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Possible Re-Utilization of Municipal Solid Glass Waste: A Critical Review

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Abstract

The recent study summarizes the possible applications of glass waste and identifies their new eventual applications. Several possibilities of re-use were revealed and classed into three categories construction materials (concrete, cement and mortars), ceramic materials (ceramic glass, tiles, porcelain brick and glazes) and miscellaneous (zeolite, filtration media and abrasive media). The preparation procedures of these materials from waste glass as an aluminosilicate precursor are taken into consideration. The impact of this strategy on the environment and the economy is shortly reviewed. The results exhibited here show new prospects for glass cullet valorization, in various fields, providing an innovative and eco-friendly solution for waste minimization as well as resources conservation.

Keywords: Wastes glass • Porous materials • Construction materials • Zeolites

Introduction

Every year, a large quantity of waste glasses is discharged from cities and factories in the word, which cannot be efficiently recycled or reused. For example, according to the recycling association in 2022, the output of waste glass in China is 22.75 million tons in 2021 while the recycling of waste glass is only 10.05 million tons, this value represents about 46% of the total waste. In the United States, close to 11.6 million tons of solids waste glasses was produced in 2012 and approximately 28% was recovered more or less 700,000 tons of glass is consumed, in Spain each year and only 70% of the total is recycled. The glass packaging institute (2015) estimated that about a tonne of natural raw materials can be saved per tonne of recovered glass used in the production of new glass products. Furthermore, using 10% of glass cullet, in the preparation of new glass may leads energy savings of 2-3%. It was also improved that the one tonne of CO_2 released can be avoided by recycling six tonnes of glass waste from post-consumer containers. Facing this enormous numbers, and because of the non-biodegrability propriety of waste glass, it has been shown that valorization and recycling of waste glass becomes a necessity to obtain durability and to maintain natural resources by minimizing the area of the depot, conserving money and energy. Numerous researches reported the use of glass cullet in construction materials (concrete, mortar and cement, it is re-utilization as a sustainable building material is among the researches that have received considerable attention in the construction industry as it may reduce the greenhouse emissions and potential environmental menace. Glass waste was used as potential material in ceramic-based products (ceramic glass, tile, porcelain, and glaze). Apart from its use in building and ceramic industry, glass cullet has been found to install some interesting properties in other applications, it was confirmed that waste glass is a potential raw material for zeolites materials abrasive and filtration media.

Literature Review

In this short paper the available glass wastes are reviewed and the possible strategies for their transformation into very high added materials are considered.

Glass wastes: A brief summary

Glass waste derived from household waste can be classified into three categories depended on glass composition of the glass. Glass is essentially made up of network formers (70-72% SiO_2 and 1-2%

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Al_2O_3) and network modifiers or "fluxes" (0-1% MgO, 9-14% CaO, 10-13% Na_2O and 0-1% K_2O). The type of chemical bonds formed between the oxygens of the formers and the network modifiers causes the formation of Q_3-like structures, Q_2, Q_1 and Q_0 which are less stable compared to Q_4 (in the quartz structure), involved the formation of fused silicates called "Glass". The advantage of alkaline earths in the composition of glass (Be, Mg, Ca, Sr, Ba, etc.) is the constitution of more stable and less polarized bonds compared to fully ionic bonds formed by alkali metals (Li, Na, K, Rb, Cs). These last elements are used industrially in order to decrease the melting temperature during the manufacture of glass. The addition of chemical elements from the family of poor metals (sometimes called post transition metals or post-transitional metals Ga, Zn, Al, Cd, Pb, etc.) leads to the modification of the viscosity glass.

- Hollow glass: Bottles, food jars and jars, perfume bottles, goblets, glasses, and other glass containers, except those made of crystal;
- Flat glass: Sheet glass and mirrors;
- Technical glass: Television and computer screens, light bulbs, fluorescent tubes, crystal, glasses, Pyrex plates and dishes and ceramic hobs. More than 95% of the glass manufactured is silico-sodo-lime glass (their silica content is between 70 to 75%). Glass was considered as inert material under common environmental conditions that can be reused in different ways without modifying its chemical properties

Household waste: Glass recovered from household waste are generally, broken glass, bottles and other containers of clear and colored glass, which is normally expensive to be sorted by color. Because only clear cullet glass (recycled glass typically containing 20% flat glass and 50-90% hollow glass) can be used to produce new clear glass containers, clear glass waste is more valuable than cullet, with a mixture of colors that has a relatively low commercial value.

Windshields: Each year, vehicles contribute significantly in the production of waste. In recycled vehicle waste, glass accounts for about 3% by weight. Laminated windshield glass ends up in landfills because of the adhesive Polyvinyl Butyral (PVB) films between the two glasses. Spent PVB film leads to a laborious recycling process to separate the glass from the film.

Fluorescent tubes: Fluorescent tubes generally consist of a glass tube of variable diameter at each end of the electrodes made of a tungsten filament. The inner face of the tube is induced with a fluorescent powder, with a small amount of mercury (limit of 3.5 mg per bulb). Based on data published by the Protection Administration Environmental (EPA) of Taiwan, the average number of spent fluorescent lamps produced each year is about 3.8 tubes per person.

Electronic waste: Monitors and television screens represent the principal glass components in electronic waste. Cathode Ray Tubes (CRTs) are discharged glass envelopes containing an electron gun and a fluorescent screen: They are facilities used as video display components of outdated technology televisions and computers. They represent the main e-waste problem as their weight is between 50% and 85% of the total weight of a computer monitor or TV. They are composed of different glass components (neck, funnel, glass panel and frit) to which several coatings are applied. These coatings interfere with the recycling and reuse of CRT glass. They are also made of glass of different compositions, containing dangerous and hazardous elements (lead, strontium, antimony, barium, europium, selenium, etc.). The neck and funnel glasses contain PbO (25% and 22-28% respectively), while the panel glass is made of a barium-strontium glass, and the connection between the panel and the fried named cone is made of low melting point glass (high P or Bi glass). Not functioning Liquid Crystal Displays (LCDs) represent also a constant fraction of electronic waste. About 10% of the total mass of LCD waste is made up of the front frame, the LCD panel, which mainly consists of two glass plates with a mixture of liquid crystals sandwiched between them. Glass for this application is generally nearly alkali-free and free of As, Sb, and Pb. It includes significant amounts of B_2O_3 along with silica, alumina, and alkaline earth oxides. It is possible to salvage liquid crystals from LCD screens from the not working LCDs, thus the glass panels are lost. Glass recycling is the process of transforming waste glass into usable products. For this reason, waste glass must be separated by its chemical composition (separated into different colors) because the glass retains its color after recycling.

Discussion

Possible reuse of glass

The reuse of glass waste has received an increasing attention in, many parts of the word, for example the reutilization of glass containers is a practice that has become entrenched. This strategy was envisaged as the best sustainable one, because there is no reprocessing and pretreatment to need. In the UK a recent study, improve that the delivered-to doorstep containers for milk found that returnable glass containers have the same environmental impact terms as competing products. The modification toward worldwide integration has implied that food and drink glass containers are diverse in forms and, often come from remote areas, for these reasons, the reuse of container was considered as uneconomical and impractical way in terms of logistics. That's why, in many countries, the recovery of intact glass bottles has seen a decline, magnifying the need for recycling. In the recent study, three potential factors were considered to evaluate the suitability of glass waste for each application: Process ability, technical performance and environmental impact. The first one depends on physical and chemical properties of the glass waste such as particle size and chemical characteristic, which makes some specific process impractical. The second parameter is the technical performance, which means that even if glass waste can be easily treated, the obtained product cannot be used unless it exhibited excellent technical properties. Finally, the third factor is the impact on the environment. The valorization of glass waste must be at minimum energy consumption and carefully weighed against producing new pollution sources elsewhere (Table 1).

Potential use of glass waste
• **Cementous materials** • Cement production • Concrete • Ultra-high-performance concretes • Glass-based mortars • Self-compacting concrete • Ordinary concrete through the construction of sidewalks and slabs
• **Ceramic** • Bricks • Tiles • Glass ceramic • Porcelain • Glaze
• **Miscellaneous** • Abrasive media • Zeolite • Filtration media

Table 1. Possible application of glass waste.

Considering these three factors as well as the characteristics of glass waste, numerous potential applications for glass waste were identified and grouped into three categories (Table 1). A detailed description of each utilization is discussed in the following lines, along with specific technical and environmental considerations.

Construction materials: Glass waste was considered as non-hazardous materials due to their mineral and inert character but very stable and non-degradable material.

There are two main methods for recovering glass waste:

- Reuse them if they are intact.
- Recycle them as raw materials.

After collection, the glass still undergoes several stages of automatic sorting to remove impurities, before being crushed to cullet, to be introduced with the raw materials in order to form the melting bed. The use of cullet has many environmental advantages, it does not require the extraction of natural raw materials and avoids the consumption of 60 kg of fuel oil per ton of cullet used for the extraction of raw materials, it avoids the transport of natural raw materials over long distances to transport the cullet over shorter distances. It limits air pollution due to displacement. It limits the release into the atmosphere of pollutants (carbon dioxide and sulfur dioxide) caused by making glass from natural raw materials, it reduces the melting temperature and therefore saves 40 kg of fuel per ton of cullet used. One possible way to reuse glass waste is its incorporation in construction materials.

Cement production: Cement was considered as the key material the concrete industry, which is a fine powder that sets after being mixed with water. Portland cement is one of the most common types and is manufactured from limestone ($CaCO_3$) mixed with clays and other materials containing alumina and silica. This mixture is then heated in rotary kilns at temperatures between 1540 and 1600°C. The resulting product is called "clinker" and consists of different proportions of Tricalcium Silicate ($3CaO·SiO_2$), Tricalcium Aluminate ($3CaO·Al_2O_3$), and Dicalcium Silicate ($2CaO·SiO_2$), together with small amounts of magnesium and iron compounds. Gypsum is often added (4% (w/w)) to slow the hardening process.

Use of waste glass in a cementitious matrix: Glass waste can be used in the form of glass aggregates as well as in powder form. Many researchers have highlighted the pozzolanic nature of glass. This pozzolanic activity is sometimes similar or greater than to certain additives or additions cementitious such as fly ash or silica fume. On the other hand, the presence of alkalis and alkaline earth metals (Na^+, K^+, Ca^{2+}) as well as the amorphous silica in glass waste makes it possible to be used as a raw material to manufacture cements geopolymers. It should be noted that these cements are more ecological than Portland cements and the durability of the cementitious matrix containing glass powder was also the subject of several works.

Pozzolanic activity of glass: The pozzolanic activity of glass waste has been observed according to several protocols. All work showed that powder glass is a pozzolanic material with delayed activity compared to other additions cementitious That's why powder glass can be employed to substitute quartz powder in ultra-high-performance concretes, Soliman, et al. demonstrate that compressive strength values of about 196 and 182 MPa after two days of hot curing can be achieved when replacing 50% and 100% of quartz sand with glass sand, respectively, compared to 204 MPa for reference ultra-high-performance concretes containing 100% quartz sand [1]. Other studies consider that glass waste as substitute cementitious binders.

Use as aggregates and granular corrector: The use of aggregates or glass powder as a granular corrector is one of the more suitable ways for the recovery of glass waste. On the one hand, their mechanical properties are near to those of quartz (sand) also, they are available in the form of aggregates approximately 1 to 5 cm, which makes it possible to adapt the grain size so as to achieve compactness structural strength possible. The use of glass as a granular corrector requires optimization of the granular mixture. Wang studied the influence of the incorporation of glass as fine aggregates in three different mixtures to obtain strengths, 21 MPa, 28 MPa, and 35 MPa, at a replacing level ranging from 0% to 80% [2]. The results exhibited that compressive strength declined significantly when the replacement level outmoded 20%. The particle size of glass waste used as fine aggregate by Tuaum, et al. was in some way less than the fine aggregate [3]. Abdallah and Fan investigated the characteristics of concrete containing finer crushed glass used as fine aggregate in the best ratio to obtain the highest compressive strength of concrete blocks, and the effect of glass aggregate replacement level on the rate of the expansion resulted from the alkali-silica reaction [4]. Borhan, et al. discussed the properties of glass aggregate to produce concrete reinforced with chopped basalt fiber [5]. The results demonstrated that there is a negligible decrease in compressive and tensile strength by increasing glass aggregate to more than 20%. Sikora, et al. concluded that glass waste can be used as reinforcement with normal fine aggregate in cement concrete without reduction in samples performance [6]. Furthermore, the use of glass waste as fine aggregates can reduce the thermal conductivity and the absorption rate of cement

Alkali-silica reaction of glass powder: Numerous studies have carried out on the behavior of glass (crushed and granular) in a cementitious matrix. It appears that fine glass classes similar to the cement granulometry and have a significant pozzolanic activity without any risk of alkali-silica reaction. On the other hand, glass aggregates present both an activity pozzolanic less important (compared to the glass powder) and a very important alkali-silica reaction responsible for the formation of the gel (N, K–C–S–H) inside the aggregates (Table 2).

Areas of application: Glass waste can be employed in several applications, like:

- Ultra-high-performance concretes through the construction of a footbridge based on crushed glass.
- Glass-based mortars.
- Self-compacting concrete.
- Ordinary concrete through the construction of sidewalks and slabs.

Glass waste sources	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	Na_2O	K_2O	TiO_2
Urban glass waste	2.72	54.44	27.51	1.51	6.38	1.51	3.13	1.27
Urban glass waste	11.20	72.10	1.73	0.70	0.28	13.15	0.63	0.05
Urban and industrial glass waste	12.53	83.57	2.43	-	0.86	-	0.33	-
LCD glass waste	2.70	64.28	16.67	0.20	9.41	0.64	1.37	0.010
LCD	8.61	71.10	16.50	1.23	0.27	0.04	0.04	-
Bottle glass	22.06	65.60	2.37	2.17	2.40	1.99	0.86	-
Bottle glass	9.83	67.79	3.90	1.97	0.93	13.83	0.68	0.10
Bottle glass	9.44	70.00	3.51	0.87	0.52	13.89	0.86	0.06
Bottle glass	11.15	72.27	1.49	-	-	13.37	-	-
Fluorescent lamp glass	7.43	68.80	2.40	2.70	0.11	15.18	1.42	-
Lamp glass	5.98	74.00	2.04	-	-	12.45	-	-
Ground container glass	12.30	70.30	1.90	1.68	0.42	12.80	0.23	-
Recycling facility glass	8.85	71.65	2.12	7.55	0.16	0.30	-	-
By-product of industrial glass bead	9.70	72.50	0.40	3.30	0.20	13.7	0.10	-

Table 2. Chemical composition of glasses that have been studied in alkali-activate materials preparation/manufacturing (wt.%).

Ceramics: Due to their interesting properties, Ceramics based materials are employed in several fields. Those compounds are manufactured generally from malleable and earthy materials (clay) at high temperatures. Silica was considered as the most commonly inert used in the glazing of ceramic structure in combination with stiffeners and melting agents. In respect to the wide range of existing ceramic requests and the manufacturing procedure involving high temperatures, and high consummation of silicate-based natural raw materials, glass waste was considered as a potential candidate to substitute the natural resources. The ceramic industry involves building ceramics (bricks, tiles), the manufacture, of glass ceramic, pottery, porcelain and glazes.

Bricks: Dondi, et al. studied the influence of introducing two types of glass cullet, from crushed TV sets and PC monitors (screen glass) at different levels (2% and 5%), on the performance of bricks containing carbonate-rich and fine-grained clay [7]. The authors demonstrated that the application of glass cullet as raw material had almost no change on the working moisture of the unvaried clay bricks (variation between 32.3% and 33.9%), which is the desired amount of water transfer a specific consistence during the forming procedure. Also, they observed a slight modification in the Pfefferkorn plastic index when glass waste from crushed TV glass were introduced, but the use of screen-based glass cullet resulted in a little increase, which may be due to the higher shear resistance. The authors also reported that the addition of glass cullet from screen glass caused a slight decrease in dry flexural strength, which may result in a greater susceptibility of dried clay bodies to breaking during handling and when exposed to the weight of other unfired bricks placed over them.

Tiles: The application of glass cullet in the production of ceramic tiles is reported by numerous studies. Lin, et al. effects of sintering temperature on the properties of ceramic tiles produced from solar panel waste glass, they demonstrate that solar panel waste glass can be employed at 30-40% with tolerable modifications of the technological comportment and performance of ceramic tiles [8]. The obtained ceramic tiles have a high added value similar to other applications in which the solar panel waste glass can be used. Furlani, et al. demonstrated that a mixture with 60 wt.% steel slag and 40 wt.% glass cullet can be sufficient to obtain ceramic tile with high performance. The tile contains LCD waste glass as a flux material substituting for the traditional feldspar was studied by Kim, et al. The results showed that, the eco-friendly ceramic tile prepared from the glass waste are sintered at 1150°C during industrial production [9]. However, the results of the present work show that depending on glass cullet content the desired ceramic tile properties can be achieved even at 1100°C. This means that the energy consumption and the use of feldspar in the tile industry can be replaced by the introduction of the glass waste.

Glass ceramics: Vitreous substance can be prepared from glass cullet by two processes. The petrurgic method is one of the currently available strategies for recovery glass cullet which consist to covert glass cullet into glasslike by cooling very slowly from its molten state. The powder method, is considered as the second process to treat glass cullet into ceramic products where the glass is fine-grained, compacted and then exposed to high temperatures. Numerous results, discussed the effects of glass cullet on the density of glass-ceramics and improved that increasing the glass cullet content typically increase ethe matrix density. Lu, et al. used waste glass to prepare sintered glass-ceramics from waste with the addition of different Magnesium Oxide (MgO) contents as modifying agent to improve the bulk density of the prepared product [10]. Sintered glass-ceramics was synthetized from fly ash mixed with clay and recycled soda-lime glass by Ponsot, et al. was focused on the development of glass-ceramic composites using industrial waste [11]. Ceramics were produced using a simple powder technology route (dry pressing) were produced. The obtained products were characterized by high crystalline microstructure and high-density values. Which confirm that the obtained material demonstrates, good durability.

Porcelain: Different types of glass waste were used in the preparation of porcelain materials Andreola, et al. observed a decrease in the viscosity of quartz dissolution and liquid phase formation after incorporating glass cullet as Na-feldspar substitute in porcelain tiles [12]. The authors also observed the porcelain materials contain 5% glass cullet and presented good apparent density and lower porosity. However, it was reported that the increase in amounts of glass cullet (up to 35%) could cause some modification on the ceramic microstructure, and leads to the appearance of new crystalline phases. Glass cullet can be also a potential, substitute for a relatively small amount of feldspar (around 35%) to act as a blending agent to facilitate the glazing at lower temperatures.

Glaze: Glass waste was considered as good candidate on the constitution of glaze to finish ceramic products. During firing this layer, with different colors (be glossy or matte), is melted and fused with the clay's surface. Andreola, et al. investigated the possibility of including the glass cullet as ceramic frit substitute for the production of pigmented, flame-hardened and silk-screened glazes for floor tiles. The authors improved that the tiles glazed with glass waste presented the same aesthetics and chemical properties to the control tiles. Dal Bó, et al. studied the possibility of replacing ceramic engobes by ceramic frits with glass waste [13]. The authors observed that, increasing the glass content in the engobe formulation, can increase the linear shrinkage water absorption decreased. Pulverized glass cullet was applied by Caki, et al. as sodium and potassium feldspar substitute of ceramic glazes [14]. It was observed that the increasing of glass content leads to slight difference in the colors of obtained product (cobalt blue and copper green), increase in the thermal expansion coefficient and caused surface cracking. Ponsot, et al. used zircon and borosilicate glass to adjusted the shrinkage, viscous flow and glaze's color. Dima, et al. observed that the incorporation of glass in the glaze preparation affect the linear thermal expansion coefficient, for this reason the authors indicated that the inclusion of glass cullet should be made with care taking into account the thermal expansion coefficient [15].

Miscellaneous

Glass as abrasive media: Due to their hardness property glass material, suitable for use as an abrasive media. This normally require the form of using crushed cullet in a conventional shot peening setup. However, the utilization of recycled glass in this area has also been introduced, as well as the use of aluminum oxide particles included in "sponge media" made from recovered glass to clean metal surfaces. Ben arungro , et al. founded successful results with supports made from molded and sintered glass powder used for vibrational mass finishing instead of ceramic particles bonded to polyester resin 16 .

Zeolite matrix: Zeolites are crystalline porous minerals. They are aluminosilicates materials. Those compounds can be natural or synthetic. They are employed in many industrial fields in adsorption, separation, catalysis, medicine, agriculture and sensors. Due to their high silica content, waste glass has been considered as an important raw material in the preparation of zeolites products. The idea of using glass waste to prepare synthetic zeolite is based on the fact that both materials have a similar chemical composition, namely a high content of aluminosilicate, contains minerals, such as SiO_2 and Al_2O_3 which are important in the synthesis of zeolite materials. The first study conducted on the preparation of porous materials (ANA and GIS zeolites) was carried out using bottle glasses. In 2014 Alves, et al. prepared LTA, and HS zeolites using from industrial glass used alkaline fusion followed by hydrothermal treatment in the zeolitezation of the waste 17 . Kim, et al. synthesized successfully LTA zeolite of uniform size from windshield waste, by high-energy grinding and low-temperature hydrothermal treatment. Terzano, et al. showed the feasibility of synthesizing zeolites from glass and aluminum waste 18 . They obtained by hydrothermal treatment at 60 C for 7 days a zeolitic material containing 30% LTA zeolite when NaOH is used as a mineralizing agent and 25% edingtonite when KOH was used following a hydrothermal treatment at 90 C for 7 days. Electronic waste such as LCD panel glass and glass from cathode ray tube funnels have also been used in the preparation of LTA, FAU and Na-P1 zeolites by alkaline activation. HS and Na-P1 zeolites were prepared by microwave alkaline activation of glass cullet. Zeolites Na-P1, Na-LTA and Na-FAU were successfully obtained using waste glass issue from fluorescent tubes and aluminum scraps Sayehi, et al. reported the zeolitization of Powder Glass (GP) derived from fluorescent tubes and Aluminum Scraps (AS) into Na-P1 and Na-FAU zeolites using alkaline fusion technique followed by hydrothermal treatment and Na-LTA zeolite using only hydrothermal crystallization at mild temperature (60 C) 19 .

Filtration media: Several Studies exhibited the ability of recovered glass as a filter medium. It has found that it is potentially extremely effective at elimination suspended solids from water. A. Korkosz, et al. investigated the use of glass cullet as filtration medium, showing comparable results to filtration on sand regardless of larger negative zeta potential of cullet particles when compared to silica sand 20 . It can be expected, that modification of glass enhanced filtration medium surface properties given up better separation efficiency. Other researchers reported that the smooth surface of glass reduce the area to which solid particles become devoted, although the use of coagulants can rectify this behaviour, or through the use of dual-media beds containing glass and coarser anthracite.

Economic and environmental advantages of recycling glass waste

The re-use of waste glass as raw materials in the preparation of ecofriendly materials has many benefits, it can reduce the charge associated to the disposal of glass waste into landfills, which are supposed to increase because of the landfill tax and the air pollution resulting from the production cement clinker. The production of cement consumes enormous quantities of raw materials and energy. This activity was usually accompanied with CO_2 emission, that's why the cement industry was considered as ma or contributor to the greenhouse effect and the global warming of our planet. It was estimated that for each ton of cement prepared approximately the same quantity of CO_2 is generated. The use of glass cullet as raw materials, reduce CO_2 emissions, thus contributing to minimize global warming. Besides, the valorization of waste glass can minimize the need for natural resources and conserve precious materials for future generations. That's why, the re-use of waste cullet in the preparation of new materials can be considered a significant factor in improving the environmental aspects. The economic advantages from valorization of waste glass in concrete industry may also be quite potential. For example, in the USA, the tipping charge of landfill typically arrayed from 40 to 100 ton, the supplementary cementing materials price between 30 and 80 ton, and the cost of the concrete aggregates around 5-15 ton. Also, the grinding fee possibly is about 15 and 30 ton. On the other hand, the market for synthetic zeolitic materials is approximated at US 5.2 billion per annum with this value expected to increase to US 5.9 billion per annum by 2023 in 2018 The market size for zeolites in detergent market is about US 1.4 billion, this value was estimated to rise US 1.8 billion in 2028 20 .

Conclusion

This study reports numerous applications for glass cullet and highlights the relative benefits of these utilizations. Based to recent knowledge, these applications are faced from an engineering and environmental view point, displaying the defects of each method, but also emphasizing their advantages. In most situation, it is hard to define clearly the safe conditions for each application, neither from an environmental standpoint nor from a technical point of view, and this has conduct systematically to the incorporation of waste in applications where it could be effectively recovered with great environmental advantages. The results exhibited here are encouraging, since they proved new real possibilities for this waste's valorization in a short-term, in several fields, from construction and ceramics materials to zeolites. Successful application of this glass cullet will have great benefits in waste minimization as well as naturals resources conservation and this fact seems to be pushing both the and research community to create good alternatives for discharge.

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