Version 2 – March 3, 2023

Glass Uncertainty Report

1 Introduction

1.1 Purpose of the document

The purpose of this document is to report on the methodology and calculations of the flat glass uncertainty factors used in EC3. This document provides reference to the data and calculations performed to determine uncertainties associated with the reported global warming potential (GWP) reported in environmental product declarations (EPD) for flat glass products. The methodology for quantifying the uncertainty of a material or product category is described in the General Uncertainty Methodology document [1], which outlines the types of uncertainties captured in this analysis including those due to batch, product, facility, supply chain, and manufacturer specificity. Please refer to this documentation for more detailed definitions, vocabulary, equations, and explanations of this methodology.

1.2 Scope of the analysis

The uncertainties in GWP discussed herein are related to A1-A3 impacts and refer to EPDs under the NGA Product Category Rules (PCR) for Flat Glass: UN CPC 3711. Where possible, the analysis is conducted for the North American context.

1.3 Data sources

As discussed in the General Uncertainty Methodology documentation [1], conducting an uncertainty analysis requires analyzing a base life cycle assessment (LCA) model for the product. The base LCA model used for this analysis is the Ecoinvent 3.7 model for flat glass [2], and post-processing analysis has been conducted in Microsoft Excel. In addition, the fuel types and quantities have been updated to represent the North American market where available. When additional North American-specific data becomes available, this analysis will be updated with that data.

2 Background

2.1 Description of the production process

The float glass procedure is the most common manufacturing process of flat glass sheets for the construction industry [3]. The largest inputs to the process are materials containing silica (sand and glass cullet) and carbonates (soda ash and limestone). Raw materials for the glass batch are blended in the correct proportion to produce a range of glass compositions. In typical float glass compositions, the oxides of silicon, sodium, calcium and magnesium compose about 98 % of the glass [4]. The total cullet introduced in the furnace is typically around 20%; however, the use of post-consumer recycled cullet is generally limited by the availability of the correct quality and chemical composition and is typically less than 5% of cullet usage [5].

To form molten glass, raw materials are placed in a furnace at approximately 1600°C for melting. Lower temperatures are required for feedstocks with higher recycled content. According to the IPCC Mineral Industries Report, some carbon dioxide is released as process emissions at this stage (approximately 0.20 $kgCO_2e$ per kg of flat glass produced) [6]. Next, the molten glass is fed onto the top of a molten tin bath, where a flat glass ribbon of uniform thickness is produced under controlled heating. At the end of the tin bath, the glass is slowly cooled. The thickness of the glass is controlled by changing the speed at which the glass moves into the annealing lehr. A variety of glass thicknesses are possible, but the typical thickness of flat glass supplied into the construction market is between 3-12 mm. Figure 1 illustrates the production process for flat glass manufacturing. Note that further processing of flat glass (*e.g.,* tempering, laminating) is common; however, this analysis solely investigates the variability in global warming potential of flat glass, which is aligned with the North American PCR.

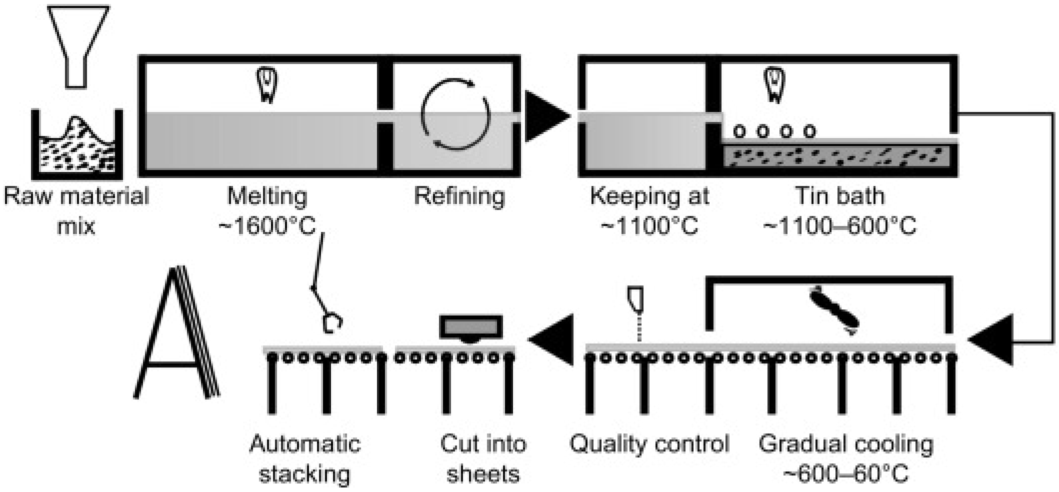

Figure 1 - Illustration of flat glass production; adapted from Achintha [3].

Energy Information Administration (EIA) data indicates that the fossil fuel energy source for flat glass furnaces in the United States is entirely natural gas [7]. Electricity can also be used to heat the furnace as a complement to natural gas via electric boosters. Electricity is also used as an energy source to control the temperature of the float bath and operate other machinery and provides around 25% of the total energy consumption for flat glass manufacturing [8].

The energy usage distribution for a typical float glass process is shown in Figure 2, although this can vary slightly. Approximately 83% of the energy used in float glass plants is spent on melting glass. Forming and annealing takes another 5% of the total energy use. The remaining energy is used for services, control systems, lighting, factory heating, and post-forming processes such as inspection and packaging [4].

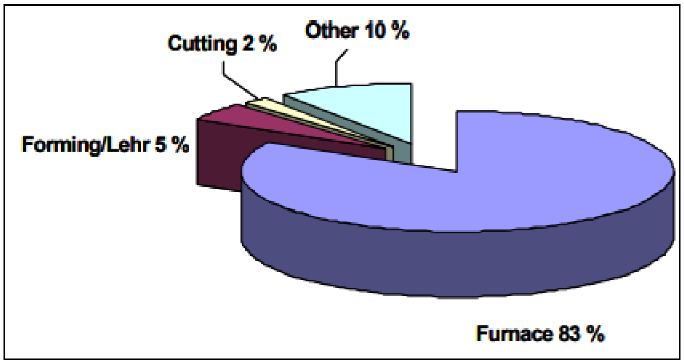

Figure 2 - Typical energy usage for the float glass process [3].

Table 1 shows the average energy required for each step of the flat glass production process reported by Roudier et al. [4].

Table 1. Average energy requirements for each process in float glass production.

Process	Energy Required – (MJ/kg)
Furnace	7.50
Forming	0.45
Cutting	0.18
Other	0.90
Total	9.04

Since approximately 75% of processing energy comes from natural gas and 25% comes from electricity, approximately 6.78 MJ sourced from natural gas and 2.26 MJ sourced from electricity on average. The Ecoinvent 3.7 base model has been updated to reflect these more up-to-date average energy requirements.

3 Identifying Uncertainty Sources

3.1 Supply Chain Uncertainty

Supply chain uncertainties for flat glass production are due to variations in GWP due to upstream processing emissions from the raw materials. The processing of sand, limestone, and cullet are small contributors to flat glass GWP impact (<3% each) according to Ecoinvent 3.7 data, and thus, their variation in GWP impact is considered negligible [2]. On the other hand, manufacturing of soda ash is an energy-intensive process due to high temperatures and the calcination of limestone. The process emits between 200 and 400 $kgCO_2e$ per metric ton of soda ash [9]. In order to map this limit to a normal distribution, the minimum and maximum (200 and 400 $kgCO_2e$) are approximated as two standard deviations from the mean (which represent the 2nd and 98th percentiles).

Table 2. Summary of supply chain variables

Variable Long Name	Assumed Distribution	Parameters	Reference
Soda ash emission intensity	Normal	Mean = 0.30 $kgCO_2e$ / kg Std. dev. = 0.05 $kgCO_2e$ / kg	[9]

When the soda ash emission intensity distribution is sampled using a Monte Carlo simulation of the base LCA model, the following distribution results in an uncertainty factor of 1.1%.

Table 3. Summary of supply chain uncertainty factor

Uncertainty Group	Uncertainty Factor$_\sigma$
Supply Chain	1.1%

3.2 Facility Uncertainty

Facility uncertainty is variation in GWP impact which may be obscured when the GWP impacts are reported as an average of a manufacturer’s facilities.

Factors that affect energy consumption at the plant-level are a source of GWP variability plant-to-plant. For instance, variability in energy consumption during manufacturing is dictated by the size and age of the furnace. The age of a furnace leads to an increase of energy consumption equivalent to 1 – 1.3% per year, on average. According to Roudier et al. [4], energy consumed for melting are typically between 5.2 and 8.7 GJ per metric ton of melted glass, mainly depending on the size and age of the installation, with an average value of 7.5 GJ per metric ton of glass.

Furthermore, the quantity of post-consumer recycled cullet is a potential source of plant-to-plant differences in energy consumption since recycled cullet reduces the required furnace temperature. Currently, less than 5% of cullet comes from post-consumer sources [5]. The ranges in furnace energy requirements are assumed to take this variability in temperature requirements into account. When improved secondary cullet data becomes available, this variability will be accounted for directly.

Another source of variability in GWP impact at the facility-level is the electric grid emissions intensity, which differs regionally. If GWP impact for facilities are averaged, then the variation arising from the emissions intensity of the electric grid are obscured. Building Transparency has conducted a balancing authority-level analysis of the US electric grid weighted by consumption to determine a mean and standard deviation of electric grid intensity to use in EPD uncertainty analyses.

Table 4. Summary of facility-level variables

Variable Long Name	Assumed Distribution	Parameters	Reference
Quantity of energy consumed by furnace	Triangular	Min = 5.2 GJ Mode = 7.5 GJ Max = 8.7 GJ	[4]
Electricity emission intensity	Normal	Mean = 0.153 kgCO_2e per MJ produced Std. dev. = 0.046 kgCO_2e	Building Transparency Electricity Uncertainty Analysis
Natural gas emission intensity	Normal	Mean = 0.064 kgCO_2e per MJ Std. dev. = 0.007 kgCO_2e	Building Transparency Natural Gas Uncertainty Analysis

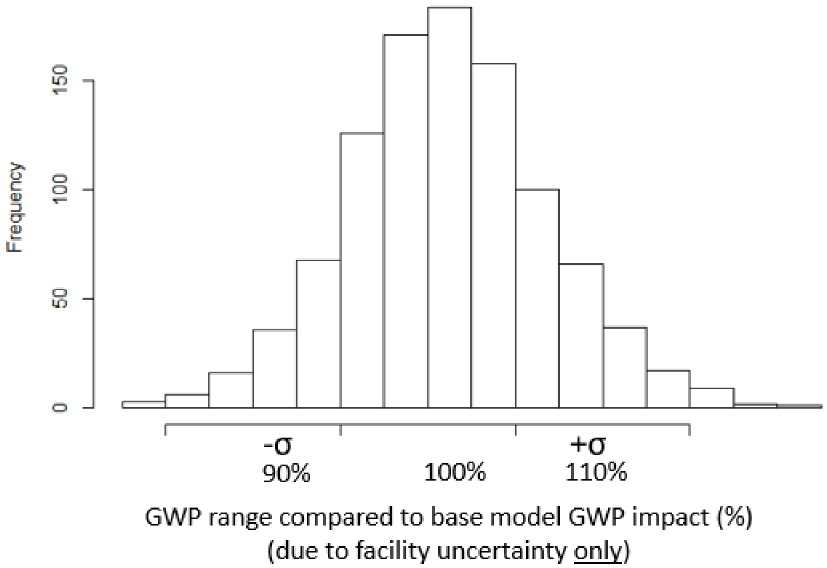

Figure 3. Variability in GWP due to Monte Carlo simulation of facility-level uncertainty.

Table 5. Summary of facility-level uncertainty factor

Uncertainty Group	Uncertainty Factor$_\sigma$
Facility	10.1%

3.3 Batch Uncertainty

Currently, no data is available which indicates batch-to-batch variation in GWP impact for flat glass production. Therefore, a nominal uncertainty of 1% is used.

3.4 Manufacturer Uncertainty

For flat glass production, there is little evidence to suggest that differences in GWP between manufacturers are due to variabilities that are not already covered by facility, supply chain, product, and batch uncertainty. Nevertheless, EPDs that are not even manufacturer-specific are assumed to have even greater scope for supply chain and process variation. For that reason, the default manufacturer uncertainty is set at 5%. (This uncertainty only applies to industry-wide EPDs)

3.5 Product Uncertainty

Product uncertainty is variation in GWP impact which may be obscured when the GWP impacts are reported as an average of multiple products. However, for the flat glass industry, there is very low variability in GWP associated with averaging multiple flat glass products (e.g., a set of differently tinted products or different thicknesses) together in one EPD. For tinting, there appears to be no data showing significant GWP differences between distinct products. For thickness, only a few select manufacturers report differences in GWP (per kilogram of product) due to thickness differences. Product uncertainty is assumed to be limited to the relative standard deviation of the spread of GWP values for the range of 3-12 mm flat glass production, which is 1.1% for the single manufacturer reporting GWP values per product thickness (shown in Table 6).

Table 6. Differences in GWP due to thickness of flat glass product

Thickness (mm)	Reported GWP (kgCO$_2$e per kg) from EPD reporting thickness GWP differences
3	1.287
4	1.270
5	1.264
6	1.260
8	1.250
10	1.248
12	1.247

Table 7. Summary of product uncertainty factor

Uncertainty Group	Uncertainty Factor$_\sigma$
Product	1.1%

3.6 Residual Uncertainty

Lastly, a residual uncertainty (UF$_R$) of 3% is applied to all EPDs since even EPDs which have uncertainty factors of 0% for the supply chain, facility, manufacturer, product and batch still have a small amount of uncertainty from variability sources not covered elsewhere.

3.6 LCIA Uncertainty

Flat glass is currently using the default LCIA uncertainty factor described in the EC3 General Uncertainty Methodology, which is set at 3%. This is expected to sufficiently cover most of the potential differences in results stemming from changes in GWP characterization factors in this category.

3.7 Summary of all uncertainty factors

Table 8. Algorithm for calculating $UF_{total,\sigma}$, for an EPD.

	True	**False**
1. EPD is product-specific	**$UF_P = 0\%$**	**$UF_P = 1.0\%$**
2. EPD has specific LCI information for s% of the supply chain. (The supply chain contribution must be reported in GWP contribution, not by mass.)	**$UF_S = 1.1\%* (1-s)$**	**$UF_S = 1.1\%$**
3. If the EPD uses facility-specific data from the manufacturing plant	**$UF_F = 0\%$**	**$UF_F = 10.1\%$**
4. EPD is batch-specific, meaning it includes data for the specific batch produced.	**$UF_B = 0\%*$**	**$UF_B = 1\%$**
5. EPD is manufacturer-specific (i.e., it is not an industry-wide EPD)	**$UF_M = 0\%$**	**$UF_M = 5\%$**

All of the applicable group uncertainty factors are then used to calculate the total uncertainty factor ($UF_{total,\sigma}$) via the equation below for a given EPD.

If the EPD is an industry-wide EPD, then all uncertainty groups are applied.

$$UF_{total,\sigma} = \sqrt{UF_{S,\sigma}^2 + UF_{F,\sigma}^2 + UF_{P,\sigma}^2 + UF_{B,\sigma}^2 + UF_{M,\sigma}^2 + UF_R^2} \qquad \text{Equation 1}$$

4 Limitations and Future Work

The items below summarize the current limitations of this analysis, which will be updated when appropriate data becomes available.

- The data point representing percentage of processing energy coming from natural gas and electricity is based on European data.
- Batch uncertainty is estimated at 1% due to availability of data.
- Variability in transportation GWP impact has not yet been assessed in terms of uncertainty.
- Effect of tints on product GWP is currently unknown, and currently assumed to be negligible.

5 References

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