Cradle-to-grave carbon footprint of Elium-based recyclable composites vs. epoxy-based composites

According to GHG protocol standard

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Revision

Date	Version	Description
February 5th, 2024	1.0	Draft report
March 13th, 2024	2.0	Final report
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Abbreviations

ABS: Acrylonitrile Butadiene Styrene
BPA: Bisphenol A
CH_4: Methane
CO_2: Carbon dioxide
CO_2eq.: Carbon dioxide equivalent
Elec.: Electricity
EOL: End-of-life
GHG: Greenhouse Gas
GWP: Global Warming Potential
IPPC: Intergovernmental Panel for Climate Change
Kg: kilogram
MMA: Methyl MethAcrylate
N_2O: Nitrous oxide
PA: Polyamide
PE: polyethylene
PET: PolyEthylene Terephtalate
PMMA: Poly Methyl MethAcrylate
PPE: Personal Protective Equipment
PVC: Polyvinylchloride
RM: Raw materials

SF_6: Sulfur hexafluoride

Sources

- Composite manufacturing data provided by Neo Sailing Technologies (bill of materials, transport of raw materials and consumables, energy for molding)
- Plastics Europe eco-profiles for emission factors of MMA, PMMA, BPA and ABS
- Ecoinvent v3.9 for emission factors of epichlorohydrin, PET, PVC, para-phenylene diamide and ethylene diamine and all other emission factors
- Glass fiber Europe for glass fiber emission factor (fabrics, short fibers)
- MMA two calculator: https://www.mmatwo-footprinter.eu/ for thermolysis carbon footprint
- EuCIA Eco Impact Calculator for thermoplastics and composites compounding data (https://ecocalculator.eucia.eu/)
- 2022 Annual report of Beneteau, extra-financial performance statement

1. Executive summary

ARKEMA is a world leader in specialty materials: coatings, adhesives and high-performance materials. Among its wide material portfolio, the Elium® resin is a thermoplastic resin making possible to produce recyclable composites with better mechanical properties than thermoset. The Elium® resin addresses several markets, such as wind industry, infrastructures and marine.

The objective of this study is to calculate the cradle-to grave carbon footprint (in $kgCO_2$/kg of composite) of a boat hull made by infusion from Elium® and glass fiber and to compare it with a boat hull made of epoxy resin and glass fiber by using the same process. Three options for the end-of life of the boat hull and for production wastes treatment have been studied, depending on the nature of the resin: two options taking advantage of the Elium® recyclability (1a and 1b) and one option for the epoxy resin (2). The final goal of this study is to determine which option is the best solution considering greenhouse gas emissions.

- Option 1a (Elium®): production wastes during composite part manufacturing (neat Elium® and composites wastes) and the boat hull at the end of its life are treated by thermolysis, a thermal recycling process during which PMMA is depolymerized into MMA monomer with a yield of 77% and short glass fibers are recovered with a yield of 90%.
- Option 1b (Elium®): production wastes during composite part manufacturing and the boat hull at the end of its life are treated by mechanical recycling. After grinding and extrusion, a fiber-reinforced compound is produced with a global yield of 83%.
- Option 2 (Epoxy): production wastes during composite part manufacturing (epoxy resin and composites wastes) are incinerated with energy recovery and the boat hull is landfilled at the end of its life.

The calculations have been done in accordance with GHG Protocol standard and chemical sector guidelines, with results in $kgCO_2eq$/kg of composite being presented in Figure 1.

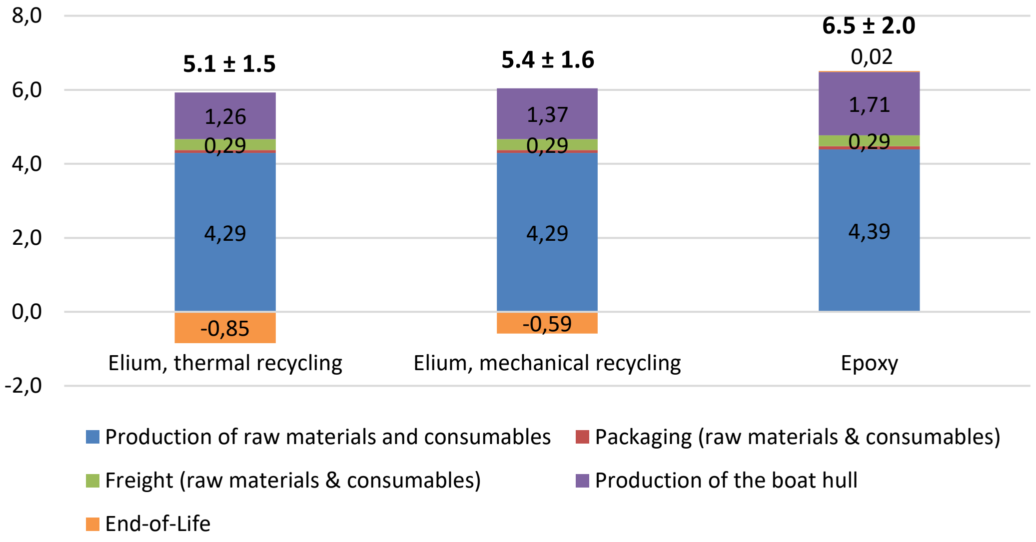

Figure 1: cradle-to-grave carbon footprint, in $kgCO_2eq$/kg of composites

For option 1a, it was considered that recovered glass fibers can replace short glass fibers and not woven glass fabric. So recovered glass fibers can be used for the production of mat or veil, or be used as filler in sinks or other molded products.

The following categories have been considered in the carbon footprint calculation: production of all raw materials and their packaging (resins, core materials, glass fibers and consumables), freight of these raw materials and consumables to the shipyard, production of the boat hull (energy consumption, wastes treatment and factory infrastructure) and the end-of-life of the boat hull. Carbon emissions related to employee commuting and business travels during the production of the boat hull have not been considered. The use phase, including the transport of the boat from the shipyard to the harbor, has not been taken into account since the type of resin and the end-of-life scenarios have no impact on greenhouse gas emissions of the use phase.

The use of Elium® resin allows the reduce by 16-22% the cradle-to-grave carbon footprint of a boat hull, as compared to the epoxy resin. The highest reduction is achieved with the thermolysis recycling process. To have a better understanding of the greenhouse gas emission differences between all options, the CO_2eq emissions have been calculated for the full life cycle of a 1000 kg composite boat hull, and the avoided emission have been converted into airplane travel distance for 1 passenger:

- Using Elium® with a thermal recycling process for a 1000 kg boat hull (option 1a), allows to avoid the emission of 1424 kgCO_2eq as compared to using epoxy, which is equivalent to 4535 km by plane for one passenger.
- Using Elium® with a mechanical recycling process for a 1000 kg boat hull (option 1b), allows to avoid the emission of 1051 kgCO_2eq as compared to using epoxy, which is equivalent to 3348 km by plane for one passenger.

2. General information and scope

2.1 Studied product name and description

The objective of this study is to determine the cradle-to-grave carbon footprint of 1 kg of a boat hull made of Elium® resin or epoxy resin and considering different scenarios for waste treatment (production wastes and end-of-life):

- Option 1a (Elium®): production wastes during composite part manufacturing (neat Elium® and composites wastes) and the boat hull at the end of its life are treated by thermolysis, a thermal recycling process during which PMMA is depolymerized into MMA monomer with a 77% yield and glass fibers are recovered with a 90% yield.
- Option 1b (Elium®): production wastes during composite part manufacturing and the boat hull at the end of its life are treated by mechanical recycling. After grinding and extrusion, a fiber-reinforced compound is produced with a global yield of 83%.
- Option 2 (Epoxy): production wastes during composite part manufacturing (epoxy resin and composites wastes) are incinerated with energy recovery and the boat hull is landfilled at the end of its life.

The same weight of resin and glass fibers is considered for all options (Elium® and epoxy).

2.2 Functional unit

The functional unit of this study is the manufacturing and end-of life of 1 kg of a boat hull.

Depending on the resin and the waste treatment option, some co-products have to be included into the system:

- Option 1a: co-production of 0.24 kg of MMA and 0.54 kg of short glass fibers during recycling,
- Option 1b: co-production of 0.76 kg of glass-reinforced compound, considered as equivalent to an ABS-GF30 (30% glass reinforced ABS),
- Option 2: no co-products.

2.3 Type of inventory

A cradle-to-grave inventory has been selected to allow the comparison of different end-of-life scenarios.

2.4 GHGs included in the inventory

Emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), perfluorocarbons (PFCs) and hydrofluorocarbons (HFCs) are taken into account in this study.

2.5 Sector-specific guidance used

This study has been performed according to the Product Life Cycle Accounting and Reporting Standard from the GHG Protocol.

2.6 Limitations

All emission factors for raw materials, transport, energy and wastes are from Plastics Europe eco-profile and Ecoinvent 3.9 databases and they are not specific to the suppliers of each raw material, so uncertainties have to be taken into consideration to communicate externally. Since this study is focused on climate impact only, other environmental impacts (toxicity, eutrophication, ozone depletion, etc.) are not taken into account. As a consequence, the results of this study should not be used to communicate the overall environmental performance of the Elium® resin, but only its carbon footprint.

3. Boundary settings

3.1 Life cycle stage definitions and descriptions

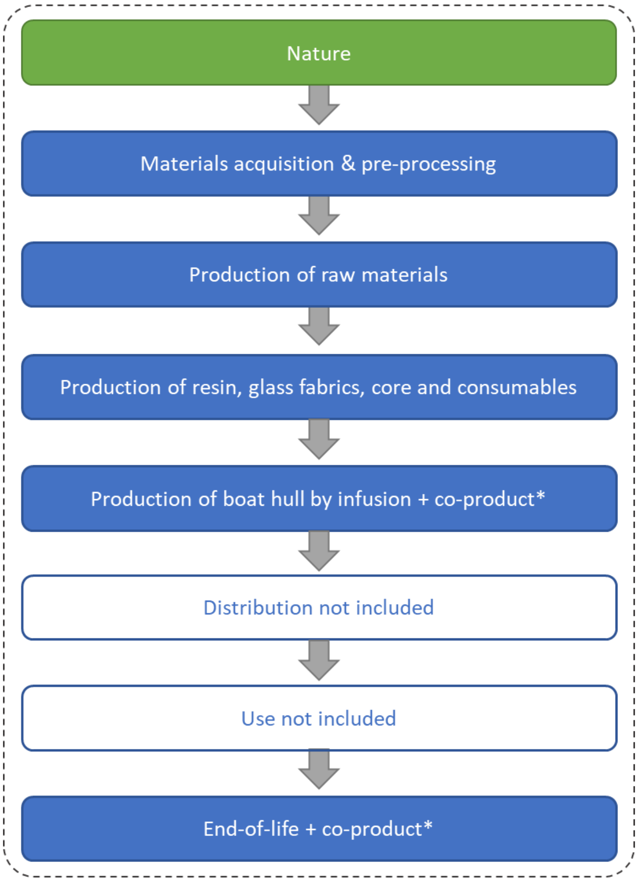

Figure 2: life cycle stages considered in this study.

Co-products are 0.24 kg of MMA and 0.54 kg of short glass fibers for option 1a and 0.76 kg of glass reinforced compound, equivalent to ABS-GF30, for option 1b.

The material acquisition & pre-processing stage is also taken in account and corresponds to the extraction of natural resources and their transformation into energy, equipment and raw materials which are necessary to produce resin, glass fibers, core material and consumables.

3.2 Non-attributable processes

Non-attributable processes for this study are typically corporate activities and services (quality, research and development, administrative functions, sales and marketing…). These processes have not been taken into account in this evaluation, as it is usually done.

3.3 Excluded attributable processes

All attributable processes have been included in this study.

4. Allocation

Some allocations have been made for the co-products of options 1a and 1b. Since these co-products have well known manufacturing process, with known emission factors, an allocation by substitution has been selected. The emission factors from Plastic Europe have been chosen for MMA and ABS, and the emission factors from Glass Fiber Europe for short fibers.

5. Data collection and quality

5.1 Data sources

Activity data have been collected from Neo Sailing Technologies, Arkema, EuCIA calculator for mechanical recycling and MMAtwo calculator for thermal recycling. Emissions factors used in this study are from Ecoinvent v3.9 database, Plastics Europe eco-profile (MMA, PMMA, BPA and ABS) and Glass Fiber Europe data.

5.2 Data quality and efforts to improve it

The quality of data is assessed based on their completeness, reliability and representativeness on three axes (technology, geography and time) and is considered as medium-to-good for this study. In order to improve the quality of data, the main action would be to get additional data from suppliers, notably for the formulated epoxy resin and for the industrial scale recycling process since they are main contributors in the carbon footprint.

6. Uncertainty

The uncertainty of these evaluations has been estimated at 30% since raw materials emission factors are from databases and not specific from suppliers, and the exact formulation of the epoxy resin-hardener is not known.

7. Inventory results

7.1 General information

The emission factors and the bill of material of the boat hull are listed in Appendix 1.

For the Elium® resin, it was assumed a formulation made of 80% of MMA, 20% of PMMA and 1% of peroxide (MEKP).

For the epoxy resin, a standard bisphenol A liquid epoxy resin, without fillers, has been considered. For the hardener part, a formulation containing 50% of an aromatic diamine (modelled by para-phenylene diamine from Ecoinvent) and 50% of an aliphatic diamine (modelled by ethylenediamine from Ecoinvent) has been considered. The liquid resin to hardener ratio has been set at 100:30 by mass.

The selected core material is a PET foam made of 30% recycled material PET or boat hull made of Elium® resin. In case of a boat hull made of epoxy resin, core material is a PVC foam.

The glass fiber fabric has been modeled by weaving some glass fiber direct roving.

All consumables for the infusion process were considered in the calculation: peel ply, release agent film, drain grate, diadrain, vacuum bagging film, sealing material, tubings, T connectors, spiral net, taps, gloves, rags, individual protections.

The hypothesis on the packaging of all raw materials and consumables are the following ones:

- the packaging of glass fiber fabric, peel ply, release agent film, drain grate, diadrain, vacuum bagging film is a pallet which represents 10% of material weight,
- the packaging of sealing material, tubings, T connectors, spiral net, taps, gloves, rags, individual protections is a carton board box which represents 3% of consumables weight,
- the packaging of resin and hardener is a metallic drum which represents 3% of raw material weight.

Upstream transportation has been calculated based on the distance from the raw material suppliers to the plant, with Ecoinvent v3.9 database. It was considered that 60% of consumables come from countries bordering France and are transported by truck with a distance of 500 km, 20% of consumables are transported by truck with a distance of 1 500 km and the remaining 20% are transported by sea freight (20 000 km) and truck (500 km).

The boat hull is produced in France and the recycling is made in Europe (for electricity emission factor). The composite part (68% glass fiber and 32% resin) represents 80% in weight of the boat hull and the remaining 20% is the PET-based core material. The scrap and operational losses of resin, glass fiber and core material during composite manufacturing has been assumed to be 10%.

For the Elium® boat hull manufacturing, it was considered a total energy consumption of 16.9 MJ/kg, based on Neo Sailing Technologies data, with a 33/67 split between electricity and natural gas. For the epoxy molding, it was assumed a 25% higher energy consumption than Elium®, due to the post-curing process. This value is conservative since Neo Sailing Technologies data are showing up to 45% higher energy consumption for epoxy molding.

For wastes treatment during boat hull production, it was assumed that:

- Option 1a: neat Elium resin and composites wastes are treated by thermal recycling process. After thermolysis, the PMMA is depolymerized into MMA monomer with a yield of 77% and fibers are recovered with a yield of 90%.
- Option 1b: neat Elium resin and composites wastes are treated by mechanical recycling (grinding and extrusion-compounding). After grinding and extrusion, a compound is produced with a global yield of 83%. It was assumed that grinding step requires 0.29 MJ/kg of starting material. The carbon footprints of thermoplastic compounding and composite compounding are respectively 0.57 kgCO_2eq/kg and 0.76 kgCO_2eq/kg according to EuCIA data.
    - For both options 1a and 1b, it was assumed that 100% of the recycling environmental burdens and 100% of the recycling environmental benefits are attributed to the waste producer.
- Option 2: epoxy resin and composites wastes are incinerated with energy recovery.
- For all options: consumables, personal protective equipment and core material scraps are incinerated with energy recovery. Glass fiber scraps are landfilled.

A distance of 50 km by road was considered for the transport of all wastes to the incineration treatment plant (or landfill aera) and a distance of 500 km by road for the neat resin and composites wastes, from the boat hull production plant to the recycling sites.

Greenhouse gas emissions due to infrastructure have been estimated with the Ecoinvent dataset “plastic process factory” and employee commuting and business travels have not been considered due to lack of data.

For end-of life, it was assumed that:

- Option 1a: Elium® composites parts are treated by thermal recycling process (same conditions as those described for wastes treatment) and core material is landfilled.
- Option 1b: Elium® composites parts are treated by mechanical recycling (grinding and extrusion-compounding, same conditions as those described for wastes treatment) and core material is landfilled.
- Option 2: the epoxy boat hull is landfilled (composites + core material).

A distance of 50 km by road was considered for the transport of materials to the landfill area and a distance of 500 km by road for composite parts to recycling sites.

7.2 Elium resin

The Figure 3 presents the breakdown of the cradle-to-grave carbon footprints of 1 kg of a boat hull made of Elium® resin in which composites and resin wastes and composites hull are recycled by thermolysis or mechanical processes.

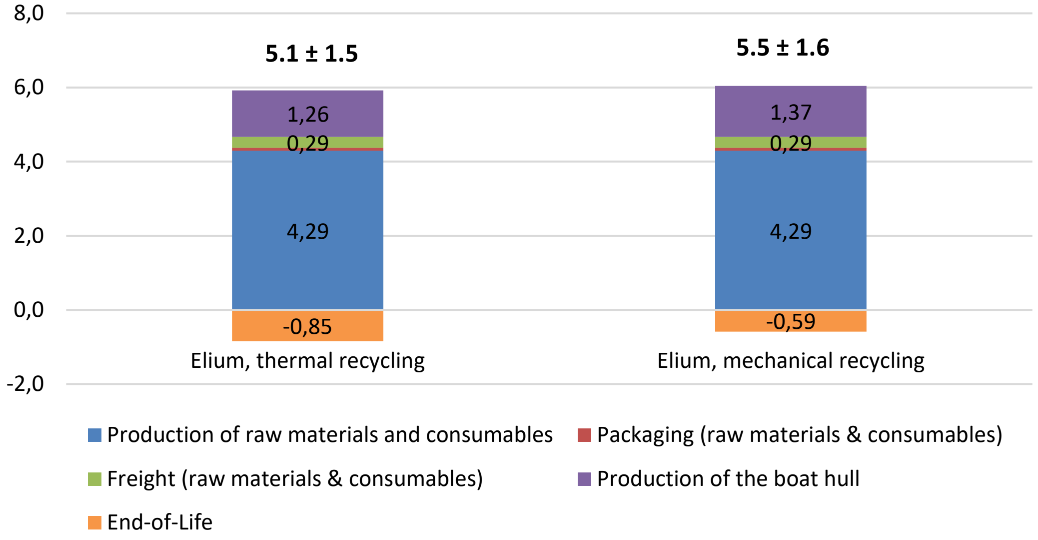

Figure 3: breakdown of main contributors for Elium® carbon footprint, in $kgCO_2eq/kg$ of composite

The main contributor are raw materials and consumables (85% for thermolysis and 79% for mechanical recycling) and boat hull production (25%) followed by freight of raw materials and consumables (5-6%) and packaging (2%). End-of-life of boat hull is of -0.85 $kgCO_2eq/kg$ for thermal recycling and -0.59 $kgCO_2eq/kg$ for mechanical recycling.

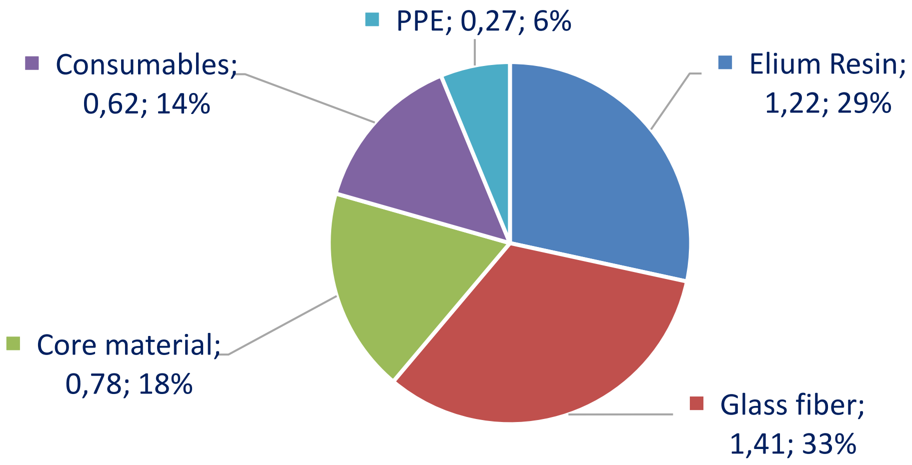

Figure 4: breakdown of GHG emissions for raw materials and consumables, in $kgCO_2eq/kg$ of composite (both recycling scenarios)

The Figure 4 represents the breakdown of GHG emissions for raw materials and consumables for the composite part made of Elium® resin. Main contributors are glass fiber (33%) and Elium® resin (29%) followed by core material (18%) and consumables (14%). The remaining 6% are due to personal protective equipment (PPE).

7.2.1 Thermal recycling for production wastes and end-of-life

The Figure 5 represents the breakdown of the GHG emissions of the boat hull production step, for which the main contributors are natural gas (49%) and wastes treatment of consumables, core material and PPE (20%), followed by the plant infrastructure (12%), electricity (8%) and waste freight (1%). The Elium® resin and composite wastes give a credit of -0.16 $kgCO_2eq/kg$ due to the allocation by substitution of the generated co-products during recycling. It is assumed that 100% of the recycling environmental burdens and 100% of the recycling environmental benefits are attributed to the waste producer. In that case, the benefit corresponds to the generation of 0.04 kg of MMA and 0.05 kg of short glass fiber. The burdens correspond to the GHG emissions associated to thermolysis recycling of 0.03 kg of resin and 0.09 kg of composite (yield of 77% for resin and 90% glass fibers).

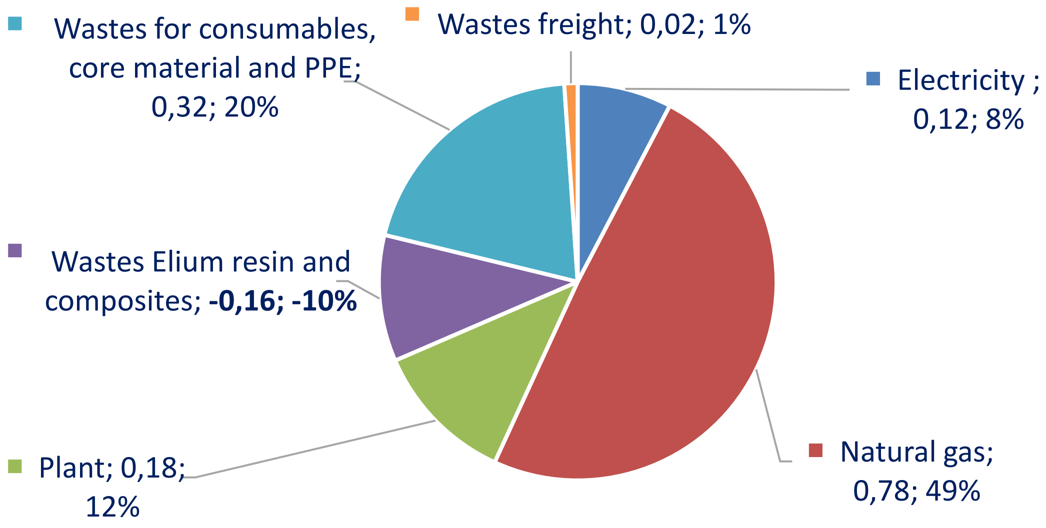

Figure 5: breakdown of GHG emissions for boat hull production, in $kgCO_2eq/kg$ (Elium resin and thermal recycling scenario)

The end-of-life of the composite part gives a credit of -0.83 $kgCO_2eq/kg$. It is also assumed that 100% of the recycling environmental burdens and 100% of the recycling environmental benefits are attributed to the waste producer. In that case, the benefit corresponds to the generation of 0.2 kg of MMA and 0.49 kg of short glass fiber. The burdens correspond to the GHG emissions associated to thermolysis recycling of 0.8 kg of composite (with a yield of 77% for resin and 90% for glass fibers).

For option 1a, it was considered that recovered glass fibers can replace short glass fibers and not woven glass fabric. So recovered glass fibers can be used for the production of mat or veil, or be used as filler in sinks or other molded products.

7.2.2 Mechanical recycling for production wastes and end-of-life

The Figure 6 represents the breakdown of GHG emissions of the boat hull production step whose main contributors are natural gas (53%) and wastes treatment of consumables, core material and PPE (22%), followed by the plant infrastructure (13%), electricity (8%) and waste freight (1%). The Elium® resin and composite wastes are giving a credit of -0.05 kgCO$_2$eq/kg due to the allocation by substitution of co-products. It was assumed that 100% of the recycling environmental burdens and 100% of the recycling environmental benefits are attributed to the waste producer. In that case, the benefit corresponds to the generation of 0.10 kg of compound that means that CO$_2$ emissions are avoided for not producing 0.10 kg of ABS-GF30 compound. The burdens correspond to the GHG emissions associated to mechanical recycling of 0.03 kg of resin and 0.09 kg of composite with a global yield of 83%.

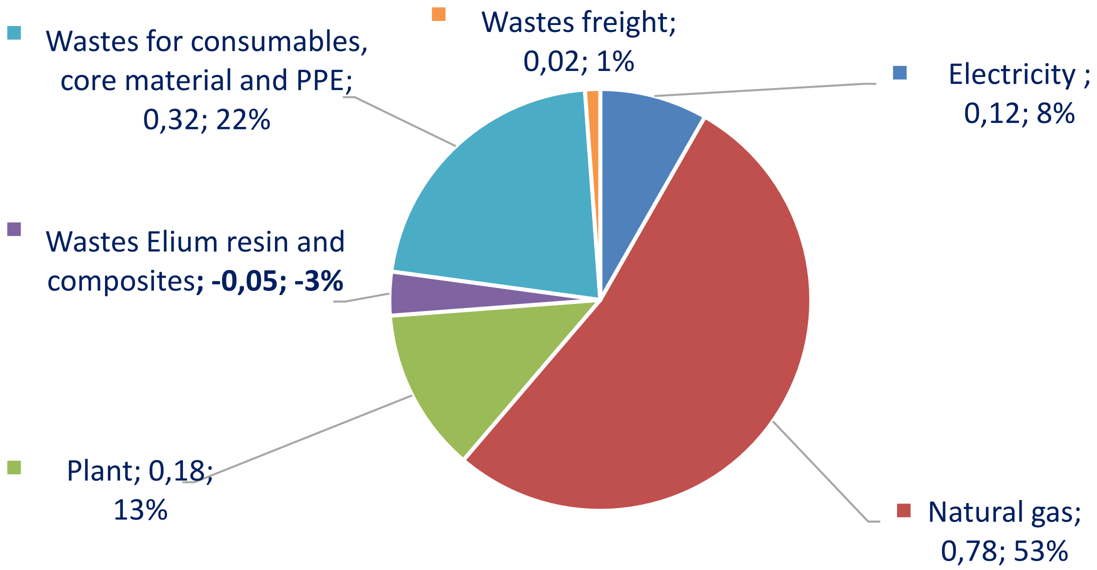

Figure 6: breakdown of GHG emissions for boat hull production, in kgCO$_2$eq/kg (Elium resin and mechanical recycling scenario)

The end-of-life of the composite part is also giving a credit of -0.59 kgCO$_2$eq/kg due to co-products. It was also assumed a 100% allocation of environmental burdens and benefits to the waste producer. In that case, the benefit corresponds to the generation of 0.66 kg of compound that means that CO$_2$ emissions are avoided for not producing 0.66 kg of ABS-GF30 compound. The burdens correspond to the GHG emissions associated to mechanical recycling of 0.8 kg of composite with a global yield of 83%.

7.3 Epoxy resin

The Figure 7 presents the breakdown of the cradle-to-grave carbon footprint for 1 kg of a boat hull made of epoxy resin which is of 6.5 ± 2.0 kgCO$_2$eq/kg.

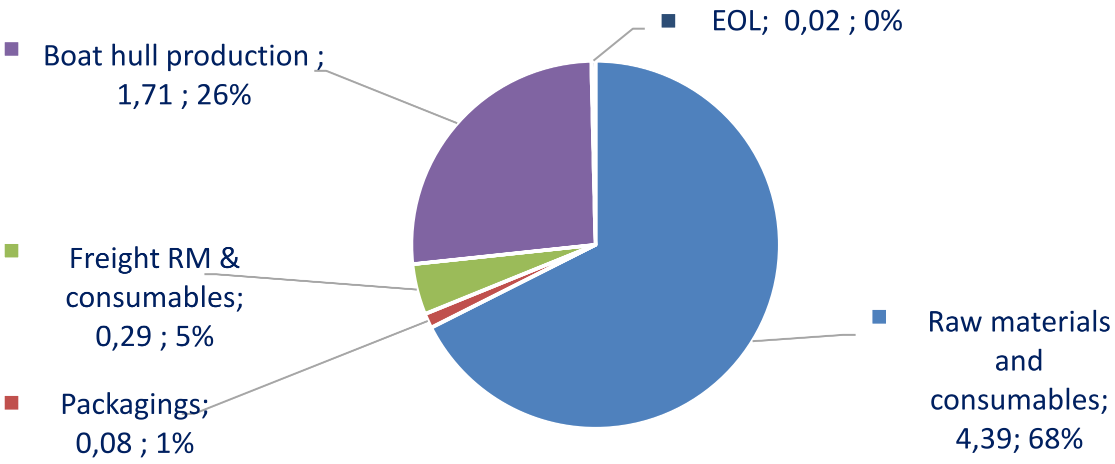

Figure 7: breakdown of main contributors for the epoxy boat hull, in kgCO$_2$eq/kg of composite

The main contributor are raw materials and consumables (68%) and boat hull production (26%) followed by freight of raw materials and consumables (5%) and packaging (1%).

The Figure 8 represents the breakdown of GHG emissions for raw materials and consumables. Main contributors are epoxy resin (33%) and glass fiber (32%), followed by core material (15%) and consumables (14%). The remaining 6% are due to personal protective equipment (PPE). The calculated emission factor for the formulated epoxy resin is 4.6 kgCO$_2$eq/kg (including the amine hardener).

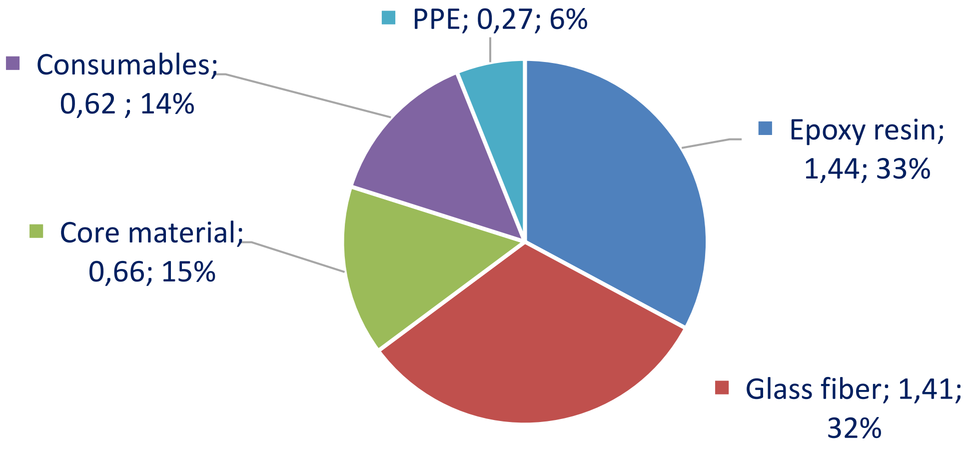

Figure 8: breakdown of GHG emissions for raw materials and consumables, in kgCO$_2$eq/kg (epoxy resin and incineration + landfilling scenario)

The Figure 9 represents the breakdown of GHG emissions for the epoxy boat hull production. The main contributors are natural gas (57%) and wastes treatment of consumables, core material and PPE (19%), followed by plant infrastructure (11%) and electricity (9%). The remaining 4% are due to wastes treatment of epoxy resin and composites. Avoided emissions due to energy recovery represent 77% of the total CO_2eq emissions of wastes treatment.

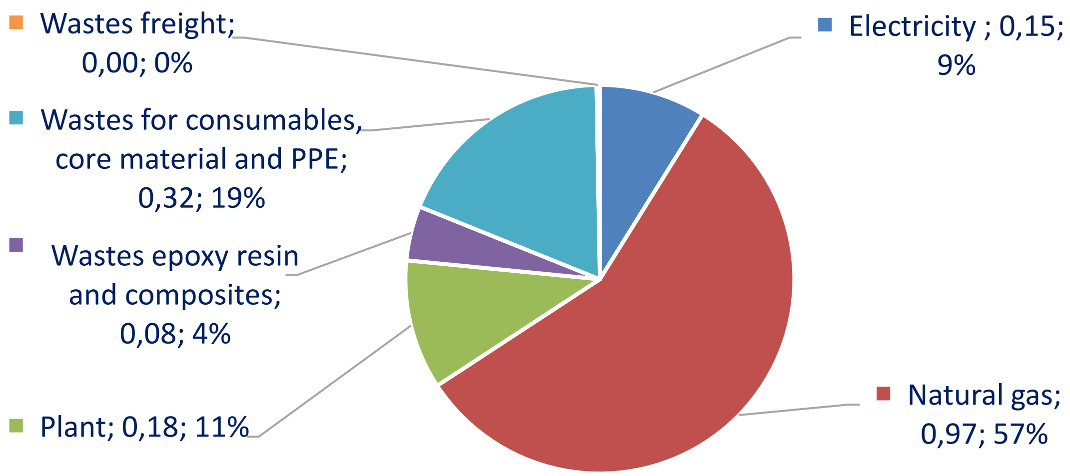

Figure 9: breakdown of GHG emissions for the epoxy boat hull production, in kgCO_2eq/kg of composite

7.4 Sensitivity analysis

A sensitivity analysis has been performed to check the influence of the resin carbon footprint (Elium®, epoxy) and also the country where the boat hull is produced. Three countries/areas have been selected (Europe, France and Poland, since France has an emission factor 4.8 times lower than Europe and Poland has an emission factor 2.6 times higher than Europe) and the use of electricity from renewable resources has also been assessed (wind electricity).

For the epoxy resin, a high-value of the carbon footprint at **6.57** kgCO_2eq has been tested (which corresponds to a calculation from the emission factors of Ecoinvent 3.9 for liquid epoxy resin and ethylenediamine/meta-phenylene diamine for hardener). A low-value at **2.24** kgCO_2eq has also been tested, which corresponds to the emission factor of the Idemat database for epoxy resin.

For the Elium® resin, a high-value for the emission factor at **7.30** kgCO_2eq has been used (which correspond to a calculation performed with the emission factors of Ecoinvent 3.9 for MMA and PMMA). The carbon footprint of **4.86** kgCO_2eq correspond to the value used by Lalou Multi for their 2023 GHG accounting. All results for CO_2 emissions are included in Table 1, with the % of GHG emission reduction vs. the epoxy option.

	Hypothesis			Results		
	Elium® carbon footprint	**Epoxy carbon footprint**	**Emission factor of electricity**	**Elium®, chemical recycling (option 1a)**	**Elium®, mechanical recycling (option 1b)**	**Epoxy, incineration & landfilling (option 2)**
Base case	**3.90**	**4.61**	**France**	5.1 (-22%)	5.5 (-16%)	6.5
Scenario 2 Elium® high carbon	**7.30**	4.61	France	6.1 (-6%)	6.5 (0%)	6.5
Scenario 3 Elium® medium carbon	**4.86**	4.61	France	5.4 (-17%)	5.8 (-12%)	6.5
Scenario 4 Epoxy high carbon	3.83	**6.57**	France	5.1 (-29%)	5.5 (-23%)	7.1
Scenario 5 Epoxy low carbon	3.83	**2.24**	France	5.1 (-12%)	5.5 (-5%)	5.8
Scenario 6 Elec. medium carbon	3.83	4.61	**Europe**	5.5 (-22%)	5.9 (-16%)	7.0
Scenario 7 Elec. high carbon	3.83	4.61	**Poland**	6.4 (-22%)	6.8 (-17%)	8.2
Scenario 8 Elec. low carbon	3.83	4.61	**Wind electricity**	5.0 (-22%)	5.4 (-16%)	6.4

Table 1: sensitivity analysis for different resin carbon footprint and countries of boat hull production, cradle-to-grave carbon footprint in kgCO_2eq/kg and difference with option 2 in %

The sensitivity analysis shows the impact of the country where the boat hull is produced, but in all cases the option 1a (Elium® resin with thermal recycling) always remains the best-case scenario and option 2 (epoxy resin) remains the worst case scenario, even when the Elium® emission factor is high or when the epoxy emission factor is low.

Communicating on a 10-20% reduction of CO_2eq emissions when using Elium® instead of epoxy seems a robust environmental claim.

8. Critical review

A first party verification has been performed and the reviewer made some correction and confirmed the final results are in conformance with the GHG Protocol Product Life Cycle Accounting and Reporting standard.

9. Recommendations & inventory changes

9.1 Base inventory and current inventory

This inventory is the base inventory.

9.2 Recommendations

For all options, the main improvements that could be done to further reduce the carbon footprints are:

- Assess the possibility to manufacture Elium® from bio-circular MAM, that could be produced from bio-circular acetone (typically acetone made from olefins produced from used cooking oil),
- Compare glass fiber suppliers and select the ones with the lower carbon footprint (linked to the use of low carbon energy and high energy efficiency ovens),
- Select consumables incorporating a high ratio of recycled materials,
- Select a core material with recycled PET content higher than 30%,
- Improving the yield of thermal recycling and mechanical recycling processes,
- Use electricity from renewable resources for the production of boat hull and recycling processes,
- Use biogas instead of natural gas for workshop heating during boat hull manufacturing.

10. Appendix

10.1 Emission factors

Ademe, avoided emission by energy recovery, medium plastics
Ademe, avoided emission by energy recovery, PET
Base Carbone v19, 1900 - 3850 EVP (Europe)
Plastics Europe eco-profile, MMA/PMMA
Plastics Europe eco-profile, ABS
Plastics Europe eco-profile, BPA
EuCIA data, TP compounding
EuCIA data, Composites compounding
Glass fiber Europe, Glass fiber direct roving, 2023
Glass fiber Europe, Glass fiber dry chopped strands, 2023
Idemat, butadiene rubber and butyl rubber
MMAtwo calculator, MMA recycled by thermolysis
Ecoinvent v3.9, epoxy resin, liquid, epoxy resin production, liquid, RER
Ecoinvent v3.9, epichlorohydrin production from allyl chloride, RER
Ecoinvent v3.9, para-phenylene diamine, resorcinol production, GLO
Ecoinvent v3.9, market for ethylenediamine, RER
Ecoinvent v3.9, polyethylene terephthalate production, granulate, RER
Ecoinvent v3.9, market for polyethylene terephthalate, granulate, recycled, Europe,
Ecoinvent v3.9, polyvinylchloride production, suspension polymerisation, RER
Ecoinvent v3.9, extrusion, plastic film, RER
Ecoinvent v3.9, injection moulding, RER
Ecoinvent v3.9, extrusion, plastic pipes, RER
Ecoinvent v3.9, market for weaving, synthetic fibre, GLO
Ecoinvent v3.9, nylon 6-6 production, RER
Ecoinvent v3.9, market for textile, nonwoven polyester, GLO
Ecoinvent v3.9, polypropylene, granulate, polypropylene production, granulate, RER
Ecoinvent v3.9, granulate, polyethylene production, low density, granulate, RER
Ecoinvent v3.9, carton board box production, with offset printing, carton board box production service, with offset printing, CH
Ecoinvent v3.9, EUR-flat pallet production, RER
Ecoinvent v3.9, transport, freight, lorry 16-32 metric ton, EURO6, RER
Ecoinvent v3.9, transport, freight, lorry 7.5-16 metric ton, EURO6, RER
Ecoinvent v3.9, market group for electricity, medium voltage, RER
Ecoinvent v3.9, market for electricity, medium voltage, FR
Ecoinvent v3.9, market for electricity, medium voltage, PL
Ecoinvent v3.9, electricity, high voltage, wind, <1MW turbine, onshore, FR
Ecoinvent v3.9, market for natural gas, burned in gas turbine, GLO
Ecoinvent v3.9, market for plastic processing factory, GLO
Ecoinvent v3.9, hazardous waste, for incineration, Europe without Switzerland
Ecoinvent v3.9, treatment of waste plastic, mixture, municipal incineration, RoW
Ecoinvent v3.9, waste mineral wool, for final disposal, inert material landfill, Europe
Ecoinvent v3.9, treatment of inert waste, sanitary landfill, Europe without Switzerland

10.2 Bill of materials for 1 kg of composite (boat hull) made with Elium® resin

	Type	Raw materials / nature	Data	Unit
RAW MATERIALS AND CONSUMABLES	Resin	MMA	0,31	kg
	Core material	PET	0,24	kg
	Glass fabric	Glass	0,66	kg
	Peel ply	PA	0,01	kg
	Release gant film	PA	0,01	kg
	Drain gate	PE	0,02	kg
	Diadrain	polyester	2,29E-03	kg
	Vacuum bagging film	50%PE/50%PA	0,03	kg
	Sealing material	butyl rubber	0,01	kg
	tubings	PE	0,01	kg
	T connectors	PP	1,79E-03	kg
	Spiral net	PE	0,02	kg
	Taps	PE	0,01	kg
	PPE and rags	10% nitrile/90% PE	0,07	kg
PACKAGING OF RAW MATERIALS AN CONSUMABLES	Elium	Metallic drum	0,31	kg
	Core material	Cardboard	0,01	kg
	Glass fabric	Pallet	0,07	kg
	Peel ply	Pallet	1,45E-03	kg
	Release gant film	Pallet	1,23E-03	kg
	Drain gate	Pallet	2,01E-03	kg
	Diadrain	Pallet	6,87E-05	kg
	Vacuum bagging film	Pallet	3,04E-03	kg
	Sealing material	Cardboard	1,80E-04	kg
	tubings	Cardboard	2,88E-04	kg
	T connectors	Cardboard	5,36E-05	kg
	Spiral net	Cardboard	4,70E-04	kg
	Taps	Cardboard	1,85E-04	kg
	PPE and rags	Cardboard	2,10E-03	kg
FREIGHT	Raw materials and consumables	road freight	0,90	ton.km
	Raw materials and consumables	seafreight	6,02	ton.km
BOAT HULL PRODUCTION	Electricity	medium voltage, France	1,56	kWh
	Natural gas	natural gas	3,13	kWh
	Factory	plastic factory	1,00E-09	unit
	Elium wastes	thermal or mechanical recycling	0,03	kg
	Composites wastes	thermal or mechanical recycling	0,09	kg
	Freight for composites wastes	road freight	0,06	ton.km
	Freight for wastes (without composites)	road freight	0,01	ton.km
	Wastes consumables	incineration with energy recovery	0,12	kg
	Wastes EPI	incineration with energy recovery	0,07	kg

	Wastes fabric	landfilling	0,06	kg
	Wastes Core material	incineration with energy recovery	0,04	kg
EOL	Freight	road freight	0,41	ton.km
	EOL core material	incineration with energy recovery	0,20	kg
	EOL composite	thermal or mechanical recycling	0,80	kg

10.3 Bill of materials for 1 kg of composite (boat hull) made with epoxy resin

	Type	Raw materials / nature	Data	Unit
RAW MATERIALS AND CONSUMABLES	Resin	Epoxy	0,31	kg
	Core material	PVC	0,24	kg
	Glass fabric	Glass	0,66	kg
	Peel ply	PA	0,01	kg
	Release gant film	PA	0,01	kg
	Drain gate	PE	0,02	kg
	Diadrain	polyester	2,29E-03	kg
	Vacuum bagging film	50%PE/50%PA	0,03	kg
	Sealing material	butyl rubber	0,01	kg
	tubings	PE	0,01	kg
	T connectors	PP	1,79E-03	kg
	Spiral net	PE	0,02	kg
	Taps	PE	0,01	kg
	PPE and rags	10% nitrile/90% PE	0,07	kg
PACKAGING OF RAW MATERIALS AN CONSUMABLES	Epoxy	Metallic drum	0,31	kg
	Core material	Cardboard	0,01	kg
	Glass fabric	Pallet	0,07	kg
	Peel ply	Pallet	1,45E-03	kg
	Release gant film	Pallet	1,23E-03	kg
	Drain gate	Pallet	2,01E-03	kg
	Diadrain	Pallet	6,87E-05	kg
	Vacuum bagging film	Pallet	3,04E-03	kg
	Sealing material	Cardboard	1,80E-04	kg
	tubings	Cardboard	2,88E-04	kg
	T connectors	Cardboard	5,36E-05	kg
	Spiral net	Cardboard	4,70E-04	kg
	Taps	Cardboard	1,85E-04	kg
	PPE and rags	Cardboard	2,10E-03	kg
FREIGHT	Raw materials and consumables	road freight	0,00E+00	ton.km
	Raw materials and consumables	seafreight	0,00E+00	ton.km
BOAT HULL PRODUCTION	Electricity	medium voltage, France	1,95	kWh
	Natural gas	natural gas	3,91	kWh
	Factory	plastic factory	1,00E-09	unit
	Elium wastes	incineration with energy recovery	0,03	kg
	Composites wastes	incineration with energy recovery	0,09	kg
	Freight for composites wastes	road freight	0,01	ton.km
	Freight for wastes (w/o composites)	road freight	0,01	ton.km
	Wastes consumables	incineration with energy recovery	0,12	kg
	Wastes EPI	incineration with energy recovery	0,07	kg
	Wastes fabric	landfilling	0,06	kg

	Wastes Core material	incineration with energy recovery	0,04	kg
EOL	Freight	road freight	0,05	ton.km
	EOL core material	landfilling	0,20	kg
	EOL composite	landfilling	0,80	kg