Life Cycle Analysis for Glass Manufacture in a Small Island Developing Country Situation

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Abstract: *A Life Cycle Analysis has been carried out on the operations of a container glass manufacturer on a small island state in the Caribbean, together with its product distribution and post use glass recovery (cullet) for recycle through the process. The analysis was carried out over a full calendar year with the following results:*

1) *All of the 10 of the environmental impacts calculated reduced with increasing cullet % charged to the glass production process*.
2) *An analysis of the sources of cullet recovered from the trade showed that, whereas cullet recovery from the Caribbean was equivalent to the amount of container glass sold into the Caribbean, only 20% of that sold into the local market was recovered.*

It is proposed that the local recovery system be upgraded by waste separation at source, cullet recovery at the garbage dumps, and the introduction of Beverage Container Legislation requiring bottle deposits. These actions would significantly increase local cullet recovery and eliminate the need for extra regional importation of cullet, leading to cost reduction and lower environmental impact.
Keywords: *cullet, recycle, glass production, glass recovery, life cycle analysis*.

1. Basic Objective of Study

Trinidad and Tobago is a small island developing country located in the Southern Caribbean. The islands' economy is oil and gas based, but it does have a range of manufacturing companies which utilize the hydrocarbon base to produce goods not only for the local market, but also for export. One such company in the country produces container glass for the local beverage and processed food industry, but also for export around the Caribbean, and particularly the English-Speaking Caribbean.

The company operates with 2 furnaces using local sand, calcium carbonate imported from elsewhere in the Caribbean, with soda ash and the other minor raw materials being sourced globally. Container glass manufacture requires the use of recycled glass, in the form of cullet, in order to better control the melting process, but also to reduce operating costs. Cullet is supplied internally from reject bottles, but also from bottles returned from the trade. Glass bottles in the trade present a significant pollution problem, so that it is imperative that there be an efficient system of collection for return to the company in order to minimize pollution. An analysis of the production of glass bottles, together with a knowledge of how the bottles are used in the bottling processes and their subsequent movement into and through distribution and use, is therefore important towards understanding how the bottles could be recovered for reuse in the manufacturing process. This could lead to minimizing the number of bottles that end up in the waste dumps and littered around the community. This is normally formalized as a Life Cycle Analysis which quantifies the movement of the product, glass in this case, through the various stages in its lifetime.

The basic objectives of the study presented here were twofold:

1) To estimate the effect of increasing cullet use in the bottle production process on reducing pollution

2) To identify the flows of glass from the company throughout its life cycle with a view to determining how the overall system could be modified to maximize cullet return to the plant.

In fulfilling the above, relevant data was taken from plant operations over a full year on a month by month basis.

2. Life Cycle Assessment

2.1 The Concept of Life Cycle Assessment

Throughout the world, there is an increased awareness of the importance of environmental protection, and the possible impacts associated with products, both manufactured and consumed, has increased interest in the development of methods to better understand and address these impacts (Dongyub Han 2014). Life cycle assessment (LCA) is a tool which provides a holistic approach to evaluating environmental performance. It considers the potential impacts from each stage of manufacture, product use and end-of-life stages, also called a cradle-to-grave approach.

The International Organization for Standardization (ISO) defines the life cycle of a product as including raw material extraction and acquisition, through energy and material production and manufacturing, to use and end of life treatment and final disposal (ISO14040 2006). The assessment includes examination and interpretation of the inflows and outflows associated with a product throughout these steps. Inflows include the raw materials needed to make and transport the product, while outflows include the emissions and the waste product created throughout its life (**Error! Reference source not found.**).

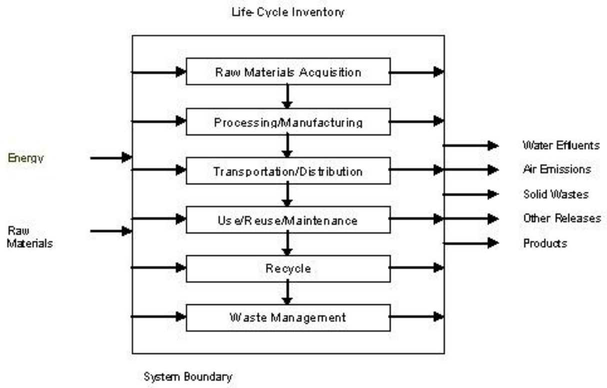

Figure 1: Life Cycle Inventory

2.2 Life Cycle Assessment Application to Container Glass

Glass manufacture is a high temperature, energy intensive process. As stated in the Cullet Energy Study done by Glass Technology Services Limited in 2004, for a 12-month period, the glass container sector consumed approximately 4.64TWh of delivered energy. Over 70% of this was used to melt the glass (Glass Technology Services Ltd 2007). The fuel related Carbon dioxide emissions amounted to approximately 650,000 tonnes for that one-year period. The raw materials utilized in the process are sand, limestone and soda ash, the latter two decomposing during the melting process to liberate additional Carbon Dioxide.

The specific Life Cycle Analysis for container glass, showing Cradle to Cradle and Cradle to Gate boundaries, is shown in Figure 2.

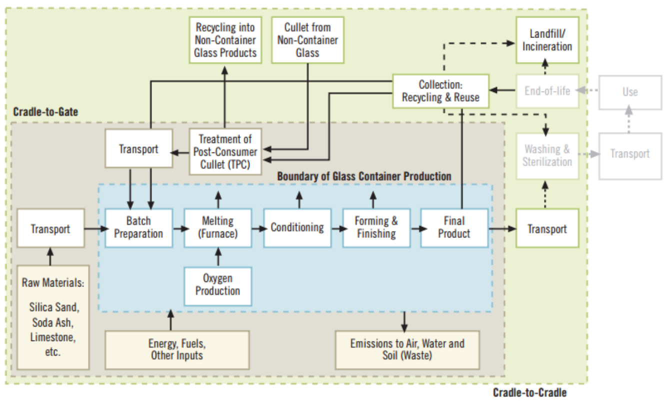

Figure 2: Life Cycle Analysis for Container Glass

It is important to note that glass can be recycled endlessly with no loss in quality or purity. In fact, the use of recycled glass up to ~60% assists the melting process. An estimated 80% of recovered glass containers are made into new glass bottles. According to the Glass Packaging Institute, in the US in 2012, 41% of glass beer and soft drink bottles were recycled, over 34% of wine and liquor bottles, and over 34% of all glass containers. In some states, like California, glass bottle recycling reaches over 80%.

2.3 Benefits of Recycling Container Glass

Recycling glass containers provides for unmatched production efficiencies and significant environmental benefits:

- Saves raw materials — Approximately 1.2 tonnes of natural resources are conserved for every tonne of glass recycled.
- Lessens the demand for energy — Energy costs drop about 2-3% for every 10% cullet used in the manufacturing process.
- Cuts CO_2 emissions — For every six tons of recycled container glass used, a ton of carbon dioxide, a greenhouse gas, is reduced. A relative 10% increase in cullet reduces particulates by 8%, nitrogen oxide by 4%, and sulfur oxides by 10%.
- Extends furnace life — Including cullet in the manufacturing mix makes it less corrosive and lowers the melting temperature, prolonging furnace life.
- No processing by-products — Glass recycling is a closed-loop system, creating no additional waste or by-products. (Glass Packaging Institute 2010)

The perfect Glass Cycle is shown in Figure 3.

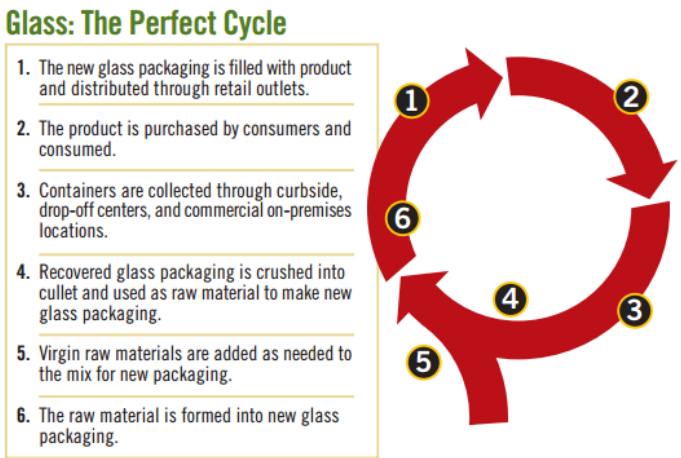

Figure 3: Container Glass: The Perfect Cycle

Figure 3 effectively depicts the ideal system to which every glass plant should aim. The problem is generated at Item 3 of the cycle whereby not all used containers are collected.

3. Methodology

3.1 Analysis of % Cullet Use on Pollution

This aspect of the study is effectively the determination of the Life Cycle Inventory (LCI) of the pollutants which are emitted into the atmosphere from the process.

SIMAPRO software from Pre consultants (Mark Goedkoop Jan 2016) was used as the primary source for the life cycle inventory (LCI). This software contains LCI data for over 2500 processes typically used in the packaging industry.

SIMAPRO version 8.0.4.30 was used to perform the LCI. The input data for this software was acquired from the company for each month in the year 2015, when the plant operated continuously for the full year utilizing 2 furnaces and 6 bottling lines. A significant number of different types of bottles were produced during the year, involving job (mould) changes on the plant on a regular basis. This was incorporated into the data collection.

This basic software was used to estimate the environmental impacts, some of which are listed in Section 2.3, associated with operating the plant.

Input data used were Raw Materials Consumption, Electricity Consumption and Natural Gas Consumption.

The raw materials considered were:
- Sand
- Limestone
- Soda Ash
- Cullet (Imported and local)
- Calcined alumina
- Carbon (processed)
- Iron oxide

It should be noted that the cost of transporting imported cullet both from Canada and various locations around the Caribbean was incorporated into the software determination.

3.2 Life Cycle Analysis

In the second aspect of the project the monthly production data, together with the data associated with receipt of cullet from the trade was used to plot the glass flows throughout the Life Cycle as far as possible. Reference is made to Figure 2 which was the basis for effectively better understanding the movement of glass in the overall system. If, as the results from the LCI expect to show that the more cullet that is fed to the plant, the less the environmental impacts, then it is imperative to lay down a framework for increasing the recycle of glass back from the trade. The LCA quantifies the potential for this to happen, after which a suitable plan can be devised and effected to this end.

It is also important to note that operating costs reduce with increasing cullet supply to the plant.

4. Results from Study

4.1 Life Cycle Inventory - LCI

SIMAPRO used the TRACI 2.1 V1.02 / Canada 2005 database to assess the effects of each of the inputs to the process.

It was determined that the cullet supply to the plant varied during the year over the range 43.8% to 57.3%, so the environmental impacts which were calculated using the software are presented at these two extremes

Table 1 shows the specific environmental impacts as calculated.

Table 1: Impact Categories

Impact category	*Unit*	*43.8% Cullet*	*57.3% Cullet*
Ozone depletion	kg CFC-11 eq	0.000016	0.0000149
Global warming	kg CO2 eq	20000	14000
Smog	kg O3 eq	155	110
Acidification	kg SO2 eq	400	290
Eutrophication	kg N eq	2.1	1.5
Carcinogenics	CTUh	0.00105	0.00075
Non carcinogenics	CTUh	0.00008	0.00007
Respiratory effects	kg PM2.5 eq	10	7
Ecotoxicity	CTUe	50000	36000
Fossil fuel depletion	MJ surplus	28000	19000

Reference to Table 1 shows a clear reduction in environmental impacts in all impact categories.

4.2 Life Cycle Analysis

The monthly data collected from the plant operation, as identified in Section 3.1, was annualized to effectively enter glass flows into the equivalent of Figure 2. The LCA diagram for the specific local situation is presented as Figure 3. This is effectively a Cradle to Gate evaluation which summarizes the sale of glass bottles into the trade together with the return of cullet from the trade from the three main sources i.e. national, regional and extra-regional (Canada). Table 2 shows the annual tonnage inputs to and outputs from the factory:

Table 2 Showing Total Inputs and Outputs for 2015.

Source	Amount/ Metric Tonnes
Raw Materials	34759
Local Cullet Returns	5205
Regional Export Cullet Returns	8094
Extra-regional Imported Cullet	9232
Glass Sold to Local Market	25136
Glass Sold to Regional Market	7293

The following should be noted:
1) More was produced than sold in 2015, with the excess being put in store to supply customers in accordance with contractual agreements.
2) Rather more cullet was bought from the trade than was used in 2015. This was because of minimum shipment requirements in respect of the extra-regional purchase. It would have been used in 2016.
3) More cullet was received from the Caribbean region than glass sold. This would be because cullet from other glass providers would be incorporated into the collection.
4) Of the 25135 tonnes of container glass sold into the local market only 5200 tonnes of glass was returned to the plant.

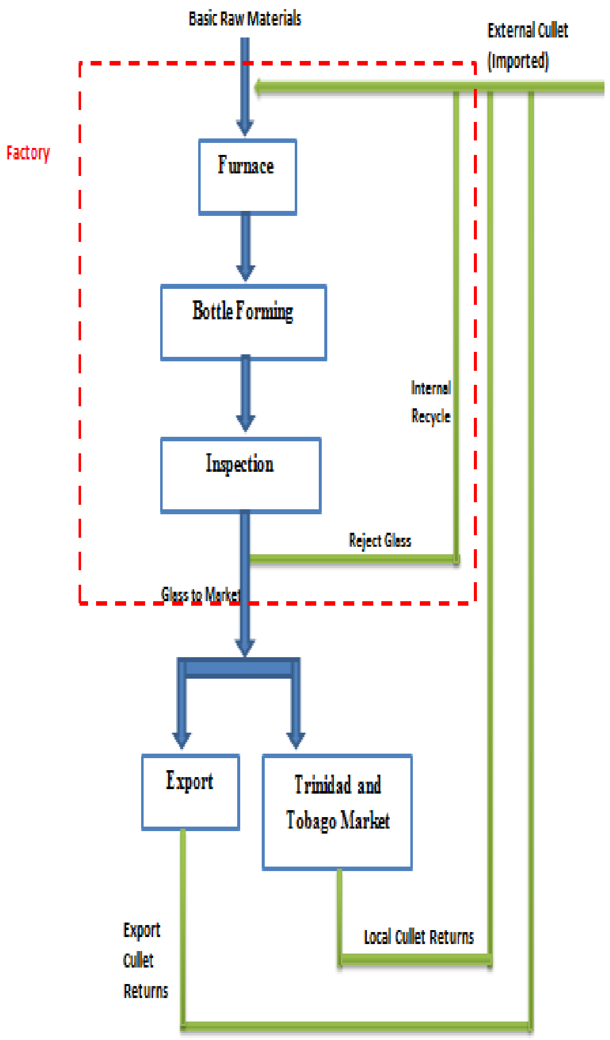

Figure 3: LCA for Glass Plant under Analysis

5. Discussion of Results

Reference to Table 1 clearly shows that maximising cullet recycle into the plant will minimise environmental impacts in all identified categories. Since this will also minimise raw material costs it is clear that there should be a major push towards increasing cullet recycle.

The cost of importing cullet from North America is significantly higher than importing from regional sources which is also higher than recycling from local sources. The approach should therefore be towards eliminating the extra regional source. Regional cullet was in balance with export to the Caribbean, but of the 25,135 tonnes of glass put into the trade in Trinidad and Tobago, only 5,200 tonnes was recovered from the trade for recycling through the plant. It is this area which needs to be addressed as almost 20000 tonnes of glass is lost as litter or in the waste collection dumps.

It is instructive to note that the three main modes of recovery from the trade were:

- Brewery - 44%
- Strategically placed collection barrels – 33%
- Small contractor collection - 23%

The distribution of brewery products entails a bottle deposit, so the return to the glass plant is from the brewery when the bottles are deemed to be unfit for reuse. The glass plant pays the brewery for these bottles. Small contractors are paid by the tonne. The barrel collection system which is through strategically placed barrels which are emptied when filled, is operated by the glass plant.

It is clear that there needs to be a review of the system, geared towards significantly increasing the collection of used bottles for recycle. Some of these are as follows:

1) Introducing separation at the point of collection from homes, schools etc. i.e. separate containers for separate recyclable products. The garbage collection systems can then sell the glass to the company
2) If this cannot be introduced completely across the nation, such separation can also be affected at the garbage dumps
3) Beverage container legislation involving bottle deposits and collection points at convenient locations e.g. malls
4) Expansion of the collection barrel and contractor collection systems
5) Education of citizens to use the available deposit systems

Item 1) could be very effective if more difficult to introduce. Item 2) was in place some years ago but was closed down by the Waste Management Company because it was difficult to manage the personnel involved. It could however be reintroduced. Item 3) is the preferred system at this time as it has been made to work in other countries e.g. Barbados. Legislation has been drafted, but is being opposed by the soft drink manufacturers. However, if and when introduced it could recover a significant proportion of the bottles which are currently littered or end up in the garbage dumps.

Regional collection of glass should be maintained even expanded if deemed appropriate.

Extra regional importation of cullet should be eliminated.

6. Conclusions and Recommendations

It is concluded that:

1) All of the 10 environmental impacts calculated reduced with increasing cullet % charged to the glass production process, thereby stressing the importance of maximizing cullet use in the process.
2) An analysis of the sources of cullet recovered from the trade showed that, whereas cullet recovery from the Caribbean was equivalent to the amount of container glass sold into the Caribbean, only 20% of that sold into the local market was recovered.

It is recommended that the local recovery system be upgraded by waste separation at source, cullet recovery at the garbage dumps, and the introduction of Beverage Container Legislation requiring bottle deposits. These actions would significantly increase local cullet recovery and eliminate the need for extra regional importation of cullet, leading to cost reduction and lower environmental impact.

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