

# Evaluation about drinking bottle's reduce and reuse effectiveness: Super light returnable glass bottles and life cycle assessment

Shuichi Tamura<sup>1,\*</sup>, Robert William Marek<sup>2</sup>

<sup>1</sup>Graduate School of Environment and Information Sciences, Yokohama National University, Yokohama, Japan

<sup>2</sup>Public Works Department, Sasebo, U. S. Naval Facilities Engineering Command Far East, Sasebo, Japan

## Email address:

tamura-shuichi-jg@ynu.jp (S. Tamura)

## To cite this article:

Shuichi Tamura, Robert William Marek. Evaluation about Drinking Bottle's Reduce and Reuse Effectiveness: Super Light Returnable Glass Bottles and Life Cycle Assessment. *International Journal of Environmental Protection and Policy*. Vol. 2, No. 5, 2014, pp. 153-160. doi: 10.11648/j.ijjepp.20140205.12

**Abstract:** "Reduce, Reuse, and Recycle are terms which are familiar to us as the "3Rs. " The 3Rs enable us to decrease pollution in the environment. The "Super Light Returnable Glass Bottle " is a light and reusable glass bottle generated by advancements in the technology of glass engineering. By manufacturing and using "Super Light Returnable Glass Bottles " as opposed to other container types, potentially we can reduce up to 80% of CO<sub>2</sub> emissions. This article introduces what "Super Light Returnable Glass Bottles " are, shows how glass bottles are manufactured, and then proposes an approach to promote its use. We show the potential environmental benefits of Super Light Returnable Glass Bottles by conducting a Life Cycle Assessment (LCA) analysis for drinking containers. We demonstrate the effectiveness of "Reduce " and "Reuse " in the 3Rs by simulating the change in CO<sub>2</sub> emissions resulting from glass bottle reuse and reduction in glass bottle weight.

**Keywords:** 3R, Super Light Returnable Glass Bottle, Life Cycle Assessment

## 1. Introduction

### 1.1. Introduction to Reduce and Reuse

Let us think about returnable bottles. When you return the empty bottles to the store, the store sends the empty bottles back to the manufacturers. The bottles are refilled and then shipped back to the stores to be sold again, thereby enabling us to conserve resources and reduce wastes. The use of returnable bottles also reduces CO<sub>2</sub> emissions. This research provides an approach to improve the reduction of CO<sub>2</sub> emissions through the use of Super Light Returnable glass bottles.

Figure 1 demonstrates the concept of this research. The CO<sub>2</sub> reduction by the weight reduction of glass bottles are demonstrated on the left side, whereas the CO<sub>2</sub> reduction through the reuse of glass bottles is demonstrated on the right side. Regarding the CO<sub>2</sub> reduction by the weight reduction of glass bottles, they are created with less amount of raw materials where additional numbers of glass bottles can be created with the same amount of raw materials. Regarding glass bottle reuse, reusing the glass bottles will

saves the raw materials for glass bottle creation. Weight reduction of glass bottles and reusing glass bottles leads to the same effect: they reduce the quantity of raw materials for glass bottle creation and will concurrently reduce the amount of CO<sub>2</sub> emission through the manufacturing process.

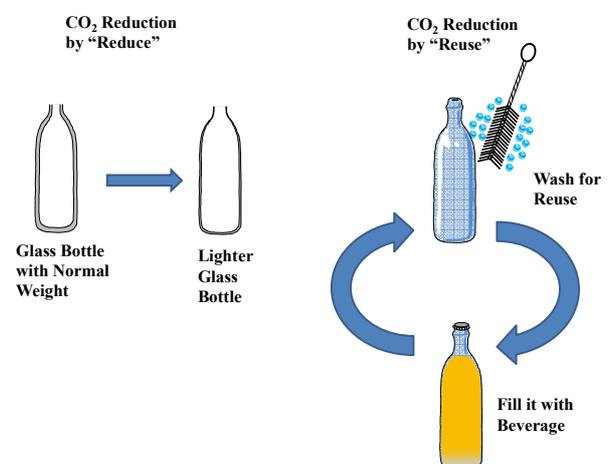


Figure 1. Concept for CO<sub>2</sub> Reduction by "Reduce " and "Reuse "

### 1.2. Glass Bottle Lightness Index Value L

As an index which determines the lightness of glass bottles, Japan Glass Bottle Association adopted the glass bottle lightness index value L for use in the glass bottle industry[1].

$$\text{Value L} = 0.44 \times \text{Bottle Weight (g)} \div \text{Capacity When Full (ml)}^{0.77} \quad (1)$$

We contacted the Japan Glass Bottle Association and were provided the following historical information about the Value L equation:

"Mr. Eddingston, who worked for Emhart Glass S.A., proposed it as a glass bottle lightness index in 1976. It is said that he collected the information for glass bottle products in the European market at that time and modeled the regression equation from the statistic analysis. Emhart Glass S.A. and Mr. Eddingston lost the related documents so details are not clear "

In the glass bottle industry, glass bottle lightness index value L is now understood in the following way.

Glass bottle lightness is considered as being proportional to glass bottle thickness. If the thickness value is lower, the lightness value is lower too. Therefore the following equation holds:

$$\text{Glass Bottle Thickness} = \text{Glass Volume} / \text{Glass Bottle Area} \quad (2)$$

Given that a bottle is spherical and taking "r" as radius, the equation to calculate "Glass Volume" is " $\frac{4}{3}\pi r^3$ ". The equation for "Glass Bottle Area" is " $4\pi r^2$ ".

As for "Glass Volume," the following equation holds:

$$\text{Glass Volume} = \text{Weight} / \text{Glass Density} \quad (3)$$

In the equation of "Glass Bottle Thickness" we substitute "Glass Volume" with "Weight/Glass Density." We next cancel "r" in " $\frac{4}{3}\pi r^3$ " of "Glass Bottle Area" (which is found in the "Glass Bottle Thickness" equation) by substitution. We then rearrange the "Glass Volume" equation to the "r" equation as follows:

$$\text{Glass Volume} = \frac{4}{3} \pi r^3 \rightarrow r = (\text{Glass Volume} \times \frac{3}{4\pi})^{1/3} \quad (4)$$

If we substitute this with "r" in "Glass Bottle Area =  $4\pi r^2$ ":

$$\text{Glass Bottle Area} = 4\pi \times (\text{Glass Volume} \times \frac{3}{4\pi})^{2/3} \quad (5)$$

Given that  $4\pi \times (\frac{3}{4\pi})^{2/3}$  is K :

$$\text{Glass Bottle Area} = K \times \text{Glass Volume}^{2/3} \quad (6)$$

This is combined with "Glass Volume = Weight/Glass Density:"

$$\text{Glass Bottle Thickness} = (\text{Weight} / \text{Glass Density}) / K \times \text{Glass Volume}^{2/3} = \text{Weight} / (K \times \text{Glass Density}) \times \text{Glass Volume}^{-2/3} \quad (7)$$

The equation above closely corresponds to Glass Bottle

Lightness Value L = "K×Glass Density, or  $4\pi \times (\frac{3}{4\pi})^{2/3} \times \text{glass density}$ ."  $\frac{2}{3}$  Power is represented as "0.67", which is close to "0.77." The 0.77 is greater than  $\frac{2}{3}$  because bottles are not a sphere. Because a glass bottle is not a sphere and the shape of bottles vary, the results of statistical investigation show that 0.77, which is larger than  $\frac{2}{3}$  (i.e., 0.67) can be substituted in the equation.

Manufacturers say that the difficulties with manufacturing the actual glass bottle are as follows:

1. Larger bottles are easy to make light whereas smaller bottles are hard to make light.
2. Bottles with a large neck are hard to make light.

The reason is that weight of a glass bottle is determined by the type of bottle neck and bottle size. Small size bottles and bottles with a large neck tend to be hard to make light because the bottle neck weight of small size bottles and bottles with a large neck need a larger proportion of material than that of normal bottles.

## 2. Method

We interviewed manufactures of glass bottles on the glass bottle creation process. Regarding reduction, reuse and recycling, we interviewed and collected administrative documents from public organizations such as city halls, nonprofit organizations (NPO), and others. The Life Cycle Assessment for this research is based on "Workshop for Containers' Comparison, A Report on Comparison of Various Containers by LCA Method 2001 "

## 3. Results and Discussion

### 3.1. Lightness Value L Less than 0.5 Glass Bottle (Super Light Glass Bottles)

Bottles lighter than Value L 0.7 Glass Bottles were developed by Toyo Glass Co., Ltd. and Nihon Yamamura Glass Co., Ltd. Toyo Glass Co., Ltd. developed glass bottles with Value L 0.5 while Nihon Yamamura Glass Co., Ltd developed glass bottles with Value L 0.6.

Glass bottles with value L less than 0.5 are not available on the market, but they are considered as the lightest bottles in the world.

As for the name of the light bottles, Toyo Glass Co., Ltd. calls glass bottles of Value L less than 0.6 as "Extremely Super Light Bottles" and glass bottles of Value L less than 0.5 as "Extremely Extremely Super Light Bottles". Nihon Yamamura Glass Co., Ltd. calls glass bottles of Value L below 0.6 as "Super Super Light Bottles". Glass bottles of Lightness Index Value L 0.5 are not on the market, so Japan Glass Bottle Association does not give a name to these bottles.

Figure 2 shows glass bottles of Value L that are less than 0.5. Picture is taken at Toyo Glass Co. Ltd.



Figure 2. Glass Bottle less than Value less than 0.5

For the bottle samples shown in the above photograph, volume when full is 624ml, weight is 160g, and the Glass Bottle Lightness Index Value L is 0.496.

As for glass bottles with Glass Bottle Lightness Index Value L less than 0.5, the information in the following table is provided:

Table 1. Glass Bottle Lightness Index Value L

Displayed Volume	Volume When Full	Value L Less Than 0.5
100ml	(110ml)	Less Than 42g
500ml	(525ml)	Less Than 140g
1000ml	(1050ml)	Less Than 240g

For glass bottles with a volume 500 ml, when we compare bottles of Value L less than 0.7 with ones of Value L Less than 0.5, we get a 27% weight reduction.

Hereafter this research refers to Value L less than 0.5 as "Super Light Bottles."

### 3.2. Glass Bottle Manufacture Processes: Blow and Blow Process; Press and Blow Process; Narrow Neck Press and Blow Process

Investigations into manufacturing processes of light glass bottles were made. Roughly speaking, glass bottle manufacture processes are divided into two types. They are (1) Blow and Blow Process, and (2) Press and Blow Process.

First we discuss the Blow and Blow Process. A "Gob," which is a block of glass goes into the mold and air is sent in from below. The mold then is turned upside down and air is forcefully blown to form the bottle.

Bottles created with this process are used as normal lightness bottles.

The Press and Blow Process goes through the same manufacture process but with one difference being that the air is blown only one time. Instead of the process which sends the air to the gob, the plunger (or mold) creates the shape of the glass bottles.

Super Light Glass Bottles are created by the Narrow Neck Press and Blow Process which is the applied Press and Blow Process.

The Narrow Neck Press and Blow Process is almost the same process as Press and Blow, the difference being the long and thin plunger.

With this manufacturing process, we can create Super Light Glass Bottles.

### 3.3. Returnable Coating: Plastic Coating

We next turn to the returnable coating sprayed on returnable bottles, which is a plastic coating used only for returnable bottles.

The coating consists of a base layer which is formed of styrene butadiene rubber and a top layer which is formed of urethane resin[2].

It has a buffer effect and anti-shattering effect. According to Toyo Glass Co., Ltd., originally the coating was invented for bottles used in vending machines, and then it was applied as a coating for returnable bottles.

In Figure3 (the bottle on the left), we show a bottle before the plastic coating is sprayed onto it, and on the right we show a bottle after the plastic coating is applied.



Figure 3. Glass Bottles without/with Plastic Coating

The plastic coating is sprayed on the bottle from below the bottle neck to above the grounding block. The Plastic Coating is sprayed only on the outside of the glass bottles. Returnable bottles that are sprayed by Plastic Coating have lower loss percentages from breakage during the bottle washing process.

Plastic Coating does not affect the recycling properties of the bottle except for giving it an amber color in appearance because of the carbon contained in the Plastic Coating. Plastic Coating does not affect glass bottle strength.

The present research selects Super Light Glass Bottles sprayed by Plastic Coating as the most environmentally friendly glass bottles.

### 3.4. Reflections on the Relationship between Safety and Environment with Super Light Returnable Glass Bottle Use

Super Light Returnable Glass Bottles are considered to have two safety issues:

- (1) The glass bottles can break an impact inside vending machines, and
- (2) The glass bottles might break when they contain soda.

Because Super Light Glass Bottles are created very thin, their strength is easily assumed to be lower than normal glass bottles.

Because Super Light Glass Bottles are created very thin, their strength is easily assumed to be lower than normal glass bottles.

Glass bottles receive impacts when they are dropped, including Water Hammer. Water Hammer Phenomenon and damages from dropped impacts can destroy glass bottles.

The following paragraph explains Water Hammer Phenomenon when a glass bottles is dropped inside a vending machine[3].

A glass bottle with liquid is dropped to the board inside the vending machine. At this time the glass bottles accelerates whereas the liquid inside does not. This causes a cavity to form at the bottom of the glass bottle, and the glass bottle head space is pressurized. When the cavity is destroyed, a liquid micro jet is generated that causes erosive forces (i.e. damages). A pressure from 350—3500MPa is generated but the duration time is very short and local. Therefore damages created by the Water Hammer Phenomenon are very small. After that, the pressurized glass bottle head space moves the liquid and it gives the dynamic pressure to the bottom of the glass bottle. The glass bottle is destroyed from the inside.

Next we turn to the issue that "glass bottles might break when they have soda inside them. "

The typical inner pressure of a glass bottle filled with soda is 0.2-0.4MPa under normal temperatures. When the temperature is 40°C, the inner pressure is going to be 0.35-0.6MPa. For soda glass bottles there is a test method and standard for resistance of inner pressure, which is JIS S 2303 and JIS S 2351[4].

The virgin strength of materials for glass bottles is approximately 70MPa[5]. Therefore, Super Light Returnable Glass Bottles should be able to contain soda without any problems; however, some damages will occur when glass bottles are used repeatedly as returnable glass bottles are.

Glass bottles are breakable products and at the same time they are environmentally friendly. The issue at stake is how society will balance the environmental benefits of glass bottle use against safety concerns, which ultimately will be a trade-off relationship.

Safety is being improved because of technological advancements. In particular, the plastic coating (a kind of returnable coating) used for Super Light Returnable Glass Bottles has anti-shattering properties; however, note that this coating does not entirely sweep away all safety concerns.

### **3.5. A Proposal for Promotion of Super Light Returnable Glass Bottle Use**

We propose to introduce an environmental tax on

containers, which increases the product cost in proportion to the amount of environmental pollution such as carbon dioxide emissions associated with the type of container. The introduction of an environmental tax has been widely discussed. The expected effects are to promote bottle lightness as well as their reuse regarding containers. Returnable containers will tend to be cheaper than single use containers because they will have less CO<sub>2</sub> emissions, and therefore a lower tax. In the same manner, light weight containers will tend to be relatively cheaper because they have less CO<sub>2</sub> emissions. The environmental tax will create competition, which will favor light weight returnable glass bottles over other containers.

As a result, containers with greater CO<sub>2</sub> emissions will be difficult to sell and containers which have less CO<sub>2</sub> will be easier to sell because of the environmental tax.

Not only containers, but also other products which have less CO<sub>2</sub> emissions should get a larger share of the market because of the introduction of the environmental tax.

The environmental tax will be most effective if it is implemented at the Federal or national level of government. A Federal tax at the national level will avoid inequalities in the tax system at the local levels of government and will ensure that the tax is applied fairly and universally.

The present research does not promote the adoption of deposit systems because Japan has many small retail stores such as convenience stores, for which deposit systems are not considered suitable.

Deposit systems may be supported by people who want smaller government involvement and responsibility because it is based on the Extended Producer Responsibility. We first need to prioritize the establishment of a system in Japan, considering the fact that Japan does not have a system similar to a country like Germany.

We need to realize that deposit systems must promote "Reuse " not "Reduce. "

### **3.6. Comparison of Containers by LCA Analysis**

We propose to introduce an environmental tax on containers, which increases the product cost in proportion to the amount of environmental pollution such as carbon dioxide emissions associated with the type of container. The introduction of an environmental tax has been widely discussed. The expected effects are to promote bottle lightness as well as their reuse regarding containers. Returnable containers will tend to be cheaper than single use containers because they will have less CO<sub>2</sub> emissions, and therefore a lower tax. In the same manner, light weight containers will tend to be relatively cheaper because they have less CO<sub>2</sub> emissions. The environmental tax will create competition, which will favor light weight returnable glass bottles over other containers.

The LCA analysis in the present research is made based on the framework of "A Report on Comparison of Various Containers by LCA Method "[6]. Assumed basic values for Life Cycle Assessment are gained from:

1. Plastic Bottle: The website of The Council for PET

**Bottle Recycling**

The basic data for LCA of plastic bottles is: 500ml, plastic bottle weight 31.87g, PP cap 2.87g, LDPE packing 0.29g, PS1.29g, coating material 1.00g, yield rate 97% and recycling rate 41%[7].

2. Aluminum Can : The website of Japan Aluminum Can Recycling Association[8].

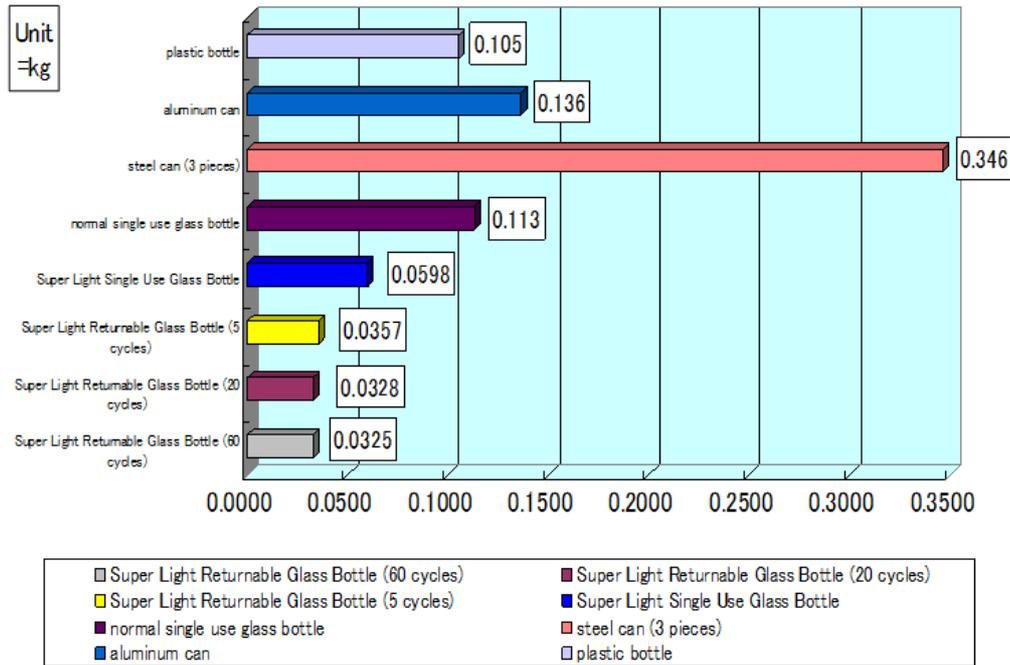
The basic data for LCA of aluminum cans is: 500ml, aluminum weight 15.2g, aluminum top 3.2g, aluminum tab 0.4g, coating material 0.57g, yield rate 80.34% and

recycling rate 87.3%.

3. Steel Can : The website of Japan Steel Can Recycling Association[9].

The basic data for LCA of steel cans is: 500ml, steel can weight 77.87g, aluminum top 3.5g, aluminum tab 0.4g, coating material 0.57g, yield rate 98.7% and recycling rate 88.5%.

The present LCA analysis gives the values in the table in Figure 4.



**Figure 4.** Comparison of Containers by LCA Analysis

Containers which emit the greatest amount of CO<sub>2</sub> are steel cans (3 pieces). Aluminum cans, normal single use glass bottles, plastic bottles, Super Light Single Use Glass Bottles, and Super Light Returnable Glass Bottles follow them in this order, respectively. When we compare "Super Light Returnable Glass Bottles (5 cycles)," with "Super Light Returnable Glass Bottles (20 cycles)" and "Super Light Returnable Glass Bottles (60 cycles)," "Super Light Returnable Glass Bottles (60 cycles)" emit the smallest amount of CO<sub>2</sub>.

The amount of a steel can (3 pieces) CO<sub>2</sub> emission is 10.6 times as much as the Super Light Returnable Glass Bottles (60 cycles). (the amount of Super Light Returnable Glass Bottles CO<sub>2</sub> emission is 9.4% of the steel can (3 pieces) CO<sub>2</sub> emission.)

The amount of the aluminum can CO<sub>2</sub> emission is 4.18 times as much as the Super Light Returnable Glass Bottles (60 cycles). (the amount of Super Light Returnable Glass Bottles CO<sub>2</sub> emission is 23.9% of the aluminum can CO<sub>2</sub> emission).

The amount of normal single use glass bottle CO<sub>2</sub> emission is 3.48 times as much as the Super Light Returnable Glass Bottles (60 cycles). (the amount of Super

Light Returnable Glass Bottles CO<sub>2</sub> emission is 28.8% of the normal single use glass bottle CO<sub>2</sub> emission).

The amount of plastic bottle CO<sub>2</sub> emission is 3.23 times as much as the Super Light Returnable Glass Bottles (60 cycles)(the amount of Super Light Returnable Glass Bottles CO<sub>2</sub> emission is 31% of the plastic bottle CO<sub>2</sub> emission).

The amount of Super Light Single Use Glass Bottle CO<sub>2</sub> emission is 1.84 times as much as the Super Light Returnable Glass Bottles(60 cycles). (the amount of Super Light Returnable Glass Bottles CO<sub>2</sub> emission is 54.3% of the Super Light Single Use Glass Bottle CO<sub>2</sub> emission). This result is useful in considering the effect of cycles (trips). In the next chapter, we further examine cycle (trip) variations. If the containers have more weight, we find the effect more easily. So we use normal returnable glass bottles for the simulation.

Normal single use glass bottles are compared with Super Light Single Use Glass Bottles. The amount of a normal single use glass bottle CO<sub>2</sub> emission is 1.89 times as much as the Super Light Single Use Glass Bottles (the amount of normal single use glass bottle CO<sub>2</sub> emission is 52.8% of the Super Light Single Use Glass Bottle CO<sub>2</sub> emission).

In this connection, the weight of Super Light Single Use

Glass Bottles is 58.3% as much as the normal single use glass bottles. By reduction of glass bottle weight, we recognize the reduction of CO<sub>2</sub> emission. The next chapter further examines glass bottle weight reduction.

Normal single use glass bottles are compared with Super Light Single Use Glass Bottles in the next section.

**3.7. Environmental Pollution Reduction by Super Light Returnable Glass Bottle**

We simulate the Super Light Glass Bottles reduction in environmental pollution from CO<sub>2</sub> emissions. We replace all drinking containers with Super Light Returnable Glass Bottles (60 cycles). It is assumed that all containers are 500ml and that all glass bottles are single use glass bottles.

The weight of each container is as follows:

1. weight of an Super Light Returnable Glass Bottle 0.146kg
2. weight of a normal single use glass bottle 0.348kg
3. weight of a steel can (3 pieces) 0.082kg
4. weight of an aluminum can 0.019kg
5. weight of a plastic bottle 0.037kg

In Japan, the total amount of drinking container weight is as follows:

1. total weight of normal single use glass bottle 1,010,000,000kg [10]
2. total weight of steel can (3 pieces) 710,000,000kg [11]
3. total weight of aluminum can 299,000,000kg [12]
4. total weight of plastic bottle 535,000,000kg [13]

Total weight of containers is divided by weight of each container. We are able to calculate the number of all containers used in Japan.

1. Numbers of normal single use glass bottles 2,910,000,000
2. Numbers of steel cans (3 pieces) 8,660,000,000
3. Numbers of aluminum cans 15,800,000,000
4. Numbers of plastic bottles 14,400,000,000

We calculate the CO<sub>2</sub> emission difference between each container and the Super Light Returnable Glass Bottle, as follows:

1. CO<sub>2</sub> difference of a normal single use glass bottle 0.0807kg
2. CO<sub>2</sub> difference of an steel can (3 pieces) 0.318kg
3. CO<sub>2</sub> difference of an aluminum can 0.135kg
4. CO<sub>2</sub> difference of a plastic bottle 0.0737kg

By multiplying this CO<sub>2</sub> emission difference with the number of all containers in Japan, we calculate the total CO<sub>2</sub> emission difference of each container, as follows:

1. Total CO<sub>2</sub> emission difference of normal single use glass bottles 235,000,000kg
2. Total CO<sub>2</sub> emission difference of a steel cans (3 pieces) 2,750,000,000kg
3. Total CO<sub>2</sub> emission difference of an aluminum cans 2,130,000,000kg
4. Total CO<sub>2</sub> emission difference of plastic bottles 1,060,000,000kg

The sum of them is 5,620,000,000kg (5,620,000 tons).

This number represents CO<sub>2</sub> emission reduction that would be achieved by replacing all containers with Super Light Returnable Glass Bottles. Separately we are able to calculate 6,990,000,000 kg (6,990,000 tons) as CO<sub>2</sub> emission of all drinking containers. As a result, in total we would be able to achieve an 80.4% CO<sub>2</sub> emission reduction.

**3.8. Simulation of Environmental Pollution Variation with the Number of Cycles**

We next simulate reduction of CO<sub>2</sub> emissions based on the number of cycles (trips). When we simulate Super Light Returnable Glass Bottle CO<sub>2</sub> emissions, Super Light Returnable Glass Bottles is very small.

However we see significant improvement using normal returnable glass bottles because CO<sub>2</sub> emission with normal glass bottles is large.

The value changes are demonstrated in Figure 5:

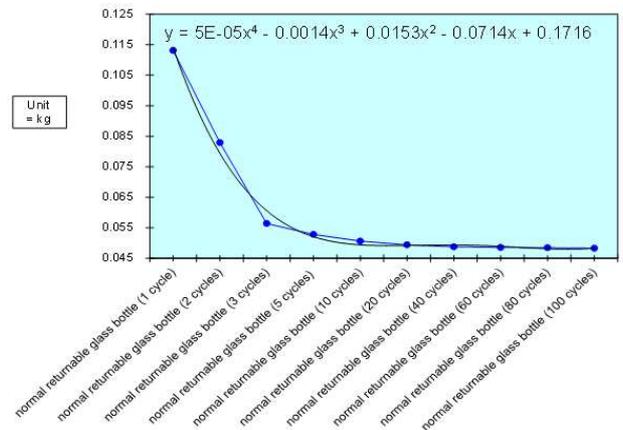


Figure 5. Cycle Number and CO<sub>2</sub> Emission Amount

1. normal returnable glass bottle (1 cycle) 0.113 kg
2. normal returnable glass bottle (2 cycles) 0.0617kg
3. normal returnable glass bottle (3 cycles) 0.0564kg
4. normal returnable glass bottle (5 cycles) 0.0531kg
5. normal returnable glass bottle (10 cycles) 0.0508kg
6. normal returnable glass bottle (20 cycles) 0.0496kg
7. normal returnable glass bottle (40 cycles) 0.049kg
8. normal returnable glass bottle (60 cycles) 0.0488kg
9. normal returnable glass bottle (80 cycles) 0.0487kg
10. normal returnable glass bottle (100 cycles) 0.0485kg

Collection rates get up to 99% when cycles reach 100 times. The number seems impossible. Remember that survival rates in washing processes are 99.75% (400 cycles). Theoretically, it is possible. There is a steep drop in CO<sub>2</sub> emissions for use cycles between 1 and 3. The Value flattens out when 3 use cycles are exceeded.

Figure 5 demonstrates the relationship between cycle number and the amount of CO<sub>2</sub> emission. We also added the trendline. This 4th order polynomial trendline could be considered as an approximation which we are looking for.

The equation for the trendline would be:

$$Y = a X^4 + b X^3 + cX^2 + d$$

Where:

$Y = \text{CO}_2 \text{ Emission Amount for Glass Bottles,}$

$X = \text{Cycle Number}$

a, b, c, d = Coefficient and Residue for Glass Bottle's  $\text{CO}_2$  Emission Amount (9)

"Coefficient and Residue for Glass Bottle's  $\text{CO}_2$  Emission Amount " are  $5E-5$ (i.e. 0.000005), 0.0014, 0.0153, 0.0714 and 0.1716 respectively.

**3.9. Simulation of Glass Bottle Lightness Variation**

We next simulate  $\text{CO}_2$  emission changes verses changes in glass bottle lightness.

We calculate the  $\text{CO}_2$  emission of 500ml glass bottles demonstrated in Figure 6:

- 1. value L 1.22 weight 343.3 g
- 2. value L 1.1 weight 310.7 g
- 3. value L 1.0 weight 282.5 g
- 4. value L 0.9 weight 254.2 g
- 5. value L 0.8 weight 226 g
- 6. value L 0.7 weight 197.7 g
- 7. value L 0.6 weight 169.5 g
- 8. value L 0.5 weight 141.2 g
- 9. value L 0.4 weight 113 g
- 10. value L 0.3 weight 84.7 g
- 11. value L 0.2 weight 56.5 g
- 12. value L 0.1 weight 28.2 g

The graph given above has the following amounts of  $\text{CO}_2$  emission:

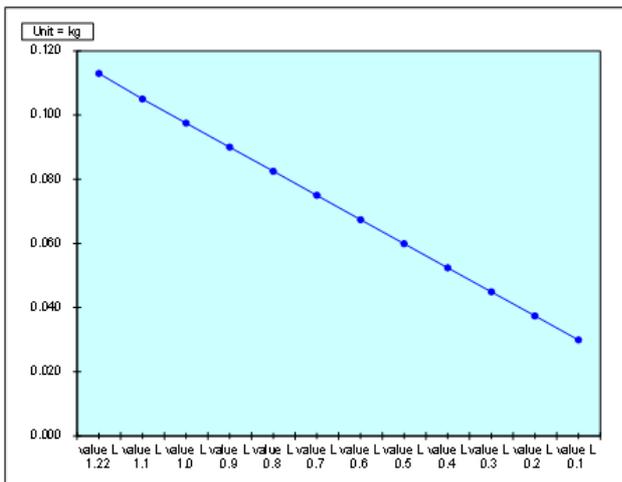


Figure 6. Relationship between  $\text{CO}_2$  Emission and Value L

The graph given in Figure 6 has the following amounts of  $\text{CO}_2$  emission:

- 1. value L 1.22 0.113 kg
- 2. value L 1.1 0.105 kg
- 3. value L 1.0 0.0975 kg
- 4. value L 0.9 0.0900 kg
- 5. value L 0.8 0.0825 kg
- 6. value L 0.7 0.0750 kg

- 7. value L 0.6 0.0674 kg
- 8. value L 0.5 0.0599 kg
- 9. value L 0.4 0.0524 kg
- 10. value L 0.3 0.0449 kg
- 11. value L 0.2 0.0374 kg
- 12. value L 0.1 0.0299 kg

Although value L of the lightest glass bottle is 0.5, we make the simulation even for glass bottles lighter than value L 0.5 in order to understand the effect of the weight reduction. From the graph above, lightness index value L is changed in proportion to glass bottle weight. When we compare this with the simulation of cycle changes, the simulation of cycle changes shows a rapid change up to 5 cycles. This simulation is different from it.

To obtain the formula for generalization, we created Table 2.

Table 2. Glass Bottle and Lightness Index Value L

	Value L (=X)	$\text{CO}_2(=Y)$ kg	Subtraction $(X_n - X_{n+1})$ kg	Subtraction $(Y_n - Y_{n+1})$ kg
1	1.22	0.113	0.12	0.00800
2	1.1	0.105	0.1	0.00750
3	1	0.0975	0.1	0.00752
4	0.9	0.0900	0.1	0.00750
5	0.8	0.0825	0.1	0.00752
6	0.7	0.0750	0.1	0.00750
7	0.6	0.0674	0.1	0.00752
8	0.5	0.0599	0.1	0.00750
9	0.4	0.0524	0.1	0.00752
10	0.3	0.0449	0.1	0.00750
11	0.2	0.0374	0.1	0.00752
12	0.1	0.0299		

We find that  $\text{CO}_2$  emission weight and Value L are in direct proportion to each other. In this connection, we would like to refer the following equation addressed in Section 1.2.

$$\text{Value L} = 0.44 \times \text{Bottle Weight (g)} \div \text{Capacity When Full (ml)}^{0.77} \quad (1)$$

This equation cannot be applicable to the relationship between  $\text{CO}_2$  Emission Value L because the capacity of all glass bottles is 525ml.

Now we have acquired the following equation:

$$Y = aX + b$$

Where:

$Y = \text{CO}_2 \text{ Emission Amount for Glass Bottles,}$

$X = \text{Value L}$

a = Coefficient for Glass Bottle's  $\text{CO}_2$  Emission Amount

b =  $\text{CO}_2$  Emission Amount for Non-Glass Bottle Portion (such as a Cap and a Label) (9)

"Coefficient for Glass Bottle's  $\text{CO}_2$  Emission Amount " for this research is approximately 0.0751 for Value L. " $\text{CO}_2$  Emission Amount for Non-Glass Bottle Portion " is 0.0224.

## 4. Conclusion

When we consider simulation of cycle (trip) changes in the section 3.8 ( "Reuse " in the 3Rs) and simulation of lightness index value L changes in this section ( "Reduce " in the 3Rs), we find that both are effective. The point is that both of two environmental pollution reduction approaches can be made at the same time. Super Light Returnable Glass Bottles, which have the effects of both (Reduce and Reuse) inherent in them have a potential for 80.4% reduction of CO<sub>2</sub> emissions compared to the present.

"Reduce " and "Reuse " from the 3Rs are well- known as effective ways to reduce environmental impacts. When they meet advanced technology which creates Super Light Returnable Glass Bottles, they might realize a quite amount of reduction of CO<sub>2</sub> emissions.

## Acknowledgements

The authors would like to thank Yokohama City Hall, the Toyo Glass Co. Ltd., Japan Glass Bottle Association and for their assistance with data collection and useful suggestions. Our appreciation also goes to Mr. Joseph Voellinger for useful suggestions.

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