Handbook
Of
Alternative Uses
For
Recycled Glass

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A Municipal Handbook
For
RECYCLED GLASS & ITS ALTERNATIVE USES

RATIONALE

Public and private waste managers are increasingly relying on commingled collection of recyclables in an effort to improve efficiencies and reduce costs. This continues to generate increasing amounts of 3-color "mixed" glass cullet, which often includes ceramic and other contaminants that sharply reduce the quality and value of the recovered feedstock and restrict its use as a raw material for the manufacture of new containers and fiberglass insulation. (Ref. 1)

Similarly, more and more of the glass diverted for recycling through the State's Bottle Law is being color-mixed. Although reverse vending machines (RVM) do a reasonable job separating glass by color, handlers within the retail outlets, often due to limited space, commingle 90% of the glass into a 3-color mix. Together, Bottle Law (RVM-generated) and Material Recovery Facility (MRF-generated) glass have become increasingly difficult to market for recycling. Even when end-users can be identified, it is often cost-prohibitive (in terms of tip fees and hauling charges) to supply them with mixed glass.

NEED FOR ALTERNATIVE USES

In light of the advent of commingled collection and an absence of viable markets for mixed glass, the big question for New York's recyclers today remains "How to cost-effectively manage glass and keep it out of landfills?" Its relatively low value, combined with increasing transportation costs and expensive tip fees, has necessitated the validation of alternative uses for glass beyond traditional applications. Furthermore, based on glass' chemical and physical properties, and its natural fit as a substitute for sand or gravel in a variety of proven uses, economics suggest that towns, villages, municipalities, and counties would be best served by processing and recycling the glass locally and using it themselves.

BENEFITS

The benefits associated with New York communities using their own recycled materials can be enormous. For example, the avoided cost savings related to transporting and disposing of glass would accrue directly to the locality. In addition, reclaimed glass is a lower-cost, acceptable replacement for virgin aggregates (primarily sand and stone) in several construction applications. As a substitute for sand and stone, using glass would extend the life of an existing quarry and reduce demand for new quarry sites. Similarly, besides cost, burying glass in a landfill shortens the useful life of the landfill.

LITERATURE REVIEW

Glass is an inert material with good compressive strength, hardness, compactability, permeability and workability, making it suitable for a wide array of uses. The following literature review offers information about current and potential uses for waste glass, and the impact that these alternative applications are likely to have on domestic markets.

This report is divided into two, distinct categories:

I. Alternative uses for which there are well-established markets, or high-volume, acceptable uses, and;

II. Promising markets for which glass has yet to be fully accepted, or that still require additional study.

I. ESTABLISHED ALTERNATIVE MARKETS

The established alternative markets for recycled glass reviewed for this study represent data culled from reference manuals, reports, articles and the Internet (Ref. 1-24). These applications are presented in five major categories, with each further subdivided into a variety of specific end uses. These are, for the most part, low-value, high-volume applications that allow a municipality to employ most, if not all of the glass it generates. Minimal handling and processing of the glass does add some costs that are almost certainly going to be offset by the elimination of transportation and tip fees, and the avoided purchase of raw materials otherwise needed for the job.

Established alternative markets include:

1. Construction Aggregates
    A. Roadway construction
    B. Paving Applications (Glass in asphalt)
    C. Bedding & Backfill – (Pipe and utility trenches, retaining walls, foundations, embankments)
    D. Drainage – (French drains)
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6. Economics for Recycling Glass

1. Construction Aggregates

Many communities already have the capability and are processing recovered glass for use in low-end, civil engineering applications. Considerable technical evaluation and pilot-scale demonstrations at the federal and state levels have shown that recycled glass is a viable substitute for stone, crushed rock and concrete aggregates as long as it costs less and performs as well as the materials it is replacing in the field.

It is repeatedly suggested in the literature, that the limiting factor to greater utilization of glass as an aggregate is inadequate knowledge of its engineering characteristics. That may have been so several years ago, but as the references in this report clearly indicate, the only thing lacking is in-field trials to determine the extent to which glass can play a substantive role as a construction aggregate.

For example, engineering analyses included in a recent study by the PA DOT suggest that "as long as glass cullet meets American Association of Highway Transportation Officials #10 (or #8) classification, its strength characteristics and overall engineering performance will be comparable to or exceed those of natural aggregates of the same gradation regardless of the actual processing procedure."… "It should be possible for local municipalities to generate reliable sources of glass cullet with these attributes without the sophisticated crushing equipment associated with quarry operations." (Ref. 51)

Similarly, an unnamed report reviewing engineering properties of MRF glass concludes that glass cullet between ¼-inch and 200-sieve will perform as a highly stable (angular) fine aggregate material, as either a structural fill or granular base material (Ref. 52). However, the suggestion is made that monitored field demonstration programs should be undertaken to better document the performance of granular glass bases in actual applications.

Table 1 lists construction applications for cullet, along with the level of importance (H=high, L=low) that material properties (specific gravity, relative density, durability, soundness) and engineering characteristics (compaction, gradation, permeability, shear strength, workability, safety) has on glass' performance (Ref. 11).

A. **Roadway Construction**

The use of recycled glass as a construction aggregate has been technically well established, and at least 13 states have amended their Department of Transportation (DOT) specifications to allow its use in road projects. DOT's in Minnesota, Kentucky, Oregon, Alaska, Washington, Wisconsin, Connecticut, California, New Hampshire and New York encourage contractors to use glass cullet in road sub-bases, as long as an adequate supply of glass is available that meets the states' specification.

In New York State, in order to use up to 30% recycled glass (by weight) in the sub-base, the glass must be crushed to a maximum particle size of 10 mm, and must not contain more than five percent, by volume, of deleterious material (typically paper and plastic).

To date, performance of sub-base mixtures containing recycled glass has been very favorable. The biggest problem noted in the literature was not the efficacy of using glass, but rather the lack of sufficient quantities of processed material available for major roadway projects. So, contractors instead tend to employ glass aggregate in the construction of town trails, pathways and parking lots.

However, in the State of Hawaii contractors are required to use a minimum of 10% crushed glass aggregate in the base course of public roads as long as enough glass is available at a price no greater than that of an equivalent aggregate. (Ref. 25)

Limitations to glass' use include the recycler's ability to reduce deleterious materials to 5%, as this requires careful processing and vigilance. The recycler must also be able to crush the glass to 10 mm, which often requires processing more than once, slowing operations. There also are safety risks related to handling glass before it's been processed. And, as noted above, there is often not enough material available relative to the volumes necessary for roadway construction. (Ref. 26)

Glass as a component of road sub-base material has another significant obstacle: Even if there is a consistent available supply of glass for this application, there is often enough material removed during the design and construction of a road to put back in the sub-base. Otherwise, that dirt and gravel would have to be disposed!

Table 1.

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However, almost all of the currently acceptable engineering applications for crushed glass, including as a component of road sub-base, are required to meet similar standards. A relatively inexpensive pulverizing system available from Andela Tool & Machine, Inc. (Richfield Springs, NY) can eliminate the drawbacks for processors while efficiently crushing and screening the material to $3/8^{th}$ inch or smaller while leaving virtually no deleterious products behind, producing a safe product to handle even without gloves, and processing up to 20 tons glass/hour. Saratoga Springs, New York and Abilene, Texas currently operate Andela Pulverizing Systems and use glass aggregate in road sub-base. (Ref. 27)

Data from the Federal Highway Administration (FHWA) show that approximately 75% of all paved road surfaces are under local town, municipal and/or county jurisdiction, as compared with four percent under Federal jurisdiction and 21% under State jurisdiction (Ref. 28), making this a viable end-use for almost any locality.

B. Pavement Application: Glass in Asphalt

A glass-and-asphalt paving material, commonly referred to as "glasphalt," was invented over 35 years ago at the University of Missouri-Rolla and is now in use throughout the world to pave roads, parking lots, park trails, roadway shoulders, as sub-base course for roads, driveways and even on general aviation airport/parking aprons and taxiways. (Ref. 29)

According to Delbert Day, one of glasphalt's inventors, "No special equipment is needed, and glass of any color and type from bottles, windows, to glass used from baking and tableware can be used." Crushed to -3/8 inch, large quantities of glass that would otherwise have to be buried in landfills has found a use in glasphalt paving material as a substitute for rock and sand.

In his treatise "Reuse/Recycling of Glass Cullet for Non-container Uses," John Reindl cites over 40 glasphalt references covering a 30-year period from 1967 through 1997(Ref. 20). Included in these references were several municipal studies in 12 states assessing the efficacy of glasphalt in government projects. Overall, findings suggest that glasphalt should be:

a. Limited to pavements with operating speeds under 40 mph;
b. Minus 3/8 to -¼ inch in size;
c. Restricted to 20% of the aggregate mix (Studies to date recommend the amount of allowable glass/aggregate be between 10% - 30%. New York allows for up to 30% of the mix to be glass.), and;
d. Used in conjunction with an anti-stripping agent. Bonding of the asphalt to the glass particles will deteriorate under adverse environmental conditions leading to stripping away of the asphalt from the aggregate. An anti-stripping agent such as hydrated lime or calcium hydroxide can be used to minimize such occurrences. It is worthy to note that during the 1990s, New York City employed 30% glass aggregate successfully without using stripping agents. As a result of the overabundant availability of asphalt aggregate, NYC opted to discontinue its use of glass.

Data emanating from the Turner-Fairbank Highway Research Center (Ref. 30) and published in a late 1990's Federal Highway Administration (FHWA) report, suggest that the use of glass aggregate percentages greater than 25% by weight, and large pieces of glass (greater than 12.7mm = 1/2 inch), contribute most to stripping and raveling problems reported during the early test pavement demonstrations of the 1960s and '70s.

The FHWA report reviewed performance records, engineering properties, mix designs, and material processing requirements, as well as provided an additional 37 references. It noted that the high angularity of cullet as compared with the more roundedness of sand can enhance the stability of asphalt mixes when properly sized cullet is used. Stabilities comparable to and in many cases better than conventional mixes have been reported. Other beneficial characteristics of glass aggregate included its low absorption and specific gravity, and its low thermal conductivity, which reportedly offers enhanced heat retention in mixes with glass. As a result, another desirable characteristic is its ability to reduce the depth of frost penetration due to its thermal insulating properties.

Since the mid-1990s, some 15 states and localities have used or experimented with glasphalt in roads, park trails, bicycle paths, parking lots and airport aprons. In

2003, for example, the Iowa Department of Natural Resources dedicated two new glasphalt projects: A parking lot in Ames and a recreational trail in the City of Wellman (Ref. 31). Approximately 70 tons of recycled glass was used in these projects. According to IA DOT engineer Mike Heitzman, the glasphalt paved surfaces are just as smooth and safe for vehicle tires and pedestrians as those made from the more traditional asphalt mixes.

Also in 2003, in England 35,000 tons of glasphalt developed and produced by RMC Aggregates was used as a base and binder course on several miles of a highway resurfacing project (Ref. 32). Test monitoring performed by TRL Research Laboratories, UK, showed that glasphalt matches the performance of road base materials constructed entirely of traditional aggregate.

Overall, research to date shows that glasphalt performs well compared with conventional pavements. There is no doubt that local recyclers or municipalities can employ recycled glass aggregate, properly sized and screened to specifications, in this application. Although low-end in nature, it would use a large volume of glass and offset the cost of transport and disposal.

C. Bedding and Backfill

A 1993 evaluation of recycled glass aggregate and its chemical and physical properties, performed by consultants from Dames & Moore, Inc., and sponsored by state agencies in Washington, New York, Oregon, Minnesota, California, and by Waste Management of North America and Browning Ferris Industries, enabled Washington's Clean Washington Center to compile a Best Practices report entitled *Model Specifications for Glass Aggregate*, which served as a primary source of information (Ref. 33) for this report. In it, CWC provided specifications for glass aggregate as general backfill, and for trench bedding for utility pipes and fiber optic lines.

Crushed glass can be used by itself as a backfill material, but more generally it is blended with natural aggregate to provide backfill, structural fills and base course. Glass has the added advantage of being free draining when used as a general fill.

D. Drainage

Glass has been found to work exceptionally well wherever improved drainage is required: foundation drains, draining blankets, French drains. Glass is more permeable than sand, compacts easily, holds grade, absorbs no water (unlike sand and gravel) and is relatively inert. (Ref. 34)

NYS DOT's Syracuse-based regional office recently employed glass aggregate between ½ and 3/8 inch for use as filter media for a hydro-demolition bridge project in Central NY. A crushed glass drainage bed was used to reduce the amount of cement slurry and sediment from entering nearby wetlands. The DOT found that the glass "was compatible and/or a superior substitute for conventional media (sand and stone) at a lesser cost." After the material was utilized, it was buried back within the right-of-way as construction and demolition fill. (Ref. 35)

A recent paper by G. Hoffman, Chief Engineer for the PA DOT, summarizes experimental research conducted at Drexel University demonstrating the excellent strength and drainage characteristics of crushed glass. (Ref. 36) These findings led to provisional approval by PA DOT to use crushed glass as drainage fill within the core of embankments, with one limitation: "Glass cannot be employed in top and side slopes, only contained within the core body of the embankment."

Within the core, 100% glass, by weight, can be employed. The glass must contain less than 5%, by weight, of non-glassy material. All the glass particles must pass the 9.5mm (3/8 inch) sieve, and less than 5% can be smaller than the 75um (200) sieve.

Monitoring of PA embankment projects using crushed glass will continue for a period of five years.

E. Septic Fields

Gravel is traditionally used as the medium in septic fields because it is relatively inexpensive and readily available, not because it necessarily outperforms other treatment media. The advantages of gravel-less systems employing glass or other material are that they work as well, if not better than gravel systems and are easy to maintain. (Ref. 37)

In a recent study, crushed glass, along with other media, was found to remove BOD and TSS to the same extent as sand and gravel for similar effective sizes, uniformity and grain shape (Ref. 38). In fact, glass performed well enough to be approved as a substitute for sand in "drain field" applications in several states. (Ref. 39)

F. **Landfill Cover**

Primarily to control flies, rodents, odors, and windblown litter, landfills are required to be covered daily with 6-12 inches of dirt, or approximately 25% by weight of the new solids being placed in the landfill. Alternative Daily Cover (ADC) represents the use of a material other than dirt, such as crushed glass. (Ref. 40)

Processed glass as ADC is a low-value, high-volume application. Crushed glass that exhibits low to moderate conductivity can be mixed with virgin soil to act as an effective ADC material. (Ref. 41) Glass is used as ADC at landfills across the country in NY, MN, MA, and CO, to name a few. (Ref. 42)

Earlier studies had also suggested that pulverized glass could be used as the protective cover and leachate drainage layer without compromising the liner or leachate collection system. (Ref. 43)

G. State Specifications and Guidelines

NYS DOT specifications, regulations and/or guidelines for using recycled glass. (Ref. 44-45)

As an underdrain filter material:

The glass must meet requirements of section 203-2.02 F

Gradation	sieve size	percent passing by weight
12.5 mm	½ inch	100%
9.5 mm	3/8 inch	90-100
75.0 um	200 sieve	0-5

Road Sub-base or in Embankment Construction:

Glass has been approved for use as a component of road sub-base and in embankment construction. In these applications, the processed glass must have a maximum particle size of 10 mm (3/8th inch) and cannot contain more than 5% by volume of deleterious material (paper, plastic, aluminum, ceramics etc. The blended aggregate cannot contain more than 30% crushed glass by weight.

In Hot-Mix Asphalt:

Currently, a special note is included in contract proposals for all hot mix asphalt (HMA) paving projects which allows the contractor to include 3-6% crushed glass, as a fine aggregate, in HMA supplied to agency projects.

The NYS Department of Environmental Conservation (DEC) has established several Beneficial Use Determinations (BUDs) allowing recycled glass to be used as a construction aggregate in a variety of applications: as general fill, in sub-base, foundation drains, as a landfill barrier protection, in glasphalt, and as a filler in the manufacture of plastics.

The following list provides NYS BUD #'s and descriptions of use:

BUD #	USE	Description
137-7-34	aggregate	Manufacture hot mix asphalt
160-6-23	base (road)	Supplement crusher run stone in highway projects
185-6-25	base (sub)	Green glass in Highway construction
161-5-16	base (sub)	Subbase for access road to county landfill
234-0-45	base, filter(sand)	Use glass as subbase for roads & as a substitute for aggregate in the construction of sand filters/foundation drains
229-8-51	fill	Green glass as fill
227-0-0	fill, base,(sub)	Use glass as fill or road subbase
381-4-13	filler (plastics)	Commingled glass, 1-2mm in size, as commercial filler in manufacture of plastics
248-5-58	landfill barrier	Use green glass as fill for Bola Landfill barrier, gas protection layer/gas vent layer

172-1-30	landfill, base,(road)	Use glass aggregate to stabilize landfill roads at the Oceanside Landfill

The specifications being employed to define cullet as construction aggregate in WA, OR, CA, CN, NH and NY appear in a Clean Washington Center (CWC) report on recycled glass from Nov., 1996. (Ref. 46)

Wisconsin's DOT currently recommends limiting the amount of recycled glass to 10-15% by weight in applications where high strength is required. (Ref. 47)

In February, 1999, MN DOT released its aggregate specification 3138(aggregate for surface and base courses), which allows for the use of up to 10% reclaimed glass as aggregate base in road construction projects. (Ref. 48)

Vermont has approved the use of glass aggregate in roadway, bedding and drainage applications. (Ref. 49)

Hawaii lists specs for:

Roadway applications: From 10-15% cullet, by weight, can be blended with natural aggregates. Contaminants must be reduced to 0.2-0.3% of cullet weight, depending on the specific application.

Trench Bedding and Backfill: The contractor can use 100% cullet, with a maximum 0.3% debris level based on the weight of cullet.

Drainage Applications: Drainage media can be comprised of 100% cullet, with 0.2% maximum debris level based on the weight of the cullet.

For any application in HI, 100% of the glass cullet must pass through a 0.375-inch sieve. (Ref. 50)

2. Recycled Aggregate in Concrete

Portland cement, invented in 1824 by Joseph Aspdin, is the fundamental ingredient in concrete. Portland cement consists of calcium (from limestone), silicone (from clay and/or sand), and iron ore. These ingredients are heated in a kiln to form clinker pellets, which are then ground and mixed with gypsum to make the fine, gray powder known as Portland cement.

Standard concrete is composed of 11% Portland Cement, 16% water, 26% sand, 41% coarse aggregate (gravel or crushed stone) and 6% air. (Ref. 53) These ingredients are blended to produce concrete suitable for particular jobs.

There is growing worldwide evidence that, processed adequately, glass aggregate can substitute for sand in the production of concrete. Concrete is durable, moldable and could provide municipalities or private recyclers an opportunity to employ glass as a partial replacement for sand in its manufacture.

The benefits of utilizing glass in concrete include savings on the avoided waste management of the glass, lower-cost concrete, environmental benefits related to the replacement of natural aggregate with recycled material, and secondary market development for local recyclers. However, scientists have not reached consensus on its long-term success, particularly for load-bearing applications.

A. Cement/concrete applications

CSIRO in Australia has performed extensive field and laboratory tests that show that recycled glass crushed and screened is strong, safe and economical to use as a substitute for sand in concrete. Glass reduced to less than 2.46 mm exhibits properties similar to sand, and up to 20% crushed glass has been employed successfully for this purpose. (Ref. 54) CSIRO has published a guide outlining pre-mix instructions for preparing concrete using ground glass. (Ref. 55)

There have been several analyses looking at compression and shrinkage of concrete made with glass sand. CSIRO’s tests showed comparable results to those of standard concrete, and have cleared the way for glass concrete to be employed in a range of construction applications like bike paths, footpaths, curbs, walks and other, similar uses. However, the conclusion is not as straightforward for structural applications of the material.

Ansari, et al. (Ref. 56) saw a reduction in compressive strength as a function of curing age for concrete made using crushed glass, and have suggested that the crushed glass concrete not be used in structural and load bearing applications. Uncertainty remains regarding the long term load bearing characteristics of the material.

Naik and Wu (Ref. 57) studied the use of crushed glass as a partial replacement of sand in concrete. They concluded that both strength and splitting tensile strength decrease slightly with an increase in the replacement rate of sand with crushed glass.

Historically, Columbia University's Civil Engineering Department has been in the forefront of research on concrete technology. Initial studies there suggested that the use of glass was problematic because of the chemical reaction between the alkali in cement and the silica in the glass. This alkali-silica reaction (ASR) created a gel that swells in the presence of moisture, causing cracks damaging to concrete. The result of this phenomenon may not become visible for years. Columbia has found several ways to mitigate this problem, including (Ref. 58):

1. Use of ASR suppressing admixtures, such as metakaolin, to absorb the alkali ions responsible for the reaction;
2. Fine grinding the glass to less than 100-mesh sieve appears to minimize ASR induced damage;
3. Green glass, because of the chromium oxide that gives it color, causes little or no ASR reaction; and,
4. Apply protective coatings to the glass to prevent the ASR reaction from occurring.

Columbia has produced several viable, value-added products utilizing 10% glass substitution for sand, including masonry blocks, and non-structural floor and wall tiles and paving stones. (Ref. 59)

In a Best Practice report by Washington's CWC, *Recycled Glass in Portland Cement Concrete* (Ref. 60), it is suggested that cullet first be washed to expedite the removal of sugar that can cause an unpredictable increase in setting time and decrease concrete's ultimate strength.

Shehata, et.al. (Ref. 61) evaluated the possibility of using up to 20%, 3/8-inch diameter granulated window glass to partially substitute for sand in concrete composites. Three ASTM standard mechanical tests were conducted to assess the product's compressive, flexural and splitting tensile strengths. The primary finding suggested that glass can successfully substitute for sand and acts as a crack arrestor compared to other recycled materials tested.

Shayan (Ref. 62) found that when glass was finely ground to a powder, it could substitute for up to 30% of the cement itself in a concrete mix with no apparent loss of compressive strength. It was suggested that this resulted from the glass acting as a pozzolanic material. Likewise, the finer the glass, the less likely ASR would pose problems compared to when coarse glass particles were employed.

Glass filler has been in regular use in ready-mix concrete production in Sweden since 1995. In a report published by the European Ready-mix Concrete Organization (ERMCO), it was noted that when glass is ground to the texture of Portland cement and added as filler in ready-mix concrete the following results were obtained (Ref. 63):

1. Glass improved the rheological properties of fresh concrete;
2. Workability improved by increased flowability and stability;
3. The need for super-plasticizers and water reducing agents was reduced;
4. Long-term strength was improved due to pozzolanic reactivity of the product; and,
5. Glass improved the frost resistance capacity of concrete designed for frost durability.

Additional tests are presently underway at Stowell Concrete LTD., Bristol, UK, (Ref. 64) designed to optimize the use of glass cement and ensure adequate concrete strength development.

The importance of recycled post-consumer glass within the cement and concrete industries is apparent, as the topic has been the focus of day long seminars attended by scientists, industry representatives and government personnel. For example, in 2004 the University of Dundee, in the U.K. (Ref. 65) ran a series of seminars covering a variety of uses for glass aggregate in cement and concrete applications, including chemical reactivity, engineering properties, durability and specifications for each application.

B. Concrete Stone Pavers, Blocks, Countertops and Tiles

For now, the economics of manufacturing end products such as pavers, countertops, or wall and floor tiles may be beyond the reach of municipal governments or private recyclers. However, recycling programs that provide steady supplies of crushed, screened glass, might attract and develop cottage industries based on raw material availability.

These types of products can be produced in three distinct ways. Manufacturers can utilize a concrete matrix to form a "glascrete." Or, they can use epoxy-type binders as a cementing agent. Finally, they might fuse the glass at exceptionally high temperatures in a kiln.

1. Glascrete

Using research funds provided by New York's Environmental Investment Program, Columbia University developed specifications for the production of paving stones made with more than 80% recycled glass. Subsequently, Columbia licensed the technology to established manufacturer, Grinnell Pavingstone of Sparta, NJ, who has since developed a paving stone made of glass concrete. Although not yet fully commercialized, their development efforts are now in the industrial testing phase. (Ref. 66)

Another recycled product developed with NY EIP support, Ice Stone is marketed as a low cost alternative to natural stone for use in countertops, vanities, partitions, and interior non-structural walls. Originally developed by Great Harbor Design Center in 1998, the Brooklyn business has changed hands and is now called Ice Stone LLC.

Syndesis Inc., in Santa Monica, CA (Ref. 67) makes a pre-cast, lightweight concrete product (Syndecrete) with recycled glass chips. It is less than 1/2 the weight of normal concrete with twice the compressive strength.

Spartan Tiles, based in Ardleigh in the U.K., (Ref. 68) employs glass in specialist concrete tiles. The properties of glass, low absorption of moisture and relative hardness, make it well suited for this use.

American Specialty Glass Inc., UT,(Ref. 69) makes a concrete floor and wall tile consisting of 25% Portland cement and 75% recycled glass chips, which gives the products a terrazzo tile look.

Similarly, Counter Production, LLC, in CA (Ref. 70) manufactures Vitrazzo and Vitracrete, a durable mineral solid surface made of 80%-95% recycled glass. When polished, it is as smooth as marble, four times stronger than standard concrete, and serves as an excellent countertop surface.

2. Binders

Extensive analytical work performed in the late 1990's by Washington's CWC (Ref. 71) tested a number of inorganic binders with recycled glass in the production of paving tiles. It is probable that these early research efforts paved the way for the establishment of many of today's tile and countertop businesses employing post-consumer glass in their finished product line.

EnviroGlas Terrazzo (Ref. 72), a product of the American Terrazzo Co., Garland, TX, is made from recycled post-consumer glass and tinted epoxy resin in a ratio of 80% glass to 20% resin that serves as the matrix. The batch mix is poured in place, troweled onto a floor or counter, allowed to dry for 24 hours, sanded and then polished.

Headwaters Composites Inc., Montana, (Ref. 73) creates custom countertops made of recycled glass and power plant waste with 99% recycled content. The countertops are sanded smooth and protected by a food-compatible acrylic sealant, resulting in a product now marketed as Albian™.

3. Fused or Kiln-Fired tiles

Sandhill Industries, AK, (Ref. 74) a manufacturer of glass wall and floor tiles, has developed a process for making pavers from 99% recycled container glass. By using a controlled de-vitrification kiln strategy, the glass pavers become non-absorbent, as well as opaque and skid-resistant for outdoor applications. According to the manufacturer, they are thinner, lighter, denser, stronger, and perform better in paving applications than brick or concrete.

Other Kiln produced tiles can be found at:

Oceanside Glass Tiles, Carlsbad C
http://www.glasstile.com

Bedrock Industries Inc., Seattle WA, Blazestone Tiles
Tel 206-283-7625 or http://www.bedrockindustries.com

Winona ORC Industries Inc. make fused glass tiles. Contact Bill Harris, 507-452-1855.

3. Decorative Glass Aggregate

a. Colored Glass Gravel

There appears to be growing demand worldwide by architects and designers for “green” materials to use in landscaping and garden design. Because of its physical and engineering properties, noted in the construction aggregate section of this review, recycled glass is well suited for use as a decorative element to: Fill vases, as a surface covering for potted plants, as a mulch covering for flower beds, trees and shrubs, to add sparkle to fountains and ponds, as a surface coat for pathways or driveways, as a filler around tiles and paving stones, and in the production of garden accessories, such as benches, feeders, trivets, coasters, tables, sculptures etc.

The only significant complaint related to the use of glass in landscape applications is that it tends to adhere to shoes and track into homes or offices.

A 1996 study by the CWC provided recommendations for utilizing glass in landscaping (Ref. 75), including:

1. Use -3/8 inch or finer glass cullet;
2. Remove dust fines before application;
3. Utilize a crushing system, (like an Andela Pulverizer), to produce rounded, non-sharp edges safe to handle;
4. Washed glass is more esthetically pleasing;
5. Contaminants, like loose paper, plastic and metal caps, should be screened off;
6. Be able to provide select colors, or color schemes integral to a site’s appearance, (Since the CWC report, major technological advances enable glass to be color-coated, allowing designers to choose any spectrum of the rainbow to meet project needs.) and;
7. Prices will vary from free, to $2,000/ton, depending on quality and color.

A testament to the growth of this diverse application is the number of businesses that have evolved worldwide for the marketing of glass aggregate for decorative purposes. The following are only a handful of examples of businesses already recycling glass for decorative purposes. There are many more. The extent will become apparent as the reader visits additional referenced Web sites.

In California, landscape artist Andrew Cao created a contemporary glass garden (Ref. 76) that captures memories of his homeland, Vietnam, using colored crushed glass. From rice fields to design pools, he used glass to create a variety of different looks and feelings.

Specialist Aggregates in the United Kingdom employs a colorfast coating to a wide array of aggregates used in aquatics and decorative garden projects. Their product is marketed worldwide as Crystaleis (Ref. 77), and is made entirely of crushed glass. It is safe to use around home and garden. It sells in bulk for about $500/ton. It is effective in retaining moisture in the soil, and tends to repel slugs. The Crystaleis grains are strong enough to resist shattering, and the tumbling process employed in its manufacture removes cracked pieces.

The Good Hope Garden Supply Center in Maryland (Ref. 78) specializes in garden and landscape planning with an Asian flair. The business offers the newest in garden couture-sparkling smooth glass pebbles made from 100% recycled glass in a wide variety of colors and sizes.

Winona ORC Industries, Minnesota, (Ref. 79) has developed garden stepping stones, trivets, coasters, plant stands, all from recycled post-consumer glass.

Bedrock Industries, Washington, (Ref. 80) is a clearinghouse for recycled glass (tumbled, crushed or developed into decorative tiles). Tumbled glass is marketed to fill spaces around paving stones, in fountains, and as planter toppings, while crushed glass aggregate substitutes for sand as sub-base material under pathways.

Scatter Creek Enterprises, also in Washington, (Ref. 81) uses 50-65% recycled glass content to produce “glasscrete” stepping stones, benches, birdbaths, and other garden accessories.

Decogem in the United Kingdom (Ref. 82) employs 100% recycled glass with no sharp edges in a wide variety of gardening applications.

According to Campbell's Nursery in Nebraska, (Ref. 83) glass is one of the most popular trends in garden décor today. One unique application is to use recycled glass to produce hand blown glass spheres for making bird feeders.

Décor Glass is an Australian product manufactured by Pebble-Mix Co. Ltd. using 100% recycled glass. It can be covered with a polyurethane coat in 36 brilliant colors and has a wide range of uses, including planter boxes, aquariums, and as landscape mulch. (Ref. 84)

So, similarly, to any of the businesses referenced above, municipal and private recyclers have an opportunity to make and market a value-added, decorative glass product that has a multitude of landscape applications, and which can absorb a large amount of glass. Municipalities could easily use processed glass mulch in a number of park settings or as a colorful embellishment for fountains or gardens. Besides the obvious savings on avoided transportation and waste management, these end uses would reduce raw material costs for the community.

And, an exciting opportunity is just on the horizon that will enable recyclers to easily make decorative glass products. Andela Tool & Machine Co. has just completed development of a relatively inexpensive, modular glass processing and coloring system that not only produces a furnace-ready cullet, but also color coats and dries glass for use in landscaping and garden projects. The average cost for colored glass gravel right now is $1.50-$2.50/pound, and in bulk, $1,350-$2,000/ton, depending on the color needed.

Note:

1. Approximately 10 pounds of 3/8" glass gravel covers one square-foot, one inch deep;
2. One cubic yard of -3/8" cullet weighs about 2,500 pounds, and;
3. The recommended depth for glass mulch laid over a plastic ground cover is three inches.

b. Fountain and Aquarium Gravel

Two types of recycled glass serve as fountain or aquarium gravel: Tumbled or frosted sea glass (naturally or artificially produced), and clear, transparent recycled container glass.

Thelma's Glass (Ref. 85) is an example of real sea glass collected by hand from the shores of the Chesapeake Bay and sold on E-Bay for $5/pound. Similarly, Sea Gems (Ref. 86) constitutes polished glass gravel similar to sea sand that sells for $2-$6/pound, depending on color.

An example of the second type is a transparent glass gravel produced by American Specialty Glass, Inc., Salt Lake City, UT (Ref. 87) that may be lighted from underneath for a spectacular looking aquarium showpiece. The average cost for this transparent glass gravel is $2/pound. Aqua tables, domes and columns employing this clear type colored glass gravel can be found at a number of retail outlets and pet supply stores (Ref.'s 88-92).

By the time large, wholesale distributors begin marketing a product line its producers can be reasonably assured that the product has been publicly accepted. Allsuperstore.com (Ref. 93) sells several types of "sea glass" ranging in price from $2-$3/pound ($4,000-$6,000/ton).

AJ McCormack & Sons, another United Kingdom recycler, (Ref. 94) markets a tumbled glass similar to marine gravel, employing a landscape membrane under the gravel to prevent weed development. AJ charges the equivalent of $115/meter^2 for material ground cover and $94/meter^2 for installation.

However, although tumbled glass sells for as much as $8.50/pound it is time consuming to produce and bulk demand is questionable. Thus, tumbled glass would probably not be economical or feasible for municipal or small-scale recyclers. On the other hand, clear transparent glass in a variety of natural glass colors, clear (flint), amber (brown) and green glass, either separately or commingled as a "mixed" glass, could potentially be worth pursuing by a local processor. This option would depend on whether a local chain or distributor was interested in marketing aquarium gravel to regional wholesale or retail outlets.

4. Abrasives

a. Blast media

One of the most successful local uses for recycled glass is as a blast media. Since glass does not contain heavy metals, and consists of amorphous rather than crystalline silica (the cause of silicosis, a fatal lung disease), it is safer to use than other typical abrasives like boiler slags, sands and heavy metals. It can even be captured and reused several times.

Unfortunately, acceptance within the industry remains a significant hurdle, and it is unlikely that glass will be accepted as a blast media until environmental or health regulations are imposed on the alternative materials being used. The only rational explanation for the industry's resistance to glass is that there must be a strong lobbying effort by slag producers to maintain the status quo and preventing newer, safer products from making inroads.

Based on NIOSH (National Institute for Health and Safety) studies conducted in 1998 by industry test laboratory, KTA-Tator (PA), comparing 40 different abrasives, glass works as effectively and is safer to use than other media presently employed. So, why glass is not the number one abrasive used for blasting, and particularly for coating removal, remains a mystery. (Ref. 95)

The literature is replete with comparative tests that show conclusively that, for most applications, glass outperforms traditional abrasives employed to clean, finish, peen, de-burr, frost and engrave a variety of different substrates. They can be employed dry or wet, using a variety of blasting equipment with variable pressure adjustments. Glass works well in standard blasting equipment whether wet or dry.

Two excellent sources of information about the use of glass as an abrasive include a CWC Best Practice paper (Ref. 96), and two New York State EIP reports on behalf of Boro Recycling Inc. (Ref. 97) that analyzed how to design a state-of-the-art glass recycling facility and evaluated alternative uses for glass.

Boro, following the NIOSH protocols and KTA's testing facility, repeated the earlier NIOSH experiments that utilized recycled container, "Type A glass media," which had not been tested during the original NIOSH comparative analysis. Glass media, regardless of size, performed well against all 40 abrasives to remove mill scale and lead paint plus mill scale. Glass blasting actually removed corrosion from carbon steel surfaces to a "near white" condition. Plus, its most significant benefit from a public health standpoint is that airborne concentrations of crystalline silica were non-detectable during all phases of the investigation looking at container glass. It was this finding that led the investigators to conclude that “the absence of free silica as an airborne contaminant will eventually be the key to entering the abrasive market.”

Appendices 4 and 5 of this report are included as an addendum and serve to outline the breadth of the abrasive industry and the fact that glass can play a substantive role as an abrasive medium.

Worldwide, articles attesting to glass’ success as a blast media have led to several applications, including:

- In Liverpool, England, graffiti is a persistent problem. The standard practice for removing unwanted graffiti involves a solvent pre-treatment of the surface, followed by wet blasting with sand. When recycled glass particles between 250 - 600 microns are used in a wet blast system, cleaning is more efficient and there is no need for the solvent pre-treatment. This represents an opportunity to reduce raw material costs and eliminate potential health risks associated with silica sand, slags, and cleaning solvents.

- In Kent County, England, glass was used for a major renovation of the Grove Ferry Bridge (near the Village of Upstreet). According to the project manager, the glass performed excellently. Cleaning rates were better than with copper slag (commonly employed), and there was none of the dusty surface residue that you sometimes get from copper slag. Using glass, the community also eliminated any risk of copper slag residue falling into the river. (Ref. 98)

- VISY Glass (Queensland, Australia) is a recycled glass abrasive that is safe to handle, achieves a good profile, cleaning rate and anchor pattern using lower pressures. With this product, the contractor saves on fuel and power costs for compressors, and causes less wear and tear on hoses and nozzles. (Ref. 99)

- In its technical Bulletin, *Micro-Abrasive Media Selection Guide* (Ref. 100), Comco Inc. of Burbank, CA documents the effect of micro-abrasives (<200 microns and up to 0.008 inches) focusing on the glass’ shape, hardness and particle size. In it, glass is compared to six other media. The manufacturer suggests that glass should be used in a micro-abrasive apparatus "where only a light degree of abrading is desired." (This is very different than when glass media is employed as "grit" in larger blasting equipment. As grit, the big particles scour the rust off steel and other hard surfaces.

♦ Grand Northern Products, MI offers 13 different loose abrasives for a variety of applications (Ref. 101). Unfortunately, information provided by the company on glass abrasives lacks the detail needed to help the consumer understand the value of glass in particular applications, and how glass compares in performance with the 12 other, more traditional media.

♦ Aloha Glass Recycling, Maui, HI uses an Andela pulverizer to produce a coarse, medium and fine abrasive for commercial sale as a blast media or as a filter aid in water filtration. (Ref. 102)

Optimistically, larger glass grit is increasingly recognized as a safe, environmentally-preferable and cost effective alternative to traditional abrasives used by the shot blast industry. Since it is inert, free of toxic metals and crystalline silica, disposal costs are less than for other blast media.

Cost comparisons show that, pound-for-pound, glass grit should head the list of preferred shot blast for all users. On a tonnage basis, the average price of common abrasives in the same size range is: Glass grit, $1,200/ton; Steel Grit, $1,500/ton; Walnut shell, $2,000/ton; Silicon Carbide, $3,200/ton; and Aluminum Oxide, almost $4,000/ton.

So, if glass performs as well, if not better than most abrasives at a lower cost, why wouldn't municipalities employ glass as a substitute for other blast media? Any locality could purchase a small glass processing system and generate its own abrasive from MRF-generated glass. With the proper crushing system, like the Andela Raptor, and a series of vibratory screens, a multitude of different-sized particles can be isolated, including blast media.

By making their own abrasives, communities could reduce the need to purchase higher priced materials, offset the cost for managing the glass, eliminate the need for extensive on-site inventories, and allow for one, readily available media in varying size ranges to be used to handle most, if not all tasks requiring blasting. Machine maintenance, bridge maintenance, truck and trailer renovation, rail and rail car maintenance, graffiti removal, building cleaning, statue and park bench refurbishment are just some of the applications local governments are responsible for.

Converting glass already diverted for recycling as a blast media is a simple, cost-effective end use for the material.

b. "Sand" Paper

True sand paper (ie. backing paper covered by grains of sand) is no longer available commercially, but has been replaced by backing sheets covered with glass, aluminum oxide, silicon carbide, garnet or other type grit. The size of grit is used to classify the "glass paper" by grade as follows:

Grit Size	Grade
40-60	course
80-100	medium course
120-150	medium
180-220	fine
>240	extra fine

True glass paper is composed of quartz granules on a paper backing. It is an inexpensive, relatively soft abrasive for sanding painted or natural timber, metal and other materials. It wears fairly quickly and is best at providing a rough finish before attempting a smooth surface. (Ref. 103)

c. Traction Sand

Scranton, PA DOT employs ground glass for anti-skid purposes on roads. Apparently, it does not clog disbursing equipment the way traditional materials often do. But, PA's DOT has not yet approved glass for this purpose. (Ref. 104)

A second reference described the use of crushed glass as traction sand by railroads to provide traction under the wheels of trains. (Ref. 105)

4D. State Specifications for Abrasives

A literature search did not reveal any New York State specification for the use of glass as an abrasive or blast media. The only citation came from the Center to Protect Workers Rights (CPWR). The research arm of the Building and Construction Trade Department, AFL-CIO, states unequivocally: “The use of abrasive coatings containing more than 1% crystalline silica is prohibited.” (Ref.106) As there is no crystalline silica in recycled container glass, this material fulfills this stipulation.

APPENDIX 4. THE ABRASIVE INDUSTRY

1. Tasks performed by abrasives include:

de-burring	beveling	cutting	dicing
shaping	dressing	marking	peening
etching	de-scaling	polishing	texturing
lapping	trimming	engraving	contouring
cleaning	stripping		

2. Type of equipment employed range in size from table top models to self contained, fully automated buildings 50ft wide, 60 ft. high, 120 ft long for stripping, priming and painting box cars.

pencil type blasters	bench cabinets	airblast rooms
wheelblast cleaners	tumble blasters	vibrating finishers
paint stripping booths		

3. Type of materials used as an abrasive:

nylon	rice hulls	garnet-Gemblast
apricot pits	walnut shells	dry ice pellets
corn cob grit	cut wire	sand/silicates
zircon	pumice	coal slag/ Black Beauty
glass beads	fine-grind cullet	steel shot
steel grit	plastic beads	sodium bicarbonate
poly carbonates	sub-micron powders	metal oxides/ aluminum oxide

4. Abrasives, which differ in hardness, are used to remove;

grease/oils/grime	oxidation	paint
scale	coatings	flashing
burrs	surface contaminants	rust/corrosion

Or their used to polish, peen or texture the surface.

5. Industrial Uses and/or Industries Served:

airplane	aerospace	aluminum industry
automotive parts	railroads	trucks/trailers
ship building	structural steel	heavy equipment industry
machine die-casting	pressure vessels	transformers
coatings	foundries	electrical switch gear
cleaning molds	forging	medical equipment
composites	plastic industry	cleaning circuit boards

APPENDIX 5. Abrasive Type and Characteristics

Abrasive Type	Shape	Hardness (MOHS)	Bulk Density lbs./cu.ft.	Dust	Reuse Factor
Aluminum Oxide	Irregular	8/9	120	low	good
Steel Shot	Spherical	8	250	very low	high
Garnet	Subangular	7	140	moderate	fair
Mineral Slag	Angular	7	85	moderate	fair
Fine-Grind Glass	Angular/SubA	6	90/100	low	fair
Glass Beads	Spherical	5.5	90/100	low	fair
Silica Sand	Rounded/Irreg	5/6	100	high	low
Corn Cobs	Angular	4	30	low	good
Nut Shells	Subangular	3	45	low	good
Plastic Grit	Angular	3	60	low	good

ANCHOR PATTERN - SURFACE PROFILE

Abrasive Description	Sieve Size	Mesh in MM	Anchor Profile/Mil Depth
Extra Coarse	4-16	4.75 - 1.18	4.0 - 5.0 mils
Coarse	12-30	1.7 - 0.6	2.5 - 3.5
Medium Coarse	16-40	1.18 - 0.425	1.5 - 2.0
Medium	20-50	0.85 - 0.30	1.0 - 1.5
Medium Fine	40-100	0.43 - 0.15	0.5 - 1.0
Fine	50-120	0.30 - 0.125	0.5 minus
Very Fine	80-200	0.18 - 0.075	0.5 minus

For Comparison Purposes

Ground Coffee - Medium Coarse - 16/40 mesh
Table Sugar - Fine - 50/80

GlassBlast/ fine grind/ 30-60 mesh provides a profile consistent with other abrasives, based on KTA's results, between 2.0 and 3.0 mil depending on the protocols employed.

Factors For Selecting Abrasives - There are, at least 12 factors that should be considered in the selection of an abrasive medium.

TYPE - May be Natural, Diatomaceous Earth
By-Product, Mineral Slag
Manufactured, Glass
Manufactured abrasives cost about 10 times that of the other two. Included in this group: Steel grit, aluminum oxide, silica carbide, plastic grit, glass beads, and glass fine-grind.

COMPOSITION - Glass is amorphous silica, whereas silica sand is crystalline in form and a potential health risk

SHAPE - Angular/Sub-angular, round, spherical, cubical, irregular
Angular cleans some 30% faster than round, produces a deeper profile, and a cleaner surface.

HARDNESS - Measured in MOHS or Rockwell Scales - The degree of hardness influences the type of material that can be cleaned; the cleaning rate, grit size, dusting and reuse factors. Depending on the material to be cleaned, generally, the harder the abrasive, the better.

BULK DENSITY - Weight in lbs./cu.ft. - The heavier the grain the faster the velocity of the particle.

DUST FACTOR - Concern for health and safety of the worker. The softer the grain, or the lower the MOHS rating, the more friable the abrasive.

FREE SILICA CONTENT - A major health concern and OSHA regulated. Glass is an amorphous, as opposed to a crystalline silica and is considered a nuisance dust. It is non-hazardous because it generally contains less than 1% free silica. In the KTA studies conducted, free silica was non-detectable as an airborne contaminant when glass was being used as an abrasive.

BREAKDOWN FACTOR - Determines the number of times an abrasive media can be reused. Type A container glass is less friable than plate glass and has a lower breakdown rate. The ability to recycle the medium directly correlates to the use cost of the medium.

MESH SIZE - The National Bureau of Standards sets the screen sizes for uniformity of end products. The mesh size, or range of particle sizes within the medium, directly affects cleaning rate and anchor pattern (surface profile).

CONSISTENCY – The ability to provide media with similar characteristics from batch to batch.

Availability - The ability to produce, and the end user's location are critical to any project and directly impact cost.

PRICE - Cost/ton FOB manufacturer's door.

5. Filtration

A. Waste Water & Potable Water

Mounting evidence indicates that processed glass functions well as a water filtration medium (Ref.'s 107). According to Piccirillo and Letterman (Ref. 108), recycled pulverized glass of proper grain size is an effective alternative to silica sand as a filter medium in slow sand filter systems. Studies performed at San Jose State University (Ref. 109) confirmed the efficiency of recycled glass filter media, describing it as "incredibly superior to the efficiency of sand" in the removal of turbidity. Filtering with 40-mesh glass is more efficient, and takes less time and requires less water volume to backwash than comparably sized sand.

In addition, research by Dryden Aqua Corp. in the United Kingdom (Ref. 110) indicates that recycled glass can successfully substitute for traditional media used to treat municipal and industrial wastewater, and filter swimming pools. Dryden Aqua produces and markets AFM (active filtration media) using green and amber glass. Although more expensive than traditional sands, the performance and operational cost benefits associated with AFM's use in water treatment include enhanced particle removal, reduced bacterial contamination, easier backwashing, extended media life cycle and improved safety.

In 1997, the town of Oswego, NY (Ref.'s 111-112), with the approval of the NYS DEC, constructed a 15,000 gal/day re-circulating intermittent granular media filter for wastewater treatment. The filter media consisted of crushed 3/8th inch, recycled container glass cullet rather than sand. An evaluation of system costs and performance data from the facility indicated that the recycled glass cullet is an effective alternative to natural sand.

Pilot studies by G.E. Vans, et.al. (Ref. 113) confirm that the performance of glass media in a potable water treatment application was similar to that of a typical sand medium of similar effective size and uniformity under all conditions tested.

Likewise, pilot studies at the PA American Water Co.'s Hershey water treatment plant in 1993 showed that glass outperformed sand as a filtration medium, experiencing longer filter runs, better turbidity reduction, and glass backwashed readily with less water loss. (Ref. 114)

B. Pool Filtration

Unlike gravity systems generally associated with wastewater treatment, pool-type filters operate under pressure, pushing water through the filter from the suction side of the system. Crushed recycled glass has demonstrated strong potential as a replacement for sand and diatomaceous earth (DE) in swimming pool filters. Glass has unique properties compared to traditional media that allow it to perform well in this application:

a. Ground glass has a net, negative electrical charge that serves to attract particles to its surface; and,

b. The smooth surface of the glass makes it difficult for bacteria to adhere allowing for increased backwash efficiencies.

DE is naturally-occurring amorphous silica made from the remnants of algae called diatoms. For all practical purposes, a diatom, in its living state, is a biological cell encased in glass. The microscopic pores in DE filters typically catch smaller particles of dirt than sand filters. It is a surface filter medium, in that any dirt or suspended solid that is filtered is held on the exposed surface of the DE powder.

In home pool systems, DE is introduced in a slurry, usually through the pool skimmer, while the pump is running. DE flows into the filter and forms an even coat over the septum (the cloth that covers the grids or filaments) inside the filter. The coat formed is usually 1/8 - 1/4 inch thick. Within a pool environment, body oils, dirt and pollen act as binding agents holding the DE cake to the septum, even when there is no flow. Removal of the DE and contaminants occurs through a backwash mechanism requiring that the DE be recharged when the difference between starting pressure and ending pressure approaches 6 lbs/square-inch.

In 1999, with support from New York’s EIP, Boro Recycling Inc., Maspeth, NY (Ref. 97) undertook a study to determine if crushed, pulverized glass could substitute for DE in pool filtration systems. In a series of pilot studies (using a 40 gallon/minute Hayward EC 40-75 DE pool filter), HydroQual Inc., a NJ-based water testing facility, found that:

a. Glass has the ability to pre-coat and sustain its pre-coat similar to DE. Neither media slumped (fell from the septum) over a twenty four hour period;

b. Total suspended solid removal efficiencies and filter effluent quality were similar to DE, and;

c. Finely ground recycled glass contained fibers consistent with paper and cellulose acetate fibers, a normal constituent of cigarette filters;

d. The presence of these fibers probably contributed to the medium’s ability to filter out suspended solids, and;

e. Glass can be substituted for DE in pressurized pool filtration systems.

As a note, in a separate study to determine whether similar glass media could be employed in an industrial application for primary stages of beer filtration, the results suggested that glass is not as effective as DE when suspended solids are very high in concentration.

In New Zealand, a filter media consisting of recycled glass and developed by the Recovered Materials Foundation called Filter Crystal exceeded all standard specifications for swimming pool filter media. (Ref. 115)

Seattle, WA-based Tri-Vitro sells a screened glass filtration media for local swimming pools.

Dryden Aqua’s AFM filtration media has been used by the commercial and private swimming pool industry for years. Based on quantitative analyses of the performance of AFM versus sand filter media, AFM provides significantly better water quality, reduces the need for chlorine, and presents a much lower risk for bacteria, fungi and parasitic infections. AFM is self-sterilizing, and tends to prevent bacterial development in the filter bed.

AFM is in use in over 40 pools and spas in Great Britain and none of the filters have failed or needed to be changed. Unlike sand filter media, which needs to be replaced every few months, AFM under similar conditions will last for several years. The product is proving so successful that Dryden Aqua built a new production facility to manufacture 100 tons/day of AFM.

In 1997, side by side tests comparing two Triton filters (model TR 140) with 75 gal/min filtering rates were performed to assess the difference between sand and crushed glass of similar size in pool maintenance in a water park in Lubbock, TX. Glass was found to be superior to sanitized sand, less expensive, required less energy to operate, filtered more material per unit time, required less backwashing time and was easily cleaned and sanitized for re-use. (Ref. 116)

In 1999, Leem Filtration Products Inc. of Ramsey, NJ employed several tons of crushed glass filter media to solve a turbidity problem encountered in three huge ponds at the Westin Maui Resort hotel in Hawaii. After replacing silica sand with glass, and PVC laterals (used to clarify flow) with stainless steel laterals, the Westin reported a 50% reduction in make-up water consumption, thousands saved in labor and maintenance, and all three ponds became and remained clear. (Ref. 117)

An EIP-sponsored research, development and demonstration project by Pantec, Inc. (Port Gibson, NY) showed empirically that glass sand performed at least as well as silica sand in residential pool filters, and saved homeowners on operating costs (Ref. 118). However, when the company attempted to do a similar, side-by-side comparison at the commercial scale, State regulators would not allow it, even though the project was to be carefully monitored and included funds for restoring the three pools (one at a local YMCA, one at a large theme park and one at a local school) if problems arose.

In general, worldwide use of processed glass as filter media for improving water quality in wastewater, storm water runoff, swimming pools and home septic systems is definitely growing. However the use of alternative filter media here in the U.S. is still largely limited to research, despite the fact that crushed glass has been repeatedly shown to work better.

It seems the key to achieving greater acceptance of glass as a filtration media in the U.S. continues to rest on approval for this application by State and local officials, who continue to resist the notion that a recycled glass product could perform as well, if not better than traditional materials and not lead to adverse health or environmental impacts. When this is finally accepted, local demand for glass filter media will easily employ the majority of municipally-generated recycled glass.

5C. State Specifications for Filtration Media.

Despite an abundance of references citing the use of recycled glass and its approval in a wide variety of filtration applications, there are no New York State specifications for glass as a filter media for either pool or potable water filtration.

Instead, State Health Department guidelines listing swimming pool design standards (Section 6-1.29 10.1.1) state that, "Filter media sand or other media shall be carefully graded and meet manufacturer's recommendation for pool use."

So, as long as design filtration rates in section 6-1.29 10.1 for rapid sand filters, or section 6-1.29 10.2 for pressure or vacuum filters, are met it would appear the choice of media is left to the manufacturer. However, as noted in the discussion of glass as a pool filter media, New York Health Department regulators are hesitant to allow the use of glass media in public pools. DOH approval of processed, recycled glass in commercial-scale filtration applications would go a long way toward establishing a long-term, viable market for recycled glass, a material that has access to very few, economical end-uses.

As a reminder, Active Filtration Media (AFM) made from 100% recycled container glass has been approved and has been used for several years in the United Kingdom for home pool filtration because it works better and more efficiently than traditional sand media.

In Australia, *Zelbrite* is an advanced filtration material that outperforms traditional pool filtration media, sand and diatomaceous earth. It is manufactured from zeolitic material, which is formed as a result of volcanic activity. Glass, as previously discussed, acts like a zeolite. (The active ingredient in *Zelbrite* is the mineral Clinoptilolite.)

6. THE ECONOMICS OF RECYCLING GLASS

For the purpose of this discussion, let's assume that a municipality wants to process all the glass collected locally and not incur any cost for transporting it to a recycler or landfill, and avoid related tip fees.

Andela Products,Ltd. (Richfield Springs, NY) has developed a computer-based cost/benefit analysis for total glass recycling by both private and public entities. Since each recycler collects varying amounts of material of different quality, and faces diverse labor rates, distance from landfills, tip fees, etc., Andela's analysis tool allows the user to prepare a custom spreadsheet that assesses the most cost-effective management practices for their glass (free of charge).

A simplified description of the spreadsheet analysis can be found in a 1998 article written by Cynthia Andela and published in Solid Waste Technologies. (Ref. 133) However, given the value of glass stemming from alternative use markets developed since 1998, Andela has modified its software to reflect the value to municipalities that utilize the glass themselves, as an abrasive, filtration media, construction aggregate, or decorative landscape aggregate. This type of alternative, local utilization is then compared with the cost of land filling or processing the glass for more traditional end uses like in container or insulation manufacture.

For a free consult and cost saving analysis, call Cynthia Andela or David Hula at Andela Products,Ltd. (315) 858-0055.

II. PROMISING ALTERNATIVE MARKETS

For the most part, alternative end-uses for recycled glass are just beginning to achieve a level of market penetration that could, over the next few years, potentially create new markets. However, these applications require a level of processing (in some cases to micron-size particles) that goes well beyond most municipal capital budgets. Likewise, a good deal of research is still needed to justify specifications for glass in several of the applications described here. The attractiveness of these markets will stem from their high-end value, which range from $200/ton to as much as $25,000/ton.

a. Fillers – For glass to be employed as an industrial filler needs to be ground to a consistency of a fine powder. At that point, it could be used to replace calcium carbonate in paints, as an additive to plastic lumber, and in tire production to replace a variety of clay fillers. (Ref. 97)

b. Hydroponics – In a study conducted by CWC (Ref. 119-120), researchers found no statistical difference between glass-grown basil and control-grown basil employing an expanded clay aggregate as the soil substrate.

c. Soil amendment – In another CWC study (Ref. 121), topsoil replacing 60% of the sand with glass cullet produced plants of equal or greater growth size compared with plants grown in a standard topsoil.

d. Foamed glass insulation is an inorganic insulator that does not burn, has a low heat conductivity, exceptionally high strength, and tends to be water insoluble and corrosion resistant in most acids. (Ref. 122)

e. Traction Deicer – Michigan Technology University has incorporated glass, limestone waste and food waste into a new product called Trac-Deicer (Ref. 123). The mixture of crushed glass and CMA (calcium magnesium citrate) is proving as effective as salt for maintaining winter roads and appears to be much less corrosive on steel and road surfaces.

f. Glass Cable – Replacing steel with glass fibers may extend the life of a typical bridge from 50 years to 200 years. Surprisingly, glass when woven is stronger than steel. (Ref. 124)

g. Frictionator – Glass has been found to serve as a "frictionator" for lighting and firing in the production of matches, match book striker surfaces and ammunition. (Ref. 125)

h. Fluxing agent – Glass as a brick fluxing agent reduces firing temperatures and firing time, leading to an increase in production capacity and reduced fuel consumption. (Ref.'s 126-127)

i. Medical uses – Micron-size ground glass serves as a fine abrasive in dentistry. Radiation housed in micro-spheres of glass bead is also being used to fight inoperable liver cancer. U.S. FDA recently approved glass' use in this application.(Ref. 128)

j. Insecticide – Terrestrial insects breathe through a complex network of air tubes called Trachea that open to the outside through a series of small, valved apertures (spiracles) along the sides of the body. Operators of fine grind facilities note that insects are seldom seen near by, suggesting that fine, micron-size glass dust particles may clog the spiracles and cause suffocation.

k. Adsorbent and cation exchange material – Glass can substitute for zeolites (naturally-occurring compounds used to separate molecules based on differences in size, shape and polarity) or in ion exchange systems like water softeners that swap softer alkaline metals for "hard" calcium.

l. Glass end products –
   Marble production (Ref. 129)
   Jewelry and art deco projects (Ref. 130)
   Pressed glass (Ref. 131)
   Wine goblets (Ref. 132)

These are examples of some of the many end products that can be produced using recycled glass today.

Summary of Main Alternative Uses of Waste Glass (excluding remelting)

Insert here

REFERENCES

The following reports and studies are referenced throughout this Handbook. They offer information on a variety of secondary uses for glass cullet:

1. EPA-USA – 2003
   http://www.epa.gov/epaoswer/non-hw/recycle/jtr
   Click "Search JTR Net"
   Scroll down to Commodities
   Click "Glass" (Provides 18 Glass categories with references relating to each topic

2. University of New Hampshire – Technology Transfer Ctr.
   Pulverized Glass Aggregate – Alternative Uses
   http://www.t2.unh.edu/spring03/pg6.html

3. Glass Packaging Institute – Secondary Uses for Cullet
   http://www.gpi.org/cullet.html

4. WRAP – Waste & Resources Action Program, Oxon, UK
   http://www.wrap.org.uk

5. EPA, Wexford, Ireland and Clean Technology Centre, Cork, Ireland, *A Strategy for Developing Recycling Markets in Ireland*
   http://www.epa.ie   http://www.ctc-cork.ie
   Open EPA site
   Click "Research & Development"
   Click Reports, Report #7
   Select Fact sheets –Glass

6. University of Exeter, UK, *Alternative Uses of Glass*
   http://www.ex.ac.uk/CSM/wtrc/glass

7. Clean Merseyside Center, UK
   http://www.clean-merseyside.com/markets/materials.html

8. Remade Kent& Medway, UK
   http://www.remade-kentmedway.co.uk

9. Tri-Vitro Corp., Kent, WA, *Alternative Uses*
   http://www.trivitro.com/news/news.html

10. Clean Washington Center, *Alternative Glass Use Briefs*
    http://www.cwc.org

11. REMADE Scotland, *Glass Recycling Technology Handbook*
http://www.remade.org.uk
Click on "glass"
Click on "documents"

12. Montana Public Interest Research Group, *Alternatives*
http://www.pirg.org/montpirg/issues/waste.html

13. Minpro International Ltd., Ontario, Canada
http://www.minproint.com/glass/result.html

14. Strategic Materials Inc. Houston, TX
http://www.strategicmaterials.com/products/products.html

15. Re-Sourcing Associates
http://www.rsarecycle.com/glass.shtm

16. Sustainable World, UK
http://www.sustainableworld.org.uk

17. Andela Products Ltd., NY
http://www.andelaproducts.com/glassuses.html

18. Universal Ground Cullet, Inc., Ohio
http://www.groundcullet.com/htdocs/applications.htm

19. Glass Aggregate Systems, MN
http://www.glassagg.com

20. John Reindl, *Reuse/Recycling of Glass Cullet for Non-Container Uses*, 132 pp., July 17, 2003
http://www.glassonline.com
Click on "Research & Surveys"
Last Report in Sequence
E-mail: reindl@co.dane.wi.us

21. King County, WA - Environmental Purchasing Program
http://www.metrokc.gov/procure/green/glass.htm

22. Christ Church City Council, New Zealand
http://www.ccc.govt.nz/CityScene/2002/May
Click on *Real Recycling Made Easy – Glass from Curb to Flooring*

23. Oregon Department of Environmental Quality, *Oregon Container Glass Recycling Profile* http://www.deq.state.or.us/wmc/solwaste/glass.html

24. Michigan Technological University, *Mining Glass from the Waste Stream - Alternative Uses* http://www.imp.mtu.edu/information/wgpc.html

25. HI Statute 103D-407, Construction projects, roadway materials; recycled glass content requirements.
http://www.capitol.hawaii.gov/hrscurrent
Click on "vol02 Choo46-0115"
Click on "hrs0103D"
Click "hrs0103D 0407"

26. NY DOT, *Solid & Hazardous Waste Reduction Policy,* August 1999.
http://www.dot.state.ny.us/eab/manual/wastered.pdf

27. TX DOT Recycling Coordinator, Rebecca Davio (512)416-2086

28. U.S. DOT *Reauthorization of the Federal Surface Transportation Research Program: Recycled Material Research*
http://www.FHWA.dot.gov/reauthorization/rmrt01.htm

29. *Glasphalt May Pave the Way for Aviation in the 21st Century*
http://www.sciencedaily.com/releases/1997/11/971110064723.htm

30. FHWA Turner-Fairbank Highway Research Center, *Report on Waste Glass – User Guidelines*
http://www.tfhrc.gov/hnr20/recycle/waste/wg3.htm

31. IA Department of Natural Resources
http://www.iowadnr.com
Click on "DNR News"
Scroll and click on "eco news 2003"; Archive
Scroll to "April 18, 2003"

32. *Glass Proves Clear Choice for Motorway Renewal*, RMC Aggregate: The Environmentalist, Oct. 2003
http://www.barrett-byrd.com
Click on "StopPress (left side)"
Scroll to "Oct., 2003" article

33. CWC, *Model Specifications for Glass Aggregate*, 1997
http://www.cwc.org gl-bp-4-01-04.pdf
Click on "Best Practices"
Click "Glass"
Scroll & click on "Table of Contents"
Scroll to report.

34. B. Terney, *Pulverized Glass Aggregate*, 2003.
University of NH Technology Transfer Bulletin
http://www.t2.unh.edu/spring03/pg6.html

35. C. Anderson, *Glass Helping NYS DOT Manage Storm Water Runoff*, 2003.
http://www.nerc.org/bulletin/20030901.html

36. G. Hoffman, PE, PA DOT: *Embankments Incorporating Crushed Glass,* Report #400-02-02, Aug. 2002

37. Pipeline News Report: Gravelless & chamber systems: alternative drainfield designs.
http://www.septic-info.com/doc/display/9.html

38. U.S. EPA National Risk Management Research Lab, 2/04. *On-site Wastewater Treatment System Technology Fact Sheet #10 – Intermittent Sand/Media Filters*
http://www.epa.gov/ord

39. Clean Washington Center. *Crushed Glass as a Filter Medium for the On-site Treatment of Wastewater*, Report #GL 97-2, 1997.
http://www.cwc.org

40. *WI Employs ADC.*
http://www.uwex.edu/ces/shwec/uwgb/landfill.htm

41. Ontario Waste Division Organization, *Minpro Crushed Glass Demo Project*, WDO Report OPT-R2-06, Nov. 2001

42. *Glass Contamination Results in Some Glass not Being Recycled,* Larimer County, CO
http://www.co.larimer.co.us/natural/glassadc.htm

43. B. Schmucker,PE & Buffalini, R., *Pulverized Glass and Landfill Liner Systems*, Waste Age, P. 252, 4/95.

44. NY DOT Standard Specifications, January 2002
http://www.dot.state.ny.us/specs/files/17605120.000.wpd

45. NY DOT Solid & Hazardous Waste Reduction Policy, 8/99.
http://www.dot.state.ny.us/eab/manual/wastered.pdf

46. State Specifications for the Use of Cullet as Construction Aggregate.
http://www.cwc.org
Click on "Best Practices," glass

47. WI Transportation Bulletin #20, Using recovered Materials in Highway Construction, 1999.
Copy Available: Transportation Information Center
LT/AP – (800) 442-4615

48. Minnesota Technology Transfer Program
http://www.cts.umn.edu/T2

49. HI, Crushed Glass Specifications
http://www.state.hi.us/dot/highways/specs94

50. VT Waste Management Div., *Procedure Addressing Acceptable Uses of Solid Waste*, July, 2000.
(802) 241-3444

51. PA DOT SEM Program Office, *PennDOT Partners With Private Industry on Glass Recycling*, 2002.
Contact Kenneth Thornton, (717) 783-3616.

52. Waste Glass – User Guidelines
http://www.tfhrc.gov/hnr20/recycle/waste/wg3.htm

53. Portland Cement Association, *Concrete Basics*.
http://www.cement.org

54. CSIRO, Australia
http://www.cmit.csiro.au/innovation/2002-04/glass.htm
E-mail: Robert.Peile@csiro.au or Tel: 61 3 9252 6587

55. CSIRO, Australia
Contact Ken Anderson E-mail: Ken.Anderson@csiro.au

56. F. Ansari, et.al. *Recycled Materials in Portland Cement Concrete*, NJ DOT Report #FHWA 2000-03, 6/00.

57. Naik, T.R. and Z. Wu. *Crushed Post-Consumer Glass as a Partial Replacement of Sand in Concrete*, Report #CBU-2000-17

58. Christian Meyer, *Concrete Materials Research at Columbia University*, Technical Publication Review, 8/00. E-mail: meyer@civil.columbia.edu

59. *Development of Glass Concrete Products*, Columbia University, NYS ESD Contract #C 003089, 1999.

60. Clean Washington Center – Best Practice Report, *Recycled Glass in Portland Cement Concrete* http://www.cwc.org

61. Shehata, I. et.al. *The Use of Solid Waste Materials as Fine Aggregate Substitutes in Cementitious Concrete Composites*, 1996.
Semisesquicentennial Transportation Conference Paper.
http://www.ctre.iastate.edu/pubs/semisesq/session2/shehata/

62. Shayan, A., *Value Added Utilization of Waste Glass in Concrete*, AARB Transport Research, Australia, IABSE Symposium, Melbourne 2002

63. *ERMCO '98 In Action Report: Section – Recycled Glass as Filler in Ready Mixed Concrete.* Http://www.apeb.pt/congress/theme9.htm

64. *Using Ground Cullet as Cement Replacement.* http://www.wrap.org.uk/conglasscrete/project115.asp

65. University of Dundee, UK. Seminar Series: *Use of Recovered Glass in Concrete.* February & March 2004
http://www.dundee.ac.uk/civileng/research/concrete/fmglass.htm

66. *Glass Concrete Paving Stones*, 8/03
http://www.civil.columbia.edu/meyer/paving.html

67. Syndesis Inc., Santa Monica, CA
http://www.syndesisinc.com/crete/fcrete.html

68. Spartan Tiles
http://www.remadeessex.org

69. American Specialty Glass Inc., Utah
http://www.americanspecialtyglass.com/

70. Counter Production, Berkeley, CA
http://www.counterproduction.com

71. CWC Report No. GL-99-2: *Testing of Recycled Glass and Inorganic Binder Paving Tiles*.
http://www.cwc.org

72. American Terrazzo Company, Garland, TX
http://www.americanterrazzo.com

73. Headwaters Composites Inc., Three Forks, Montana
Deborah Hedley (406) 285-3949

74. R. Kirby. *Development of Recycled Glass Paving Materials*, EPA Contract# 68D01043
Sandhill Industries Tel: 907-451-6508
http://www.sandhillind.com/productgallery.asp

75. *Landscaping Applications for Recycled Glass*
http://www.cwc.org bp/gbp4-0601.htm
Click on "Best Practices"
Scroll down & click "Table of Contents"
Scroll to bottom, "Landscaping"

76. The Glass Garden Inc., CA
http://www.landscape2go.com

77. Specialist Aggregates, UK
http://www.specialistaggregates.co.uk/products.html

78. The Good Hope Garden Inc., MD
http://www.montgomerycountymd.com/home/goodhope.htm

79. Winona ORC Industries, MN
http://www.moea.state.mn.us/lc/purchasing
Click on left, "Glass: stepping stones"

80. Bedrock Industries, WA
http://www.bedrockindustries.com
Click on "Gifts and Garden"

81. Scatter Creek Enterprises, WA
http://www.scattercreek.homestead.com

82. Decogem, UK
http://www.decogem.com

83. Campbell's Nursery, NE
http://www.campbellsnursery.com

84. Pebble-Mix Co. PTY., LTD. Australia
http://www.decorpebble.com.au/html/decorglass.html

85. Thelma's Sea Glass Collection
http://pages.ebay.com/search/items/basicsearch.html
Type in: Sea, beach, aquarium, jewelry or mosaic
Click "Search Exact Phrase"
Click "Search title" & "Description"

86. Sea Gems
http://www.gelstuff.com/seagems.html

87. American Specialty Glass
http://www.americanspecialtyglass.com

88. Custom Aquarium
http://www.customaquarium.com

89. Stohans Gallery
http://www.stohans.com/bubblepanel3.html

90. Pool and Spa
http://www.poolandspa.com/catalog/product000779000044.cfm

91. Pet-Care-Plus
http://www.pet-care-plus.com/dynamic/aquarium-gravel/23.htm

92. World Pet Store
http://www.worldpetstore.com/worldpets/aqcoftabaq25.html

93. AllSuperStore.com
http://www.allsuperstore.com
Click on "W – water well planters"
Click on "Sea Glass"

94. AJ McCormack & Son, UK
http://www.tmac.clara.net/paving

95. KTA-TATOR, Evaluation of Substitute Materials for Silica Sand in Abrasive Blasting, PA, 1998.

Phase 1. Laboratory Studies, NTIS PB 99-105553
Phase 2. Field Studies, NTIS – PB 99-140964

Phase 3. Comparison of Field & Lab studies,
NTIS – PB 99-140972

96. Clean Washington Center, Best Practices BP-GL4-04-02 *Using Glass as a Blasting Abrasive*, http://www.cwc.org
Click "Best Practices"
Click "Table of Contents"
Scroll to "Industrial Minerals"

97. Boro Recycling Inc., NY Dept. of Economic Development, Office of Recycling Market Development Contract # C003206, *Glass Recycling: A Proposed Plant Design and Alternative Market Analysis*, 1998,Contract # C003316, *Glass Recycling: An Evaluation of Recycled Glass and its Contaminants*, 1999.

98. ReMade Essex – Shot Blasting Case study
http://www.remadeessex.org.uk/shotblasting.htm

99. Visy Recycling – Recycling Made Easy
http://www.visyrecycling.com.au
Click on "Recycling Made Easy"
Click on "Glass"
Click on "Recycled Products"

100. Comco Inc., Technical Bulletin: *Micro-Abrasive Media Selection Guide*, 2001.
http://www.Comcoinc.com

101. Grand Northern Products, MI – Blasting Products
http://www.gnpltd.com/products/media/blasting

102. Aloha Glass Recycling, Maui, HI
Tom Reed, (808) 871-8544

103. Diytools Inc., UK, Bulletin: *Glass Papers - Types & Their use.*
http://www.diydata.com/tool/abrasives/sandpaper.htm

104. L. Shedlock, Glass for Traction: A cutting edge Idea, Scranton Times Tribune, 12/10/2003.
http://www.zwire.com/site/news.cfm?newsid=10639977

105. Universal Ground Cullet, Brookpark, OH.
Traction Sand: Contact #216-267-8057

106. Model Specifications for the protection of Workers from Lead on Steel Structures. August 2002. The Center to Protect Worker's Rights, 8484 Georgia Ave., Suite 1000, Silver Spring, MD. 20910. 301-578-8500

107. a. Clean Washington Center, *Evaluation of Crushed Recycled Glass as a Filter Medium in Slow Sand Filtration*, 1995. Technology report GL95-4

b. Clean Washington Center, *Crushed Glass as a Filter Medium for the On-Site treatment of Wastewater*, 1997. Technical report GL97-2

108. Picirrillo,J. & R. Letterman, *Examination of Pulverized Waste Recycled Glass as Filter Media in Slow Sand Filtration*, 1997. New York State Energy, Research & Development Authority, Report# 97-13 .

109. Dr. Guna Selvaduray, San Jose State University, (408) 924-3874

110. Dryden Aqua, UK
http://www.drydenaqua.com/afm

111. R. Elliott, PE. *Evaluation of the Use of Crushed Recycled Glass Filter Media in a Re-circulating Granular Media Filter*, 1997.
http://www.nesc.wvu.edu

112. Thiel, T., A *New Use for Mixed Glass Cullet*.
http://www.americanrecycler.com/12glass.html

113. G.E. Vans et.al., *Use of Recycled Crushed Glass as a Filtration Medium in Municipal Potable Water Treatment Plants*, 2002. Water Supply vol.2 No5-6 pp. 9-16.

114. *Recycled Glass Used to Recycle Water*.
http://www.ccc.govt.nz/ourenvironment/23/recycledglasswater.asp

115. RMF Glass Products, Christ Church, New Zealand
http://www.rmf.org.nz/index.cfm/products1

116. Texas Water Rampage, Lubbock, TX, Sand Filter Media: Glass vs. Sand, Final Report, October 9, 1997.

117. Leem Filtration Products Inc. Ramsey, NJ (201) 236-4833

118. Contact Project Manager, Brenda Grober at Empire State Development's Environmental Services Unit, (518) 292-5342, or bgrober@empire.state.ny.us

119. Clean Washington Center Report #GL 96-2, *Testing the Use of Glass as a Hydroponic Rooting Medium*.

120. *Hydroponics as a Hobby*. http://www.ext.vt.edu

121. K. Moller & Leger, S.,*Crushed Glass Cullet Replacement of Sand in Topsoil Mixes*. CWC Report #GL97-10, 1998. http://www.cwc.org

122. Foamed Glass http://www.permonline.ru

123. Michigan Technology University, *Researchers Seek Replacement of Road Salt*, Technical Topics: 1997. http://whyfiles.org/shorties/nosalt.html

124. Glass Bridges http://www.popularmechanics.com/science/transportation

125. Secondary Uses of Cullet: Frictionator http://www.gpi.org/cullet.html

126. Fluxing Agent, Universal Ground Cullet, (216) 267-8057 Http://www.groundcullet.com/htdocs/applications.htm

127. Fluxing Agent, PA DOT: Recyclable Materials Supply & Demand Workpaper, Alternative Uses. http://www.dep.state.pa.us Search for "fluxing agents"

128. University of Missouri-Rolla, Research News, Delbert Day Elected into the National Academy of Engineering for Cancer Research, 2/12/2004. http://www.umr.edu/index.php?id=1586&tt_news

129. Marble Production

http://www.landofmarbles.com/marbles-make.html

130. Art Deco Sites:
http://www.recycledglassworks.com/homepage.html
http://www.flatbottle.com
http://www.auroraglass.org

131. T. Gedik & Krebs, K., Fire & Light Unites Recyclability with Beautiful Local Glassware. Fire & Light Inc., 5/96, Arcata, CA
(800) 844-2223 or (707) 825-7500

132. Green Glass Inc., USA. Schofield, WI.
Contact: Sean Penrith, (715) 355-1897
http://greenglass.org/contact.php

SUMMARY OF MAIN ALTERNATIVE USES OF WASTE GLASS (EXCLUDING REMELTING)

APPLICATION	PRODUCTS TO BE REPLACED	POTENTIAL ADVANTAGES OF RECYCLED GLASS PRODUCT	POTENTIAL DISADVANTAGES OF RECYCLED GLASS PRODUCT
CONSTRUCTION AGGREGATE BASE COURSE FOR ROADS, LAND DRAINS,BACKFILL	CRUSHED ROCK AGGREGATE	SIMILAR OR LOWER COST. RESISTANT TO LOAD UNDER COMPRESSION AND IMPACT. GOOD DRAINAGE PROPERTIES	ENGINEERING SPECIFICATIONS CAN BE MATERIAL SPECIFIC OTHER RECYCLED MATERIALS (E.G. CONSTRUCTION WASTE) AVAILABLE.
CONSTITUENT IN CONCRETE	CRUSHED ROCK AGGREGATE / GRAVEL. PARTIAL REPLACEMENT OF PORTLAND CEMENT AND POZZOLANS SUCH AS FLY ASH	LOW COST AND DECORATIVE COLOR. FINELY GROUND GLASS SUPPRESSES ALKALI SILICA REACTIVITY	CAN CAUSE REDUCTION IN MECHANICAL STRENGTH DUE TO ALKALI-SILICA REACTION (ASR)
GLASPHALT	CRUSHED ROCK AGGREGATE	SIMILAR OR LOWER COST. ENHANCED NIGHT VISIBILITY LOWER BULK DENSITY	GLASS CAN BE DE-BONDED FROM THE SURFACE. GLASS PARTICLES COULD CAUSE CUTS AND TIRE DAMAGE. INCREASED GLARE.
DECORATIVE AGGREGATE	CRUSHED ROCK AGGREGATE/GRAVEL	DECORATIVE COLORS PLUS FACTORS GIVEN ABOVE	IMPURITIES SUCH AS LABELS. AL RINGS AND STEEL CAPS NEED TO BE REMOVED. PERCEPTION OF CUT POTENTIAL.
ABRASIVE	SILICA SAND,STEEL SHOT/GRIT,GARNET, GLASS BEADS,COPPER & NICKEL SLAG, OLIVINE AND ALUMINUM OXIDE	COMPETITIVELY PRICED. EFFECTIVE PERFORMANCE WITH ANGULAR PARTICLES. IMPROVED SAFETY- GLASS CONTAINS NO CRYSTALLINE SILICA AND HAS A LOW HEAVY METAL CONTENT	NONE IDENTIFIED
FILTRATION MEDIA	SILICA SAND, DE, ANTHRACITE	LOW COST. RESISTS BACTERIAL GROWTH.	LOCAL HEALTH REGULATORS NEED TO APPROVE ITS USE.
FILLER IN PAINT AND PLASTICS	CLAY, CARBONATES.		REQUIRES EXPENSIVE PROCESSING – FINE GRINDING
FLUX/BINDER IN CERAMICS & BRICKS	MINERAL FLUXES, SUCH AS CLAYS.	LOW SOFTENING TEMPERATURE. REDUCED FIRING TIME AND FUEL CONSUMPTION	NONE IDENTIFIED
ADSORBENT AND CATION EXCHANGE MATERIAL	NATURAL CLAYS & ZEOLITES, CALCIUM SILICATE HYDRATE	LOW COST. DOES NOT BECOME "STICKY" WHEN WET	NO COMMERCIAL PRODUCTION FACILITY TO DATE
FRICTIONATOR FOR MATCHES & AMMUNITION	GLASS IS THE PREFERRED MATERIAL		NONE IDENTIFIED
HYDROPONIC ROOTING MEDIUM	EXPANDED CLAY AGGREGATE	FREE FLOWING AND EASILY STERILIZED	CAN CAUSE CUTS WHEN HANDLED WITHOUT GLOVES DEPENDING ON PROCESSOR