Method Report

Life Cycle Assessment of Container Glass in Europe

commissioned by

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ACRONYMS

AP	Acidification Potential
BTU	British Thermal Units
CML	Institute for Environmental Sciences, Leiden University, The Netherlands
CO_2	Carbon dioxide
COD	Chemical Oxygen Demand
CTP	Cullet Treatment Plant
DG	Directorate-General
DQC	Data Quality Check
EoL	End-of-life
EP	Eutrophication Potential
EPA	Environmental Protection Agency
FEVE	European Container Glass Federation
f&f	Formed & finished (glass)
GaBi	Ganzheitliche Bilanzierung (German for holistic balancing)
GPI	Glass Packaging Institute
G&S	Goal and Scope
GWP	Global Warming Potential
H+	Hydrogen
HCl	Hydrochloride acid
HDPE	High density polyethylene
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
kg	kilogram
KWh	kilowatt hour
l	Litre
lb	pound
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LDPE	Low density polyethylene
MJ	mega Joule (energy unit)
mL	Millilitre (volume unit)
mm	Millimetre
Nm^3	Normal cubic meters
NOx	Nitrogen oxides
oz	Ounce
POCP	Photochemical oxidant potential
PED	Primary Energy Demand
PM	Particulate matter
PP	Polypropylene

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SO_2	Sulphur dioxide
TRACI	Tool for the Reduction and Assessment of Chemical and other environmental Impacts
VOC	Volatile organic compounds
WWF	World Wildlife Fund

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GLOSSARY[1]

Allocation

Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems.

Batch

The virgin materials used for the manufacturing of glass containers without considering the cullet (post-consumer and internal) input.

Closed loop & open loop

A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials.

An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems.

Comparative assertion

Environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function.

Cradle-to-grave

Addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal.

Cradle-to-cradle

Addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal, including the recovery of materials in a closed loop in the same or other production system.

Cullet

Scrap glass for recycling.

[1] Based on ISO 14040:2006, Environmental management - Life cycle assessment - Principles and framework, International Organization for Standardization (ISO), Geneva ISO 14044:2006, Environmental management - Life cycle assessment - Requirements and guidelines, International Organization for Standardization (ISO), Geneva. Available at www.iso.ch

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Direct Energy Consumption

Direct energy consumption is the amount of energy consumed on site in the form of usable energy (e.g. electricity) and energy carriers (e.g. coal) calculated on the basis of net calorific values and gate-to-gate.

Functional Unit

Quantified performance of a product system for use as a reference unit.

Internal Cullet

Scrap glass generated on site – as internal loop on site.

Life cycle

Consecutive and interlinked stages of a product system; from raw material acquisition or generation from natural resources to final disposal.

Life cycle assessment - LCA

Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.

Life cycle inventory analysis - LCI

Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle.

Life cycle impact assessment - LCIA

Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product.

Life cycle interpretation

Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations.

Melting

The term “melting” used in this report refers to the step in glass manufacturing to created melted glass in the furnace. This term includes the production of fuels and electricity (including electricity for oxygen production both onsite and purchased) and emissions from decomposition of batch materials and cullet (post-consumer and internal) and combustion emissions from the fuels during melting.

Non-Melting

The term “non-melting” used in this report refers to all steps in the glass manufacturing plant not directly related to melting (see “melting” definition above). Non-melting includes the

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energy consumed and waste generate to heat/cool the plant, operate fans, compressors, forming & finishing steps, abatement technology, mix batch materials, etc.

Normalization

Calculation of the magnitude of category indicator results relative to reference information.

Primary energy demand

Primary energy demand is the quantity of energy directly withdrawn from the hydrosphere, atmosphere or geosphere or energy from a source without any anthropogenic change. Cradle-to-gate or cradle-to-cradle energy.

Post-consumer cullet

Scrap glass for recycling – after it has been used by a consumer.

Production volume

Total amount of formed & finished glass produced during the calendar year 2007.

Thermal energy:

The term thermal energy used in this study accounts for the production and combustion of a fuel e.g. hard coal, natural gas, heating oil. The whole fuel supply chain is considered including resource extraction, processing and transport to the plant as well as the conversion (combustion) of the fuel.

Weighting

Conversion and possibly aggregation of indicator results across impact categories using numerical factors based on value-choices; data prior to weighting should remain available.

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1 GOAL OF THE STUDY

Note:

The study covered glass packaging in North America and Europe. The focus of this method report is on the European part of the study, but still describes goal & scope for both regions.

The goal of the study was to analyse the life cycle environmental performance of glass packaging in North America and Europe. This study provides life cycle inventory and environmental impact data as regional averages (North America and Europe) across the industry and for various technologies. The Life Cycle Inventory (LCI) data consists of the total inputs and outputs of the product system (e.g. carbon dioxide emissions); while the Life Cycle Impact Assessment uses the LCI data to assess impacts such as Global Warming Potential. The life cycle assessment is an original ISO 14040/44[2] compliant study. Consistent methodology and modelling will be used for the GPI and FEVE portions of this study and will result in two parallel, but consistent, reports specific to each region.

The intended audience of this study includes GPI, FEVE, manufacturers of container glass, government, customers and retailers and non-governmental organizations.

A third party critical review panel was engaged to ensure that the highest level of compliance with the ISO 14040/44 standards[2] was met. This study does not include a comparative assertion and it is not a goal within this project.

The life cycle stages of product systems that were studied included:

- Cradle-to-gate production of raw and relevant ancillary materials needed for the manufacture of container glass,
- Transports of relevance over the life cycle of the glass containers under study,
- Manufacture of container glass,
- End-of-life of glass containers covering recycling, reuse and disposal.

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[2] ISO 14040:2006, Environmental management - Life cycle assessment - Principles and framework, International Organization for Standardization (ISO), Geneva ISO 14044:2006, Environmental management - Life cycle assessment - Requirements and guidelines, International Organization for Standardization (ISO), Geneva. Available at www.iso.ch.

2 SCOPE OF THE STUDY

The following section describes the general scope of the project to achieve the stated goals. This includes the supporting product systems (e.g. furnaces, technologies assessed, etc), the boundary of the study, allocation procedures, and cut-off criteria. For reference, a brief description of the glass making process is provided in Appendix I: Glass Making Overview.

2.1 SYSTEM DESCRIPTION OVERVIEW

Figure 1 shows the life cycle stages associated with the functional unit of this study. Each system analysed is defined by the use of coloured boxes; the light blue box indicates the system boundaries from the glass container production (gate-to-gate), the red box indicates the system extended due to the upstream processes (cradle-to-gate), finally the green box indicates the complete system including also the close loop recycling and end-of-life scenarios (cradle–to-cradle). Light grey boxes and dotted line arrows in Figure 1 indicate processes that are either excluded or only assessed in a generic way in this study (e.g. filling and use). Shaded boxes indicate intermediate process (e.g. raw materials) and elemental flows (e.g. emissions); inputs and outputs associated with processing relevant raw materials were included in this study (see Chapter 1 for more details). Transportation of batch materials to the melting facility is included in this study.

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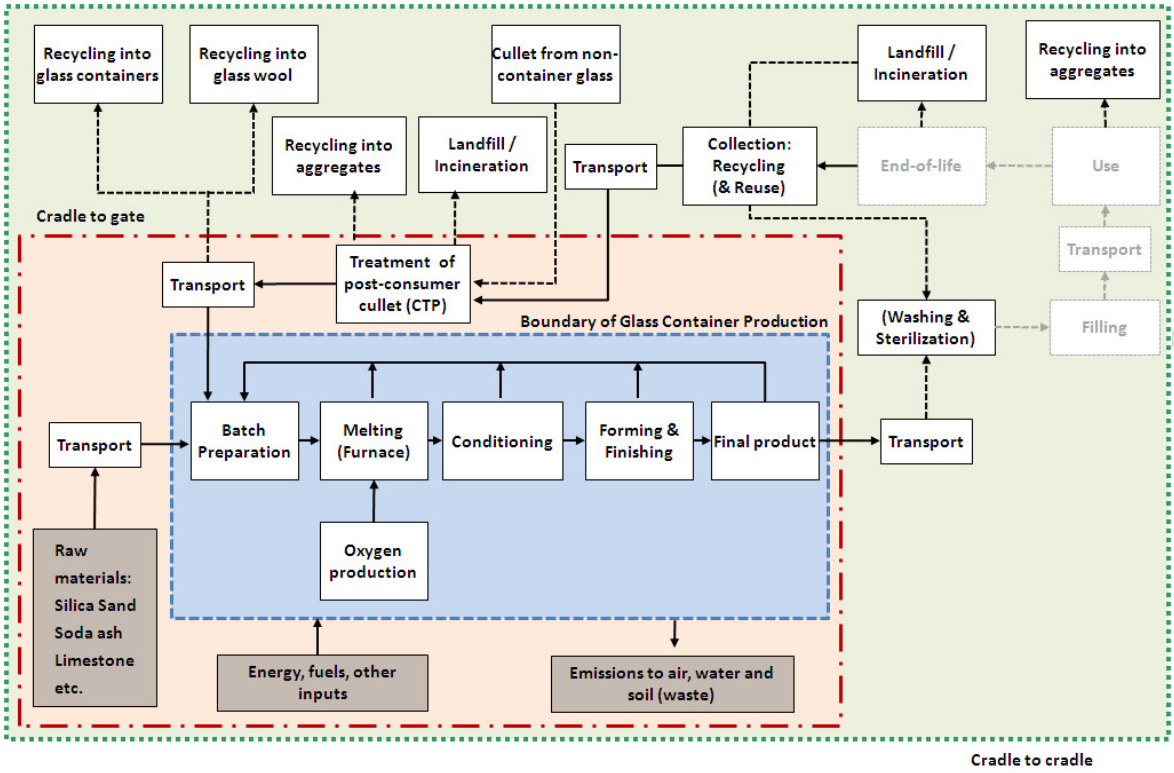


Figure 1: Life cycle flow diagram for system analysed

2.2 FUNCTIONAL UNIT

The functional unit (basis for comparison) used in this study is

one kilogram of formed & finished glass as containers delivered to the end user of products contained.

The function of the unit assessed is a material to be used as a packaging material[3].

The function of products made using glass would be to store and contain liquids and/ or solids (e.g. wine, jam, beer, spirits, non alcoholic beverages, food, etc); specific packaging designs can be assessed with the information included in this report. Production of specialty flacconage, cosmetic, pharmaceutical and perfume glass containers was excluded from this study.

[3] Also known as packed glass within the container glass industry.

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Whereas the environmental profile of the basic material, the container glass, is mainly a function of mass, the contribution of labels, closures and packaging is specific to the packaging design and product application.

The functional unit of one kilogram of industry average container glass has been chosen over specific glass packaging designs because;

- different manufacturing processes with respect to the overall production are not significant (e.g. blow – blow / press - blow),
- labels and closures vary significantly (weight and material) for the different designs and therefore need to be seen relative to the final design.

2.3 SYSTEM BOUNDARIES

The study includes upstream processing and production of materials and energies that make up the production of the stated functional unit; transport of materials to container glass production sites, production of container glass, transport to warehouses and customers, and end-of-life disposal. The filling and use phase of the filled product (including transport to the end-user) is excluded from this study since it is independent from the finished container. Non-melting phase is included to capture the energy used to run compressors, fans, conveyer belts, forming and finishing, etc. at the manufacturing facilities while capital equipment is excluded due to its minor contribution to overall burden. Table 1 summarizes what will be included and excluded in the cradle-to-gate study.

Table 1: System boundaries

Included	Excluded
• Batch materials • Processing of materials • Post-consumer cullet treatment • Melting • Production of energy • Operation of primary production equipment • Transport of batch materials • Internal transportation of batch materials • Non-melting (heating, lighting, forming, finishing, etc) of manufacturing facilities	• Construction of major capital equipment • Maintenance and operation of support equipment • Human labour and employee transport • Manufacture and transport of packaging materials not associated to final product • Use of product (including transport to end-user) • Furnace rebuild (refractory) & moulds[4] • Packaging of final products • Filling

2.3.1 Technology Coverage

In the study, site-specific data representative of current technology used in North America (> 75% of production volume) and Europe (> 72% of production volume) of reference year 2007 were collected and analysed. 2007 was a normal year for glass manufacturing operation. In cases where no primary data were available, either estimations provided by the

[4] Sensitivity analysis showed that furnace rebuilds and moulds do not have a significant contribution and qualify under the cut-off criteria to be excluded.

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involved companies or calculated data were used. Sources and relevance of data were documented and are described in Chapter 1. For other ancillary or process materials, such as the production of chemicals, fuels and electricity, average industry or country mix, profiles from the GaBi 4 Software system were utilized.

2.3.2 Geographic Coverage

The geographical coverage of this study for GPI is container glass produced in the United States, Canada, and Mexico. For the FEVE study, the geographical boundary covers glass containers produced in the EU 27, as well as Switzerland and Turkey.

2.3.3 Time Coverage

Primary data were collected on container glass production for the year 2007. These data were based on annual average data for the year 2007. The representative upstream data (mainly raw materials, energies, fuels, and ancillary materials) were obtained from the GaBi 4 database 2006 and are representative of the years 2000-2005, based on data availability.

2.4 SELECTION OF LCIA METHODOLOGY AND TYPES OF IMPACTS

A set of environmental indicators were investigated including the following inventory flows and environmental impact categories: primary energy demand, global warming potential, eutrophication potential, acidification potential, and photochemical ozone creation potential (smog formation potential). The details of each impact category are shown in Table 2 and described in more detail in the Appendix III: Description of Selected Inventories and Impact Categories.

In 2004 a group of environmental leaders released a report describing the shortcomings of toxicity and hazard characterization within LCA, the Apeldoorn Declaration[5]. As per this declaration, it is the position of this study that "even though LCIA can use the models and the methodologies developed for Risk Assessment; LCA is designed to compare different products and systems and not to predict the maximal risks associated with single substances." Human and eco-toxicology results are best suited to per case- and site-specific studies that accurately model dispersion pathways, rates, and receptor conditions.

A selection of TRACI (Tool for Reduction and Assessment Chemicals and other environmental Impacts)[6] and CML[7] Life Cycle Impact Assessment methodology impacts were used in this study. TRACI, the US EPA LCA impact methodology, uses data specific to North American regional conditions to convert emissions to common metrics while the CML methodology uses European based data. Therefore, TRACI impacts were used for the GPI study while CML impacts were used for the FEVE study due to the regional differences in

[5] Ligthart et al. (2004) Declaration of Apeldoorn on LCIA of Non-Ferro Metals. http://www.uneptie.org/pc/sustain/reports/lcini/declaration%20of%20apeldoorn_final_2c.pdf
[6] EPA http://www.epa.gov/nrmrl/std/sab/traci/
[7] University of Leiden http://www.leidenuniv.nl/cml/ssp/index.html

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the impact methodology calculations. The methodologies provide results on similar impact indicators (e.g., Acidification Potential) but use different calculations and occasionally different units, making it difficult to compare the results directly. The impact of Global Warming Potential is calculated in both methodologies based on the same source of information from the Intergovernmental Panel on Climate Change (IPCC). GPI results calculated using CML are presented in an appendix of the GPI report.

Table 2: Environmental indicator descriptions

Impact Category (issue)	Indicator	Description	Unit	Reference
Energy Use	Primary Energy Demand (PED)	A measure of the total amount of primary energy extracted from the earth. PED is expressed in energy demand from non-renewable resources (e.g. petroleum, natural gas, etc.) and energy demand from renewable resources (e.g. hydropower, wind energy, solar, etc.). Efficiencies in energy conversion (e.g. electricity, heat, steam, etc.) are taken into account.	MJ	An operational guide to the ISO-standards (Guinée *et al.*) Centre for Milieukunde (CML), Leiden 2001.
Climate Change	Global Warming Potential (GWP) (100 years)	A measure of greenhouse gas emissions, such as CO_2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, magnifying the natural greenhouse effect.	kg CO_2 equivalent	Intergovernmental Panel on Climate Change (IPCC). *2006 IPCC Guidelines for National Greenhouse Gas* Inventories. 2006.
Eutrophication	Eutrophication Potential (EP)	A measure of emissions that cause eutrophying effects to the environment. The eutrophication potential is a stoichiometric procedure, which identifies the equivalence between N and P for both terrestrial and aquatic systems	kg Phosphate equivalent kg Nitrogen equivalent	An operational guide to the ISO-standards (Guinée *et al.*) Centre for Milieukunde (CML), Leiden 2001. Bare et al., TRACI: the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts JIE, MIT Press, 2002.
Acidification	Acidification Potential (AP)	A measure of emissions that cause acidifying effects to the environment. The acidification potential is assigned by relating the existing S-, N-, and halogen atoms to the molecular weight.	kg SO_2 equivalent mol H+ equivalent	An operational guide to the ISO-standards (Guinée *et al.*) Centre for Milieukunde (CML), Leiden 2001. Bare et al., TRACI: the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts JIE, MIT Press, 2002.

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Impact Category (issue)	Indicator	Description	Unit	Reference
Photo-oxidant formation	Photochemical Ozone Creation Potential (POCP)/ Smog Potential	A measure of emissions of precursors that contribute to low level smog, produced by the reaction of nitrogen oxides and VOCs under the influence of UV light.	kg Ethene-equivalent g NOx equivalent	An operational guide to the ISO-standards (Guinée *et al.*) Centre for Milieukunde (CML), Leiden 2001. Bare et al., TRACI: the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts JIE, MIT Press, 2002.

Optional elements of the ISO 14040/44 standard include normalization, grouping, and weighting factors. Normalization was not applied because the main purpose of these studies is to generate life cycle inventory data to be able to understand the environmental impacts of container glass. Weighting and grouping were not included because they require subjective value judgment.

2.5 DATA COLLECTION

All data were collected and provided in a consistent way; in addition consistent upstream data are used for all production and transportation processes. In addition to primary process data, each model utilizes GaBi upstream data. Where participating companies have access to data e.g. on raw material extraction and preparation, and (particularly) on cullet logistics and treatment, these data were used.

2.5.1 Production Phase

Data for the manufacture of container glass were supplied by manufacturing companies. The provided data represent the energies, auxiliary materials and process materials needed as well as the emissions related to the production process. Production flow charts were provided by the container glass manufacturing companies. In cases where oxygen was produced on-site, data on these processes were also collected from the production site – see description of furnace technologies in the following section.

An overview of the glass making process is presented in Appendix I: Glass Making.

2.5.1.1 Furnace Technologies

Four furnace technologies were distinguished in the data collection to enable appropriate internal benchmarking. Brief descriptions of these technologies are provided below. Abatement technologies may be used at furnaces to reduce emissions; these include scrubbers to reduce sulphur oxide emissions and electrostatic precipitators to reduce particulate emissions. Particulate that is collected is usually used as an input into the furnace.

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The share of electric boosting can be as high as 5 – 20 % of the total energy directly consumed at the furnace. Extra heat is added to a glass furnace by an electric current through electrodes immersed in the molten glass. It is often necessary for coloured glass types, to allow higher pull rates for a given sized furnace, and to offer reductions in operating temperatures and certain direct air emissions.

Regenerative Furnace

In a regenerative furnace, waste heat is used to preheat air for combustion in a heat recovery system. The burners in a regenerative furnace are fired in cycles while in the two regenerative chambers air and gases are circulated allowing one chamber to be heated with waste gases while the other is preheating combustion air.

Recuperative Furnace

Recuperative furnaces are generally smaller than regenerative furnaces. They use another form of heat recovery system, by pre heating combustion air with a metal heat exchanger. Heat recovery is less than in regenerative furnaces and furnaces have smaller capacity.

Oxy-fuel Furnaces

Oxy-fuel furnaces use pure oxygen (91 - 99.5% O_2 (vol. %)) rather than combustion air and generally do not use heat recovery systems, as this technique avoids heating the nitrogen in combustion air. The use of oxygen thus may thus result in energy savings with respect to regenerative or recuperative furnaces and avoids the formation of nitrogen oxides. However, the overall energy requirement will also include the primary energy for the electricity needed for oxygen production.

Electric Furnaces

Electric furnaces heat molten glass by using electrodes which generate a current through the molten glass, this resistive heating provides heat to the glass melt. Though the efficiency of electrical glass melting is high and direct emissions low, the overall environmental balance depends on the impacts related to upstream electricity production. Fossil fuels are necessary initially to start up the furnace.

2.5.1.2 Forming and Finishing

Although different container glass forming methods are employed (“blow and blow,” “press and blow”, “narrow neck press and blow”) it was not possible to collect data that differentiated between the processes, as different glass forming methods can be used on different glass forming machines, on the same furnace, at the same time.

The finished products that may be assessed include wine, beer, spirit and non-alcoholic beverage bottles and food jars. Companies may do an assessment with the data provided. The production of more specialized glass containers (e.g. Flacconage, Pharmaceutical, Cosmetic and Perfume bottles) is not included in this study.

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2.5.2 Transportation

Transportation was included for both the raw materials to the factory gate in this study as well as delivery of the final product (empty glass container) to warehouses and customers as well as for end-of-life logistics. Average transportation distances and modes of transportation were collected from the container glass manufacturers and aggregated to create a regional average. Average data were used to approximate the distance and modes of transportation for collection of container glass at its end-of-life.

2.5.3 End-of-Life Phase

A model was developed for various scenarios for the end-of-life of container glass, including landfill and processing of cullet for recycling. Data were collected on the energies and materials and chemicals needed as well as for direct emissions from facilities handling glass at end-of-life. Average datasets on landfilling, transport and energies were taken from the GaBi 4 database 2006. End-of-life scenarios are described in Chapter 6.

2.5.4 Fuels and Energy – upstream data

National averages for fuel inputs and electricity grid mixes were obtained from the GaBi 4 database 2006[8]. Datasets on US average mixes for fuels (e.g. natural gas, diesel, heavy fuel oil and petroleum coke) and electricity were used for the GPI study, while European datasets were used for FEVE study.

2.5.5 Raw and process materials – upstream data

Primary data for the production of natural soda ash were collected. Data for all other upstream raw materials were obtained from the GaBi 4 database 2006.

2.5.6 Co-product and By-product Allocation

There is no allocation necessary for the glass manufacturing process.

Allocation of upstream data (energy and materials):

Energy data (e.g. refined products like diesel, gasoline, fuel oil and propane) are allocated by mass in relation to the refinery emissions and energy demands are allocated by energy content in relation to the crude oil consumption.

Materials and chemicals needed during manufacturing are modelled using economic allocation when multiple products are manufactured by the respective processes.

2.5.7 Emissions to Air, Water and Soil

Emissions data associated with the production of the stated functional units were determined by primary technical contacts familiar with the specific operations.

[8] GaBi Software and data base for Life Cycle Engineering, PE International GmbH, www.gabi-software.com

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Direct emission of carbon dioxide emissions from melting are more accurately calculated rather than measured, therefore calculated carbon dioxide factors were used, see following chapters for details.

Data for all upstream materials and electricity and energy carriers were obtained from the GaBi 4 database 2006. These datasets include all the inputs and outputs for all materials, energy, and emissions (including emissions that may contribute to toxicity impacts).

To capture the impacts from transportation, energy use and the associated emissions were calculated using pre-configured transportation models from the GaBi 4 database 2006.

End-of-life emissions were determined by municipal waste operations data associated with landfilling and incineration. Emissions associated with reprocessing post-consumer glass cullet so that it can be remelted, were collected from participating companies who have access to such data.

2.5.8 Cut-off Criteria

For the material and energy input to the gate-to-gate data, no cut-off criteria were applied as it was intended to capture the complete material input.

The following cut-off criteria were applied in the study all upstream data:

- Mass – If a flow is less than 2% of the cumulative mass of the model, it may be excluded, providing its environmental relevance is not a concern.
- Energy – If a flow is less than 2% of the cumulative energy of the model it may be excluded, providing its environmental relevance is not a concern.
- Environmental relevance – If a flow meets the above criteria for exclusion, yet is thought to potentially have a significant environmental impact, it will be included. Material flows which leave the system (emissions) and whose environmental impact is greater than 2% of the whole impact of an impact category that has been considered in the assessment, must be covered. This judgment will be done based on experience and documented as necessary.

The sum of the excluded material flows must not exceed 5% of mass, energy or environmental relevance.

2.5.9 Data Quality Requirements

Data quality is judged by its precision (measured, calculated or estimated), completeness (e.g. are there unreported emissions?), consistency (degree of uniformity of the methodology applied on a study serving as a data source) and representativeness (geographical, time period, technology). To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent, upstream LCA information from the GaBi LCI database were used. This upstream information from the GaBi LCI database is widely distributed and used with the GaBi 4 Software. The datasets have been

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used in LCA-models worldwide for several years in industrial and scientific applications for internal as well as critically reviewed studies. In the process of providing these datasets, they have been cross-checked with other databases and values from industry and science.

Precision and completeness

- **Precision:** As the relevant foreground (gate-to-gate) data is primary data or modelled based on primary information sources of the owner of the technology, no better precision is reachable within these projects. All upstream data is consistently GaBi professional data with the documented precision.
- **Completeness:** All relevant, specific processes for the different options are considered and modelled to represent each specific situation. Any upstream processes are taken from the GaBi databases (see GaBi 4 documentation).

Consistency and reproducibility

- **Consistency:** To ensure consistency only primary data of the same level of detail and upstream data from the GaBi databases are used. While building up the model cross-checks concerning the plausibility of mass and energy flows are continuously conducted. The provided primary data of the technology representatives was checked and recalculated by PE several times. No inconsistency could be found.
- **Reproducibility:** The reproducibility is given for internal use since the owners of the technology provided the data and the models are stored and available in a database. Sub-systems are modelled by ´state of art´ technology using data from a publicly available and internationally accepted database. For the external audience it is possible that no full reproducibility in any degree of detail will be available for confidentiality reasons. However, experienced experts will easily be able to recalculate and reproduce suitable portions of the life cycle system as well as key indicators.

Representativeness

- **Time related coverage:**
  - Glass manufacturing: actual production data for 2007
  - Upstream data: 2002 to 2007
- **Geographical coverage:**
  - The geographical coverage for GPI is US, Canada and Mexico
  - The geographical covered for FEVE the EU, Switzerland and Turkey
- **Technological coverage:**
  - Glass manufacturing is modelled using specific values, representing the specific technology for the different process steps using mass and energy

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balancing and LCI modelling. Over 72% of the yearly production volume in each region is covered by the included production sites.

As a measure of data quality, it was reported whether the data were measured, calculated, an average value, or estimated. In addition, the origin of the data was documented. Wherever possible, measured data from the facilities were utilized.

Container glass production was modelled based on:

- Primary process data on energy and materials consumption as well as measured direct emissions provided by GPI and FEVE member companies;
- Calculated CO_2 emission using emission factors for CO_2 emissions from natural gas combustion and direct carbon dioxide emissions related to batch materials (soda ash, limestone, dolomite, and coke)
- transportation mode and distance per material; and
- GaBi upstream data

Transportation data were based on:

- Logistical (distance and mode) information provided by member companies; and
- GaBi upstream data

In addition, models for various end-of-life scenarios were developed and analysed.

Data were collected and modelled to ensure that:

- All materials are modelled according to the same boundary conditions,
- The results represent current technology and up to date upstream data.

Sensitivity analysis was used to address the precision and uncertainty of relevant data used in this study.

2.5.10 Exceptions

No exceptions to the scope of this study on container glass are given. The production of flacconnage and cosmetic flasks/bottles was excluded.

2.6 SOFTWARE AND DATABASE

The LCA model was created using the GaBi 4 Software system for life cycle engineering, developed by PE INTERNATIONAL GmbH. The GaBi database provides the life cycle inventory data for several of the raw and process materials obtained from the upstream system.

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2.7 INTERPRETATION

The results of the LCI/LCIA are interpreted according to the Goal and Scope. The interpretation addresses the following topics:

- Identification of significant findings, such as the main batch materials contributing to the overall results, the contribution of the main energy carriers used in the process and the potential contribution of emissions for main impact categories in the context of the whole life cycle.
- Evaluation of completeness sensitivity and consistency, to justify the inclusion or exclusion of data from the system boundaries as well as the cut-off criteria and data quality checks described in chapters 2.5.8 and 2.5.9.
- Conclusions, limitations and recommendations, should state the appropriateness of the definitions of the system functions, the functional unit and system boundary.

2.8 CRITICAL REVIEW

Because the study is intended to support external communications, a critical review was conducted.

The critical review process was completed in three stages:

- **Stage 1: Review of the Study Purpose, Boundaries, and Data Categories**

  Goals of Stage 1:

  - Ensure the purpose and goal of the study was clearly defined
  - Ensure that all necessary data categories (inventory and impact) were covered to meet goal
  - Understand how results will be used
  - Ensure that the study meets quality requirements

- **Stage 2: Mid-project review at point of LCI completion**

  Goals of Stage 2:

  - Ensure recommendations of Stage 1 were addressed
  - Verify adequacy of data collection and model
  - Ensure that data quality meets quality requirements

- **Stage 3: Review of the Draft Final Report**

  Goals of Stage 3:

  - Ensure feedback of Stage 2 were addressed

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- Confirm that the observations and conclusions from the study were consistent with the stated purpose
- Ensure overall study quality and how the study meets the data quality specifications that are relevant to the stated purpose

The steps for realization of each stage of the critical review are detailed below:

- **Stage 1: Review of the Study Purpose, Boundaries, and Data Categories**
  - Convene brief teleconference with reviewers to make introductions and determine a Chairperson of Technical Review Committee (who will be the primary communication point)
  - Web presentation of goal and scope (G&S) to reviewers; receive feedback from panel
  - Incorporate reviewer feedback into G&S; distribute Final G&S to panel
- **Stage 2: Mid-project review at point of LCI completion**
  - Presentation/discussion of LCI model with panel
  - Panel discusses potential revisions/adjustments to LCI model and communicates feedback
  - Incorporate feedback into revised LCI model
- **Stage 3: Review of the Draft Final Report**
  - Preparation of Draft Final Report and web conference to present results/report to reviewers; feedback from panel
  - Incorporate feedback into revised Draft Final Report and distribute by email to all reviewers for final comment
  - Incorporate final comments and prepare Final Report for presentation

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3 DATA QUALITY

Data used for this project, as stated in Section 2.5.9, are a mix of primary data collected from participating companies (gate-to-gate) and data from the GaBi databases 2006. In the preceding sections the specific data sources and methods for data collection are described. Overall, the quality of the data used in this study is considered to be high and representative of the described systems by the authors of this study and the reviewers. All appropriate means were employed to guarantee the data quality and representivity as described below.

Gate-to-gate

Data processing materials and producing glass were collected in a consistent manner and level of detail to ensure high quality data. All submitted data were quality checked multiple times for plausibility of inputs and outputs and compared against existing datasets and other data collected. All questions regarding data were resolved with individual companies. All calculation procedures (e.g. determining averages) have been applied consistently throughout this study.

Upstream Data

All data from the GaBi databases 2006 were created with consistent system boundaries and upstream data. Expert judgment and advice was used in selecting appropriate datasets to model the materials and energy for this study and has been noted in the preceding sections. Detailed database documentation for GaBi datasets can be accessed at http://documentation.gabi-software.com/

3.1 DATA QUALITY CHECK

Questionnaires for data collection were defined and revised together with participating member companies, ensuring an adequate understanding of the coverage of questionnaires, meaning of data positions as well as completeness and consistency in reporting. Data have been reported based on different reference quantities, e.g. natural gas in kWh, MJ, BTU, kg, Nm³, etc. To ensure consistency the conversion factor to a common unit has been discussed with the member companies.

The data quality check (DQC) was based on benchmark comparisons as well as plausibility checks.

As a result of the DQC, plausible ranges per data position and questionnaire (given process step) were defined and companies asked to either confirm values seen to be out of range (or reported as zero) or revise the values. This data revision was done per individual furnace.

The consistency and completeness of data was analysed on a gate-to-gate basis in relation to 1kg per unit process:

- Each batch material per kg of batch

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- Batch, internal cullet, post-consumer cullet, fuels inputs and emissions at furnace (melting) level per kg of melted glass
- Cullet (process), water, non-melting and fuels consumption, wastes and other (not coming from melting) CO_2 emissions per kg of formed & finished glass

The benchmarking checks were done with the following objectives:

- To identify the main flows from the batch materials and melting (energy, fuels consumption and emissions).
- To verify the completeness of data collection between furnaces with similar technology.
- To identify missing data, zero values or values out of range to be cross checked again with member companies for confirmation or revision of data.

In addition to the benchmarking checks a comparison with the values reported in the BREF[9] document (gate-to-gate) and other available data sources (cradle-to-gate data from commercial databases and confidential sources) was done as well as plausibility checks e.g. regarding the CO_2 emissions from decomposition of batch materials and combustion of fuels.

Values were confirmed, revised and completed based on the DQC. After integrating all changes new average values were calculated confirming the ranges and magnitudes from the first benchmarking analysis.

3.2 SENSITIVITY ANALYSIS

The sensitivity analysis provides information on how sensitive the balance is in relation to various parameters, quantities or evaluations. It is possible that variations of individual parameters can have a minor effect on the balance results despite a pronounced variation range. Minor modifications to other parameters may cause major changes in the results.

Within the study two approaches of sensitivity check were applied with the following purposes:

- To ensure that the omission of other materials (not part of the final product) is appropriate and does not require a redefinition of the system boundaries.
- To compare the results obtained using certain given assumptions for the key parameters identified using a variation of ±15%.

[9] Glass Manufacturing Industry, Reference Document on Best Available Techniques in Glass Manufacturing Industry, December 2001. European Commission, Joint Research Centre http://eippcb.jrc.ec.europa.eu/reference/

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3.2.1 Moulds, Refractory and Lubricant Oil Sensitivity Analysis

A sensitivity analysis was performed on average data for moulds, lubricant oil and furnace rebuilds (refractory) materials. As a result, all were excluded since their contribution to the environmental impact categories assessed is not of relevance (<0.7%).

3.2.2 Hot End and Cold End Coating Chemicals

A sensitivity analysis was performed on average data for hot end and cold end coating chemicals. As a result these were excluded since their contribution to the environmental impact categories assessed is not of relevance (<0.1%). Although these chemicals do not have a significant impact on the environmental indicators assessed, they may contribute significantly to emissions of VOC, HCl, tin / organo-tin and tin-oxide dust.

3.2.3 Key Parameters Sensitivity Analysis

The influence on the results, if varying key data by a range of ± 15 % was checked. Both results were then compared and expressed as the percentage of change. On this basis, significant changes in the results (e.g. larger than 10 %) were not identified.

The results of the study were used as a base scenario. A deviation of 15% in negative and positive was used for the analysis.

The key parameters analysed are: batch, heavy fuel, natural gas and electricity consumption at furnace level per 1 kg of glass formed and finished. Synthetic soda ash was also analysed since it is the main contributing material from the batch.

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4 CRADLE-TO-GATE LIFE CYCLE MODEL DESCRIPTION

The following sections are specific to the FEVE study and represent the European container glass industry; separate sections were developed in parallel for GPI - North American study.

4.1 GLASS CONTAINER MANUFACTURING

Data were collected for container glass manufacturing furnaces with a total annual throughput of 14.31 million metric tons of formed and finished melted glass, representative of about ~72% (referring to production volume) of European container glass production (~20 million metric tons in 2007). All common furnace technology types are represented in this study. For the data collection, glass plants data were separated into colour (amber, flint, green and mix[10]) and technology.
Results are presented on the overall industry average.

4.2 LIFE CYCLE INVENTORY

The container glass cradle-to-gate life cycle model in Figure 2 shows the main phases included in the study, a brief description of each follows below.

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[10] The mixed colours category includes all furnaces which produced more than one colour glass in 2007, with the exception of furnaces that only produced different shades of green as these are included in the "Green" category.

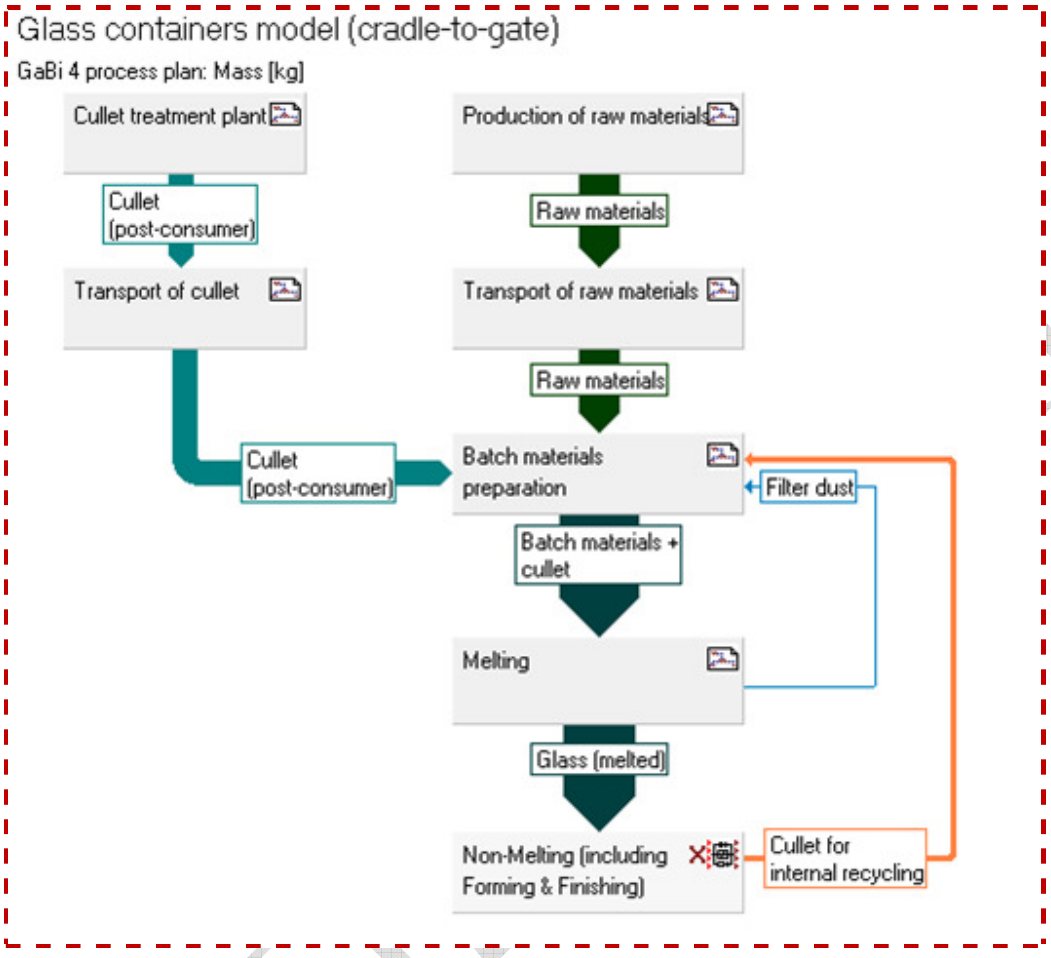


Figure 2: Container glass cradle-to-gate model

BATCH phase: all transported virgin materials and cullet (post-consumer treated) plus the filter dust are mixed in this step. Although for the purpose of this study the term “BATCH” refer only to the upstream production of virgin materials and has not direct consumptions or emissions.

MELTING phase: includes the fuels, electricity (including consumption for oxygen production), batch, cullet (post-consumer and internal) amounts as inputs and emissions during the melting process.

FORMING & FINISHING phase: reports the yield at gate-to-gate level and internal cullet loop (from process) for recycling.

NON-MELTING phase: includes the waste generated, water input & output, CO_2 emissions and the energy consumption (without furnace) which was not separated into further process steps (i.e., conditioning and forming and finishing) due to data availability.

4.2.1 Batch Materials

This study includes the upstream production of batch materials, including transportation to glass manufacturing sites. A screenshot of the model is shown in Figure 3; each box in the figure represents a cradle-to-gate dataset for the batch materials. The model uses a Sankey diagram to scale the size of the arrows based on the mass of material.

Quartz sand, synthetic soda ash, limestone and feldspathic sand comprise approximately 90% of the virgin batch material. Dolomite, feldspar and natural soda ash contribute another 6% mass. The remaining materials each contribute less than one percent of total production volume based average batch mass.

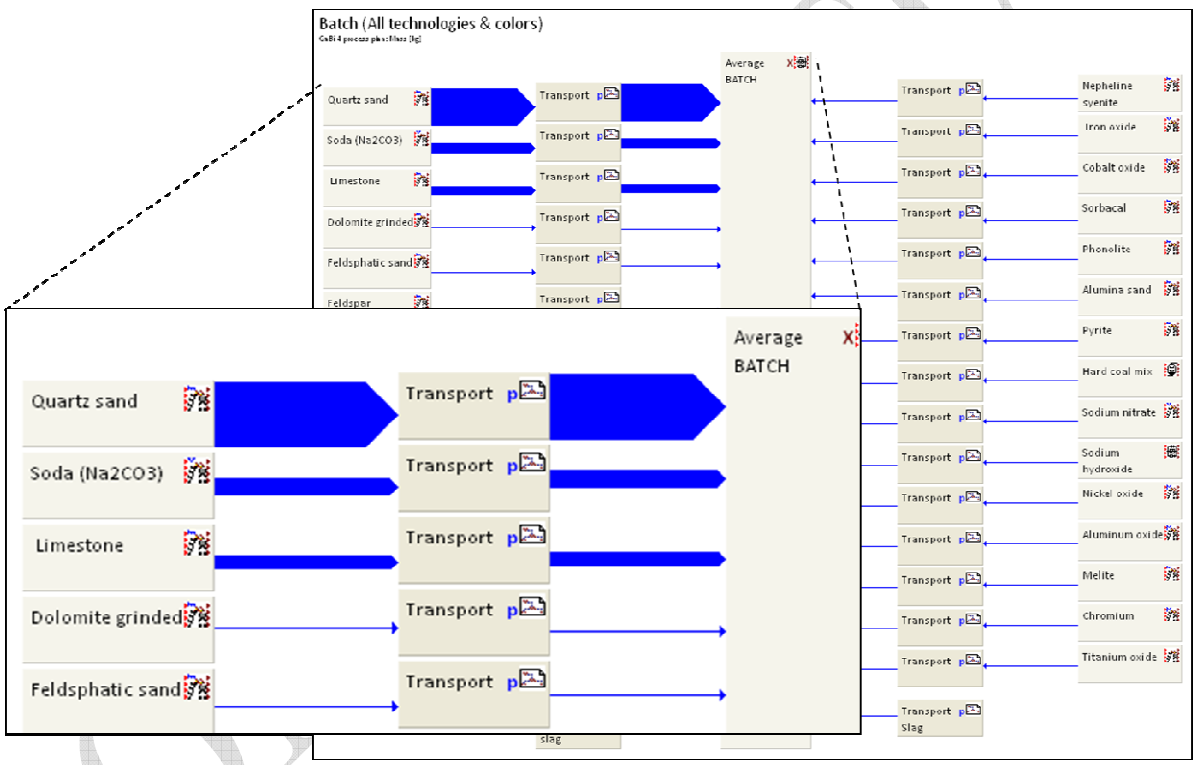


Figure 3: Virgin batch materials (without cullet) production and transport model

The study covers 99.97 % of the mass of upstream production of virgin batch input materials. Batch material quantities (excluding cullet) were assessed on the dry weight, except for quartz sand which might contain up to 5% of moisture. Data for the production of natural soda ash were obtained from the Industrial Minerals Association – North America as it is considered as a good estimation for the study. Most of the soda ash reported for this study is synthetic, this and all other material profiles for this study were obtained from the GaBi 4 databases 2006 and represent average material profiles for materials used in the European glass industry.

A by-product from the production of synthetic soda ash (Na_2CO_3) is calcium chloride ($CaCl_2$). Based on information provided by FEVE on the market (demand) situation for $CaCl_2$ an economic allocation was applied and a worst as well as best case scenario were calculated. The resulting allocation of environmental burden of the production of synthetic soda ash between soda and $CaCl_2$ would be as follows: best case: Na_2CO_3 94.94 % and $CaCl_2$ 5.06%; worst case: Na_2CO_3 96.77% and $CaCl_2$ 3.23%. This allocation option was discarded because of the minor relevance that $CaCl_2$ has in the market currently. The resulting contribution on the overall LCIA results would not be significant (less than 1%). The current upstream data used in this study (based on information provided by Solvay) does not consider any allocation between Na_2CO_3 and $CaCl_2$ meaning that synthetic soda ash is carrying 100% of the environmental burden from its production process.

4.2.2 Transport of Batch Materials

Average transport distances and modes were provided by companies participating in the project. Data on transport was not available for some materials representing in sum less than 1% of total batch mass. For these cases an average distance, modelled 50% by truck and 50% by train (diesel), was taken into account.

The environmental impact of transportation, modelled in the GaBi 4 Software, consists of the fuel combustion related emissions and production of diesel fuel (truck and train), electricity (train), heavy fuel oil (ocean ship) and light fuel oil (coastal ship). As transport distances used for this study are all averages, the impact from transport will vary with specific situations.

For the transport of cullet and all batch materials a load efficiency of 85% was taken into account, whereas for the transportation of empty container glass products a load efficiency of 35% was considered.

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5 LIFE CYCLE INTERPRETATION

The goal of the study was to analyse the life cycle environmental performance of glass packaging in Europe:

The following chapter summarizes and evaluates the results of the Life Cycle Assessment of container glass and characterizes the key aspects related to the Life Cycle Inventory data covered, the Life Cycle Impact Assessment categories considered as well as the life cycle stages addressed. A sensitivity analysis, conclusions and recommendations in accordance with the goal and scope defined are also given in this chapter.

5.1 IDENTIFICATION OF SIGNIFICANT ISSUES

Life Cycle Inventory Data

The LCI results refer to input and output data and not to environmental impacts. Primary data (gate-to-gate) was reported by participating companies, was revised as described in the goal and scope and was averaged according to the production volume of all furnaces (without differentiation between colours and technologies)

From a mass and energy consumption perspective the main flows identified for batch materials are quartz sand (61%), synthetic soda ash (18%) and limestone (15%).

Life cycle impact assessment categories

Table 3 shows a summary of the most significant phases, processes and flows for each environmental indicator category considered.

Table 3: Life cycle significant phases, processes and flows

Contribution to results in percentage (%)			
Impact category	**Main phase contributing to overall results**	**Main production process contributing to main phase**	**Main input/output contributing to main process**
Primary energy demand from ren. and non ren. resources (net cal. value)	Melting	Natural gas Heavy fuel oil	Natural gas mix
	Batch	Synthetic soda ash	Hard coal mix Natural gas mix
	Non-melting	Electricity	Uranium mix Hard coal mix Natural gas mix
Global Warming Potential (100 years)	Melting	Melting direct emissions	Carbon dioxide
	Batch	Synthetic soda ash	Carbon dioxide

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	Non-melting	Electricity	Carbon dioxide
Eutrophication Potential	Melting	Melting direct emissions	Nitrogen monoxide
	Batch	Synthetic soda ash	Ammonia Nitrogen oxides
	Non-melting	Electricity	Nitrogen oxides

Contribution to results in percentage (%)			
Impact category	**Main phase contributing to overall results**	**Main production process contributing to main phase**	**Main input/output contributing to main process**
Acidification Potential	Melting	Melting direct emissions	Nitrogen monoxideSulphur dioxide
	Batch	Synthetic soda ash	Sulphur dioxide Nitrogen oxide
	Non-melting	Electricity	Sulphur dioxideNitrogen oxide
Photochemical Ozone Creation Potential	Melting	Melting direct emissions	Nitrogen monoxide
	Batch	Synthetic soda ash	Carbon monoxide Sulphur dioxide Nitrogen oxides
	Non-melting	Electricity	Sulphur dioxideNitrogen oxide

As can be seen in Table 3 the main contributing life cycle phase is the melting since most of the cradle-to-gate emissions are coming from the combustion of fuels (natural gas and heavy fuel oil) and batch materials decomposition, especially carbonates such as synthetic soda ash, dolomite and limestone.

Within the batch materials, synthetic soda ash is the main contributor from a cradle-to-gate perspective; since its production is high in energy consumption and registers high emissions of carbon dioxide, nitrogen oxides and sulphur dioxide. These emissions contribute significantly to all impact categories considered. A sensitivity analysis was performed to analyse the variation of results if the average consumption of synthetic soda ash increases or decreases by 15%.

The non-melting phase is not to be neglected since is covering part of the energy needed in other production processes such as conditioning, forming and finishing.

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5.2 COMPLETENESS, SENSITIVITY AND CONSISTENCY CHECKS

5.2.1 Completeness

Completeness checks were carried out at gate-to-gate level, analyzing

- the completeness of process steps considered to describe the container glass manufacturing,
- the coverage of energy and material inputs of relevance for the description of the individual container glass production steps as well as
- the coverage of significant outputs of fuel- and batch-related emissions and waste

Furthermore the completeness was checked at cradle-to-gate level with focus on the coverage of all significant upstream data. A worst case scenario was carried out for those were no data was available.

5.2.2 Sensitivity

A sensitivity analysis was carried out using the data provided by some participating companies, thus this data was not collected from all companies. This covers furnace rebuild (refractory), moulds and lubricant oil as well as hot and cold end coating chemicals.

In addition, the relevance of packaging design aspects outside the scope of the functional unit of 1 kg formed & finished glass was analysed. The user guide (see also Appendix V: User Guidance for Compiling Packaging LCAs Using Container Glass LCA Data) clearly highlights the need to consider these aspects, e.g. closures and labelling, in the analysis of packaging designs.

Furthermore a sensitivity analysis was carried out on key parameters, such as energy consumption of the melting, batch main material contributor, etc.

5.2.3 Consistency Checks

To check the consistency of data provided by member companies, plausibility checks were carried out. These checks covered e.g. cross-check calculations on fuel- and batch-related emissions, mass and energy balance as well as the screening of the yields.

In addition to the plausibility checks, there were benchmarking checks applied across individual companies and between companies, at gate-to-gate and cradle-to-gate level, as well as in comparison with other data sources.

5.3 CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS

A critical review of this study has been done as specified in the Goal & Scope sections of this report (Chapters 1 and 2).

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This study represents a comprehensive LCA of European industry average container glass production; conclusions can be drawn in general across the entire industry. The study covers all technologies and is representative of more than 72% of the production volume in Europe.

All significant Life Cycle Inventory parameters and life cycle stages are considered as described within the Goal & Scope.

The procedure applied to ensure the completeness of the study, to analyse the sensitivity of key aspects as well as to check the consistency in data and results is in line with the Goal & scope of the study.

5.3.1 Conclusions

As currently constituted, the following conclusions may reasonably be made based on the results of this study:

- Melting operations drive the life cycle profiles – For all impact categories, the melting related emissions and energy flows drive the results.
- Transportation of batch materials and cullet – The share of inbound transportation of batch materials to the glass manufacturing plant is less than 2% to each considered category. The effect of the use of cullet on the transportation related environmental effects is not of significance as the increase of cullet transportation results in a reduction of transportation of batch materials. This is based on the fact that the average logistic efforts of the dominating batch materials are in the same range.
- Batch materials – The production of the different batch materials contribute around 20-30% to the analysed impact categories with synthetic soda ash production as the defining material. Synthetic soda ash is also the second largest proportion by mass of virgin batch materials.
- Cullet rate – The numbers for all participating production sites showed a clear improvement of primary energy demand and Global Warming Potential related to an increased usage of post-consumer cullet. The benefit of the use of cullet is twofold; it results in the reduction of batch related carbon dioxide emissions (since less batch materials are needed) as well as in a decrease of direct energy needed. No statement on the influence on the other impact categories can be made as potential overlaying effects such as the use of abatement have a larger influence.
- Closures – The discussion of product examples demonstrated that the closures are of significance and therefore should be examined in detail when this study is used for life cycle studies of specific packaging designs.

The study also provides a Life Cycle Inventory representing average container glass produced for the European market to interested parties. The inventory:

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- represents one kg of formed and finished glass as containers delivered to the end user of products contained in Europe
- should be used for any kind of life cycle assessment studies on specific containers to store liquids and solids/food (see Appendix V: User Guidance for Compiling Packaging LCAs Using Container Glass LCA Data).

5.3.2 Limitations

The study gives only the average European data and thus does not take into account any regional differences. The cradle to cradle model used for the functional unit of a kg of glass containers as delivered to the end user of the contained products contains some transport and washing data which makes it not entirely suitable for assessments that would be made on a particular model. In this case LCA practitioners are invited to contact FEVE.

Furthermore the data used is describing the status of container glass production in Europe for the year 2007 and therefore not covering potential improvements in 2008 e.g. based on the implementation of abatement technologies.

5.3.3 Recommendations

The user of the generated LCI results should receive clear user guidance on correct use of the data, e.g. addressing an appropriate consideration of container glass recycling; see also the user guide as given in Appendix V: User Guidance for Compiling Packaging LCAs Using Container Glass LCA Data.

This assessment reflects the existing technical situation for the year 2007 representing 72% of the European production volume. Conditions of furnaces, due to the increasing use of abatement systems, efficiencies, rebuilds, and cleaner technologies, etc. will change over time affecting the energy and material inputs and subsequent emissions of container glass manufacturing. Additionally, more FEVE member companies may choose to participate and provide data in future LCI & LCA efforts to increase the overall coverage of this study. Collection of data from these additional sites as well as updated regional data could contribute to the improved quality of the LCI and LCIA results.

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6 CRADLE-TO-CRADLE LCI MODEL DESCRIPTION

This cradle-to-cradle discussion addressed the environmental effects of container glass recycling and reuse with the goal of quantifying the effect of both recycling and reuse.

For container glass / glass packaging the following end-of-life management scenarios are considered:

1. Closed-loop reuse of glass packaging
2. Recycling of glass packaging back into glass packaging
3. Recycling of glass packaging into a mix of non-packaging products
4. Losses via landfill, incineration, etc.

While other end-of-life management scenarios exist (e.g. recycling of non container glass and imports/exports of container glass), the above examples are considered in this study. Whereas the cradle-to-gate model and results describe the current market situation of container glass production (with average cullet (post-consumer) consumption) it is the task of a cradle-to-cradle consideration to focus in particular on the environmental benefit of reuse and recycling.

Different end-of-life (EoL) scenarios for a container glass product are described in the following section.

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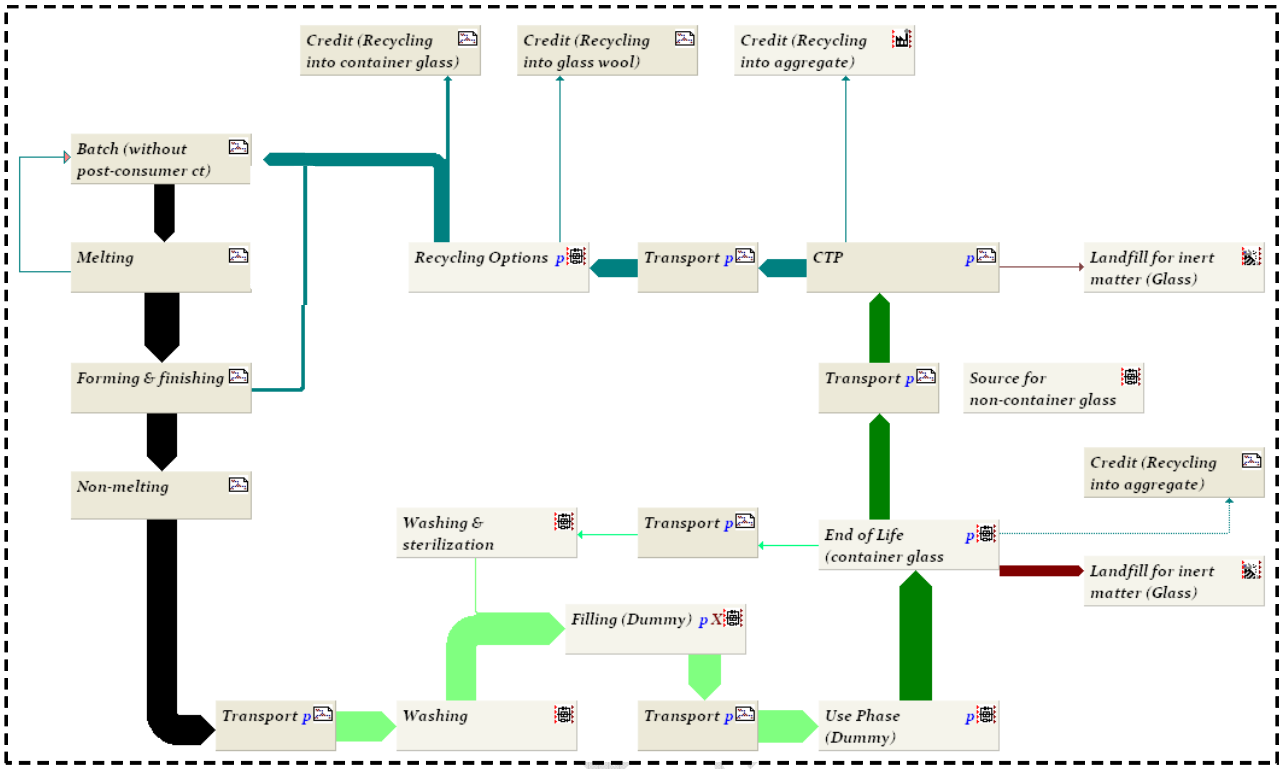


Figure 4: Container glass life cycle from cradle-to-cradle model

As can be seen from Figure 4, the life cycle of a container glass product is characterized by reuse, recycling (closed loop / open loop) and disposal (landfill / incineration).

According to ISO[11] a closed loop allocation applies, when a material is recycled into the same product system and the material does not undergo a change to its inherent properties (chemical, physical, etc.). In this case it is assumed that recycled material (100%) replaces virgin material (100%).

Whereas an open loop allocation procedure applies to systems where the material is recycled into other product systems and/or the material undergoes a change to its inherent properties.

Within the special case of an open loop system where no changes occur to the inherent properties of the recycled material, the closed loop approach is to be applied. This procedure is based on the assumption that when there are no changes to inherent

[11] According to ISO 14044, 4.3.4.3:
a) "A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials. However, the first use of virgin materials in applicable open-loop product systems may follow an open-loop allocation procedure outlined in b)."
b) "An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties."

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properties of the recycled materials the use of secondary material replaces the use of virgin (primary) materials.

In addition, transportation and preparation of post-consumer material (via cullet treatment plants, etc.) is considered.

The cradle-to-cradle LCI model includes the following modules:

- Transportation:
    - Container glass products from container glass manufacturing plant to warehouse
    - Container glass products from warehouse / washing / filling to final consumer
    - Post-consumer container glass products going to reuse
    - Post-consumer container glass products going to cullet treatment plant
    - Cullet from cullet treatment plant to container glass manufacturing sites or glass wool manufacturing sites
- Washing and (if appropriate) sterilization:
    - New container glass products
    - Post-consumer container glass products going to reuse
- Reuse of glass containers (transportation as well as washing and sterilization, see above)
- Recycling:
    - Into aggregate (directly after use, or after cullet treatment in CTP)
    - Into glass wool (considering cullet treatment in CTP)
    - Into container glass (considering cullet treatment in CTP)
- Landfill (directly after use, or after cullet treatment in CTP)
- Incineration (of inert matter)
    - As cullet in municipal waste
    - Ending up in landfill as part of the bottom ash of the waste incinerators
- Use of cullet from non-container glass (e.g. flat glass)

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<u>Transportation:</u>

Average transport distances and mode for transport from site to warehouse as well as cullet treatment plant to site were provided by some companies participating in the project. Data on transport from warehouse / filling to retailer / final consumer and of post-consumer

container glass products going to reuse was not available. For these cases a distance of 100km by truck was taken into account.

For the transport of cullet and filled container glass products a load efficiency of 85% is taken into account, whereas for the transportation of empty container glass products a load efficiency of 35% is considered. The load efficiency depends on the relationship of the payload to the total vehicle capacity.

Washing (and sterilization):

For new container glass products washing is taken into account, whereas for container glass products going to reuse a washing and sterilization step is considered.

Reuse:

The reuse of container glass products is characterized by the number of reuse cycles as well as the ratio (in percentage) of post-consumer glass container products going to reuse, see Figure 5.

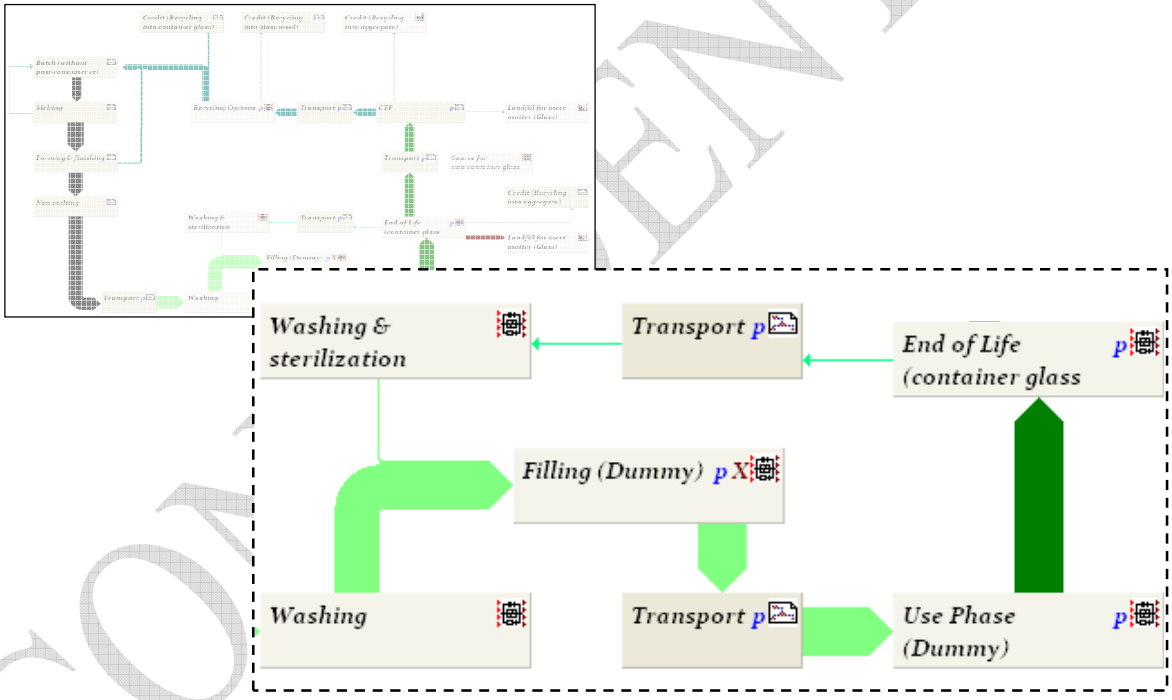


Figure 5: Cradle-to-cradle: Reuse

Recycling into aggregate (open loop recycling):

The recycling of post-consumer container glass into aggregate (directly after use or after cullet treatment in CTP) describes an open loop recycling. The approach of system boundary expansion by crediting, addressing the open loop situation, assumes that recycled

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post-consumer container glass substitutes (due to its material/product properties) another product, here aggregate.

The crediting system for recycling of container glass into aggregate is described by the substitution of gravel, see Figure 6.

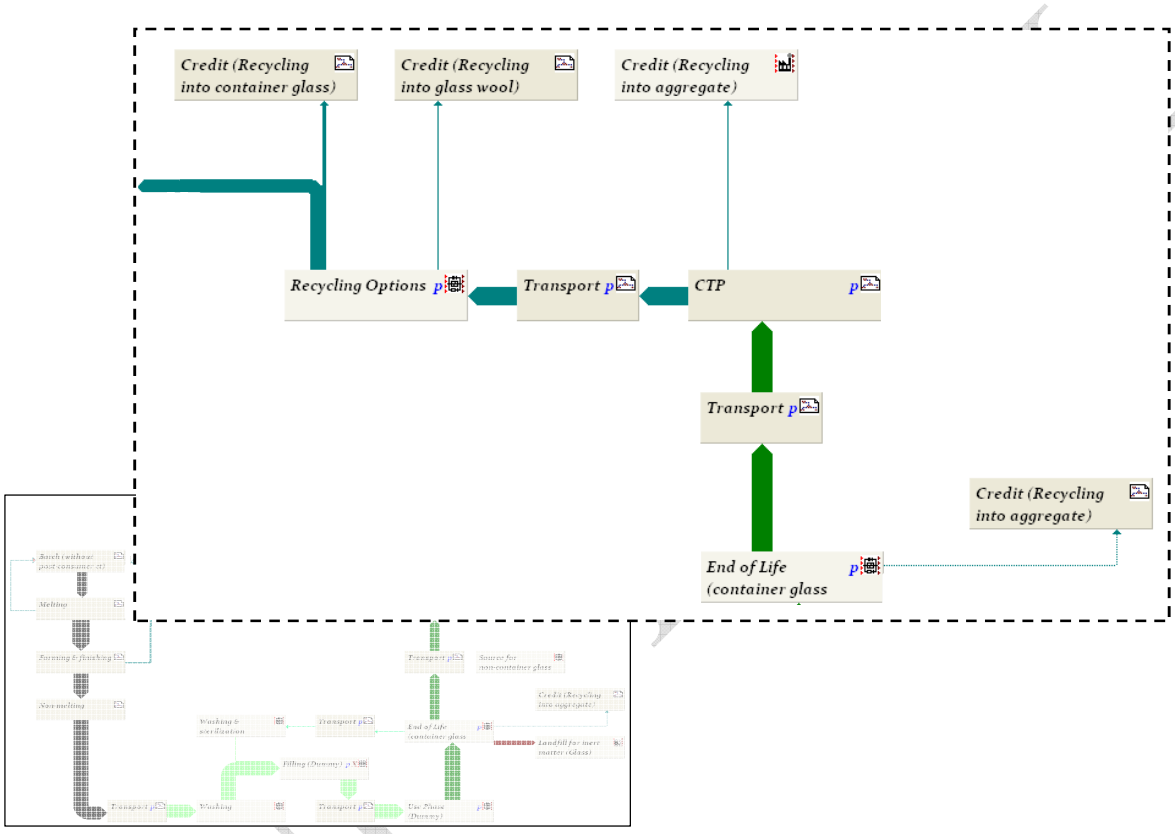


Figure 6: Cradle-to-cradle: Recycling (closed/open loop)

Recycling into glass wool (open loop recycling):

The recycling of post-consumer container glass into glass wool describes an open loop recycling system. The approach of system boundary expansion by crediting, addressing the open loop situation, assumes that recycled post-consumer container glass substitutes (due to its material/product properties) another product, here glass wool.

The crediting system for recycling of container glass into glass wool is described by the substitution of batch materials as well as reduction in energy consumption and emissions in the melting process.

Although the batch composition is different for the production of glass wool, it was agreed with the member companies and review panel member that the crediting system as applied considers it as being equivalent to container glass production.

Recycling into container glass (closed loop recycling):

The recycling of post-consumer container glass back into container glass describes a closed loop recycling system. Closed loop allocation applies to product systems, where it is assumed that recycled material (100%) replaces virgin material (100%).

The crediting system for recycling of container glass back into container glass is described by the substitution of batch materials as well as reduction in energy consumption and emissions in the melting process.

Cullet treatment plant:

Before being recycled into glass wool or container glass the post-consumer container glass products are processed in cullet treatment plants. Data on the cullet treatment plant were provided by FEVE member companies describing the energy consumption and related emissions as well as waste.

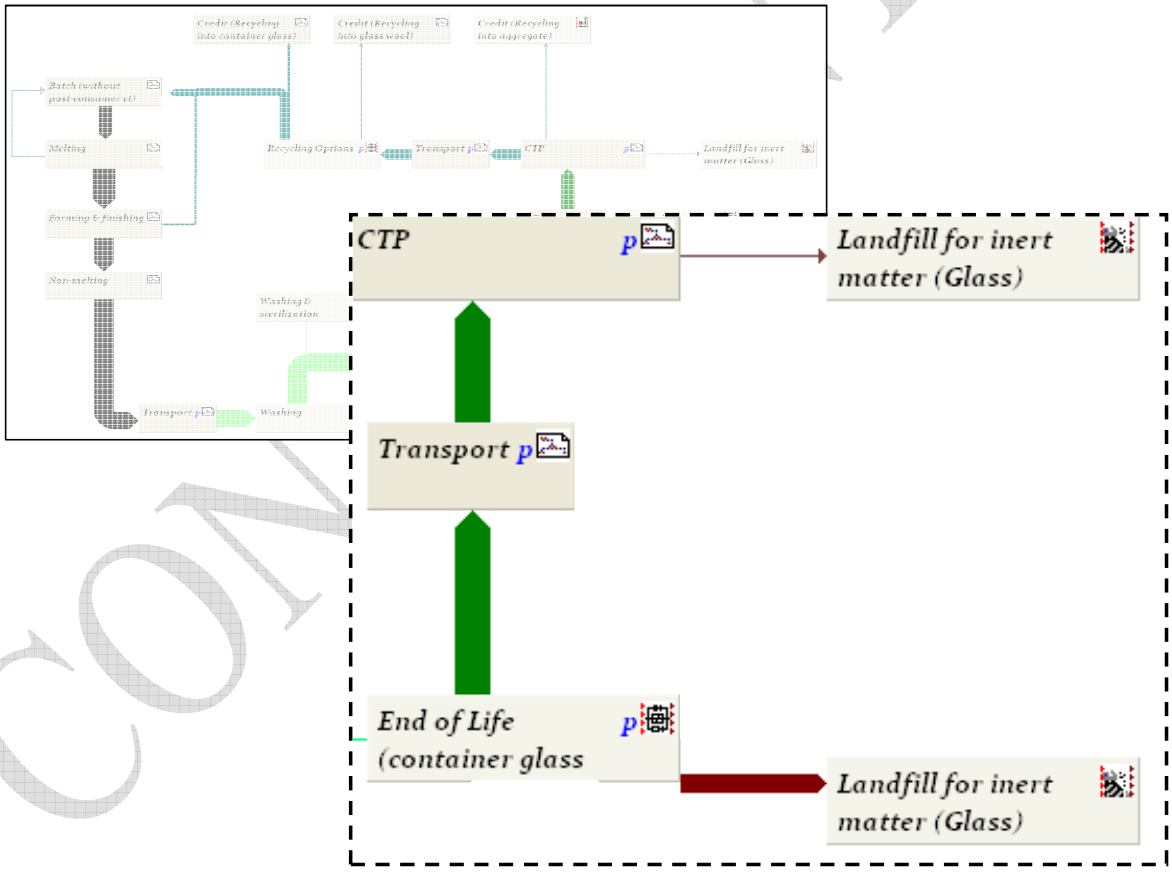


Figure 7: Cradle-to-cradle: Landfilling

Landfill (of inter matter)

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Average data on landfilling of inert material is used to account for landfilling of post-consumer container glass (directly after use, or after cullet treatment in CTP), see Figure 7.

Incineration (of inert matter)

Average data on incineration of inert materials is used to account for incineration of post-consumer container glass.

Consumption of cullet from non-container glass

The cullet consumed within the container glass production is composed of post-consumer glass material from container glass products as well as flat glass products, see Figure 8.

The intake of recovered material from post-consumer flat glass describes an open loop recycling. Here, similar to the open loop recycling of container glass into glass wool, the (in this case: inverse) approach of system boundary expansion by crediting/debiting is applied. The assumption is that the consumption of flat glass cullet in the container glass production saves virgin batch materials by the substitution of raw materials as well as reduces the energy consumption and emissions in melting process.

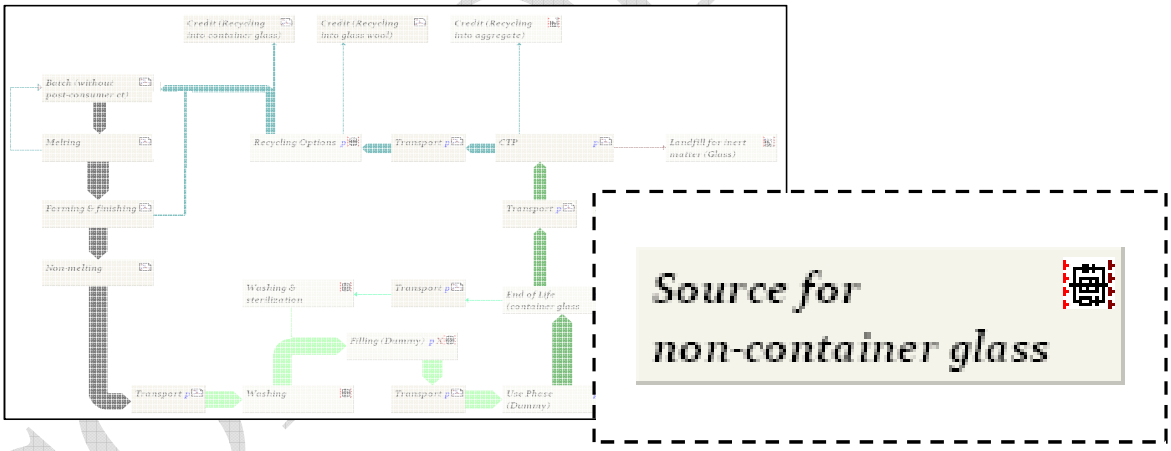


Figure 8: Cradle-to-cradle: Consumption of non-container glass cullet

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APPENDIX I: GLASS MAKING OVERVIEW

Text provided by FEVE - May 2009.

The glass industry is very diverse and covers a variety of very different types of products and technologies, including bottles & jars, flat glass, continuous filament glass fibres(not to be confused with mineral glass wool), flaconnage, tableware, mineral wool, optical fibres and special glass (lighting glass, optical glass, laboratory and technical glassware, borosilicate and glass ceramic (cookware), etc).

This section will focus on the production of container glass (bottles and jars) which is the subject of this LCA.

Container glass is made by melting together several largely naturally occurring minerals The most common raw materials used to produce glass are:

- Cullet (the name for post-consumer recycled glass)
- Silica sand
- soda ash (used to reduce the melting temperature)
- limestone (to enhance the durability of glass)
- Other materials can be added to produce different colours or properties.

The manufacturing process of glass consists of the following steps:

- Selection and controlling of raw materials.
- Preparation of raw materials: essentially weighing and mixing materials to a set batch recipe.
- Melting: the raw materials undergo fusion at high temperature (1,300 to 1,550 ℃ in a furnace.
- Forming: the molten glass is shaped and allowed to solidify
- Annealing: internal stresses in the container are removed by reheating the bottle and cooling it slowly.
- Finishing: finishing includes in particular quality control.

Container glass furnaces are generally designed to melt large quantities of glass over a continuous period of more than 15 years and range in output from 150 tonnes of glass per day to over 600 tonnes of glass per day. The glass is contained in a tank constructed of blocks of refractory materials closed by a vaulted ceiling or crown.



Heat is provided by burning fossil fuels (natural gas or heavy fuel oil) above the glass bath.

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The mass of molten glass contained in the furnace is held constant, and the mean residence time is of the order of 24 hours of production for container furnaces. A conditioning phase at lower temperatures follows the primary melting stage. During this process, the melt cools slowly to a working temperature between 900°C and 1350°C.

At the end of the furnace, the glass stream is distributed to different forehearths which feed the production lines. Here, the glass article will receive its final shape.

Glass containers are produced in a two stage moulding process by using either the press and blow, or blow-blow techniques.

There are five essential stages in automatic bottle production.

1. Obtaining a piece of molten glass (gob) at the correct weight and temperature.

2. Forming the primary shape in a first mould (blank mould) by pressure from compressed air or a metal plunger.

3. Transferring the primary shape (parison) into the final mould (finish mould).

4. Completing the shaping process by blowing the container with compressed air to the shape of the final mould.

5. Removing the finished product for post forming processes.

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APPENDIX III: DESCRIPTION OF SELECTED INVENTORIES AND IMPACT CATEGORIES

Acidification Potential

The acidification of soils and waters occurs predominantly through the transformation of air pollutants into acids. This leads to a decrease in the pH-value of rainwater and fog from 5.6 to 4 and below. Sulphur dioxide and nitrogen oxide and their respective acids (H2SO4 und HNO3) produce relevant contributions. This damages ecosystems, whereby forest dieback is the most well-known impact.
Acidification has direct and indirect damaging effects (such as nutrients being washed out of soils or an increased solubility of metals into soils). But even buildings and building materials can be damaged. Examples include metals and natural stones which are corroded or disintegrated at an increased rate.
When analysing acidification, it should be considered that although it is a global problem, the regional effects of acidification can vary. Figure A 1 displays the primary impact pathways of acidification.
The acidification potential is given in sulphur dioxide equivalents (SO2-Eq.)[12]. The acidification potential is described as the ability of certain substances to build and release H+ -ions. Certain emissions can also be considered to have an acidification potential, if the given S-, N- and halogen atoms are set in proportion to the molecular mass of the emission. The reference substance is sulphur dioxide.

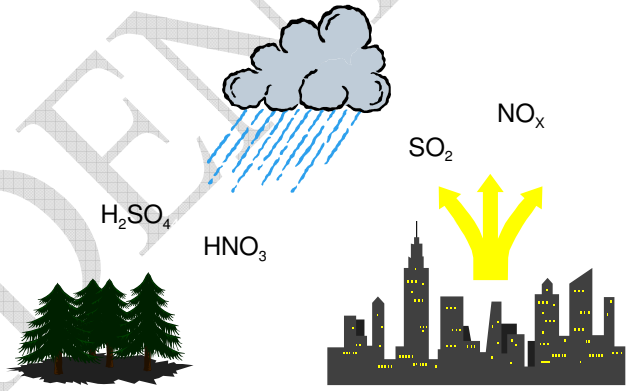


Figure A 1: Acidification Potential [Heijungs et al. 1992]

Eutrophication Potential

Eutrophication is the enrichment of nutrients in a certain place. Eutrophication can be aquatic or terrestrial. Air pollutants, waste water and fertilization in agriculture all contribute to eutrophication.
The result in water is an accelerated algae growth, which in turn, prevents sunlight from reaching the lower depths. This leads to a decrease in photosynthesis and less oxygen production. In addition, oxygen is needed for the decomposition of dead algae. Both effects cause a decreased oxygen concentration in the water, which can eventually lead to fish dying and to anaerobic decomposition (decomposition without the presence of oxygen). Hydrogen sulphide and methane are thereby produced. This can lead, among others, to the destruction of the eco-system.

[12] For TRACI reference quantity is H+ equivalent.

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On eutrophicated soils, an increased susceptibility of plants to diseases and pests is often observed, as is a degradation of plant stability. If the nutrification level exceeds the amounts of nitrogen necessary for a maximum harvest, it can lead to an enrichment of nitrate. This can cause, by means of leaching, increased nitrate content in groundwater. Nitrate also ends up in drinking water.

The causes of Eutrophication are displayed in Figure A 2. The Eutrophication potential is calculated in phosphate equivalents (PO4-Eq.)[13]. As with acidification potential, it's important to remember that the effects of Eutrophication potential differ regionally.

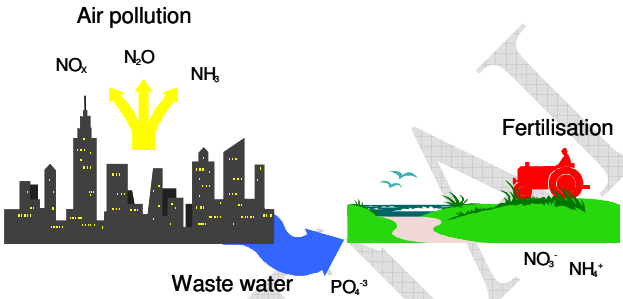


Figure A 2: Eutrophication Potential [Heijungs et al. 1992]

Global Warming Potential

The mechanism of the greenhouse effect can be observed on a small scale, as the name suggests, in a greenhouse. These effects are also occurring on a global scale. The occurring short-wave radiation from the sun comes into contact with the earth's surface and is partly absorbed (leading to direct warming) and partly reflected as infrared radiation. The reflected part is absorbed by so-called greenhouse gases in the troposphere and is re-radiated in all directions, including back to earth. This results in a warming effect at the earth's surface.

In addition to the natural mechanism, the greenhouse effect is enhanced by human activities. Greenhouse gases that are considered to be caused, or increased, anthropogenically are, for example, carbon dioxide, methane and CFCs. Figure A 3 shows the main processes of the anthropogenic greenhouse effect. An analysis of the greenhouse effect should consider the possible long term global effects.

The global warming potential is calculated in carbon dioxide equivalents (CO_2-Eq.). This means that the greenhouse potential of an emission is given in relation to CO_2. Since the residence time of the gases in the atmosphere is incorporated into the calculation, a time range for the assessment must also be specified. A period of 100 years is customary.

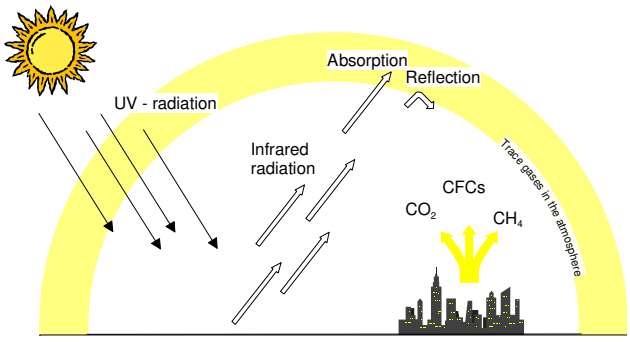


Figure A 3: Greenhouse effect [Heijungs et al. 1992]

[13] For TRACI reference quantity is N equivalent.

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Photochemical ozone creation potential

Despite playing a protective role in the stratosphere, at ground-level ozone is classified as a damaging trace gas. Photochemical ozone production in the troposphere, also known as summer smog, is suspected to damage vegetation and material. High concentrations of ozone are toxic to humans.
Radiation from the sun and the presence of nitrogen oxides and hydrocarbons incur complex chemical reactions, producing aggressive reaction products, one of which is ozone. Nitrogen oxides alone do not cause high ozone concentration levels.
Hydrocarbon emissions occur from incomplete combustion, in conjunction with petrol (storage, turnover, refuelling etc.) or from solvents. High concentrations of ozone arise when the temperature is high, humidity is low, when air is relatively static and when there are high concentrations of hydrocarbons. Because CO (mostly emitted from vehicles) reduces the accumulated ozone to CO_2 and O2, high concentrations of ozone do not often occur near hydrocarbon emission sources. Higher ozone concentrations more commonly arise in areas of clean air, such as forests, where there is less CO (Figure A 4).

In Life Cycle Assessments, photochemical ozone creation potential (POCP) is referred to in ethylene-equivalents (C2H4-Eq.)[14]. When analysing, it's important to remember that the actual ozone concentration is strongly influenced by the weather and by the characteristics of the local conditions.

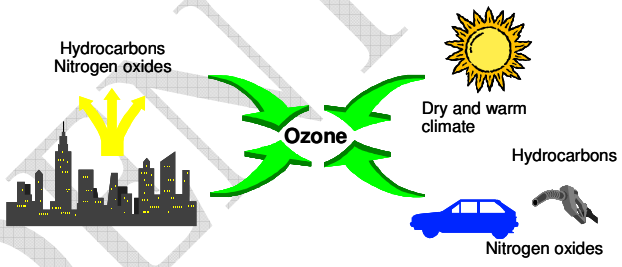


Figure A 4: Photochemical Ozone Creation Potential [Heijungs et al. 1992]

Primary energy demand

Primary energy demand is often difficult to determine due to the various types of energy source. Primary energy demand is the quantity of energy directly withdrawn from the hydrosphere, atmosphere or geosphere or energy source without any anthropogenic change. For fossil fuels and uranium, this would be the amount of resource withdrawn expressed in its energy equivalent (i.e. the energy content of the raw material). For renewable resources, the energy-characterised amount of biomass consumed would be described. For hydropower, it would be based on the amount of energy that is gained from the change in the potential energy of the water (i.e. from the height difference). As aggregated values, the following primary energies are designated:
The total **"Primary energy from non renewable resources"**, given in MJ, essentially characterises the gain from the energy sources natural gas, crude oil, lignite, coal and uranium. Natural gas and crude oil will be used both for energy production and as material constituents e.g. in plastics. Coal will primarily be used for energy production. Uranium will only be used for electricity production in nuclear power stations.
The total **"Primary energy from renewable resources"**, given in MJ, is generally accounted separately and comprises hydropower, wind power, solar energy and biomass.

[14] For TRACI reference quantity is NOx equivalent.

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It is important that the end energy (e.g. 1 kWh of electricity) and the primary energy used are not miscalculated with each other; otherwise the efficiency for production or supply of the end energy will not be accounted for.
The energy content of the manufactured products will be considered as feedstock energy content. It will be characterized by the net calorific value of the product. It represents the still usable energy content.

Appendix IV:

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APPENDIX V: USER GUIDANCE FOR COMPILING PACKAGING LCAS USING CONTAINER GLASS LCA DATA

The LCI profile represents 1 kg of formed and finished glass containers as delivered to the end user of the products contained (wine, jam, beer, spirits, non alcoholic beverages, foods, etc) as a European average. It is not representative of speciality glass containers for perfumes, cosmetics, pharmaceutical products, etc. The model follows a cradle to cradle approach appropriate to the essentially closed loop recycling achieved for glass packaging, including a complete end of life scenario which includes the reuse (refilling) of glass containers. The data thus include some washing and transport data necessary to account for these phases in the reuse end of life case. Data not including reuse end of life and associated transport and washing data are available from FEVE to enable life cycle assessments on particular models. The figures integrate a recycling rate of 44 %. Care should be taken when using LCI data from different sources as these data will not have consistent upstream data with the data results from this study (e.g. different system boundaries, fuel mixes, allocation procedures, etc.).

The LCI profile can be used for all life cycle related studies on different glass packaging designs. The LCI profile covers the cradle to cradle life cycle but excluding certain product specific information. This should be appropriately taken into account in particular concerning:

1. Closures

   Closures are specific to the individual packaging designs and therefore have to be assessed specific to the design of interest. In addition to the manufacturing of the materials the manufacturing of the closure should be assessed. The closure could be made out of a single material such as aluminium, steel, natural cork, synthetic cork, ceramic, or multiple materials e.g. steel/ aluminium or polymer with polymer seal

2. Labelling

   Labels are specific to the individual packaging designs and therefore have to be assessed specific to the design of interest. In addition to the manufacturing of the materials (e.g. paper, polymer foil, etc.), the manufacturing of the labelling as well as the printing should be assessed. In packaging designs that use engraving or other labelling techniques, these should also be assessed. Adhesives to attach the labels will likely be a minor contribution to the life cycle impacts and can likely be excluded.

3. Filling

   As filling is specific to the packaging design as well as to the product this stage of the life cycle has to be added when assessing specific products and packaging designs.

Note that the figures reflect in particular average European recycling rates (2007). No product specific integration rate of recycled material is available through the study and it is not considered pertinent to do so within the scope and goal. This is justified by the limitation

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on the use of cullet being recovery and not integration. Integration rates of recycled material for individual designs thus do not influence the overall environmental impact of glass packaging.

When assessing food packing the following additional points have to be considered:

1. Shelf life

   The material choice for the container has an effect on the average shelf life of a food product. This should be considered when comparing different materials as it has a direct influence on the amount of product which has to be thrown away. The amount of product thrown away has a direct influence on the overall environmental performance of the packaging design in the overall context.

2. Diffusion of molecules

   As different packaging materials have different levels of diffusion through the packaging (in, out as well as through) this has to be considered when assessing different packaging solutions. Diffusion of molecules is not a traditional LCA measure but as it may result in effects on the quality of the product packaged or in health effects to the consumer, these effects should be discussed when assessing different material options for packaging design.

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