LCA of Composite Waste Processing

Report SGS INTRON B.V.

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WHEN YOU NEED TO BE SURE

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Disclaimer

Contents

Summary

Introduction

Thermoset composites are designed to be durable, strong and resistant to water and chemicals. For the end-of-life waste treatment of these durable materials, multiple technologies exist at present. The technologies with the highest Technology Readiness Levels (TRLs) include treatment in cement manufacturing plants (so-called "co-processing"), mechanical milling with subsequent processing into new composites formulations, and pyrolysis with subsequent recycling of the fibres and the pyrolysis oil, while several other technologies are currently under development and are at much lower TRLs

EuCIA (the trade association for the European composites industry) asked SGS INTRON to investigate through a Life Cycle Assessment (LCA) the environmental impacts of processing glass fibre reinforced composite waste through cement co-processing.

The recycling of composite waste in cement kilns uses the mineral fraction of the glass fibre reinforced composite waste as raw material for the cement production, while the organic fraction is used as alternative fuel supplying the energy content of the resin matrix for heating the reaction.

This method is compared with incineration of glass fibre reinforced composite waste (with energy recovery), which is the most common method for the treatment of this type of production and end-of-life waste at present.

Aim of the study

The objective of this study is to investigate and quantify the benefits and burdens of this waste treatment option and to generate a data set for including these in cradle-to-grave LCA calculations of glass fibre reinforced composite components (e.g. wind turbine blades, boats, profiles, automotive body panels).

Work executed

For this study, three typical glass fibre reinforced composite profiles were defined, which are representative for a large portion of the glass reinforced composite market:

1. GF50: glass fibre reinforced composite with 50% glass fibre and 50% resin, which is a typical composition for Hand lay-up, Spray-up, and Filament winding transformation processes.
2. GF70: glass fibre reinforced composite with 70% glass fibre and 30% resin, which is a typical composition for RTM, Infusion and Pultrusion transformation processes.
3. SMC: containing 28% glass fibre, 25% resin and 47% calcium carbonate filler, which is a typical composition for SMC (sheet moulding compound) and BMC (bulk moulding compound) formulations.

EuCIA and SGS INTRON jointly established process flow charts for the waste treatments scenarios for these material profiles, and discussions were held with various parties that supply the necessary technology (shredding machines) for processing the waste in such a way that it can be used in cement co-processing.

Additionally, CEMBUREAU[1] supplied data to establish a scenario for including the avoided fuels and raw materials when replaced by using glass fibre reinforced composite waste as an alternative fuel and a source of alternative decarbonated raw material in European cement kilns.

[1] CEMBUREAU is the representative organisation of the cement industry in Europe.

Based on these inputs, LCA models were set up and calculations made for this waste treatment option. The results were compared with a conventional waste incineration process commonly used for treatment of glass fibre reinforced composite waste.

Besides reporting the results for the three different profiles, a “weighted industry average” value” was calculated using a market volume distribution of 32.6,38.4, and 29.0 % for GF50, GF70, and SMC respectively. These percentages are based on market figures provided by German composites trade association AVK in their yearly report on the European Composite Market [1].

Status of this study

This report has been subject to a third-party review by Mantijn van Leeuwen of NIBE BV. Below the statement of the reviewer is included:

Statement of Mantijn van Leeuwen on 29 September 2024:

> *“I hereby confirm that the methodology and data collection as described in the background report “LCA of Composite Waste Processing” comply with the demands set forth in ISO 14040/140444 and the EN 15804:2019+A2. The background report dates September 6th 2024.*”

The letter of approval is included in the appendix B. The verification is documented in a dialogue document which includes all questions and remarks of the reviewer and the way in which they are processed in this version of the report [2].

Results

Co-processing in cement plants uses glass fibre-reinforced composite waste as input for cement production, consuming the glass and mineral fraction as decarbonated alternative raw material, while enabling the efficient recovery of the energy content of the resin fraction, therefore reducing the fossil fuel energy consumption of the process, and considerably lowering CO_2 emissions.

Table 12 of the report provides the reduction of CO_2 emissions in the cement manufacturing process per ton for the different glass fibre-reinforced composite waste profiles. A summary of the results is given below:

GF 50	GF 70	SMC	Industry average (weighted)
-411 kg CO_2 eq	-362 kg CO_2 eq	-213 kg CO_2 eq	-335 kg CO_2 eq.

Table 14 of the report provides the avoided CO_2 emissions which are generated when glass fibre-reinforced composite waste is treated by incineration with energy recovery. A summary of the results is given below:

GF 50	GF 70	SMC	Industry average (weighted)
719 kg CO_2 eq	420 kg CO_2 eq	347 kg CO_2 eq	496 kg CO_2 eq.

In conclusion, Co-processing in a cement kiln is a more favorable waste treatment method than waste treatment in a waste incinerator. The calculations reported in this study show that recycling/ co-processing waste into cement saves 213 to 411 kg CO_2 eq. per ton of waste (weighted average 335 kg CO_2 eq.), in comparison to the generation of 347 to 719 kg CO_2 eq. per ton of waste (weighted average 496 kg CO_2 eq.), when incinerating the waste. This translates into an aggregated difference of 1130, 782 and 560 kg CO_2 eq. for GF50, GF70, and SMC respectively (or a weighted average of 831 kg CO_2 eq.),

In conclusion, each ton of End-of-Life composite waste treated by co-processing in a cement plant delivers an average combined GHG emission reduction of about 0.83 ton of CO_2 in comparison with waste incineration with energy recovery (the current common treatment for the majority of End-of-life composite waste).

Note: While the focus of this LCA study is GHG emission comparison, it also indicates that co-processing in cement brings benefit to other LCA indicators as it reduces the need for extraction and manufacturing of virgin mineral raw materials and fossil fuels. (Details are included in the SGS report).

1. Introduction

1.1. General

Thermoset composites are increasingly used in large-scale applications such as wind turbine blades and boats, are highly durable, strong and resistant to water and chemicals. For the end-of-life waste treatment of these durable materials, multiple technologies exist. The technologies with the highest Technology Readiness Level (TRL) include recycling in cement manufacturing plants (“co-processing”), mechanical milling with subsequent processing into new composites formulations, and pyrolysis with subsequent recycling of the fibers and the pyrolysis oil. Several other technologies are currently under development and at much lower TRLs.

EuCIA (European Composites Industry Association, Europe's leading trade association for the composite industry) and the seven sponsors of the present study, namely WindEurope, European Boating Industry, CEFIC UP/VE Sector Group, Epoxy Europe, CEMBUREAU, Glass Fibre Europe, Tech-Fab Europe and the European Alliance for SMC BMC, wish to provide stakeholders in the composites supply chain with objective and transparent LCA data of the waste processing of composite materials. Therefore, these associations have commissioned SGS INTRON to investigate one specific waste processing method of glass fibre reinforced composite waste and determine the environmental impacts through a Life Cycle Analysis (LCA).

Commissioner

The client of this study is EuCIA (European Composites Industry Association).Eight sponsors – being WindEurope, European Boating Industry, CEFIC UP/VE Sector Group, Epoxy Europe, CEMBUREAU, Glass Fibre Europe, Tech-Fab Europe and the European Alliance for SMC BMC – co-financed the study and share the content ownership.

1.2. Purpose and Target Group

The purpose of this study is twofold. Firstly, the environmental impact of this processing option for glass fibre reinforced composite waste has been investigated by means of doing an LCA. The target group for these calculations are LCA practitioners who calculate the LCA of composite products. In this study, the LCA results of the end-of-life processes are presented which may be applied for establishing EPDs of composite products. The benefits include the generation of recycled materials and the useful deployment of the energy content, which can save materials and energy carriers in a subsequent life cycle.

Recycling of composite waste through co-processing in cement kilns uses the mineral fraction of the glass fibre reinforced composite waste as raw material for cement clinker production, while the organic fraction of the glass fibre reinforced composite waste is used as alternative fuel, supplying the energy content of the resin matrix for heating the reaction. As a result, the consumption of a fraction of virgin raw materials and fossil fuels that are normally used to produce clinker are avoided.

The recycling process has been applied to three different material profiles with different compositions, which are representative for a large portion of the glass reinforced composite market. The main difference between these profiles is the ratio between the share (weight %) of resin and glass fibre.

Secondly, the results of this study can be used in discussions with policy makers to demonstrate the environmental benefits of co-processing in a cement kiln in comparison with standard waste processing in a municipal solid waste incinerator (MSWI).

1.3. Procedure

EuCIA, the seven associations sponsoring this study, and SGS INTRON have jointly established process flow charts for co-processing in a cement-kiln. Subsequently, discussions were held with various parties that supply technology (shredding equipment) required for processing the waste in such a way that it can be used in co-processing. Based on this, LCA models have been set up and calculations made. The concept structure and the results have been discussed with EuCIA and the sponsors of this study, after which the models have been finalized.

1.4. LCA-method

The study was performed according to the EN 15804:2019+A2 standard [3].[2] This ensures that the results may be applied in LCA-studies resulting in EPDs. SGS INTRON has performed the LCA-calculations in the SimaPro software, using Ecoinvent 3.8 [4] as the LCA database for background data. At the start of the project this was the most recent database in the LCA software. Deviations from Ecoinvent 3.8 are indicated in the text.

The study includes the results of an overall comparison which includes all burdens and benefits from co-processing. Chapter 4 includes an instruction how these results can be included in EPDs of glass fibre reinforced composite products. For the purpose of EPD calculations, the benefits of avoided transportation should be excluded.

The LCA model and the description in this report are intended to enable LCA practitioners who have specific information on the composites applied in their study to adapt the model to their specific situation and in this way make more representative calculations.

1.5. Project Team

The project was executed by Bob Roijen MSc (Senior LCA Expert) and Dr. Ulbert Hofstra (Project Leader) from SGS INTRON. Thomas Wegman and Raphael Pleynet were the leading contact persons representing respectively Cefic UP/VE and EuCIA, and supported SGS in collecting the data.

Additional data were provided by Loesche, MTB, MCR (details on shredding equipment), CEMBUREAU (details on cement composition, cement clinker manufacturing), Glass Fibre Europe (details on glass fibre composition), European Alliance for SMC BMC (details on SMC and BMC composition), Epoxy Europe, European Boating Industry, WindEurope (details on composite materials, markets).

1.6. Status

This report has been subject to a third-party review by Mantijn van Leeuwen of NIBE BV. Below the statement of the reviewer is included:

Statement of Mantijn van Leeuwen on 29 September 2024:

> *"I hereby confirm that the methodology and data collection as described in the background report "LCA of Composite Waste Processing" comply with the demands set forth in ISO 14040/140444 and the EN 15804:2019+A2. The background report dates September 6th 2024."*

[2] The EN 15804:2019+A2 standard is based on the international standard for life cycle assessments, which is laid down in the ISO 14040-series, of which ISO 14044: "Environmental management – Life cycle assessment – requirements and guidelines" is the most important document [11]

The letter of approval is included in the appendix B. The verification is documented in a dialogue document which includes all questions and remarks of the reviewer and the way in which they are processed in this version of the report [2].

2. Subject of study

2.1. Reference unit

The reference unit in this study is:

The treatment of 1 metric ton of glass fibre reinforced composite waste.

This study examines the benefits and the burdens of co-processing in a cement kiln of glass fibre reinforced composite waste. Since there is a connection with the composition of the waste, three typical glass fibre reinforced composite compositions are included:

1. GF50: glass fibre reinforced composite with 50% glass fibre and 50% resin.
2. GF70: glass fibre reinforced composite with 70% glass fibre and 30% resin.
3. SMC (sheet moulding compound) with 28% glass fibre, 25% resin and 47% calcium carbonate filler.

2.2. System boundaries

This study examines the waste processing of larger glass fibre reinforced composite objects such as wind turbine blades and boat hulls. This means that the waste consists of relatively large pieces that need to be reduced in size for final processing. The processes included in this study begin from the moment the glass fibre reinforced composite waste has been released after the demolition/ deconstruction of, for example, a wind turbine. The material is transported in relatively large pieces to locations where the final processing takes place. For co-processing, this is a cement kiln[3]. The following figure schematically represents these successive steps of this processing routes. Below this schematic representation, the processes are described in more detail.

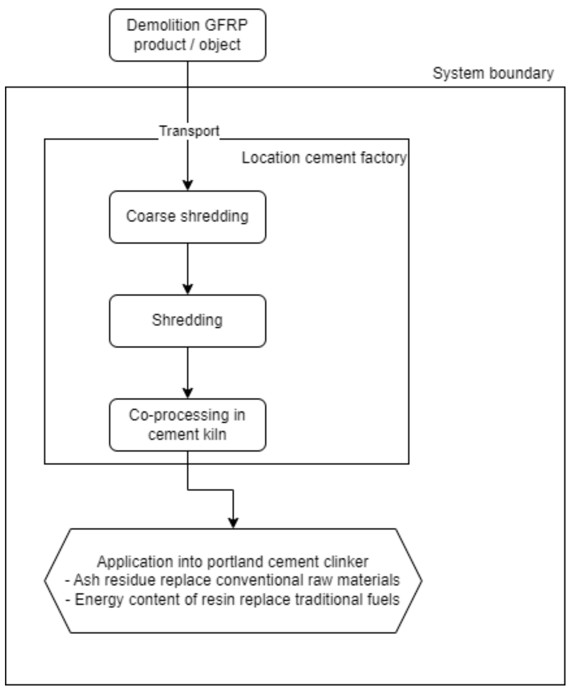

Figure 1 *Schematic overview of the system boundaries for coprocessing.*

[3] According to CEMBUREAU typically shredding is performed in a pre-treatment plant outside the premises of the cement plant.

2.3. Co-processing in cement kiln

In this processing option, the glass fibre reinforced composite waste is used to produce cement clinkers, which are the intermediate product in the cement manufacturing. Clinkers are produced in rotary kilns by heating ground limestone, clay and other raw materials to temperatures up to 1400-1500 °C. In this process large amounts of fuels are consumed for delivering the required energy. At the end of the rotary kiln, the clinker is cooled rapidly, ground into a fine powder, and mixed together with other materials for creating the cement finished product.

For co-processing in a cement kiln the glass fibre reinforced composite waste that is generated during demolition/ deconstruction is transported to/ near a cement factory with a clinker kiln. There, the material is further reduced in size so that it can be fed into a shredder. In this shredder, the material is ground to a fine and fluffy material suited to be used as an alternative source of energy fuel for the production of clinker.

In this process the organic fractions of glass fibre reinforced composite waste (resin) are combusted. The energy released is used for clinker production. The mineral fraction (glass fibre) and in some cases the mineral filler (often calcium carbonate) becomes part of the clinker. Hence both the energy content of the glass fibre reinforced composite waste and the mineral part have an added value contribution to the process. This means that the clinker can be produced using fewer primary materials and using less fuels, with reduced associated CO_2 emissions.

Regarding transport and shredding of the waste, no distinction is made between the different compositions of the glass fibre reinforced composite waste. Regarding the direct CO_2 emissions from processing in the cement kiln and the benefits of coprocessing, the difference in composition of the resin has been taken into account. The reason is that the composition of the resin influences the energy content, the CO_2 emission factor and the amount and the composition of the mineral fraction.

Transport to pre-shedder

Glass fibre reinforced composite waste results from the demolition/ deconstruction of applications such as turbine blades and boat hulls. Demolition/ dismantling of the composite structure is outside the system boundaries of this study. After demolition/ dismantling, glass fibre reinforced composite comes available in large chunks. It is assumed that the material is transported to a location nearby where the material is pre-shredded to make further transport more efficient. Transport to a pre shredder is set to 50 km (by truck).

Table 1 *Data LCA model: transport to pre-shredder (per ton of waste)*

Process	Amount	Unit	Data LCA model
Transport to pre-shredder	50	tkm	Transport, freight, lorry >32 metric ton, euro5 {RER}| market for transport, freight, lorry >32 metric ton, EURO5 | Cut-off, U

Pre-shredding

For the first coarse shredding data was provided by companies[4] which supply the equipment for this process. In the LCA model the energy usage (electricity) was included. Also, the capital goods were included based on the description of the apparatus in terms of the mass, estimated service life and glass fibre reinforced composite throughput.

[4] The data on energy use and the machinery used are obtained from three companies (Loesche (D) / MTB (F) / Mixte Composites Recyclables (MCR, F)) which provided data on their technology. These technologies differ in maturity level. As a worst-case approach the data was averaged.

Table 2 *Data LCA model: pre-shredding (per ton of waste)*

Process	Amount	Unit	Data LCA model
Electricity use	112	MJ	Ecoinvent: Electricity, medium voltage {Europe without Switzerland}| market group for | Cut-off
Capital goods	0,116	kg	Ecoinvent: Industrial machine, heavy, unspecified {RER}| market for industrial machine, heavy, unspecified | Cut-off

Transport to shredder

When glass fibre reinforced composite waste is ground into a fine enough material that is suited for feeding into a clinker kiln, the volume will increase significantly. Therefore, it is likely that the actual shredding takes place at the location of the kiln or nearby. The transport distance is set to 400 km (by truck). This distance is believed to reflect the distribution of cement kilns in Europe while also recognizing that for economic reasons a shredder must have a sufficient volume supply of waste. The amount of glass fibre reinforced composite waste is 500-1000 ktpa in Europe (kiloton per annum), (EuCIA estimates , resp. original study from 2020 and updated 2024 study recently finalized, now close to publication). At a typical processing rate of 100 ktpa per cement factory (as per CEMBUREAU estimates), 10 cement factories are required for processing the total amount of waste. For information, the total number of cement factories in Europe is close to 200.

Table 3 *Data LCA model: transport to shredder (per ton of waste)*

Process	Amount	Unit	Data LCA model
Transport to shredder	400	tkm	Transport, freight, lorry >32 metric ton, euro5 {RER}| market for transport, freight, lorry >32 metric ton, EURO5 | Cut-off, U

Shredding

For shredding data was provided by companies which supply the equipment for this process. In the LCA model the energy usage (electricity) was included. Also, the capital goods were included based on the description of the apparatus in terms of the mass, estimated service life and glass fibre reinforced composite throughput.

Table 4 *Data LCA model: shredding (per ton of waste)*

Process	Amount	Unit	Data LCA model
Electricity use	65,7	MJ	Ecoinvent: Electricity, medium voltage {Europe without Switzerland}| market group for | Cut-off
Capital goods	0,094	kg	Ecoinvent: Industrial machine, heavy, unspecified {RER}| market for industrial machine, heavy, unspecified | Cut-off
Shredder blades	0,322	kg	Ecoinvent: Steel, chromium steel 18/8, hot rolled {GLO}| market for | Cut-off

Co-processing in cement kiln

The shredded material is fed with other fuels into the cement kiln. In a typical cement kiln several options for the place to feed the material are possible: main burner, precalciner, preheater inlet, etc. Independent of the input place, the organic part of the glass fibre reinforced composite waste is combusted and delivers (part of) the energy to produce clinker. The mineral fraction (glass fibre, and in SMC also calcium carbonate) is incorporated in the clinker. This section covers the emissions of this process. The beneficial aspects are described in the next section.

Emission of CO_2

Due to the high temperature and the long residence time the combustion of the resin in glass fibre reinforced composite waste will be near to complete. The embodied carbon in the resin will be released as CO_2.This means that for every kg carbon (C) in the resin, 3.67 kg of CO_2 is formed (i.e. a conservative calculation). Assuming no CO_2 capture and storage, in the LCA calculation this is modelled as an emission to air. The amount of emission is proportional to the resin content in glass fibre reinforced composite waste and the carbon content of the resin. The resins in this study and their carbon content are included in the following table.

Table 5 *Carbon content and heat of combustion (lower heating value: LHV) of resins in this study*

[The information in the following table is from article of Williamson [5]

Matrix Material	*Calorific Value (MJ/kg)*
Phenolic Resin	29.18
Polyester Resin	30.29
Epoxy Resin	33.88
Vinyl Ester Resin	36.62

Table 5 - Energy content of matrix material from ultimate analysis

Substance	**C content (kg C / kg resin) [5]**	**Lower heating values (LHV) [6]**
Orthophthalic acid based unsaturated polyester resin	0,722	30,3
Isophthalic acid based unsaturated polyester resin	0,713	30,3
Maleic unsaturated polyester resin	0,675	30,3
Dicyclopentadiene based unsaturated polyester resin	0,750	30,3
Bisphenol A epoxy based vinyl ester resin	0,675	36,3
Epoxy resin, liquid	0,423*	33,9

* For epoxy resin [6] mentions a mass fraction for C of 0,87. For consistency reasons the Ecoinvent values are used. Since the content of the resin in this study is low, the impact of using the higher C content on the results of this study would be very small.

The composition of the resin and the associated CO_2 emission factor per type of glass fibre reinforced composite is included in the table below.

Table 6 *Resin composition of the types of GFRP waste in this study and the associated emission factor and lower heating values*

Substance	**GF 50**	**GF 70**	**SMC**
Orthophthalic acid based unsaturated polyester resin	50 %	50 %	50 %
Isophthalic acid based unsaturated polyester resin	10 %	10 %	
Maleic unsaturated polyester resin			50 %
Dicyclopentadiene based unsaturated polyester resin	35 %	30 %	
Bisphenol A epoxy-based vinyl ester resin	5 %	5 %	
Epoxy resin, liquid		5 %	
CO_2 emission factor [kg CO_2 / kg glass fibre reinforced composite waste]	**1,34**	**0,78**	**0,64**
CO_2 emission factor [kg CO_2 / kg resin]	2,67	2,61	2,56
Lower heating value [MJ / kg resin]	30,60	30,78	30,30
Lower heating value [MJ / kg glass fibre reinforced composite waste]	15,30	9,23	7,58

The filler in SMC (often calcium carbonate) will also calcinate in the cement kiln. However, the associated CO_2 emissions is not included, since this emission would also occur if primary limestone was used.

Other emissions

Emissions other than CO_2 are included using the Ecoinvent process for waste incineration of polyethylene terephthalate.

Table 7 *Data LCA model: other air emissions from resin combustion*

Process	Amount	Unit	Data LCA model
Air emissions from resin combustion	1 kg/ kg resin in glass fibre reinforced composite waste	kg	Ecoinvent: Waste polyethylene terephthalate {CH}| treatment of waste polyethylene terephthalate, municipal incineration | Cut-off, U (adapted: air emissions only)

Avoided materials

Since the mineral fraction is included in the clinker means that primary materials use can be reduced. The mineral fraction originates from the glass fibre and the filler in SMC.

The main raw material for manufacturing glass fibre used in GFRP are silica sand, limestone and kaolin clay The composition of the glass fibre used in GFRP (expressed as oxides) includes silicon dioxide (SiO_2), calcium oxide (CaO) and aluminium oxide (Al_2O_3). There are some minor constituents such as boron- and magnesium oxide (B_2O_3, MgO). SiO_2, CaO and Al_2O_3 are also the minerals that build cement clinker. For this study EuCIA established a typical glass fibre composition based on the ASTM-D578 standard:

1. SiO_2, 57% of the glass fibre.
2. CaO, 21% of the glass fibre and 3% of MgO.
3. Al_2O_3, 14% of the glass fibre.

There are some minor constituents in the glass fibre which also are included in the clinker. As a conservative approach, these materials are not included in the amount of raw materials saved because they are not among the desired main components for clinker production.

By replacing these primary input materials with secondary materials fewer primary materials are required to produce the same amount of clinker. Also, fewer materials need to be transported to the clinker kiln. In the following table the data are shown that are used to model the avoided material use in the LCA calculations. These data are based on the input from CEMBUREAU.

Table 8 *Data LCA model: primary materials avoided by the minerals in residue*

Substance	Amount (of avoided material)	Unit	Data LCA model
SiO_2 replaces Si bearing material such as clay. The avoided transportation distance for this material is 50 km.	Amount of GF x 0,57	t / t glass fibre reinforced composite waste	Clay {RoW}| clay pit operation | Cut-off For transport: Transport, freight, lorry >32 metric ton, euro6 {RER}| market for transport, freight, lorry >32 metric ton, EURO6 | Cut-off
CaO (and MgO) replace CaO, The primary equivalent of this material is limestone ($CaCO_3$). Since this material already is present in its calcined form in the GF no calcination CO_2 is emitted and less material needs to be transported. Therefore each kg of CaO avoids 1,785 kg of limestone MgO is included in this figure since this material also is assumed to be present as carbonate rock in the avoided limestone. The avoided transportation distance for this material is 5 km.	Amount of GF x 0,24 x 1,7850	t / t glass fibre reinforced composite waste	Lime {Europe without Switzerland}| lime production, milled, loose | Cut-off For transport: Transport, freight, lorry >32 metric ton, euro6 {RER}| market for transport, freight, lorry >32 metric ton, EURO6 | Cut-off
$CaCO_3$ filler replaces limestone. The avoided transportation distance for this material is 5 km.	Amount of filler (in SMC)	t / t glass fibre reinforced composite waste	Lime {Europe without Switzerland}| lime production, milled, loose | Cut-off For transport: Transport, freight, lorry >32 metric ton, euro6 {RER}| market for transport, freight, lorry >32 metric ton, EURO6 | Cut-off
The primary equivalent for Al_2O_3 is bauxite. The avoided transportation distance for this material is 100 km.	Amount of GF x 0,14	t / t glass fibre reinforced composite waste	Bauxite {GLO}| bauxite mine operation | Cut-off For transport: Transport, freight, lorry >32 metric ton, euro6 {RER}| market for transport, freight, lorry >32 metric ton, EURO6 | Cut-off

Avoided fuels

The content of the resin is used for the processes in the clinker kiln. This means that conventional fossil fuels are avoided. The energy consumption for clinker production is also lowered because of the avoided calcination of limestone. In the following table the data are shown that are used to model the avoided fuels for clinker production. These data are based on the input from CEMBUREAU.

Table 9 *Data LCA model: primary fuels avoided by resin combustion and the minerals in residue*

Fuel	Amount (of avoided material)	Unit	Data LCA model
According to CEMBUREAU using glass fibre reinforced composite waste most likely will replace coal as fuel since the average % of alternative fuels in European cement kilns is only 53% (in 2021) and cement kilns can operate at 100% alternative fuels.	Amount of resin x LHV coal / LHV coal (LHV= heating value)	t / t resin in glass fibre reinforced composite waste	Hard coal {Europe, without Russia and Turkey}| market for hard coal | Cut-off This process also includes (the avoided) transportation. The HV of resin is based on the heating value of the constituents (table 6). For coal a heating value of 24,23 MJ/kg was used.

As sensitivity analysis was performed to study the effect of using alternative fossil-based fuels.			
According to CEMBUREAU the avoided CaO also means that the energy to produce this amount of CaO is avoided. Again, the avoided fuel is coal.	Amount of CaO in glass fibre x calcination energy / energy content coal	t / t CaO in glass fibre	Hard coal {Europe, without Russia and Turkey}| market for hard coal | Cut-off This process also includes transportation. The energy needed to calcine $CaCO_3$ is estimated to be 3,176 MJ/kg CaO formed. The LHV of coal is 24,23 MJ/kg In the calculations it is assumed that the consumed coal is burned at 100% efficiency. Most likely, the actual efficiency is lower than 100 %, because of energy conversion, heat transfer, and heat dissipation effects. This would mean a higher coal requirement for obtaining the necessary energy for the calcination reaction, resulting in increased CO2 emissions associated with a higher use of coal. It has been decided to take a conservative approach, and not take these effects into account.

Avoided CO_2 emissions

These avoided processes and fuels also mean that CO_2 emissions are avoided. The table below shows how these avoided emissions are included in the LCA calculations.

Table 10 *Data LCA model: avoided CO_2 emissions associated with the processes described above*

Process	**Amount (of avoided emission)**	**Unit**	**Data LCA model**
Avoided calcination of limestone due to CaO in glass fibre. For each kg CaO, 0,785 kg of CO_2 would have been produced if produced from limestone.	Amount of CaO in glass fibre reinforced composite waste x 0,785	t / t CaO in glass fibre reinforced composite waste	Emission to air: CO_2
Avoided coal combustion due to energy content resin	Amount of avoided coal x EF coal EF = emission factor	t / t CaO in glass fibre	Emission to air: CO_2 For EF coal 2250 kg/t was used.
Avoided coal combustion due to CaO in glass fibre	Amount of avoided coal x EF coal EF = emission factor	t / t CaO in glass fibre	Emission to air: CO_2 For EF coal 2250 kg/t was used.

3. Results

In this chapter the results of the calculations are discussed. Section 3.1 shows the environmental profiles of the co-processing in cement kiln options per product type. In section 3.2, the environmental profiles are further explained in a major contribution analysis. In section 3, some other scenarios were examined using a sensitivity analysis.

3.1. Results LCA calculations

In the following tables, the results of the LCA calculations are shown for each type of glass fibre reinforced composite waste in this study in the co-processing scenario. In the table the total scores for the E 15804+A2 indicators are included. In appendix A, the environmental profiles are included in more detail. In these appendices also the parameters describing energy- and resource use and waste are included. In the tables with results, abbreviations are used for the environmental indicators. Below the abbreviations and their full names are listed. The indicators in italics are only included in the environmental profiles in appendix A.

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Indicator (abbreviation)	Indicator (full name)
GWP-total	Global Warming Potential total
GWP-fossil	Global Warming Potential fossil fuels
GWP-biogenic*	Global Warming Potential biogenic
GWP-luluc	Global Warming Potential land use and land use change
ODP	Depletion potential of the stratospheric ozone layer
AP	Acidification Potential, Accumulated Exceedence
EP-freshwater	Eutrophication Potential, fraction of nutrients reaching freshwater end compartment
EP-marine	Eutrophication Potential, fraction of nutrients reaching marine end compartment
EP-terrestrial	Eutrophication Potential, Accumulated Exceedence
POCP	Formation potential of tropospheric ozone photochemical oxidants
ADP-minerals&metals	Abiotic Depletion Potential for non-fossil resources
ADP-fossil	Abiotic Depletion for fossil resources potential
WDP-fossil	Water (user) deprivation potential, deprivation-weighted water consumption
PM	Potential incidence of disease due to PM emissions
IRP	Potential Human exposure efficiency relative to U235 [1]
ETP-fw	Potential Comparative Toxic Unit for ecosystems
HTP-c	Potential Comparative Toxic Unit for humans
HTP-nc	Potential Comparative Toxic Unit for humans, non-cancer
SQP	Potential soil quality index
HWD	*Hazardous Waste Disposed*
NHWD	*Non Hazardous Waste Disposed*
RWD	*Radioactive Waste Disposed*
CRU	*Components for reuse*
MFR	*Materials for recycling*
MER	*Materials for energy recovery*
EEE	*Exported Electrical Energy*
ETE	*Exported Thermal Energy*
PERE	*Use of renewable energy excluding renewable primary energy resources*
PERM	*Use of renewable energy resources used as raw materials*
PERT	*Total use of renewable primary energy resources*
PENRE	*Use of non-renewable primary energy resources excluding non-renewable energy resources used as raw materials*
PENRM	*Use of non-renewable primary energy resources used as raw materials*
PENRT	*Total use of non-renewable primary energy resources*
SM	*Use of secondary materials*
RSF	*Use of renewable secondary fuels*
NRSF	*Use of non-renewable secondary fuels*
FW	*Use of net fresh water*

**Note that in individual LCA's of GRP products biogenic CO_2 will be calculated in such way that overall score on the full life cycle is (or close to) 0. Only biogenic methane emissions should be included (for instance from landfill processes). It is not te be expected that these types of processes play a significant role in the studied processes. Therefore, the biogenic CO_2 emissions (and uptakes) are set to 0 in the LCA calculations.*

For co-processing, the calculated values for many of the indicators are negative, meaning that the avoided impacts (by replacing primary raw materials and fuel) exceed the burdens (waste processing, combustion emissions) of the glass fibre reinforced composite waste.

Table 11 *Environmental profiles (indicators EN 15804+A2) of co-processing 1 metric ton glass fibre reinforced composite waste*

Indicator	unit	GF 50	GF 70	SMC
GWP-total*	kg CO_2 eq	-4,11E+02	-3,62E+02	-2,13E+02
GWP-fossil	kg CO_2 eq	-4,11E+02	-3,62E+02	-2,13E+02
GWP-biogenic*	kg CO_2 eq	0,00E+00	0,00E+00	0,00E+00
GWP-luluc	kg CO_2 eq	-1,44E-01	-7,43E-02	-5,61E-02
ODP	kg CFC11 eq	-4,62E-06	2,79E-07	2,34E-06
AP	mol H+ eq	-1,61E+00	-9,55E-01	-7,45E-01
EP-freshwater	kg P eq	-1,03E-01	-6,38E-02	-5,09E-02
EP-marine	kg N eq	-4,50E-01	-2,70E-01	-2,07E-01
EP-terrestrial	mol N eq	-5,63E+00	-3,41E+00	-2,65E+00
POCP	kg NMVOC eq	-1,34E+00	-7,96E-01	-6,06E-01
ADP-minerals&metals	kg Sb eq	-2,84E-04	-2,09E-04	-7,85E-05
ADP-fossil	MJ	-1,69E+04	-1,02E+04	-8,05E+03
WDP	m^3 depriv.	-1,82E+01	-1,72E+01	-2,58E+01
PM	disease inc.	-6,80E-06	-3,51E-06	-2,11E-06
IRP	kBq U-235 eq	-2,20E+00	4,21E-01	8,61E-01
ETP-fw	CTUe	-2,89E+04	-1,85E+04	-1,52E+04
HTP-c	CTUh	-1,06E-07	-5,14E-08	-2,81E-08
HTP-nc	CTUh	-5,78E-06	-3,45E-06	-2,61E-06
SQP	Pt	-1,69E+03	-8,22E+02	-4,97E+02

3.2. Major contributions analysis

In this paragraph, the result of the study is shown into more detail by taking a closer look at the results for the environmental indicator global warming potential (GWP). In the following table the results for GWP-fossil are included. The table includes all types of glass fibre reinforced composite and the contribution from individual process steps are included.

Table 12 *Major contributions for the indicator GWP-fossil profiles of co-processing 1 metric ton glass fibre reinforced composite waste*

Process	Unit	GF50%	GF70%	SMC
Transport by truck	kg CO_2 e.q.	40,8	40,8	40,8
Waste processing (pre shredding)	kg CO_2 e.q.	12,4	12,4	12,4
Waste processing (shredding)	kg CO_2 e.q.	9,1	9,1	9,1
Incineration during co-processing	kg CO_2 e.q.	1339	786	642
Avoided limestone	kg CO_2 e.q.	-4,8	-6,8	-13,3
Avoided SiO_2	kg CO_2 e.q.	-3,5	-4,8	-1,9
Avoided Al_2O_3	kg CO_2 e.q.	-1,5	-2,1	-0,8
Avoided limestone calcination $CaCO_3$	kg CO_2 e.q.	-94,2	-131,9	-52,7
Avoided coal for limestone calcination $CaCO_3$	kg CO_2 e.q.	-41,5	-58,1	-23,3
Avoided CO_2 emission from coal combustion	kg CO_2 e.q.	-1667	-1006	-826
Total	**kg CO_2 e.q.**	**-411**	**-362**	**-213**

Regarding the contribution to GWP fossil, the emission from the combustion of (resin in) glass fibre reinforced composite waste is the largest contributor. Compared to this the transportation and the shredding of the waste is significant, yet of minor importance.

Regarding the benefits of co-processing, the largest contribution results from the avoided primary fuel (coal) due to the energy content of the resin. This is followed by the avoided calcination of limestone which is replaced by the CaO in the glass fibres and the avoided primary fuel for this process. The avoided raw material extraction (and transport) of limestone, SiO_2 bearing material (sand) and Al_2O_3 (clay or bauxite) is significant, yet of lower importance.

3.3. Sensitivity analysis

In this chapter the influence of the assumptions made are analysed.

In the co-processing scenario, the fuel replaced by the combustion of resin has a large impact on the result (at least for GWP-fossil). A sensitivity analysis has been performed to analyse the impact on the results of the study if other fuels are replaced instead of coal. The results were recalculated using PET Coke (regarded as secondary fuel) and lignite (another primary fuel) as avoided fuel. The results are included in the table below.

For GWP fossil, if the avoided fuel is petcoke, the score increases. The most important reason is that Petcoke, compared to coal has a lower CO_2 emission factor (in kg CO_2//MJ) per kg of fuel. If the resin replaces lignite, the score on GWP decreases (lignite has a higher CO_2 emission factor (in kg CO_2/MJ) per kg of fuel.[5]

[5] The lower heating values used are 21.7 MJ/kg and 35 MJ/kg for lignite and petcoke respectively. The CO_2 emission factors used are 2,.43 and 3.25 for lignite and petcoke respectively.

Table 13 *Environmental profile (indicators EN 15804+A2) of 1 metric ton of co-processing GF 50*

Indicator (abbreviation)	Indicator (full name)	unit	Default (resin replaces coal)	Alternative 1 (resin replaces petcoke)	Alternative 2 (resin replaces lignite)
GWP-total*	Global Warming Potential total	kg CO_2 eq	-4,11E+02	-3,34E+02	-4,32E+02
GWP-fossil	Global Warming Potential fossil fuels	kg CO_2 eq	-4,11E+02	-3,34E+02	-4,32E+02
GWP-biogenic*	Global Warming Potential biogenic	kg CO_2 eq	0,00E+00	0,00E+00	0,00E+00
GWP-luluc	Global Warming Potential land use and land use change	kg CO_2 eq	-1,44E-01	-7,47E-02	-5,42E-02
ODP	Depletion potential of the stratospheric ozone layer	kg CFC11 eq	-4,62E-06	-2,58E-04	1,93E-06
AP	Acidification Potential, Accumulated Exceedence	mol H+ eq	-1,61E+00	-1,78E+00	-7,33E-01
EP-freshwater	Eutrophication Potential, fraction of nutrients reaching freshwater end compartment	kg P eq	-1,03E-01	-1,78E-03	-5,52E-02
EP-marine	Eutrophication Potential, fraction of nutrients reaching marine end compartment	kg N eq	-4,50E-01	-1,80E-01	-2,02E-01
EP-terrestrial	Eutrophication Potential, Accumulated Exceedence	mol N eq	-5,63E+00	-1,99E+00	-2,58E+00
POCP	Formation potential of tropospheric ozone photochemical oxidants	kg NMVOC eq	-1,34E+00	-8,81E-01	-5,95E-01
ADP-minerals&metals	Abiotic Depletion Potential for non-fossil resources	kg Sb eq	-2,84E-04	-9,04E-05	-1,17E-04
ADP-fossil	Abiotic Depletion for fossil resources potential	MJ	-1,69E+04	-1,56E+04	-8,71E+03
WDP	Water (user) deprivation potential, deprivation-weighted water consumption	m^3 depriv.	-1,82E+01	-6,90E+00	-1,16E+01
PM	Potential incidence of disease due to PM emissions	disease inc.	-6,80E-06	-8,77E-06	-2,18E-06
IRP	Potential Human exposure efficiency relative to U235 [1]	kBq U-235 eq	-2,20E+00	-6,42E+01	1,39E+00
ETP-fw	Potential Comparative Toxic Unit for ecosystems	CTUe	-2,89E+04	-9,09E+03	-1,57E+04
HTP-c	Potential Comparative Toxic Unit for humans	CTUh	-1,06E-07	-1,74E-08	-3,42E-08
HTP-nc	Potential Comparative Toxic Unit for humans, non-cancer	CTUh	-5,78E-06	-1,32E-06	-2,78E-06
SQP	Potential soil quality index	Pt	-1,69E+03	-1,40E+03	-5,85E+02

3.4. Comparison with treatment in waste incinerator

Presently, glass fibre reinforced composite waste is typically treated in waste incinerators. Compared to co-processing the treatment in waste incineration means that:

- Although some energy is recovered, it is to be expected that the thermal (and electrical) efficiency of treatment in a waste incineration will be lower compared to the efficiency of incineration in cement kilns.
- If glass fibre reinforced composite waste is used in waste incineration plants, no additional primary fuels are avoided in cement kilns. And therefore, this is CO_2 emission from the incineration of glass fibre reinforced composite waste in waste incineration.

Additionally, the ashes have no useful application and therefore no additional benefits. However, in this analysis we only included the direct emissions related to treatment in a waste incinerator and primary fuels used in a cement kiln. As a conservative approach in this result, we acknowledge that on average 53% of the thermal energy in cement kilns already originates from alternative fuels [7].

These effects have been included in the following calculation which shows the overall score on GWP fossils.

To include the benefits of recuperation of heat and electricity in waste incineration we calculated with a thermal efficiency of 31% and an electrical efficiency of 18%. This is the default scenario according to the Dutch LCA framework for construction products [8]. This means that if for instance GF50 is processed in a waste incineration plant, there is an overall emission of 719 kg CO_2 e.q. instead of an avoided CO_2 emission of -419 CO_2 e.q (the total score on GWP fossil for GF 50 in table 15).

Table 14 *Overall score on GWP fossil of waste treatment of GF50 in waste incinerator instead of coprocessing.*

Process	Unit	GF50% Treatment in waste incinerator	GF70 Treatment in waste incinerator	SMC Treatment in waste incinerator
Transport by truck	kg CO_2 e.q.	9	9	9
Waste processing	kg CO_2 e.q.	12	12	12
Incineration in waste treatment plant	kg CO_2 e.q.	1339	786	642
Avoided heat and electricity due to energy recovery	kg CO_2 e.q.	-642	-387	-317
Total	**kg CO_2 e.q.**	**719**	**420**	**347**

4. Use of these data in EPDs

The data in this study are intended to be used in the preparation of EPDs of glass fibre reinforced plastic products. When EPD programs have specific requirements, a suitable model can be compiled based on the data from this study. The model in this study describes the average European situation for co-processing.

In EPDs, the results are divided from the modules in EN 15804. Therefore, use the results from the appendix of this report. To allocate the values of the processes (columns in the tables) to the correct module, use the subdivision from the following table. The avoided transportation from (avoided) materials and fuels normally is not included in module D calculations. Therefore these are included in a separate column so they can be excluded.

Table 15 *processes included in this study and the attribution to EN 15804 modules.*

Process (column in table with environmental profile)	Module
C2 Transport to waste treatment	C2
C3 Pre shredding	C3
C3 Shredding	C3
C3 Combustion in cement kiln (air emissions)	C3
D Avoided: Quarrying raw materials (limestone)	D
D Avoided: Quarrying raw mat. (Si bearing/clay)	D
D Avoided: Quarrying raw mat. (Al bearing/bauxite)	D
D Avoided: Calcination CO2	D
D Avoided: Fuel cement kiln	D
D Avoided: Fuel CO2 emission from avoided CaO prod	D
D Avoided: Fuel CO2 due to combustion resin	D
Avoided transport	-

Note that combustion in a cement kiln is attributed to module C3 (as opposed to module C4). This is due to the efficiency of combustion in a cement kiln (as prescribed in the PCR cement [9]).

References

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Appendix A Detailed environmental profiles

Full environmental profiles co-processing

Table A1 Environmental profile of co-processing of GF50

	unit	C2 Transport to waste treatment	C3 Pre shredding	C3 Shredding	C3 Combustion in cement kiln (air emissions)	D Avoided: Quarrying raw materials (limestone)	D Avoided: Quarrying raw mat. (Si bearing/clay)	D Avoided: Quarrying raw mat. (Al bearing/bauxite)	D Avoided: Calcination CO2	D Avoided: Fuel cement kiln	D Avoided: Fuel CO2 emission from avoided CaO prod	D Avoided: Fuel CO2 due to combustion resin	Avoided transport
GWP-total	kg CO2 eq	4,08E+01	1,25E+01	9,09E+00	1,34E+03	-4,75E+00	-2,22E+00	-8,56E-01	-9,42E+01	-1,89E+02	-3,54E+01	-1,42E+03	-6,55E+01
GWP-fossil	kg CO2 eq	4,08E+01	1,24E+01	9,07E+00	1,34E+03	-4,74E+00	-2,21E+00	-8,56E-01	-9,42E+01	-1,89E+02	-3,54E+01	-1,42E+03	-6,54E+01
GWP-biogenic	kg CO2 eq	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
GWP-luluc	kg CO2 eq	1,47E-02	2,93E-02	1,91E-02	0,00E+00	-7,13E-03	-2,81E-03	-3,09E-04	0,00E+00	-1,09E-01	0,00E+00	0,00E+00	-8,72E-02
ODP_A2	kg CFC11 eq	9,75E-06	6,17E-07	4,45E-07	0,00E+00	-3,10E-07	-2,64E-07	-1,31E-07	0,00E+00	-4,57E-06	0,00E+00	0,00E+00	-1,02E-05
AP_A2	mol H+ eq	1,70E-01	6,76E-02	4,98E-02	8,40E-02	-3,89E-02	-2,17E-02	-1,03E-02	0,00E+00	-7,84E-01	0,00E+00	0,00E+00	-1,13E+00
EP-freshwater	kg P eq	2,79E-04	1,32E-03	8,45E-04	0,00E+00	-3,57E-04	-7,43E-05	-7,29E-06	0,00E+00	-1,04E-01	0,00E+00	0,00E+00	-1,12E-03
EP-marine	kg N eq	5,15E-02	8,90E-03	6,87E-03	4,01E-02	-7,56E-03	-5,57E-03	-2,97E-03	0,00E+00	-2,35E-01	0,00E+00	0,00E+00	-3,07E-01
EP-terrestrial	mol N eq	5,68E-01	1,02E-01	7,87E-02	4,71E-01	-9,75E-02	-7,15E-02	-4,31E-02	0,00E+00	-3,24E+00	0,00E+00	0,00E+00	-3,40E+00
POCP_A2	kg NMVOC eq	1,83E-01	2,83E-02	2,27E-02	1,08E-01	-2,37E-02	-1,82E-02	-8,99E-03	0,00E+00	-7,30E-01	0,00E+00	0,00E+00	-9,05E-01
ADP-minerals&metals	kg Sb eq	9,36E-05	5,60E-05	8,39E-05	0,00E+00	-2,04E-05	-1,28E-04	-2,06E-06	0,00E+00	-1,70E-04	0,00E+00	0,00E+00	-1,97E-04
ADP-fossil	MJ	6,36E+02	2,62E+02	1,74E+02	0,00E+00	-7,86E+01	-2,59E+01	-1,11E+01	0,00E+00	-1,70E+04	0,00E+00	0,00E+00	-8,73E+02
WDP	m3 depriv.	2,13E+00	2,99E+00	2,41E+00	0,00E+00	-9,04E+00	-5,22E-01	-1,47E+00	0,00E+00	-1,02E+01	0,00E+00	0,00E+00	-4,49E+00
PM	disease inc.	3,68E-06	1,80E-07	2,34E-07	2,02E-07	-3,25E-07	-3,57E-07	-1,89E-07	0,00E+00	-6,40E-06	0,00E+00	0,00E+00	-3,82E-06
IRP	kBq U-235 eq	2,76E+00	2,30E+00	1,41E+00	0,00E+00	-5,64E-01	-8,50E-02	-4,85E-02	0,00E+00	-3,87E+00	0,00E+00	0,00E+00	-4,12E+00
ETP-fw	CTUe	4,97E+02	1,50E+02	1,44E+02	3,19E+01	-5,47E+02	-7,64E+01	-3,96E+02	0,00E+00	-2,80E+04	0,00E+00	0,00E+00	-7,21E+02
HTP-c	CTUh	1,38E-08	5,68E-09	4,08E-08	6,49E-12	-2,40E-09	-7,41E-09	-3,31E-10	0,00E+00	-1,03E-07	0,00E+00	0,00E+00	-5,30E-08

HTP-nc	CTUh	5,44E-07	1,36E-07	1,27E-07	1,26E-07	-5,92E-08	-1,01E-07	-6,19E-09	0,00E+00	-5,97E-06	0,00E+00	0,00E+00	-5,77E-07
SQP	Pt	7,28E+02	3,90E+01	3,24E+01	0,00E+00	-2,36E+01	-2,56E+01	-9,25E+00	0,00E+00	-2,00E+03	0,00E+00	0,00E+00	-4,29E+02
PERE	MJ	8,10E+00	4,50E+01	3,07E+01	0,00E+00	-1,28E+01	-1,74E+00	-2,39E-01	0,00E+00	-1,49E+02	0,00E+00	0,00E+00	-3,31E+01
PERM	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
PERT	MJ	8,10E+00	4,50E+01	3,07E+01	0,00E+00	-1,28E+01	-1,74E+00	-2,39E-01	0,00E+00	-1,49E+02	0,00E+00	0,00E+00	-3,31E+01
PENRE	MJ	6,76E+02	2,75E+02	1,83E+02	0,00E+00	-8,27E+01	-2,76E+01	-1,18E+01	0,00E+00	-1,79E+04	0,00E+00	0,00E+00	-9,26E+02
PENRM	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
PENRT	MJ	6,76E+02	2,75E+02	1,83E+02	0,00E+00	-8,27E+01	-2,76E+01	-1,18E+01	0,00E+00	-1,79E+04	0,00E+00	0,00E+00	-9,26E+02
SM	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
RSF	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
NRSF	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
FW	m3	7,01E-02	2,19E-01	1,45E-01	0,00E+00	-2,51E-01	-1,46E-02	-3,49E-02	0,00E+00	-5,71E-01	0,00E+00	0,00E+00	-1,94E-01
HWD	kg	1,54E-03	1,08E-04	8,26E-05	0,00E+00	-5,11E-05	-1,41E-04	-2,89E-05	0,00E+00	-1,18E-03	0,00E+00	0,00E+00	-1,67E-03
NHWD	kg	5,96E+01	9,73E-01	2,27E+00	0,00E+00	-3,10E-01	-1,06E+00	-3,90E-02	0,00E+00	-4,97E+00	0,00E+00	0,00E+00	-1,01E+01
RWD	kg	4,31E-03	1,90E-03	1,17E-03	0,00E+00	-5,00E-04	-1,18E-04	-7,46E-05	0,00E+00	-3,47E-03	0,00E+00	0,00E+00	-5,71E-03
CRU	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
MFR	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
MER	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
EEE	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
ETE	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00

Table A2 Environmental profile of co-processing of GF70

	unit	kg CO2 eq	C2 Transport to waste treatment	C3 Pre shredding	C3 Shredding	C3 Combustion in cement kiln (air emissions)	D Avoided: Quarrying raw materials (limestone)	D Avoided: Quarrying raw mat. (Si bearing/clay)	D Avoided: Quarrying raw mat. (Al bearing/bauxite)	D Avoided: Calcination CO2	D Avoided: Fuel cement kiln	D Avoided: Fuel CO2 emission from avoided CaO prod	D Avoided: Fuel CO2 due to combustion resin	Avoided transport
GWP-total	kg CO2 eq	kg CO2 eq	4,08E+01	1,25E+01	9,09E+00	7,86E+02	-6,65E+00	-3,10E+00	-1,20E+00	-1,32E+02	-1,18E+02	-4,95E+01	-8,57E+02	-4,23E+01
GWP-fossil	kg CO2 eq	kg CO2 eq	4,08E+01	1,24E+01	9,07E+00	7,86E+02	-6,64E+00	-3,10E+00	-1,20E+00	-1,32E+02	-1,18E+02	-4,95E+01	-8,57E+02	-4,23E+01
GWP-biogenic	kg CO2 eq	kg CO2 eq	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
GWP-luluc	kg CO2 eq	kg CFC11 eq	1,47E-02	2,93E-02	1,91E-02	0,00E+00	-9,99E-03	-3,94E-03	-4,32E-04	0,00E+00	-6,82E-02	0,00E+00	0,00E+00	-5,49E-02
ODP_A2	kg CFC11 eq	mol H+ eq	9,75E-06	6,17E-07	4,45E-07	0,00E+00	-4,33E-07	-3,70E-07	-1,83E-07	0,00E+00	-2,85E-06	0,00E+00	0,00E+00	-6,70E-06
AP_A2	mol H+ eq	kg P eq	1,70E-01	6,76E-02	4,98E-02	5,04E-02	-5,45E-02	-3,03E-02	-1,45E-02	0,00E+00	-4,88E-01	0,00E+00	0,00E+00	-7,06E-01
EP-freshwater	kg P eq	kg N eq	2,79E-04	1,32E-03	8,45E-04	0,00E+00	-5,00E-04	-1,04E-04	-1,02E-05	0,00E+00	-6,49E-02	0,00E+00	0,00E+00	-7,10E-04

EP-marine	kg N eq	mol N eq	5,15E-02	8,90E-03	6,87E-03	2,41E-02	-1,06E-02	-7,80E-03	-4,15E-03	0,00E+00	-1,46E-01	0,00E+00	0,00E+00	-1,92E-01
EP-terrestrial	mol N eq	kg NMVOC eq	5,68E-01	1,02E-01	7,87E-02	2,83E-01	-1,37E-01	-1,00E-01	-6,04E-02	0,00E+00	-2,02E+00	0,00E+00	0,00E+00	-2,13E+00
POCP_A2	kg NMVOC eq	kg Sb eq	1,83E-01	2,83E-02	2,27E-02	6,46E-02	-3,31E-02	-2,55E-02	-1,26E-02	0,00E+00	-4,55E-01	0,00E+00	0,00E+00	-5,68E-01
ADP-minerals&metals	kg Sb eq	MJ	9,36E-05	5,60E-05	8,39E-05	0,00E+00	-2,86E-05	-1,79E-04	-2,89E-06	0,00E+00	-1,06E-04	0,00E+00	0,00E+00	-1,26E-04
ADP-fossil	MJ	m3 depriv.	6,36E+02	2,62E+02	1,74E+02	0,00E+00	-1,10E+02	-3,63E+01	-1,55E+01	0,00E+00	-1,06E+04	0,00E+00	0,00E+00	-5,68E+02
WDP	m3 depriv.	disease inc.	2,13E+00	2,99E+00	2,41E+00	0,00E+00	-1,27E+01	-7,31E-01	-2,06E+00	0,00E+00	-6,38E+00	0,00E+00	0,00E+00	-2,88E+00
PM	disease inc.	kBq U-235 eq	3,68E-06	1,80E-07	2,34E-07	1,21E-07	-4,55E-07	-5,00E-07	-2,64E-07	0,00E+00	-3,99E-06	0,00E+00	0,00E+00	-2,51E-06
IRP	kBq U-235 eq	CTUe	2,76E+00	2,30E+00	1,41E+00	0,00E+00	-7,89E-01	-1,19E-01	-6,79E-02	0,00E+00	-2,41E+00	0,00E+00	0,00E+00	-2,67E+00
ETP-fw	CTUe	CTUh	4,97E+02	1,50E+02	1,44E+02	1,91E+01	-7,66E+02	-1,07E+02	-5,54E+02	0,00E+00	-1,74E+04	0,00E+00	0,00E+00	-4,68E+02
HTP-c	CTUh	CTUh	1,38E-08	5,68E-09	4,08E-08	3,89E-12	-3,36E-09	-1,04E-08	-4,63E-10	0,00E+00	-6,39E-08	0,00E+00	0,00E+00	-3,36E-08
HTP-nc	CTUh	Pt	5,44E-07	1,36E-07	1,27E-07	7,56E-08	-8,28E-08	-1,41E-07	-8,67E-09	0,00E+00	-3,72E-06	0,00E+00	0,00E+00	-3,80E-07
SQP	Pt	MJ	7,28E+02	3,90E+01	3,24E+01	0,00E+00	-3,30E+01	-3,59E+01	-1,29E+01	0,00E+00	-1,24E+03	0,00E+00	0,00E+00	-2,96E+02
PERE	MJ	MJ	8,10E+00	4,50E+01	3,07E+01	0,00E+00	-1,79E+01	-2,43E+00	-3,35E-01	0,00E+00	-9,27E+01	0,00E+00	0,00E+00	-2,09E+01
PERM	MJ	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
PERT	MJ	MJ	8,10E+00	4,50E+01	3,07E+01	0,00E+00	-1,79E+01	-2,43E+00	-3,35E-01	0,00E+00	-9,27E+01	0,00E+00	0,00E+00	-2,09E+01
PENRE	MJ	MJ	6,76E+02	2,75E+02	1,83E+02	0,00E+00	-1,16E+02	-3,86E+01	-1,65E+01	0,00E+00	-1,11E+04	0,00E+00	0,00E+00	-6,03E+02
PENRM	MJ	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
PENRT	MJ	kg	6,76E+02	2,75E+02	1,83E+02	0,00E+00	-1,16E+02	-3,86E+01	-1,65E+01	0,00E+00	-1,11E+04	0,00E+00	0,00E+00	-6,03E+02
SM	kg	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
RSF	MJ	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
NRSF	MJ	m3	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
FW	m3	kg	7,01E-02	2,19E-01	1,45E-01	0,00E+00	-3,51E-01	-2,04E-02	-4,89E-02	0,00E+00	-3,55E-01	0,00E+00	0,00E+00	-1,24E-01
HWD	kg	kg	1,54E-03	1,08E-04	8,26E-05	0,00E+00	-7,15E-05	-1,97E-04	-4,05E-05	0,00E+00	-7,35E-04	0,00E+00	0,00E+00	-1,10E-03
NHWD	kg	kg	5,96E+01	9,73E-01	2,27E+00	0,00E+00	-4,34E-01	-1,48E+00	-5,46E-02	0,00E+00	-3,10E+00	0,00E+00	0,00E+00	-8,59E+00
RWD	kg	kg	4,31E-03	1,90E-03	1,17E-03	0,00E+00	-7,00E-04	-1,65E-04	-1,04E-04	0,00E+00	-2,16E-03	0,00E+00	0,00E+00	-3,72E-03
CRU	kg	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00

MFR	kg	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
MER	kg		0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
EEE	MJ		0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
ETE	MJ		0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00

Table A3 Environmental profile of co-processing of SMC

	unit	C2 Transport to waste treatment	C3 Pre shredding	C3 Shredding	C3 Combustion in cement kiln (air emissions)	D Avoided: Quarrying raw materials (limestone)	D Avoided: Quarrying raw mat. (Si bearing/clay)	D Avoided: Quarrying raw mat. (Al bearing/bauxite)	D Avoided: Calcination CO2	D Avoided: Fuel cement kiln	D Avoided: Fuel CO2 emission from avoided CaO prod	D Avoided: Fuel CO2 due to combustion resin	Avoided transport
GWP-total	kg CO2 eq	4,08E+01	1,25E+01	9,09E+00	6,42E+02	-1,31E+01	-1,24E+00	-4,80E-01	-5,27E+01	-9,41E+01	-1,98E+01	-7,03E+02	-3,29E+01
GWP-fossil	kg CO2 eq	4,08E+01	1,24E+01	9,07E+00	6,42E+02	-1,31E+01	-1,24E+00	-4,79E-01	-5,27E+01	-9,40E+01	-1,98E+01	-7,03E+02	-3,28E+01
GWP-biogenic	kg CO2 eq	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
GWP-luluc	kg CO2 eq	1,47E-02	2,93E-02	1,91E-02	0,00E+00	-1,96E-02	-1,58E-03	-1,73E-04	0,00E+00	-5,44E-02	0,00E+00	0,00E+00	-4,34E-02
ODP_A2	kg CFC11 eq	9,75E-06	6,17E-07	4,45E-07	0,00E+00	-8,53E-07	-1,48E-07	-7,34E-08	0,00E+00	-2,27E-06	0,00E+00	0,00E+00	-5,12E-06
AP_A2	mol H+ eq	1,70E-01	6,76E-02	4,98E-02	4,20E-02	-1,07E-01	-1,21E-02	-5,78E-03	0,00E+00	-3,89E-01	0,00E+00	0,00E+00	-5,60E-01
EP-freshwater	kg P eq	2,79E-04	1,32E-03	8,45E-04	0,00E+00	-9,83E-04	-4,16E-05	-4,08E-06	0,00E+00	-5,18E-02	0,00E+00	0,00E+00	-5,60E-04
EP-marine	kg N eq	5,15E-02	8,90E-03	6,87E-03	2,01E-02	-2,08E-02	-3,12E-03	-1,66E-03	0,00E+00	-1,17E-01	0,00E+00	0,00E+00	-1,52E-01
EP-terrestrial	mol N eq	5,68E-01	1,02E-01	7,87E-02	2,36E-01	-2,69E-01	-4,00E-02	-2,42E-02	0,00E+00	-1,61E+00	0,00E+00	0,00E+00	-1,69E+00
POCP_A2	kg NMVOC eq	1,83E-01	2,83E-02	2,27E-02	5,38E-02	-6,52E-02	-1,02E-02	-5,03E-03	0,00E+00	-3,63E-01	0,00E+00	0,00E+00	-4,51E-01
ADP-minerals&metals	kg Sb eq	9,36E-05	5,60E-05	8,39E-05	0,00E+00	-5,63E-05	-7,15E-05	-1,16E-06	0,00E+00	-8,46E-05	0,00E+00	0,00E+00	-9,85E-05
ADP-fossil	MJ	6,36E+02	2,62E+02	1,74E+02	0,00E+00	-2,16E+02	-1,45E+01	-6,22E+00	0,00E+00	-8,44E+03	0,00E+00	0,00E+00	-4,39E+02
WDP	m3 depriv.	2,13E+00	2,99E+00	2,41E+00	0,00E+00	-2,49E+01	-2,93E-01	-8,23E-01	0,00E+00	-5,09E+00	0,00E+00	0,00E+00	-2,25E+00
PM	disease inc.	3,68E-06	1,80E-07	2,34E-07	1,01E-07	-8,95E-07	-2,00E-07	-1,06E-07	0,00E+00	-3,18E-06	0,00E+00	0,00E+00	-1,93E-06
IRP	kBq U-235 eq	2,76E+00	2,30E+00	1,41E+00	0,00E+00	-1,55E+00	-4,76E-02	-2,72E-02	0,00E+00	-1,92E+00	0,00E+00	0,00E+00	-2,07E+00

ETP-fw	CTUe	4,97E+02	1,50E+02	1,44E+02	1,60E+01	-1,51E+03	-4,28E+01	-2,22E+02	0,00E+00	-1,39E+04	0,00E+00	0,00E+00	-3,62E+02
HTP-c	CTUh	1,38E-08	5,68E-09	4,08E-08	3,24E-12	-6,62E-09	-4,15E-09	-1,85E-10	0,00E+00	-5,10E-08	0,00E+00	0,00E+00	-2,65E-08
HTP-nc	CTUh	5,44E-07	1,36E-07	1,27E-07	6,30E-08	-1,63E-07	-5,65E-08	-3,47E-09	0,00E+00	-2,97E-06	0,00E+00	0,00E+00	-2,91E-07
SQP	Pt	7,28E+02	3,90E+01	3,24E+01	0,00E+00	-6,49E+01	-1,44E+01	-5,18E+00	0,00E+00	-9,92E+02	0,00E+00	0,00E+00	-2,19E+02
PERE	MJ	8,10E+00	4,50E+01	3,07E+01	0,00E+00	-3,52E+01	-9,73E-01	-1,34E-01	0,00E+00	-7,39E+01	0,00E+00	0,00E+00	-1,65E+01
PERM	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
PERT	MJ	8,10E+00	4,50E+01	3,07E+01	0,00E+00	-3,52E+01	-9,73E-01	-1,34E-01	0,00E+00	-7,39E+01	0,00E+00	0,00E+00	-1,65E+01
PENRE	MJ	6,76E+02	2,75E+02	1,83E+02	0,00E+00	-2,28E+02	-1,54E+01	-6,61E+00	0,00E+00	-8,88E+03	0,00E+00	0,00E+00	-4,65E+02
PENRM	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
PENRT	MJ	6,76E+02	2,75E+02	1,83E+02	0,00E+00	-2,28E+02	-1,54E+01	-6,61E+00	0,00E+00	-8,88E+03	0,00E+00	0,00E+00	-4,65E+02
SM	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
RSF	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
NRSF	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
FW	m3	7,01E-02	2,19E-01	1,45E-01	0,00E+00	-6,91E-01	-8,17E-03	-1,96E-02	0,00E+00	-2,83E-01	0,00E+00	0,00E+00	-9,70E-02
HWD	kg	1,54E-03	1,08E-04	8,26E-05	0,00E+00	-1,41E-04	-7,88E-05	-1,62E-05	0,00E+00	-5,86E-04	0,00E+00	0,00E+00	-8,43E-04
NHWD	kg	5,96E+01	9,73E-01	2,27E+00	0,00E+00	-8,53E-01	-5,92E-01	-2,19E-02	0,00E+00	-2,47E+00	0,00E+00	0,00E+00	-5,52E+00
RWD	kg	4,31E-03	1,90E-03	1,17E-03	0,00E+00	-1,38E-03	-6,60E-05	-4,18E-05	0,00E+00	-1,72E-03	0,00E+00	0,00E+00	-2,87E-03
CRU	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
MFR	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
MER	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
EEE	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
ETE	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00

Appendix B Review statement

experts in sustainability
nibe

Review statement

Opdrachtgever	Bob Roijen	SGS INTRON
Opgesteld door	Mantijn van Leeuwen	NIBE
Datum	29 September 2024	
Ons kenmerk		
Subject	**Review statement LCA report "LCA of Composite Waste Processing"**	

Dear Sir,

I hereby confirm that the methodology and data collection as described in the background report "LCA of Composite Waste Processing" comply with the demands set forth in ISO 14040/140444 and the EN 15804:2019+A2. The background report dates September 6th 2024.

The findings have been reported in "Review tabel_sgs_NIBE_sgs.xlsx" dated September 29th 2024.

The results are used to make a comparison with other fuel types in a cement kiln operation. Secondly the presented processes could be used as end of life processes in modelling composite structures for declaration in an EPD, when doing so chapter 4 applies and the data shown in the appendix of the report.

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