 95% of the ASTM D 4253 or WSDOT 606 maximum density.</td>
<td><img src="" alt=" " /></td>
</tr>
<tr>
<td></td>
<td>California Bearing Ratio</td>
<td>Samples compacted to 95% of ASTM D 1557 maximum density. Samples compacted to 95% of WSDOT 606 maximum density.</td>
<td><img src="" alt=" " /></td>
</tr>
<tr>
<td></td>
<td>Resistance <em>R</em>-Value</td>
<td>WSDOT 611 Test method.</td>
<td><img src="" alt=" " /></td>
</tr>
<tr>
<td></td>
<td>Resilient Modulus</td>
<td>Cyclic Triaxial AASHTO T 294</td>
<td><img src="" alt=" " /></td>
</tr>
</tbody>
</table>

*Other test variables: Mix percentage: 15, 50 and 100% Cullet Size: 1/4" minus and 3/4" minus
Roadway Application Example

The following paragraph is a detailed description relating roadway base and subbase applications to the relevant material properties and test methods.

Aggregates are used in roadway bases and subbases for flexible and rigid pavements. The purpose of a base layer for a rigid pavement, may be to prevent pumping, to cover a frost susceptible material, or to improve the general drainage characteristics of the section. Load-carrying capacity in this case is not a primary consideration in choosing a material - rather grain size distribution (gradation) is. In the case of bases and subbases for flexible pavements, however, load-carrying capacity is the primary consideration in selecting materials. Gradation plays an important role, but in addition, the material used in a layer of the flexible-pavement system must reinforce those layers beneath it and must be capable of withstanding and transmitting the loads it will be subjected to. Strength tests such as the triaxial compression test, California bearing ratio test (CBR), and the resistance "R"-Value test are commonly used to evaluate such materials. The resilient modulus (cyclic triaxial) test, which determines the dynamic stiffness modulus of the material, is also used.

4.2 TEST PROGRAM VARIABLES

Testing for engineering suitability of cullet for construction aggregate applications will address the three independent variables that can be controlled by affordable processing techniques.

- Physical contamination (debris) level - "high" and "low".
- Cullet size - 3/4 and 1/4-inch minus.
- Aggregate mix - 15, 50 and 100 percent cullet.

The debris level is based on the amount of non-glass particles such as plastic, paper and metal. It is expected that debris level of certain constituents will affect most engineering properties. The presence of certain substances in aggregates is undesirable. Specifications for many aggregates normally contain a section in which the deleterious materials are named and a limit placed on the amount of each that is allowable. For a discussion of the determination of physical debris levels, refer to section 2.3.

The 3/4 and 1/4-inch sizes relate to standard classifications for fine gravelly and sandy soils, respectively. These size ranges generally make up most construction aggregate, and are also gradations commonly produced by commercial crushing operations. Fine gravel is generally classified for engineering purposes (ASTM D 2488) as material which passes a 3/4-inch sieve and is retained on a No. 4 sieve (4.75 mm, .187 in.). Sand size particles are those which pass a No. 4 sieve and are retained on a No. 200 sieve (.075 mm). It is anticipated that cullet particle sizes greater than 1/4-inch will have a plate-like shape which will break down during compaction and under applied loads. Cullet particle sizes less than 1/4-inch are expected to have more equi-dimensional shapes. The two size ranges should provide insight into the effect of particle crushing.

The aggregate mix is defined as percent cullet to natural aggregate by weight. By choosing the low, medium and high percentages, the test results will allow the evaluation of the allowable usage of the cullet.
A matrix is presented for each major sample variable which relates the property with the test method and specific test conditions. Table 4.2 presents the debris level matrix, Table 4.3 presents the cullet size matrix, and Table 4.4 presents the aggregate mix matrix.

The majority of the tests will encompass all three test variables. For example, specific gravity, compaction, nuclear gage density, and permeability tests will be conducted on twelve sample specimens made of three aggregate mixes, two cullet sizes, and two debris levels. Other tests such as L.A. abrasion, thermal conductivity, cyclic triaxial, resistance R-value, California bearing ratio, direct shear, and triaxial shear are conducted on specimens of selected variables. Table 4.5 presents the estimated number of each test; test numbers shown include those used for statistical analysis (Section 4.7).
<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>TEST TYPE</th>
<th>TEST METHODS &amp; SPECIAL CONDITIONS</th>
<th>CULLET SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>Specific Gravity</td>
<td>ASTM D 854 (fine aggregate).</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASTM C 127 (coarse aggregate).</td>
<td>•</td>
</tr>
<tr>
<td>Relative Density</td>
<td>Maximum-Minimum Index</td>
<td>ASTM D 4253 (maximum density).</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASTM D 4254 (minimum density).</td>
<td>•</td>
</tr>
<tr>
<td>Grain Size Distribution</td>
<td>Sieve Analysis</td>
<td>ASTM D 422. Test all noted samples; also test samples after compaction and triaxial strength testing.</td>
<td>•</td>
</tr>
<tr>
<td>Workability</td>
<td>Angularity</td>
<td>ASTM D 2488. Samples are classified by visual methods.</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Particle Shape</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Durability</td>
<td>L.A. Abrasion</td>
<td>ASTM C 131.</td>
<td>•</td>
</tr>
<tr>
<td>Compaction</td>
<td>Light Impact</td>
<td>Standard Proctor ASTM D 698.</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Heavy Impact</td>
<td>Modified Proctor ASTM D 1557.</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Semi-Vibratory</td>
<td>WSDOT 606.</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Nuclear Density Gage</td>
<td>Manufacturer's recommended procedure. Test sample placed in a 18 x 12 x 12-inch plywood box.</td>
<td>•</td>
</tr>
<tr>
<td>Permeability</td>
<td>Constant Head</td>
<td>One sample each compacted to 90% and 95% of ASTM D 698 maximum density.</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Permeability</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Filtration Capacity</td>
<td>None (see § 4.4.3)</td>
<td>AWWA Standard B100.</td>
<td>•</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>Thermal Conductivity</td>
<td>ASTM C 518 Aggregate mix % : 50 &amp; 100, Cullet size: %-inch minus, Contamination level: &quot;low&quot; &amp; &quot;high&quot;.</td>
<td>•</td>
</tr>
<tr>
<td>Shear Strength</td>
<td>Direct Shear</td>
<td>ASTM D 3080 Normal loads = 500, 1,000, 2,000 psf.</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Samples compacted to 90% of ASTM D 1557 maximum density.</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Samples compacted to 95% of WSDOT 606 maximum density.</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Triaxial Shear</td>
<td>Consolidated, drained with volume change measurements; Confining Pressures = 500, 1,000, 2,000 psf; Samples compacted to 95% of the ASTM D 4253 or WSDOT 606 maximum density.</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>California Bearing Ratio</td>
<td>Samples compacted to 95% of ASTM D 1557 maximum density.</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Resistance &quot;R&quot;-Value</td>
<td>WSDOT 611 Test method.</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Resilient Modulus</td>
<td>Cyclic Triaxial AASHTO T 294</td>
<td>•</td>
</tr>
</tbody>
</table>

*Other test variables: Mix percentage: 15, 50 and 100%
Contamination level: "low" and "high"
### TABLE 4.4
Test Matrix by Aggregate Mix Percentage

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>TEST TYPE</th>
<th>TEST METHODS &amp; SPECIAL CONDITIONS</th>
<th>Mix Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>Specific Gravity</td>
<td>ASTM D 854 (fine aggregate), ASTM C 127 (coarse aggregate).</td>
<td>● ● ●</td>
</tr>
<tr>
<td>Relative Density</td>
<td>Maximum-Minimum Index</td>
<td>ASTM D 4253 (maximum density), ASTM D 4254 (minimum density).</td>
<td>● ● ●</td>
</tr>
<tr>
<td>Grain Size Distribution</td>
<td>Sieve Analysis</td>
<td>ASTM D 422. Test all noted samples; also test samples after compaction and triaxial shear testing.</td>
<td>● ● ●</td>
</tr>
<tr>
<td>Workability</td>
<td>Angularity, Particle Shape</td>
<td>ASTM D 2488. Samples are classified by visually.</td>
<td>● ● ●</td>
</tr>
<tr>
<td>Durability</td>
<td>L.A. Abrasion</td>
<td>ASTM C 131.</td>
<td>● ● ●</td>
</tr>
<tr>
<td></td>
<td>Heavy Impact</td>
<td>Modified Proctor ASTM D 1557.</td>
<td>● ● ●</td>
</tr>
<tr>
<td></td>
<td>Semi-Vibratory</td>
<td>WSDOT 606.</td>
<td>● ● ●</td>
</tr>
<tr>
<td></td>
<td>Nuclear Density Gage</td>
<td>Manufacturer’s recommended procedure. Test sample placed in a 18 x 12 x 12-inch plywood box.</td>
<td>● ● ●</td>
</tr>
<tr>
<td>Permeability</td>
<td>Constant Head Permeability</td>
<td>ASTM D 2434. One sample each compacted to 90% and 95% of ASTM D 698 maximum density.</td>
<td>● ● ●</td>
</tr>
<tr>
<td></td>
<td>Thermal Conductivity</td>
<td>ASTM C 518. Aggregate mix %: 50 &amp; 100, Cullet size: %-inch minus, Contamination level: “low” &amp; “high”.</td>
<td>● ● ●</td>
</tr>
<tr>
<td>Shear Strength</td>
<td>Direct Shear</td>
<td>ASTM D 3080 Normal loads = 500, 1,000, 2,000 psf. Samples compacted to 90% of ASTM D 1557 maximum density.</td>
<td>● ● ●</td>
</tr>
<tr>
<td></td>
<td>Triaxial Shear</td>
<td>Consolidated, drained with volume change measurements; Confining Pressures = 500, 1,000, 2,000 psf; Samples compacted to 95% of the ASTM D 4253 or WSDOT 606 maximum density.</td>
<td>● ● ●</td>
</tr>
<tr>
<td></td>
<td>California Bearing Ratio</td>
<td>Samples compacted to 95% of ASTM D 1557 maximum density.</td>
<td>● ● ●</td>
</tr>
<tr>
<td></td>
<td>Resistance &quot;R&quot;-Value</td>
<td>WSDOT 611 Test method.</td>
<td>● ● ●</td>
</tr>
<tr>
<td></td>
<td>Resilient Modulus</td>
<td>Cyclic Triaxial AASHTO T 294.</td>
<td>● ● ●</td>
</tr>
</tbody>
</table>

*Other test variables: Cullet size: 1/4 and 3/4-inch minus
Contamination level: "low" and "high"*
<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>TEST TYPE</th>
<th>TEST METHODS &amp; SPECIAL CONDITIONS</th>
<th>NUMBER OF TESTS</th>
</tr>
</thead>
</table>
| Specific Gravity          | Specific Gravity            | ASTM D 854 (fine aggregate).  
ASTM C 127 (coarse aggregate).                                                                 | 14              |
| Relative Density          | Maximum-  
Minimum Index       | ASTM D 4253 (maximum density).  
ASTM D 4254 (minimum density).                                                                 | 14              |
| Grain Size Distribution   | Sieve Analysis              | ASTM D 422. Test all noted samples; also test samples after compaction and triaxial shear testing. | 54              |
| Workability               | Angularity  
Particle Shape     | ASTM D 2488. Samples are classified by visual methods.                                             | 12              |
| Durability                | L.A. Abrasion               | ASTM C 131.                                                                                       | 4               |
| Compaction                | Light Impact                | Standard Proctor ASTM D 698.                                                                     | 14              |
|                           | Heavy Impact                | Modified Proctor ASTM D 1557.                                                                    | 16              |
|                           | Semi-Vibratory              | WSDOT 606.                                                                                       | 16              |
| Permeability              | Constant Head  
Permeability | ASTM D 2434. One sample each compacted to 90% and 95% of ASTM D 698 maximum density.                | 24              |
| Filtration Capacity       | None (see § 4.4.3)          | AWWA Standard B100                                                                               | ---             |
| Thermal Conductivity      | Thermal Conductivity        | ASTM C 518. Aggregate mix % : 50 & 100, Cullet size: %-inch minus,  
Contamination level: "low" & "high".                                                               | 4               |
| Shear Strength            | Direct Shear                | ASTM D 3080 Normal loads = 500, 1,000, 2,000 psf.                                                 | 6               |
|                           |                             | Samples compacted to 90% of ASTM D 1557 maximum density.                                           |                 |
|                           | Triaxial Shear              | Consolidated, drained with volume change measurements;  
Confining Pressures = 500, 1,000, 2,000 psf;  
Samples compacted to 95% of the ASTM D 4253 or WSDOT 606 maximum density. | 4               |
|                           | California Bearing Ratio    | Samples compacted to 95% of ASTM D 1557 maximum density.                                           | 4               |
|                           | Resistance "R" Value        | WSDOT 611 Test method.                                                                           | 5               |
|                           | Resilient Modulus           | Cyclic Triaxial AASHTO T 294                                                                      | 5               |

*Test Variables:  
Mix Percentage: 15, 50 and 100%  
Cullet Size: 1/4" minus and 3/4" minus  
Contamination level: "low" and "high"
4.3 CLASSIFICATION PROPERTIES

As mentioned above classification properties are those properties which help identify a material and are independent of the material state. For any project, it is necessary to know some of the classification properties in order to assess the in-place performance of the material. Descriptions of the classification properties which will be investigated are presented below.

Specific Gravity

Specific gravity, a measure of a material's density, is a widely used parameter in establishing the density-volume relationship of a soil mass. It is used to determine the amount of voids in aggregate. Typical values of specific gravity for natural aggregate are 2.65 to 2.68 (Bowles, 1988), and typical values for commercial glass are 2.49 to 2.51 (BCIT, 1991; HWA, 1992). Since density relates directly to engineering properties such as compaction and shear strength, specific gravity is an important baseline property to test.

We propose to conduct twelve specific gravity tests using standard method ASTM D 854 for particles smaller than 4.75 millimeters (No. 4 sieve) and standard method ASTM C 127 for particles larger than No. 4 sieve. The tests will be conducted on specimens made of three aggregate mixes, two cullet sizes, and two contamination levels.

Relative Density

Relative density is a measure of a soil mass's density relative to its possible range of density. For cohesionless, granular soils such as cullet, the possible range of density is determined by the maximum density and minimum density index tests. The standard methods for determining these values are ASTM D 4253 (maximum density) and D 4254 (minimum density). The maximum and minimum index density results will be used to correlate with density determinations from compaction tests such as the Proctor and WSDOT 606 (see Section 4.4). The relative density procedure is a vibratory procedure which is not expected to create much crushing of the cullet particles. This is expected to produce different results than the Proctor compaction tests which may produce substantial crushing of the cullet particles. The tests will be conducted on specimens made of three aggregate mixes, two cullet sizes, and two contamination levels.

Grain Size Distribution (Gradation)

One of the important classifications of aggregates is based on size. The gradation of a material can affect its engineering performance in many ways. For example, well-graded materials can generally be compacted to a denser state, thus will have a higher strength but lower permeability than poorly-graded materials.\(^2\) Also, the most common criteria for establishing the frost susceptibility of soils is based on particle size.

Many applications such as roadway and engineering fill use gradation as the primary or sole criteria for acceptance. Specifications dictate the distribution of particle sizes for a particular application. For example, the

\(^2\)A well-graded material has a good representation of particle sizes over a wide range. A poorly-graded one has an excess or deficiency of certain grain sizes, or has mostly the same particle size.
specified gradation for a road aggregate varies according to the purpose for which it is to be used (subbase, base, etc.). Gradation will be one of the major factors in determining the suitability of cullet for use as a construction material.

Aggregate (particle sizes greater than No. 200 sieve, .075 mm) gradation is obtained by sieve analysis. The test is conducted by shaking the aggregate through a stack of Standard U.S. sieves with specified openings. The gradation is established by measuring the portions of material retained on each sieve. Sieve analyses for this testing program will be conducted according to standard test method ASTM D 422. Approximately fifty sieve analyses will be conducted. This number includes tests to evaluate compaction characteristics and crushing potential.

Workability

Aggregate workability - the ease with which an aggregate is handled and compacted - is significantly affected by the angularity and shape of the particles. Angularity is a qualitative assessment of the sharpness of edges and corners of a particle. Shape is a qualitative assessment of the flatness and elongation of a particle. These properties will be especially important for cullet. For this testing program, particle angularity and shape will be determined by standard visual classification methods detailed in ASTM D 2488.

Durability (Abrasion Resistance - Hardness)

The qualities of a material known as hardness and toughness have historically been regarded as essential to good aggregate for roadways. The properties of hardness and toughness are closely related. Hardness is made up, in part, by abrasion resistance and toughness is generally understood to mean the power possessed by a material to resist fracture under impact.

Crushing and grinding of cullet are expected to occur during mixing, transportation, placement and compaction. To evaluate the durability of cullet and cullet-aggregate mixtures, we propose to conduct Los Angeles (L.A.) abrasion tests using standard method ASTM C 131. At present, most highway agencies specify a limit on abrasion resistance of aggregate based on the Los Angeles test. The test results, along with those of the sieve analysis will provide insight into the suitability of the material for roadway base course, fill under fluctuating loads, and sand blasting.

We propose to conduct four tests. The specimens will be made of separate samples having a 15 and 100 percent cullet content, both with 1/4-inch minus cullet size, and "low" contamination level. The 15 and 100 percent mixtures were chosen to give a range of results for interpretation. In addition, the performance of the 100 percent mixture will assist in evaluating sand blasting capability. The 1/4-inch minus cullet size and "low" contamination level was selected because cullet with "high" contamination and large size (thus high crush potential) will be unacceptable for applications relating to roadways and fill under fluctuating loads.

Soundness

The soundness of aggregates, or their resistance to the forces of weathering, is another important consideration in the selection of a material for roadway construction. The primary exposure is freezing and thawing. Most aggregate specifications from northern states included a provision for soundness. The most common soundness
requirement for aggregates is based on sodium or magnesium sulfate (ASTM C 88). Since glass is an inert substance composed almost entirely of silica, these minerals will not react with the glass. As such, we do not expect that soundness is a property which can be measured for cullet. It is more appropriate to use the L.A. abrasion test to determine the degradation properties of cullet (see Section 4.3.5).

4.4 ENGINEERING PROPERTIES

As stated previously, engineering properties are those used for engineering design. Engineering properties are dependent properties - dependent on the material state of the cullet. The engineering properties to be investigated in this test program are described below.

Compaction

The compaction characteristics of engineering fill include the relationship of the density and moisture content, the effect of compaction method on this relationship, the potential of gradation change during compaction process, and the sensitivity of the material to weather (moisture change) conditions. Since almost all engineering fills require compaction during placement, the characteristics are relevant to almost all potential cullet applications. By testing materials of different constituents with different compaction methods, the compaction characteristics of cullet and cullet mixtures can be evaluated. Compaction test results and curves will be used to develop a data base for correlation with other materials. The results of the compaction densities will also be compared with the densities from the relative density tests. Through a common parameter - dry density - other engineering properties such as shear strength, can be correlated, and the sensitivity of these properties to the material constituents and compaction methods can be studied. Three compaction test methods are proposed:

- ASTM D 698, the standard Proctor test.
- ASTM D 1557, the modified Proctor test.
- Washington Department of Transportation (WSDOT) test method 606.

The Proctor tests are widely used for field control of fill materials. Typically, engineers will specify the materials be compacted to a state such that the field density exceeds a specific percentage of the maximum density obtained from the Proctor tests. Since the engineering properties of the fill materials are related to their density, by controlling this parameter in the field, the engineering performance (strength for instance) of the materials are ensured.

ASTM D 698 results represent the effects of light compaction equipment. It uses impact compaction, and the input energy produced in the laboratory is comparable to light field compaction equipment. The test results are typically used for the field control of unloaded or lightly loaded fill. ASTM D 1557 results represent heavy impact compaction conditions. Test input energy is comparable to heavy compaction equipment. The test results are used for the field control of heavily loaded conditions. WSDOT test method 606 is used for the field control of base course material for roadway construction. The test uses vibratory compaction and its effort and mechanism are comparable to vibratory compaction equipment.
In the Proctor test, a sample is compacted in a mold by impact of a steel hammer, weighing 5.5 and 10 pounds for the standard and modified tests, respectively. Field compaction equipment, on the other hand, does not use impact compaction. Generally, the difference in compaction modes between laboratory and field is not critical if the materials are granular, natural materials. However, when a material consists of fragile and angular particles such as cullet, the difference in compaction may be significant.

A previous study has found that the standard Proctor test created minor crushing of the cullet particles (Metro Testing Laboratory, 1991). We expect moderate to severe crushing using the modified Proctor test. The degree of crushing is expected to increase with increasing cullet content and particle size. The degree of change in gradation will be investigated by conducting a sieve analysis after each compaction test. The gradation change created by each compaction method will be determined.

We propose to produce 46 compaction curves. Each curve will be defined by four points. Of these 46 curves, 36 will be produced by varying test method (standard Proctor, modified Proctor, and WSDOT 606), mix percentage (15, 50, and 100% cullet with sandy gravel aggregate described in section 4.5), cullet size (1/4" minus and 3/4" minus), and contamination level (low and high). During the production of these 36 curves, an additional 6 curves will be produced for statistical analysis by running two replicate tests for each of the three test methods. Finally, four compaction curves will be produced using the modified Proctor test method with low contamination level cullet and crushed rock aggregate (see section 4.5) by varying the mix percentage (15 and 50% cullet) and cullet size (1/4" minus and 3/4" minus).

Compaction quality control of construction aggregates is usually achieved through control of the in-situ density. Nuclear density gages are commonly used to measure in-situ density. The standard test methods are: ASTM D 2922 for density, and ASTM D 3017 for moisture content. For cullet and cullet-aggregate mixtures, these test methods must be validated for the following reasons:

- The gages are typically calibrated for natural geologic materials which have a higher specific gravity than glass cullet.
- The gage measures moisture content of materials by utilizing chemically bonded hydrogen found in the water. Waste residue in the cullet may be a source of hydrogen atoms which may cause erroneous moisture reading, and thus incorrect density reading.

In order to validate the standard test methods, we propose to conduct the following sensitivity tests, as recommended by the gage manufacturer (Troxler). Cullet or a cullet-aggregate mixture of a known quantity and moisture content will be placed in a 18 x 12 x 12-inch plywood box. A nuclear density gage will then be used to take density and moisture content readings on the sample by Backscatter Method. The readings will be compared to the known density and moisture content of the sample. We will conduct at least 24 tests, and develop typical

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3 ASTM D 2922 requires a minimum depth of 9 inches for Backscatter Method Calibration.
error ranges for density and moisture measurements. These tests will be conducted on specimens made of three aggregate mixes, two cullet sizes, and two contamination levels. Some repetitive tests will be conducted to allow for a statistical analysis. An extension of this exercise is the development of correction factors to be used in field-testing of cullet with nuclear density gages. We anticipate that the correction factor will depend on the variables being investigated, but may possibly depend on other variables which will not be investigated, such as moisture content. In addition, such correction factors may be impractical to apply in the field due to their multi-variable dependency.

Permeability

The permeability or hydraulic conductivity of a fill material plays a decisive role in drainage applications. The rate of fluid flowing through a soil mass relates directly to its permeability. In hydrogeologic studies of natural and processed materials, permeability is usually the most important property. In engineering practice, the permeability of a fill material often plays a decisive role in material selection, particularly for applications related to drainage. For granular fill material, high permeability is usually more beneficial than low. The exception to that may be for leachate treatment where a specific range of permeability may be required.

The permeability of a granular material depends on its gradation and density. Generally, a well-graded material is less permeable due to its higher relative density. It is believed that permeability is a function of surface texture, which affects drag or friction between the fluid and particle surface. As a result, a mix of aggregate and "smooth" cullet may have a higher permeability than that of "rough" natural sand and gravel.

There are two typical laboratory tests available for the determination of permeability - constant head and falling head tests. The former is used principally for coarse-grained soils (clean sands and gravels) with permeabilities (k-values) greater than \( \approx 1 \times 10^4 \) centimeters per second (cm/s), and the latter is used primarily for fine-grained soils (silt and clay) with permeabilities less than \( \approx 1 \times 10^4 \) centimeters per second (cm/s).

We propose to conduct 24 constant head permeability tests (ASTM D 2434) to characterize the permeability of the cullet and cullet-mixtures. Tests will be conducted on specimens made of three aggregate mixes, two cullet sizes, two contamination levels, and two density states - 90 and 95 percent of the maximum density as determined by the standard Proctor (ASTM D 698) method. Usually, the fill used for drainage purpose does not require a high strength, and thus is not compacted to a state of high density. As a result, the standard Proctor usually produces comparable in-situ density. The relationship between particle size, gradation, contamination level and cullet percentage, and density on permeability will be evaluated.

Filtration Capacity

Filtration is used to separate non-settleable solids from water or wastewater by passing it through a porous medium. The mechanisms involved in removing suspended solids in a granular-media filter are complex, consisting of interception, straining, flocculation, and sedimentation of impurities. (Viessman and Hammer, 1985)

Currently, the most common filtration system is gravity filtration through a layered bed of granular media such as sand and gravel. ANSI/NSF test method 53 (American National Standards Institute/National Sanitation Foundation) is a national standard for evaluating the filtration capability of porous media. The test setup includes
two separate columns, one containing the test media (e.g. glass cullet), and the other containing either a standard media pack (consisting of layers of gravel, garnet, sand and anthracite), or pure natural sand. A test solution, which can be a water mixed with a standard test dust or other contaminants, is introduced to the test columns. The filtered water is then analyzed, and comparative results are produced. A typical gravity filtration test for one set of variables costs between $25,000 and $30,000.

In order to fully study the effectiveness of cullet as a gravity filtration media a test program incorporating many variables will have to be designed and conducted. These variables will include aggregate mix percentage, cullet size, shape and angularity, contamination level and temporal effects. In addition, various wastewater may have different interactions with the cullet media; hence the variations in impurities may also be considered.

In order to determine suitability as a filtering media, this study will apply the American Water Works Association (AWWA) Standard B100 to cullet properties determined during the testing program (gradation, specific gravity, shape, hardness).

Glass cullet has been used for filtration purposes in a storm water treatment project in Seattle, Washington. (City of Seattle, 1992) The project includes an oil/water separator, sedimentation chamber, and five filtration trenches. Glass cullet was used in the trenches along with a mineral aggregate and filter fabric. The design criteria require at least 40 percent removal of solids, turbidity and total phosphorous. The performance of the system is currently under monitoring.

Based on the information obtained for potential cullet filtration applications, it appears that data obtained from additional studies may provide some technological breakthroughs. It appears that any such study will cost on the order of tens of thousands of dollars and will require several months to conduct. Filtration studies of this nature are beyond the scope of the Glass Feedstock Evaluation project.

**Thermal Conductivity**

Thermal conductivity represents the ability of the material to conduct or resist heat flow. This property can be important for applications such as bedding and backfill for conduits or other heat sources. Thermal conductivity is measured by introducing a heat source at one end of a specimen, and measuring the heat flow at the other end of the specimen. Tests will be conducted according to standard method ASTM C 518.

Four thermal conductivity tests are proposed. To evaluate the maximum thermal conductivity effects of cullet, tests will be conducted using 50 and 100 percent aggregate mixes, 3/4-inch minus cullet size, and both "low" and "high" contamination levels.

**Shear Strength (Interparticle Friction)**

For certain applications, aggregate is the primary load carrying medium. The shear strength of an engineering material is an important property for design of earthen structures such as embankments, roadway base courses, and engineering fill under foundations. Therefore it is extremely important to consider the factors which influence the load supporting capacity of an aggregate mass. These factors are grouped under the term "interparticle friction," since this is the primary mechanism by which the load is carried by a compacted aggregate mass. A number of
factors contribute to interparticle friction, namely, 1) particle surface texture, 2) particle shape, 3) void ratio (compaction), 4) particle size, and 5) particle gradation.

Of these factors it is believed that the most important single factor contributing to interparticle friction is particle surface texture. Generally speaking, in a compacted aggregate mass, rather than points of contact, areas of the aggregates are abutting each other. Hence the surface texture of the aggregate will greatly influence the resistance to displacement of two particles. As the surface roughness increases, the interparticle friction, as manifested by the angle of internal friction, \( \phi \), increases considerably.

Angularity of particles may influence to a lesser degree the interparticle friction. Particle angularity does influence the compaction of aggregate mixtures in that a mixture containing angular aggregate will compact under a given compactive effort to a lesser degree than will a mixture containing rounded aggregate. It is possible however, that cullet - a relatively angular material - may permit a greater degree of compaction, particularly when heavy rollers are used. A mix made with the rounded aggregate may actually shove and push excessively under the roller and "decompact". As a result, adding cullet to rounded aggregates may improve their strength characteristics.

Particle gradation will influence internal friction to a certain extent. The denser the gradation of aggregate, the more contact areas in the compacted aggregate mass; hence, the greater the frictional resistance.

Void ratio, or degree of packing (compaction), will influence internal friction in the same manner as gradation; that is, the lower the void ratio or the greater degree of packing for a given aggregate gradation, the greater will be the frictional resistance of the aggregate mass.

Typically, the shear strength is defined as the ultimate stress level that the material can sustain. For some cases such as base course or materials under fluctuating loading, the determination of shear strength is also based on an acceptable magnitude of shear strain. Strain is an indication of the deformation that a material undergoes while being stressed. In either case, the strength needs to be interpreted from the stress-strain behavior of the material.

For granular materials, shear strength is usually expressed in terms of the inter-particle friction angle. Based on a review of the literature, there is little shear strength data for cullet. Limited direct shear test data indicates a friction angle at the peak stress of \( \phi = 55^\circ \) (Mohr-Coulomb failure criteria) (BCIT, 1991). This is about 20 percent higher than dense natural aggregate. From a soil mechanics point of view, a 55° friction angle implies a rough surface texture and a very high degree of interlocking between particles. Based on our current knowledge of the brittleness of the glass particles, the implied strength may not be reliable. The limited available data suggests the need for a better way of defining cullet shear strength.

We propose several types of laboratory tests to determine the shear strength and deformation properties of cullet. Consolidation tests have not been considered since they are an inaccurate method of determining stress-strain characteristics of cohesionless materials such as cullet. The test measures the deformation of a sample due to compressive loading which is primarily attributed to the removal of the sample water. The consolidation test is typically performed only on relatively compressible soils comprised of silt, clay, or peat.
Direct Shear: The direct shear test is a commonly used method to determine the shear strength of soil and rock. The shear strength of the test material is obtained in terms of the Mohr-Coulomb friction angle, \( \phi \). The direct shear test generally does not reproduce in-situ stress conditions. However, this drawback is not critical when testing artificial, laboratory-formed samples. As such, the direct shear is a relatively simple, inexpensive test to determine the shear strength of cullet. There is a large data base of direct shear results for natural aggregates and processed materials.

We propose to conduct seven direct shear tests in accordance with standard test method ASTM D 3080. Normal pressures of 500, 1,000 and 2,000 pounds per square foot (psf) will be used to best simulate in-situ loads of the applications. Test specimen variables will include three aggregate mixes, one cullet size, two contamination levels, and two densities. Natural sand & gravel of the equivalent size will be used to form the mixed samples.

Triaxial Shear: The triaxial shear test allows three dimensional loading of a sample. In engineering practice, the test is regarded as superior to the direct shear test for modeling in-situ loading conditions on soil. The triaxial test will not only determine strength parameters, but also the stress-strain behavior of the tested materials.

The stress-strain-volume change data obtained from the triaxial tests will also elucidate the frictional behavior of cullet. For instance, the crushing and particle re-orientation during shearing may generate a series of strain hardening and softening curves. The Mohr-Coulomb failure criteria that is conventionally used for soil and rock may require re-interpretation. Elastic modulus and Poisson's ratio will also be obtained from the triaxial tests. By comparing these values at different stages of shearing, their sensitivity to plastic strain can also be evaluated. To obtain the elastic response, a hydrostatic loading and unloading cycle will be performed prior to shearing, and several loading-unloading cycles will be performed during shearing. The relationships of stress, strain, and volume change will be recorded for each test, and a Mohr-Coulomb diagram will be generated for each set of tests.

Four triaxial tests will be conducted under consolidated, drained conditions to simulate the in-situ drainage conditions, confining pressures of 500, 1,000 and 2,000 psf will be used to simulate in-situ loads. Test specimens will be compacted into a sample mold to achieve 95 percent of the maximum dry density as determined by ASTM D 4253 or WSDOT 606 methods. Densities based on these methods are expected to be comparable to in-situ densities and conditions. Two test variables - 100 percent cullet mix and high contamination level are not considered for the triaxial shear tests. These conditions are not likely to be applicable for applications that involve loading of aggregate.

California Bearing Ratio (CBR): The CBR test was at one time a common test for evaluating the strength of subgrade, subbase, and base course of rigid and flexible pavements. Similar to direct shear data, a large database of CBR values is available for natural and processed aggregates. The proposed tests on cullet will allow comparison to existing information for other aggregates. The CBR tests will be conducted in accordance with standard method ASTM D 1883 test method. To evaluate the gradation change during testing, a sieve analysis will be conducted after each.
Eight CBR tests are proposed. Similar to the triaxial test, CBR test specimens will not be conducted on samples with 100 percent cullet mix and high contamination level. To evaluate the effect of compaction mode on the CBR value, two compaction methods - vibration compaction (WSDOT 606), and impact compaction (ASTM D 1557) are proposed for sample preparation. These two methods are chosen also because they will produce test specimens with comparable in-situ densities, making the comparison to the existing database possible.

Resistance "R"-Value: The resistance test produces an R-value which is used by some agencies as a criteria for pavement design and for acceptance of aggregates for base course. The R-value test utilizes a kneading compactor for specimen preparation. Vertical and horizontal loads are applied to the specimen by a stabilometer. The R-value is calculated based on the observed vertical and horizontal loads and horizontal deformation. The R-value is used to determine the potential strength of subgrade, subbase, and base course materials. We propose that tests be conducted according to standard test method ASTM D 2844.

As previously mentioned, it is unlikely that 100 percent cullet mixes and "high" contamination levels will be used for road applications. For this reason only four R-value samples will be tested. The test specimens will be made of aggregate mixes of 15 and 50 percent, cullet sizes of 1/4 and 3/4 inch minus, and "low" contamination level.

Cyclic Triaxial or Resilient Modulus Test: The resilient modulus of an aggregate is determined through a cyclic triaxial test. The resilient modulus is the stiffness of the aggregate after repeated load-unload cycles which are applied with the triaxial test apparatus. Because of the potential for interparticle crushing of the cullet, cyclic triaxial tests also help to evaluate the effect of particle crushing.

Available test methods for determining resilient modulus are SHRP Protocol P 46 and other methods such as AASHTO T-294 test method (AASHTO, 1992), which are based on the SHRP Protocol. We believe that the AASHTO standard is more applicable to all co-sponsors and thus recommend that tests be conducted according to the AASHTO T 294 method. Test specimens will be compacted into a triaxial sample preparation mold to produce a density that is 90 to 95 percent of the maximum dry density as determined by ASTM D 4253 or WSDOT 606. The density based on these methods is expected to be comparable to in-situ density. To evaluate the gradation change during testing, a sieve analysis will be conducted after each.

The cyclic triaxial test is an expensive test and is not commonly conducted. In engineering practice, the resilient modulus is often obtained from other test values such as CBR. The cyclic triaxial test is used for the evaluation of critical applications such as roadways under fluctuating loads. For these applications, it is unlikely that 100 percent cullet mixes and "high" contamination levels will be used for road applications. For this reason, only four cyclic triaxial tests are proposed. The test specimens will be made of aggregate mixes of 15 and 50 percent, cullet sizes of 1/4 and 3/4 inch minus, and "low" contamination level.

4.5 NATURAL AGGREGATE FOR CULLET-AGGREGATE MIXTURES

Two types of natural aggregate are proposed for the cullet-aggregate mixture. The first type is a natural, pit-excavated, sandy gravel that is typically used for structural and drainage fill. The second is a processed aggregate (crushed natural gravel or rock) that is used for roadway base course. The materials will be obtained from the Cadman borrow pit in Issaquah, Washington. This pit has been certified by WSDOT. The sandy gravel fill
material meets WSDOT specification 9-03.12(2), Gravel Backfill for Walls. The crushed aggregate meets WSDOT specification 9-03.9(3), Crushed Surfacing (WSDOT, 1991).

Test information provided by the supplier indicates that the specific gravity of the coarse aggregate is 2.70 and the specific gravity of the fine aggregate is 2.65. The L.A. abrasion values for the coarse aggregate range from 12.5 to 14.0. Gradation curves for these materials are shown on Plates 4.1 and 4.2.

The majority of the tests will be conducted using the natural sandy gravel. Three tests - cyclic triaxial, R-value, and C.B.R. - which relate directly to pavement design, will be conducted using the base course aggregate.

The range of mixtures used in the test program is expected to cover the majority of potential construction applications for cullet. However, in some situations, the cullet gradation from a feedstock will not conform to the limits defined by a given grading specification. Therefore, in order to use cullet in many applications it will need to be mixed with natural aggregate. We expect that cullet-aggregate mixtures can be custom-blended to meet given specifications. Several methods are available to calculate blending of aggregates. A method recommended by both the Road Research Laboratory, Great Britain, and the Asphalt Institute, U.S.A., is the "Straight-Line" graphical method. We will present an explanation of this method in our final evaluation report (Task 5).

4.6 STATISTICAL DATA INTERPRETATION

The sources of variability of a test program may include material heterogeneity, state of maintenance and calibration of equipment, ambient conditions, and differences in operator and technique (ASTM E 177). Among these sources, material heterogeneity is most critical to the proposed test program. As a result, statistical control of this source is proposed. The other sources can be controlled by routine maintenance and calibration of equipment, control of laboratory environment, maintenance of same operator for same series of tests, and adherence to standardized test methods (Section 4.7).

Typically, geotechnical laboratory testing programs do not produce a large sample population that allows for statistical analyses. For the Glass Feedstock Evaluation, statistical evaluations of material heterogeneity impact on all the tested properties will be expensive. A minimum of three tests per sample would need to be conducted to develop any statistical meaning. As such, a cost-effective statistical analysis should be conducted on primary properties.

In order to determine the statistical significance of samples, we propose to conduct a minimum of three tests on one "group" of samples. The group has been chosen to maximize the effect of the major variables on results: tests will be conducted with an aggregate mix of 100 percent, cullet size of 3/4-inch minus, and "high" contamination level.

For glass feedstock, most of the engineering properties are a function of the material density, a statistical study of compaction test data will provide the insight into the effect of material heterogeneity. As discussed in section 4.4, replicate compaction tests using the three test methods will be performed. This effort will yield nine compaction curves (three for each test method) comprised of 36 points (four for each curve) for statistical comparison purposes.
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<th>% SAND</th>
<th>% FINES</th>
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REMARKS: Material Source - The Cadman Companies, Issaquah, Washington

01-11-1993 Glass Feedstock Evaluation

JOB NO.25854-001-016

DAMES & MOORE Plate 4.1
## GRAIN SIZE DISTRIBUTION

### STRUCTURAL

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<th>DEPTH (ft)</th>
<th>DESCRIPTION</th>
<th>% GRAVEL</th>
<th>% SAND</th>
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**REMARKS:** Material Source - The Cadman Companies, Issaquah, Washington

01-11-1993 Glass Feedstock Evaluation

JOB NO.25854-001-016

DAMES & MOORE

Plate 4.2
Statistical analyses on some more easily conducted tests such as nuclear gage density, relative density, and specific gravity tests are also proposed. Three repetitive tests with the above test variables will be conducted for each of these tests. The results of the statistical analyses will be expressed in terms of ASTM’s preferred precision index, i.e., 90 percent repeatability limits, and the results will be compared to published, acceptable values.

4.7 QUALITY CONTROL PROCEDURES

The quality assurance of the test program will be achieved by the utilization of calibrated equipment, qualified laboratory personnel and chain of review process. The majority of the tests will be conducted in Dames & Moore’s Seattle Soil Laboratory. The laboratory has been approved by the U.S. Navy Facilities Engineering Command and U.S. Coast Guard Facilities Design & Construction Center. All testing equipment is maintained and calibrated on a regular basis. Tests will be conducted by a senior laboratory technician under the supervision of the project engineer. Data will be reviewed by the project engineer and the final results reviewed by the project manager. For tests conducted outside of Dames & Moore’s laboratory, similar requirements will be imposed on the equipment, personnel and review process.
5.0 EQUIPMENT EVALUATION PROGRAM

The purpose of the equipment evaluation program is to select and test six to fifteen representative full scale processing machines relative to cullet production and quality. The information developed is intended to provide guidance in the selection of equipment.

5.1 BACKGROUND

Relatively small-scale systems are employed for use in cullet processing. Such systems have capacities ranging from about one to 20 tons per day (approximately 80 to 1700 lb/hr). The investigation will evaluate the ability of these systems to manufacture the required product. In evaluating small scale processing equipment we will differentiate between the following three categories:

- **Light Commercial**: As found at a facility where glass is crushed for volume reduction. They are fed manually, generally discharge to a 55 gallon drum, and have capacities in the 500 lb/hr range. Light commercial machines are generally high-speed hammermills (impactors) which produce a somewhat rounded product. Some models are noisy and dusty.

- **Commercial**: Typically used at a central recycling facility receiving large quantities of glass or possibly at a plant where large amounts of glass waste are produced. Generally, this class of equipment is conveyor-fed, and may discharge to large capacity bins. Capacities generally range from one to 20 tons per hour. Crushers are generally of the hammermill type.

- **Industrial**: Heavy-duty crushers, as utilized in applications such as sand and gravel operations and aggregate production. Capacity of industrial equipment includes many models operating at capacities less than 500 lb/hr. Types of crushers include hammermills, jaw crushers, and gyratory cone crushers. Gyratory cone crushers tend to minimize production of fine fractions and produce angular particles, both of which are generally advantageous for use as aggregate substitute. The industrial grade of crushers may be combined with air sweeping to remove lightweight debris and unwanted finely ground product. This type of equipment has very low maintenance requirements and very high reliability. Industrial equipment of this type is easily integrated into continuous-flow schemes utilizing bins, feeders, and conveyors, combined with both wet and dry screening applications.

Each of the above grades of equipment has its application in glass recycling. Industrial grade equipment will provide superior long-term performance and lowest overall cost, while the commercial grades provide lowest first cost, but higher operating and maintenance costs. Both performance and cost of potential systems will be evaluated using a rating criteria described in the following two sections.
5.2 INITIAL EVALUATION

Dames & Moore will solicit the assistance and participation of equipment manufacturers in demonstrating their products. The firms contacted will either market small scale-glass crushing equipment, or will include the nation's ten largest manufacturers of industrial grade equipment such as those used in aggregate crushing and sizing systems. These latter firms include Spokane Crusher, Allis Chalmers, Denver Equipment Company, Nordberg, Kue Ken, Greundler, Pennsylvania, and Gundlach.

Because of the large number of suppliers and available models, a standard technique will be used to readily compare and contrast information. To do this, data will be collected using the form shown in Figure 5.1. The information, gathered by mail and telephone, provides criteria by which the equipment is selected for testing. Some criteria are more important than others, so a suggested weighting system is provided. Criteria scores will range from 1 to 3, and may be weighted 1 to 5 depending on their importance. If information for an item is unavailable, a score of 1 will be assigned. The score multiplied by the weight is added up for all of the criteria to yield the overall rating for the piece of equipment. Six to fifteen of the top-rated systems will be used in the equipment performance evaluation described in the next section.

5.3 PERFORMANCE EVALUATION

As described above, performance evaluations will be conducted on a minimum of six systems. The evaluations will consist of actual demonstrations witnessed by Dames & Moore personnel. The purpose of the demonstrations is to provide actual data so that equipment efficiency and capacity may be assessed.

The operating conditions of each demonstration will be specified by Dames & Moore. These conditions include the following:

- Cullet samples shall be provided by the equipment manufacturer. Samples will consist of glass with no whole containers over one liter capacity. Glass may be broken but 90%, based on visual inspection, must be over 3/4" minus size. On-site visual inspection of glass will be performed by the Dames & Moore representative.

- The output stream will be screened to gradations of either 3/4" minus or 1/4" minus.

- Equipment will be operated at full capacity for a minimum of four hours.

- Equipment will be disassembled after testing to inspect wear.

During the demonstration Dames & Moore personnel will monitor production capacity, energy consumption, dust level, noise level, and cullet streams. Samples will be collected from the cullet streams produced in the demonstrations to provide an evaluation of contamination content, particle angularity, and dusting.
### Glass Crusher Product Profile and Initial Evaluation

**Crusher Equipment Class:**

**Manufacturer:**

**Model:**

**Type:**

**General Description:**

**Sponsor State?**: Y/N  
**Perform Test?**: Y/N

<table>
<thead>
<tr>
<th>EVALUATION ITEMS</th>
<th>DESCRIPTION</th>
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<th>RATING</th>
<th>SCORE</th>
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</table>

**TOTAL SCORE**: 0

Weighing factors: 5 = most important, 1 = least important  
Ratings: 0 = poor, 1 = acceptable, 2 = good, 3 = excellent  
Rating = 1 if no information is available.  
*rating = 3 or 0 (pass/fail), if 0 then equipment disqualified

**COMMENTS:**

**AVERAGE SCORE:** 0.00

**OVERALL RANK:**
For each demonstration, data will be collected on a form shown as Figure 5.2. Some of this information will come from the preliminary evaluation form (Figure 5.1). The remainder will be obtained during and after the actual demonstration. There are four parts to Figure 5.2. Part A, "General," includes manufacturer-supplied data for the equipment being demonstrated. Part B, "Independent Variables," consists of parameters that can be adjusted by the operator to obtain varied machine performance results. Part C, "Dependent Variables," are the measured parameters that define the machine's performance. These are collected during the test or by interview with the operator. Part D, "Calculated Results," will be completed with data collected during the performance evaluation or from laboratory tests on the resulting product. This information provides practical performance measurements that relate directly to the efficiency and effectiveness of the machine.

5.4 USER SURVEYS

In addition to the initial evaluations and equipment demonstrations, Dames & Moore will call current users of equipment to verify vendor claims of equipment wear. User lists will be requested of each manufacturer. Although equipment wear is probably the greatest maintenance problem associated with glass crushers, it is but one of many factors affecting overall cost. In addition to wear, we propose to discuss general operation, maintenance, factors affecting costs, overall reliability, local markets, and disposal costs with current users. This general information will be conveyed to the Advisory Panel, documented and reported as appropriate. This task will be accomplished concurrently with the performance evaluations.
FIGURE 5.2
GLASS PROCESSING EVALUATION CRITERIA:

Equipment Manufacturer: _______________________________ Test Date: _________________
Location: __________________________________________ Time of Day: _______________
Weather conditions: __________________________________
D&M Personnel: _________________________________ Manufacturer Personnel: ________________

A. General
  - Equipment designation and classification
  - Equipment capital cost
  - Number of equipment operators required
  - Replacement costs for motor, drivetrain, and milling mechanisms
  - Equipment life

B. Independent Variables
  - Feed rate - vendor to set to optimize product
  - Equipment Settings - vendor to set to optimize product
  - Weight of cullet fed to machine
  - Size of feed cullet
  - Contamination levels and types

C. Dependent Variables
  - Equipment energy consumption, kwh
  - Product - contamination content
    - moisture content
    - angularity/roundness coefficient
  - Product sample size data
  - Reject stream (if applicable)
    - percent of feed rejected (glass loss)
    - size, mean and distribution curve
    - moisture content for wet screening applications
  - Contamination rejection (if applicable)
    - percent of contamination in reject stream
    - physical changes to contamination
  - Equipment wear - qualitative
  - Sound (noise) levels
    - at operator station
    - at 25 feet, 4 directions
  - Qualitative issues
    - breakdowns
    - ease of operation
    - dust levels
    - hammer/liner replacement

D. Calculated Data Includes:
  - Equipment efficiency, kw-hr/ton of product, tons of product/ton input
  - Capacity, tph
  - Size, mean for product and reject streams
  - Size distribution for product and reject streams
6.0 ECONOMIC MODEL

An economic model helps identify the criteria and parameters important to the economic viability of glass aggregate production. The economic model, developed for processing recycled glass cullet into aggregate, simulates the interactive economics of the major system components. The model is simplified but retains enough complexity to address the most significant cost components.

6.1 BACKGROUND

A model depicting the current organization of glass recycling is presented below in Figure 6.1. This figure shows the existing systems processes and material flows.

Glass is collected at Materials Recovery Facilities, MRF’s, either by sorted collection or from a commingled stream where sorting then takes place at the MRF. Glass is of highest value if sorted by color. However, the sorting process is costly.

![FIGURE 6.1 CURRENT GLASS RECYCLING MODEL (showing material flows)](image-url)
Depending on the waste stream, sorting procedures, and collection characteristics, there are varying amounts of mixed color glass. The mixed color glass is usually stored, although some may be hauled to landfills as waste. The sorted glass is stored until a glass container manufacturer or third party beneficiator is willing to buy or take it from the MRF. Glass may or may not be densified by crushing to reduce storage volume and in preparation for transportation.

The existing aggregate supply industry is represented schematically in Figure 6.2, Current Aggregate Operational Model. The rock material source is normally owned by the aggregate supplier. Potentially, aggregate-sized glass cullet could be partially or fully substituted for rock aggregate, depending on the application. Internal operations for the aggregate supplier include crushing, sorting, and storage operations.

![FIGURE 6.2 CURRENT AGGREGATE MODEL (showing material flows only)](image-url)
6.2 PROCESSED GLASS AGGREGATE MATERIAL FLOW MODEL

Processing glass into a usable aggregate-sized material is the connecting link between the MRF and the aggregate supplier, and eventually the user. The key to this process is production of material that is comparable to rock aggregate for a variety of applications. The economics become the deciding factor in developing glass aggregate production. If there are a variety of applications, then the economic potential is usually increased, and the overall demand more stable. Simplifying the MRF model and combining it with the mixed color glass processing and the Aggregate Operational Model results in Figure 6.3, Processed Glass Aggregate Material Flow Model.

Figure 6.3 illustrates the activities involved in recycling glass for two alternative markets, the glass container market and the construction aggregate market. The glass container market is the only well established market for recycled glass at this time.

The flow of material shown in Figure 6.3 begins with recycling collection. Glass is accumulated by one of several collection schemes. Glass may be collected in a commingled manner with other containers and/or recyclables and separated at the plant. Alternatively, glass may be collected separately from other recycled materials either pre-sorted by color or commingled as to color.

To process glass for the glass container market, commingled glass entering the MRF is sorted from other recyclables and/or color sorted, and then stored. Broken glass which is too small to color sort efficiently is, in some systems, sorted out of the glass stream by screening, and/or positively sorting out whole glass bottles and larger glass fragments. The small-sized broken glass fraction is referred to as mixed color cullet. Handling of pre-color sorted glass is less labor intensive. Once sorted, glass is sometimes crushed for volume reduction. These activities are show in Figure 6.3 as "Color-Sorted Glass Processed and Stored."

Color-sorted glass is feedstock for glass container manufacturing. The alternative market in Figure 6.3, construction aggregate applications, is the subject of this study. This market is represented as the stream beginning with "mixed Color Glass Storage." The feedstocks for this market could include: the mixed color cullet fraction that is the by-product of color sorting, any single color glass that lacks demand in the glass container market, such as is the case with green glass in many parts of the country, and/or mixed color glass purposefully collected for mixed color glass markets, such as the construction aggregates market.

Processing glass into aggregate materials is the interconnecting activity between glass recycling and aggregate applications. Glass processing could work as an independent activity, as it is shown in Figure 6.3. Alternatively, glass processing could be incorporated by either the MRF or the aggregate supplier.

After processing, the glass aggregate then enters the "Aggregate Supplier" operation. For applications where glass must be mixed with natural aggregates to meet specifications, the addition of glass as an aggregate source will add tasks to the aggregate supplier operations. Glass aggregate mixed with rock must also be stored separately. When applications permit a 100% cullet content, it is possible for the glass processor to market directly to the end user.
Figure 6.3 Processed Glass Aggregate Material Flow Model

(Independent Production)

Notes
Shaded areas represent separate operations. The PGA Production can be independent, part of the MRF, or part of the Aggregate Supplier. It is shown here as independent. The product may be supplied to the Aggregate Supplier, as shown, or directly to the Aggregate User.
6.3 PROCESSED GLASS AGGREGATE ECONOMIC MODEL

The complete economic model, represented schematically in Figure 6.4, Processed Glass Aggregate Economic Model, shows the case where the mixed glass aggregate production is part of the MRF operations.

It must be noted that the costs shown in the model represent one scenario. There are many other possibilities depending on local conditions and recycling system configuration. Transportation distance, landfill costs, aggregate price, and aggregate markets all vary from region to region. The cost of machinery, buildings, land, and labor also affect production economics.

The model will enable recycling system planners, recycling operators, and others, to evaluate the alternative recycling market economic tradeoffs by entering the values for local conditions and operations into the model. A second component of the model, a spreadsheet, was used for calculating the costs shown in Figure 6.4. The spreadsheet will be presented in the Task 5 report in greater detail.

The prices shown in Figure 6.4 reflect current research in markets where glass recycling is established. Sources of the costs used for each component of the economic model are discussed below.

Glass Collection

Although it is beyond the scope of this project to compare the costs of garbage collection to recycling collection, an interesting possibility emerges when considering collection of glass for the aggregate market. Glass could be densified, that is, reduced in size, on the collection truck. This would reduce the number of trips the collection truck would need to make to collect glass, thereby producing a favorable impact on collection economics.

Materials Recovery Facilities

Most of the costs in the MRF were adopted from the 1992 report, "Processing Costs for Residential Recyclables at Material Recovery Facilities," by Roy F. Weston, Inc. The costs reported there are representative of commingled processing for the glass container market, that is, color sorting costs have been incorporated. The cost to color sort was allocated equally across the colors, including the mixed color fraction. Again, it should be noted that these costs may be representative only of the chosen system configuration and the choices on how to allocate costs. In the example given, processing is done at the MRF, so no transportation cost is incurred. Provision is made for a transfer fee (a calculated cost) between the MRF and the glass processor.

Mixed Glass Processing

Much of the input data on this component for the final economic analysis will be obtained during the project's equipment evaluation. Investment costs will be calculated using equipment cost, interest rate, and equipment life. Energy costs will be a direct input from the testing results. Process rate, flow rate, number of additional employees, set up time, and operating time will be calculated from process rate and cullet flow rate. The latter is the average amount of cullet processing per day, assuming a continuous process. Maintenance costs will originate from equipment manufacturer information. Storage costs are based on existing data.
Aggregate Supplier

Direct prices from suppliers, when available, will be used in the final analysis. The mixed aggregate costs will be calculated using base aggregate cost and glass mixture percentage. Note that in the case of a 100% cullet mix, a glass processor could market directly to the aggregate user at a price up to the market price for conventional aggregates, assuming an equivalent performance.
Figure 6.4 Processed Glass Aggregate Economic Model

(MRF-located Production)

Notes
Shaded areas represent separate operations. The PGA Production can be independent, part of the MRF, or part of the Aggregate Supplier. It is shown here as part of the MRF. The product may be supplied to the Aggregate Supplier, as shown, or directly to the Aggregate User. This is just one example of many possible configurations.
7.0 DUST GENERATION AND SAFETY HAZARDS

The chemical make up of glass cullet originating as post-consumer glass would be anticipated to consist of oxides of silicon, aluminum, iron, calcium, magnesium, sodium, and barium. These compounds are the common components of soda-lime glass which accounts for approximately 95 percent of all glass manufactured. Minor, trace inorganic components such as antimony, arsenic, cerium, chromium, cobalt, copper, lead, manganese, platinum, selenium, silver, vanadium, zinc, and zirconium could also be present. These inorganic materials, if present, are generally used in small quantities (generally less than 0.5 percent). The inorganic materials, particularly lead, are generally used in the production of specialty glass and would not be anticipated to represent a significant percentage of post-consumer glass.

The component present in the greatest quantity is silica. Silica may exist as either an amorphous or crystalline structure. Amorphous silica is not considered to be a significant health hazard. Crystalline silica, on the other hand, has been shown to cause fibrogenic lung disease. To cause fibrogenic lung disease, the silica must be present as particles that are small enough to enter the lungs, a condition that is termed "respirable". Respirable particles range from 0.1 to 10 microns in aerodynamic diameter.

Preliminary contacts with glass scientists indicate that glass is primarily composed of amorphous silica. Consumer glass is generally considered to be a completely vitrified material or at least is such a product with a relatively small amount of nonvitreous material in suspension. As such, the likelihood of crystalline silica being present in the post-consumer glass stream is low. However, it is possible that certain types of glass may contain crystalline silica and that these specialty glass products may be present in the post-consumer glass waste stream. If this is the case, respirable particles of crystalline silica may be generated when cullet is crushed to make a useable construction product. Workers could be exposed to dust during the crushing process or during subsequent handling or use. There is some potential for minor skin irritation from airborne particles of glass dust. This is mitigated through the use of protective clothing which limits the exposure of skin to the glass dust.

The potential for exposure to respirable particles will be assessed using two methods. First, the percentage (mass basis) of cullet with particle sizes ten microns and less will be determined by specific gravity. Crystalline silica dust present in amounts greater than one percent may pose health hazards to workers if the dust becomes airborne.

The second method used to determine potential hazards of dust exposure will be to conduct air monitoring. The Occupational Safety and Health Administration (OSHA) has established a Permissible Exposure Limit (PEL) for exposure to crystalline silica. The PEL is 0.1 mg/M³ time-weighted average. To meet regulatory requirements, exposure to crystalline silica must be less than the PEL.

Exposure monitoring will be conducted in Dames & Moore’s laboratory. Dames & Moore’s engineers will be testing the physical properties of the crushed cullet. During this testing, the cullet will be sieved. Sieving has the potential to generate a significant amount of airborne dust, if dust is present in the raw materials.

Air monitoring will be conducted according to National Institute of Occupational Safety and Health Method 7500. Air sampling pumps will be set up near the sieving operation. Air samples will be drawn through 10 millimeter cyclones, and particles will be collected on 5 micrometer polyvinyl chloride filters. A fully documented
quality assurance and quality control program will be followed for sample collection. Field blanks will be provided each day on the basis of one blank for each 5 samples collected. Samples and blanks will be submitted to an American Industrial Hygiene Association accredited laboratory for analysis, using proper chain-of-custody procedures.

Data will be reported in narrative and tabular forms. The narrative will discuss our observations concerning the appearance of the crushed cullet and the likelihood for exposure to respirable dust. The percentage of respirable material determined by specific gravity testing will be presented along with the results of air monitoring.
8.0 REFERENCES


Engineering Department, City of Seattle, 1992. Green Lake Storm Water Project, Grant Number WFG 91029.


Johnson Electro-Coag Filtration System, No date. CUBE-PAC Glass Media Potable Water Filter System.


APPENDIX A
SAMPLE COLLECTION, DOCUMENTATION, AND HANDLING PROCEDURES

A. SAMPLE COLLECTION PROCEDURES

Sample collection techniques are based on the collection of glass from either a stockpile, conveyor belt, bunker, or drop box. The procedures are outlined below and are in general accordance with ASTM D 75, Standard Practice for Sampling Aggregates. The total sample weight per source required for the testing program is 2,600 pounds. Table A.1 lists the sample volume required per source, the approximate area needed to spread and mix the glass source, and the equivalent number of shovel buckets of material needed for three general types of mechanical shovels.

### TABLE A.1
SAMPLE VOLUME REQUIRED FOR EACH SOURCE & APPROXIMATE SPREADING & MIXING AREA

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<tr>
<th></th>
<th>Whole Bottles</th>
<th>Semi-Broken Bottles</th>
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<td>Sample Volume</td>
<td>120 ft³</td>
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<td>37 ft³</td>
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<td>Spreading Area (ft²)</td>
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<td>(0.2-yd³/bucket)</td>
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</tr>
<tr>
<td>Backhoe</td>
<td>5 buckets</td>
<td>3 buckets</td>
<td>2 buckets</td>
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<td>(1-yd³/bucket)</td>
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</tr>
<tr>
<td>Front-end Loader</td>
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<td>1 bucket</td>
<td>1 bucket</td>
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<tr>
<td>(2-yd³/bucket)</td>
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</table>

1. Sampling From a Stockpile

- Spread a plastic tarp on a flat surface in a mud free area prior to glass sample collection. The tarp should have enough strength to sustain wear and tear by the glass and handling equipment.

- Collect samples at three-to-five individual sample locations taken from the top third, at the midpoint and the bottom third of the volume of the pile. Collect samples from under the outer layer of the pile. If the shovel bucket volume is greater than the volume of sample needed for each location, proportion the amount collected in the shovel bucket accordingly.

- Power equipment such as backhoe and front end loaders can be used to collect glass at the three-to-five sample locations. If power equipment is unavailable, a board shoved vertically in the pile just above the sampling location will aid in collecting the sample beneath the outer layer.

- Spread each increment using a random lateral sequence to provide systematic mixing.
Following the collection and mixing of the total volume, remove the sample at random portions of the pile and place in three 5-gallon containers with lids. Archive the remaining required amount in 55-gallon drums or other storage bins. Sample container volume and handling is shown on Table A.2.

Label each sample container according to the state, glass source type, and date, as described in Section B.

Send samples to the representatives listed in Table A.2, or archive for future use.

2. Sampling From a Conveyor Belt

Spread a plastic tarp on a flat surface in a mud free area prior to glass sample collection. The tarp should have enough strength to sustain wear and tear by the glass and handling equipment.

Collect glass feedstock samples at three-to-five randomly selected increments from a conveyor belt. You may start and stop the conveyor to collect the increments. Space two templates, of a shape conforming to the conveyor belt and the glass stream, to yield the weight of one increment. The weight of one increment (580 lbs) is one-fifth of the total weight of the source required (2,600 lbs).

Scoop the material between the templates and add to a container. Collect fines on the belt with a brush and dust pan and add to the container.

Spread each increment using a random lateral sequence to provide systematic mixing.

Following the collection and mixing of the total volume, remove the sample at random portions of the pile, and place in three 5-gallon containers with lids. Archive the remaining required amount in 55-gallon drums or other storage bins. Sample container volume and handling is shown on Table A.2.

Label each sample container according to the state, glass source type, and date, as described in Section B.

Send samples to the representatives listed in Table A.2, or archive for future use.

3. Sampling From Bunkers

Spread a plastic tarp on a flat surface in a mud free area prior to glass sample collection. The tarp should have enough strength to sustain wear and tear by the glass and handling equipment.

Remove the outer layer of the glass stockpile.

Collect samples using a mechanical shovel at three-to-five individual sample locations taken from the top third, at the midpoint and the bottom third of the volume of the pile. If the shovel bucket volume is greater than the volume of sample needed for each location, proportion the amount collected in the shovel bucket accordingly.

Spread each increment using a random lateral sequence to provide systematic mixing.

After collecting and mixing the total volume, remove the sample at random portions of the pile and place in three 5-gallon containers with lids. Archive the remaining required amount in 55-gallon drums or other storage bins. Sample container volume and handling is shown on Table A.2.
• Label each sample container according to the state, glass source type, and date, as described in Section B.

• Send samples to the representatives listed in Table A.2, or archive for future use.

4. Sampling From Drop Boxes

• Spread a plastic tarp on a flat surface in a mud free area prior to glass sample collection. The tarp should have enough strength to sustain wear and tear by the glass and handling equipment.

• Dump contents of drop box onto the tarp.

• Mix with hand shovel in different lateral sequences to provide systematic mixing.

• Remove glass from three-to-five random locations of the pile. Place in three 5-gallon containers with lids. Archive the remaining required amount in 55-gallon drums or other storage. Sample volume, container, and handling is shown on Table A.2.

• Label each sample container according to the state, glass source type, and date as described in Section B.

• Send samples to the representatives listed in Table A.2, or archive for future use.

### TABLE A.2
**GLASS FEEDSTOCK SAMPLE CONTAINER VOLUME & HANDLING PROCEDURE**

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<th>SAMPLE</th>
<th>CONTAINER</th>
<th>HANDLING</th>
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<td>Browning Ferris Industries</td>
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<td>Physical Contaminant Testing</td>
<td>5-gallon plastic</td>
<td>Send to: Dames &amp; Moore</td>
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<tr>
<td>Environmental Testing</td>
<td>5-gallon plastic</td>
<td>Send to: Dames &amp; Moore</td>
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<tr>
<td>Engineering Properties</td>
<td>55-gallon drum</td>
<td>Archive</td>
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B. GLASS SOURCE LABELING AND DOCUMENTATION

Label each glass source according to the State, type of source, and date of sample collection. For example, the type of feedstock source collected will correspond to the number and type provided in Attachment A.1, Collection/Sorting Categorization.
An example of the labeling scheme follows. The collection of curbside commingled glass only (facility sorted, mixed cullet fraction), by the State of Alaska on January 5, 1993 would be labeled as follows:

**AK-8-010593**

Another example of the labeling scheme would be the collection of commercial commingled glass by the State of Minnesota on January 25, 1993 would be labeled as follows:

**MN-3-012593**

Labels should be completed and affixed on each sample container and taped over with clear plastic tape, so that information will be retained during shipping.

Sample collection information will be documented on chain-of-custody forms and sent with the source samples to the respective parties. An example of a completed chain-of-custody form is provided in Attachment A.2. Fill out one chain-of-custody form per source and destination - white copy accompanies the sample (place inside bucket), yellow copy is retained by the collector, pink copy is sent directly to Joe Souther at Dames & Moore.
Glass Feedstocks Study
Collection/Sorting Categorization

Co-Sponsor _______________________

1. Dropbox/Barrels - Unattended

2. Dropbox/Barrels - Attended

3. Commercial - Commingled

4. Curbside - Source Separated by Consumer

5. Curbside - Commingled Glass Only - Color Sorted at Curb

6. Curbside - Commingled Glass Only - Facility Sorted - Positive Sort

7. Curbside - Commingled Glass Only - Facility Sorted - Negative Sort

8. Curbside - Commingled Glass Only - Facility Sorted - Mixed Cullet Fraction

9. Curbside - Commingled with Other (Plastics, Cans) - Positive Sort

10. Curbside - Commingled with Other (Plastics, Cans) - Negative Sort

11. Curbside - Commingled with Other (Plastics, Cans) - Mixed Fraction

12. Deposit Collection

13. Redemption Collection

14. Blue Bags - Commingled Bottles/Cans/Paper

15. Other - Please Specify
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<td>Glass</td>
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**Special Instructions/Comments:**

- Sent to Dames & Moore Seattle for physical contamination testing.

**Relinquished by:**

(Sig) Anne S. Doe
(Printed) Anne S. Doe
(Company) Alaska Dept. Fish
(Time) 1530 (Date) 1/15/93

**Received by (lab):**

(Sig) Joseph T. Souther
(Printed) Joseph T. Souther
(Company) Dames & Moore
(Time) 0300 (Date) 1/15/93
APPENDIX B

AVAILABLE SPECIFICATIONS FOR CONSTRUCTION AGGREGATES

A. NATIONAL CONSTRUCTION AGGREGATE SPECIFICATIONS


M 43-88 Sizes of Aggregate for Road and Bridge Construction
M 57-80 Materials for Embankments and Subgrades
M 147-65 Materials for Aggregate and Soil-Aggregate Subbase, Base and Surface Courses
M 283-83 Coarse Aggregate for Highway & Airport Construction


D 448-86 Standard Classification for Sizes of Aggregate for Road and Bridge Construction
D 1241-68 Standard Specification for Materials for Soil-Aggregate Subbase, Base and Surface Courses
D 2940-74 Standard Specification for Graded Aggregate Material for Bases or Subbases for Highways or Airports

B. STATE CONSTRUCTION AGGREGATE SPECIFICATIONS

1. Alaska


Part 204 STRUCTURE EXCAVATION FOR CONDUITS & MINOR STRUCTURES

Part 205 EXCAVATION, BACKFILL AND FOUNDATION FILL FOR STRUCTURES

Part 301 AGGREGATE BASE COURSE

Part 304 SUBBASE

Part 703 AGGREGATES

Other Alaska Specifications:

25854-001-016
Steel Structures Painting Council (SSPC):

SSPC-SP 6  Commercial Blast Cleaning (do not have; referred to by State of Alaska)

Department of Environmental Conservation:  (Source and document uncertain)

Septic Fields/also referred to as Drain Fields.

Draft DOT & PF:  (Source and document uncertain)

Part 02223  BACKFILLING
  02223-2.01  Fill Materials

2. Arizona


Part 203  EARTHWORK
  203-5.03(B)(1) Structure Backfill

Part 303  AGGREGATE SUBBASES AND AGGREGATE BASES
  303-2  Materials
    (see Table 303-1) (also see Notes 1 through 6, esp. Note 5 for roughness and Note 6 for abrasion resistance)

Part 501  PIPE CULVERT AND STORM DRAINS
  501-3.02(A) Bedding Material
  501-3.02(A)(1) General
  501-3.02(A)(2) Standard Aggregate Bedding Material
  501-3.02(A)(3) Cement-Treated Slurry Bedding Material (see 501-3.02(A)(1))
  501-3.04  Backfilling and Compacting
  501-3.04(A) Backfill Material
  501-3.04(A)(1) Pipe Backfill (see 501-3.02(A))
  501-3.04(A)(2) Trench Backfill (see 501-3.02(A))

Part 610  PAINTING
  610-3.02  Surface Cleaning
  610-3.02(A) General (in accordance with SSPC-SP10, we don't have)
  610-3.02(B) Blast Cleaning

3. California


Part 19  EARTHWORK
  19-3.025B  Sand Bedding
  19-3.06  Structure Backfill

25854-001-016  DAMES & MOORE
19-3.065  Pervious Backfill Material (see 90-3.02)

Part 25  AGGREGATE SUBBASES
  25-1.02  Materials
  25-1.02A  Class 1, 2 and 3 Aggregate Subbases
  25-1.02B  Class 4 Aggregate Subbase
  25-1.02C  Class 5 Aggregate Subbase

Part 26  AGGREGATE BASES
  26-1.02  Materials
  26-1.02A  Class 2 Aggregate Base
  26-1.02B  Class 3 Aggregate Base

Part 59  PAINTING
  59-2.03  Blast Cleaning (also see regulations for abrasive blasting operations adopted by the State Air
          Resources Board, Subchapter 6 in Chapter 1, of Part III of Title 17, California Code of
          Regulations).

Part 63  CAST-IN-PLACE CONCRETE PIPE
  63-1.04  Earthwork (see Section 19-3)

Part 64  PLASTIC PIPE
  64-1.05  Earthwork (see Section 19-3)

Part 65  REINFORCED CONCRETE PIPE
  65-1.03  Earthwork (see Section 19-3)

Part 66  CORRUGATED METAL PIPE
  66-1.04  Earthwork (see Section 19-3)

Part 68  SUBSURFACE DRAINS
  68-1.025  Permeable Material

Other Reference:  Joint Cooperative Committee of the Southern California Chapter American Public Works
                 Association and Southern California Districts, and Associated General Contractors of

Part 2  CONSTRUCTION MATERIALS
  200-2  Untreated Base Materials
  200-2.1  General
  200-2.2  Crushed Aggregate Base
  200-2.3  Crushed Slag Base
  200-2.4  Crushed Miscellaneous Base
  200-2.5  Processed Miscellaneous Base
4. **Minnesota**

   References: 1992 Minnesota Specifications

   Office of Waste Management:

   Underground Storage Tank--Contractor* Specifications for Backfill;
   Pea Gravel
   Crushed Stone
   (*Source is Xerxes Corporation)

5. **New York**


   Sect. 201   EARTHWORK
   (Not Specified)

   Sect. 203-2.02   EXCAVATION AND EMBANKMENT
   Select Materials and Subgrade Area Material Requirements

   Sect. 203-3.15   FILL & BACKFILL AT STRUCTURES, PIPES, CONDUITS AND DIRECT BURIAL CABLES

   Sect. 206   TRENCH, CULVERT AND STRUCTURE EXCAVATION
   (Not Specified)

   Sect. 302-2.02   BITUMINOUS STABILIZED COURSE
   Granular Material Requirements for Options A and C

   Sect. 304-2.02   SUBBASE COURSE
   Materials Requirements

   Sect. 602-3.03   BEDDING AND BACKFILLING PIPE

   Sect. 605-2.02   GRANULAR FILTER MATERIALS

6. **Oregon**


   Part 00330   EARTHWORK
   00330.12   Borrow Material
   00330.13   Selected General Backfill (*very general spec.*)
   00330.14   Selected Granular Backfill

   Part 00360   DRAINAGE BLANKETS
   00360.10   Sand Drainage Blanket
Part 00395  RETAINING WALLS
  00395.11  Mechanically Stabilized Earth (MSE) Retaining Walls
  00395.11(e) MSE Granular Backfill Material

Part 00400  DRAINAGE & SEWERS
  00405.12  Class C Bedding (see 00360.10)
  00405.13  Backfill (see 00510.13 & 00330.13)

Part 00430  SUBSURFACE DRAINS
  00430.11  Granular Drain Backfill Material (see 02660.10 - not in ref.)

Part 004700 MANHOLES AND INLETS
  00470.11  Sump Backfill
  00470.12  Base Drain Backfill

Part 00510  STRUCTURE EXCAVATION & BACKFILL
  00510.12  Granular Wall Backfill
  00510.13  Granular Structure Backfill

Part 00594  PREPARING AND COATING STEEL STRUCTURES
  00594.41  (2) Abrasives (see OSHD TM 619)

Part 00642  PLANT MIX AGGREGATE BASE, AND SHOULDERS
  00642.10  Base Aggregate (see 02630)
             Shoulders (see 02640)

Part 02610  SPECIAL FILTER MATERIAL
  02610.10(a) Special Filter Materials

Part 02630  BASE AGGREGATE
  02630.10(a) Aggregate for Base Aggregate (see Table 02630-1)
  02630.10(b) Fracture of Rounded Rock
  02630.10(c) Durability
  02630.10(d) Sand Equivalent

Part 02640  SHOULDER AGGREGATE
  02640.10  Aggregate for Shoulder Aggregate

7. Washington

           and Municipal Construction.

Part 9-03  AGGREGATES
  9.03.9  Aggregates for Ballast and Crushed Surfacing
         9-03.9(1)  Ballast
         9-03.9(2)  Shoulder Ballast
         9-03.9(3)  Crushed Surfacing
9.03.10 Aggregate for Gravel Base

9-03.12 Gravel Backfill
9-03.12(1) Gravel Backfill for Foundations (Class A & B)
9-03.12(2) Gravel Backfill for Walls
9-03.12(3) Gravel Backfill for Pipe Bedding
9-03.12(4) Gravel Backfill for Drains

9-03.13 Backfill for Sand Drains
9-03.13(1) Sand Drainage Blanket

9-03.14 Gravel Borrow

9-03.15 Bedding Material for Rigid Pipe

9-03.16 Bedding Material for Flexible Pipe

9-03.17 Foundation Material Class A and Class B

9-03.18 Foundation Material Class C

9-03.19 Bank Run Gravel for Trench Backfill

C. EXISTING OR DRAFT GLASS (CULLET) SPECIFICATIONS

1. California

Reference: 1992 CALTRANS Amendments

.i.25.01 Amendment to 25-1.02A (Class 1, 2 or 3 Aggregate Subbases)
.i.26.01 Amendment to 26-1.02B (Class 2 Aggregate Base) (possible incorrect reference 26-1.02A?)
.i.26.03 Amendment to 26-1.02C (Class 3 Aggregate Base)
.i.26.08 Amendment to 26-1.02B (Class 2 Aggregate Base)
.i.26.10 Amendment to provisions in Section 26, Aggregate Bases

2. Connecticut

Reference: 1992 Connecticut Specifications (source unknown)

SUPPLEMENTAL SPECIFICATIONS

SECTION 1.01 DEFINITION OF TERMS AND PERMISSIBLE ABBREVIATIONS

1.01.01 Reclaimed Waste (definition)
(also see Section 1.06.07, which we do not currently have)
SECTION 2.02 ROADWAY EXCAVATION, FORMATION OF EMBANKMENT AND DISPOSAL OF SURPLUS MATERIAL

2.02.03 Placement of Embankment Material
(includes qualitative description of gradation specifications for glass/embankment material mixes)

SECTION 2.07 BORROW

3. Minnesota

Reference: Minnesota DOT, 1992:

Information Sheet (refer to enclosed sieve analysis work sheets to obtain Class 5 aggregate gradation requirements).


Chapter 13 STORM DRAINS

Amend Section 13.1.5--Subsoil Drains

13.1.5(a) Approved 3/4" crushed-recycled glass aggregate is included as subsoil drain bedding material.

5. New Hampshire

Reference: 1992 New Hampshire DOT, Special Provision

AMENDMENT TO SECTION 304--AGGREGATE BASE COURSES

304.2.1 Materials
304.2.3 Processed Glass Aggregate Gradation
304.2.4 Processed Glass Aggregate/Base Course Blends
304.3.1 Construction Requirements--General
304.3.5 Material Testing

Other New Hampshire DOT References:

Physical Test Results of Crushed Recycled Container Glass and Grain Size Dist.

1992 New Hampshire Department of Environmental Services--New Hampshire Solid Waste Rules

Part Env-Wm 301 APPLICABILITY, PROHIBITIONS AND EXEMPTIONS
Part Env-Wm 308 UNIVERSAL ENVIRONMENTAL PERFORMANCE STANDARDS

25854-001-016

DAMES & MOORE

B-7
6. Pennsylvania

Reference: PennDOT, 1992, Pennsylvania Draft Amendments

WASTE GLASS AS PIPE BACKFILL
(see Section 703.2 (a) and (c), which we do not have)

WASTE GLASS AS EMBANKMENT MATERIAL
(see Section 703.2(a) and (c), which we do not have)

703.2(c) Table D--Size and Grading Requirements for Coarse Aggregates

7. Washington

Reference: 1992 WSDOT Amendments Division 9

Part 9-03 AGGREGATES

9-03.21 Recycled Material
Allows up to 15 percent glass in most aggregates listed in Part 9-03. Permits only 10 percent of the material greater than 1/4 inch sieve size, based upon visual examination and weight.
# Glass Feedstock Evaluation Project

## AVAILABLE SPECIFICATIONS FOR CONSTRUCTION AGGREGATES

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<th>AK</th>
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* Do not currently have spec on hand
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