2022

GUIDE FOR THE RECYCLING AND ECODESIGN OF COMPOSITES (GREC)

GREC HANDBOOK

Institut Français du Textile et de l'Habillement

Financé par

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Context

The project of releasing the **Guide for the Recycling and Ecodesign of Composites** (GREC) is the result of a joint reflection initiated by the three French Industrial Technical Centres which are active in the field of Composites, namely CETIM (the French R&D centre for the mechanical industries), IFTH (the French textile and clothing institute) and IPC (the French R&D centre for plastic engineering and composites). With their respective experience with manufacturers of the sector, these technical centres noticed the following:

> An increase in the regulatory pressure governing the end of life of consumer products, objects and goods. For example, the "Order of 22 June 2020 amending the requirements for power-generating facilities using the mechanical energy of the wind", whose article 20 requires that "after 1st January 2024, 95% of [the total weight of a wind turbine shall be] reusable or recyclable".

> The need to take into account the end of life of composite products in the development of new materials and new manufacturing processes and in the design of parts.

> The will of composite manufacturers to carry out their activities in a circular economy perspective and minimise all negative externalities related to their production and the use of their products.

> Strong demand from the French State for joint work on the subject of composites.

Therefore, the initiative of this project, steered by IPC, is shared by the three industrial technical centres that are active in the field of composites.

For the first time, CETIM, IFTH and IPC have decided to collaborate closely in order to jointly help all industrial manufacturers that use this class of materials.

"Composites are light and strong materials and a low-carbon asset for various sectors such as mobility, energy or building construction. Their sustained growth comes along with an ever-increasing production of waste which will have to be recycled and this constitutes a real challenge for materials which are reputedly difficult to recycle.
The Guide for the Recycling and Ecodesign of Composites was published at the right moment. It will speed up the circular economy approach within the composites industry, which is fully committed to this topic."

Jean MARTIN, Chief Executive Officer of Polyvia

"With their unique properties, composites have become essential materials for the leisure marine industry and provide pleasure boats with an exceptionally long service life. The French leisure marine industry has implemented the world's first end-of-life boat dismantling channel as part of the Extended Producer Responsibility (EPR) and is now firmly committed to a circular economy approach. We are proud to have been able to actively take part in the production of this guide, which constitutes an invaluable basis for the emergence of individual and collective ecodesign and recycling solutions."

Jean-Paul Chapeleau, Chairman of FIN (French federation of leisure marine industries)

"IPC's objective is to help our industrial manufacturers improve their competitiveness on international markets thanks to environmentally-friendly, ecodesigned and lighter products which also have a strong added value: innovative, connected and "smart". This Guide for the Recycling and Ecodesign of Composites is a first significant step in the implementation of solutions to the technical challenges of composite recycling that meet the applicable economic and regulatory constraints. I am confident that IPC teams and our partners have all the necessary skills to provide very concrete solutions to our industrial manufacturers."

Etienne Bechet de Balan, Chairman of IPC

"The ability to offer a comprehensive approach that integrates all environmental aspects is a major challenge for the development of the French industry in the years to come, as well as an essential lever for the reshoring of our production resources. The ecodesign approach and tools must enable composites to achieve the expected gains regarding structural weight reduction and the improvement of the energy efficiency of systems while ensuring consistency with the defined objectives of reduction of their own impacts."

Daniel Richet, Chief Executive Officer of CETIM

"Composites offer a considerable field of innovation to provide solutions to companies and meet the challenges related to climate change and sustainable development. This guide, prepared jointly by IFTH, CETIM, IPC, ADEME, Polyvia and APER/FIN, allows industrial manufacturers to commit to an ecodesign approach which has to be structuring and disseminated throughout all organisations. This guide also provides answers to acute problems pertaining to recycling. It is a great collaboration for the benefit of our industrial sectors and companies."

Clarisse Reille, Chief Executive Officer of IFTH

THE INTEREST OF COMBINING RECYCLING AND ECODESIGN

In the fight against climate change, all industrial manufacturers are striving to offer solutions for a low-carbon industry. Among the levers being considered are weight reduction and product lifetime extension.

In this respect, **composites offer considerable advantages**: their excellent mechanical properties and unique lightness make them particularly interesting for the design of vehicles (trains, aircraft, cars, boats), renewable energy sources (wind turbines, marine energy), buildings (panels, tubes, shells), sporting and recreational goods and consumer goods.

Composites have also become crucial in the energy transition: for example, without these materials, it is not possible nowadays to develop low-carbon technologies for hydrogen-powered transport or to build wind turbines.

However, the environmental benefits of composites conflict with the impact of their end-of-life management, which mainly leads to energy recovery or landfilling. Therefore, this end of life must be reconsidered right from the design phase, in the light of the diversity of other existing solutions: **reuse**, **repurposing** and **recycling**.

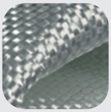
Thus, companies are developing new business models which reduce the environmental impact. Driven by the growing desire of industrial manufacturers to engage in a circular economy process, **IFTH**, **CETIM** and **IPC** have joined forces to provide assistance with this process.

1 WHAT ARE COMPOSITES?

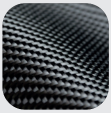
In the absence of a specific regulatory definition, composite materials can be described as follows: “solid products made up of a combination of at least two distinct phases containing a binding material (the matrix) and a material in particulate or fibrous form.”

WHAT ARE COMPOSITES MADE OF?

MAJOR FIBRES



Glass fibres
More than 85% of the composite volumes produced



Carbon fibres
associated to more than 70% with epoxy resins

Natural fibres
Wood, flax, hemp, etc.

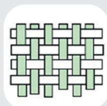
Aramid fibres
(Kevlar)

Basalt fibres

MAJOR ARCHITECTURES

Mats / Cut fibres

Unidirectional **fabrics**



Multiaxial fabrics
taffeta, twill weave fabric, satin weave fabric, etc.

MAJOR MATRICES

Thermosetting (TS) matrices	Thermoplastic (TP) matrices
Polyester	Polyamide
Vinylester	Polypropylene
Epoxy	PEEK
Polyurethane	PPS
Phenolic	PEI
Resins which harden during the manufacturing process and become infusible and insoluble (at least 70% of the composites produced)	Resins which can be processed several times

COST AND PERFORMANCE: SELECTION CRITERIA

The cost and performance of composites vary from one resin to another.

FAMILY	RESIN TYPE	HEAT RESISTANCE (MAX. CONTINUOUS)	CHEMICAL RESISTANCE	PRICE OF THE RESIN, ORDER OF MAGNITUDE, YEAR 2017
Thermoset	Standard polyester	80 °C	Low to medium	€ 2 to 4 per kg
Thermoset	Vinylester	100 to 140°C	Very good	€ 4 to 8 per kg
Thermoset	Epoxy	120 to 200°C	Very good	€ 6 to 15 per kg (>15: aerospace resin)
Thermoset	Polyimide	200 to 300°C	Good	> € 50 per kg
Thermoplastic	Polypropylene	80°C	Excellent	1
Thermoplastic	Polyurethane TP	80°C	Medium	4
Thermoplastic	Polyamide 12	110°C	Good	5
TThermoplastic	Polyamide 6 et 66	150°C	Good (but sensitive to moisture)	3
Thermoplastic	PEI	180°C	Medium	15
Thermoplastic	PPS	200°C	Good	9
Thermoplastic	PEEK	300°C	Very good	> 40

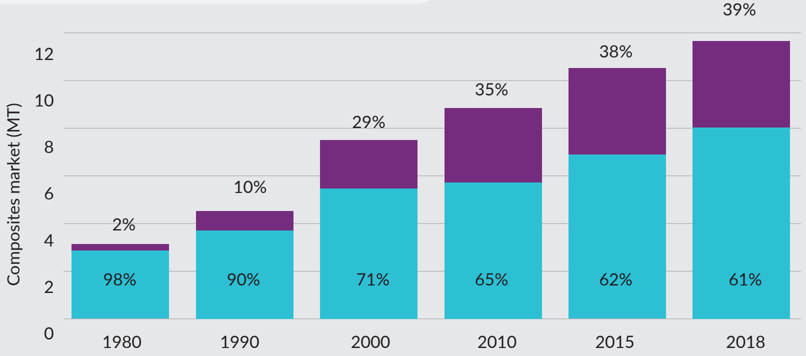
ORIGIN	FIBRE TYPE	MODULUS OF ELASTICITY GPa	ULTIMATE STRENGTH MPa	ELONGATION %	FIBRE DENSITY g/cm3	PRICE RANGE EUR/KG
Petroleum-based	Glass E	73	2500	4	2.54	2
Petroleum-based	High-strength carbon	>230	>3500	1.5	1.80	15 - 25
Petroleum-based	High modu-lus carbon	>350	>2500	0,5	1.85	>100
Petroleum-based	Aramid	124	>2500	2.5	1.45	15 - 20
Biosourced	Hemp	70	550 - 900	1.6	1.4 - 1.6	-
Biosourced	Flax	30-80	345 - 1500	1.2 - 3.2	1.4 - 1.5	6 - 10

A FEW REFERENCE MARKS ON THE COMPOSITES MARKET

In 2019, the size of the **global composites market** is estimated to **USD 89 billion**. Before the health crisis, a yearly growth rate of +**7.6%** was considered for the period 2020 to 2027.

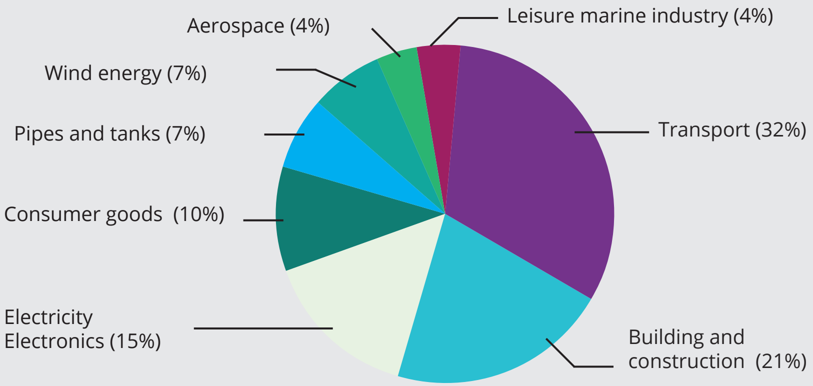
Evolution of the market shares of thermoplastic materials between 1980 and 2018

Credit: CETIM



A survey published by **JEC Group** in 2017 *[1]*, breaks down the global composites market into eight major segments: transport, building and construction, electricity and electronics, consumer goods, pipes and tanks, wind energy, aerospace and leisure marine industry.

Market shares per segment [2]



These figures are subject to change depending on the sources.

2 RECOVERING USED COMPOSITES: FROM WHICH SOURCES?

Based on cross-checked data stemming from various surveys, it is possible to estimate the sources of composite waste for the period 2022 – 2040 and to identify the main obstacles to the recycling of composites.

Among the sectors with high potential sources:

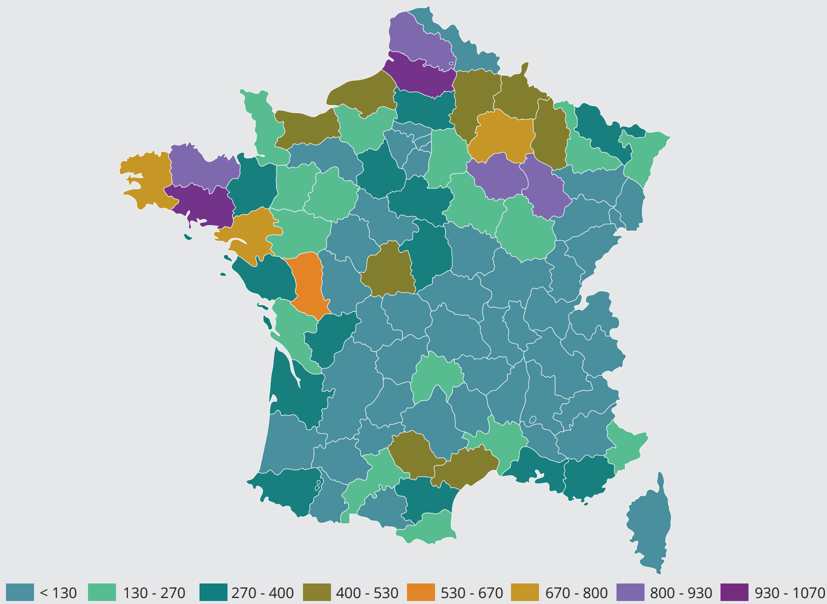
> Recreational boating
> Industrial waste
> Wind turbines
> Sporting and recreational goods (SRG)
> Heavy vehicles
> Aerospace

FOCUS: the aerospace market...

The aerospace market is of great interest, as this sector is structured over the entire territory and presents a source of composites mainly made up of carbon fibres.

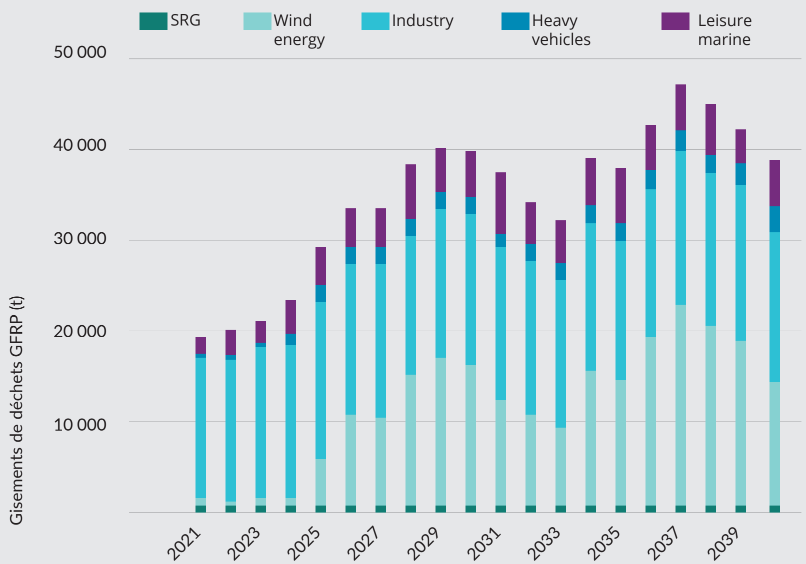
Its growth for the next few years is estimated to 7,800 metric tons in 2050 (compared to 4,100 metric tons in 2015). The European source is an opportunity for the French market which is expected to be shared among a limited number of European players, among which Tarmac Aerosave, the European leader in aircraft storage and the world leader in aircraft and engine dismantling and reclamation, whose shareholders are Airbus (33.6%), Safran (32.8%) and Suez (33.6%).

Source of post-consumer glass fibre composites (GFRP) in 2021, excluding the aerospace sector (metric tons)



Data extracted from the Guide for the Recycling and Ecodesign of Composites – Technical Report

Source of composite waste on the French national scale, excluding the aerospace sector



Data extracted from the Guide for the Recycling and Ecodesign of Composites – Technical Report

3 WASTE COMPOSITE RECOVERY OPPORTUNITIES

TECHNOLOGY	ADVANTAGES	LIMITS	COST INDICATION[1]
Reuse	• Use of the whole composite	• Cost of transport for large sized parts	Variable, depending on the application
Repurposing	• Possibility to recover the whole composite • Wide range of uses for non-consolidated products	• Need to integrate additional steps for the transformation of the composite or the material • Solution often restricted to niche applications	Variable, depending on the application
Mechanical recycling	• Low cost of implementation • Complete recycling of the composite • Versatile process • Large quantities of materials can be treated	• Deterioration of the mechanical properties of the fibres • Limited product recovery • High competition with natural fillers (in the case of TS composites)	Less than € 4.5 per kg [1]
Thermal recycling	• Process compatible for the treatment of multi-material assemblies • Possibility to recycle all the generated products and by-products • Advantageous process for the treatment of carbon fibres (preservation of the integrity and properties of the fibres) • Possibility to recover pyrolysis oils for energy recovery or material recovery • The energy cost of treatment is less than the cost of manufacture of virgin fibres	• Cost of implementation • Production of gases (CO and CO2) • Deterioration of the properties of glass fibres	Approximately € 11 to 17 per kg [1]
Chemical recycling	• Preservation of the working mechanical properties and the length of the treated fibres, thereby allowing their recovery (for carbon fibres) • Advantageous process for the treatment of carbon fibres (preservation of the integrity and properties of the fibres) • Possibility to recover the generated products and by-products • The energy cost of treatment is less than the cost of manufacture of virgin fibres	• Cost of implementation • Use of solvents that can involve toxicity risks and require end-of-life management • Deterioration of the properties of glass fibres	Approximately € 11 to 17 per kg [1]
Energy recovery	• Low cost of implementation • Complete waste management of the composite • Possible recovery of all the generated products (ashes and fibres)	• Production of gases (CO and CO2) • Poor lower heating value of the composites • Premature wear of crushers due to the abrasive nature of glass fibres	€ 0.16 per kg
Storage	• Low landfilling cost	• Environmental pollution • Progressive ban on the storage of plastic materials • An increase in the costs of storage and the General tax on polluting activities is to be expected	€ 0.12 to 0.18 per kg (taxes included)

1- The amounts indicated in this table are extracted from a publication issued in JEC Observer.
They stem from estimations and make it possible to assess the relative attractiveness of the different solutions.

The energy cost of the processes is both an indicator of the environmental impact of the composites recovery solutions and an economic indicator. The comparison is made between a recovery solution and the manufacture of a virgin fibre.

FIBRE IN QUESTION	PROCESS	ENERGY COST (MJ/KG)	SOURCES
Carbone	Manufacture	200 - 600	[3] [4]
	Mechanical recycling	0,3 - 2	[5]
	Pyrolysis	3 - 30	[6] [7]
	Solvolysis	19,2	[8]
	Fluidised bed	7,7	[9]
Glass	Manufacture	14 - 35	[1]

Energy cost required to obtain carbon fibres with different recycling or manufacturing techniques

WASTE MANAGEMENT: UNDERSTANDING THE REGULATIONS...

The “waste” framework directive No. 2008/98/EC of 19 November 2008 establishes a legislative framework for the handling of waste in the European Community. It also gives basic concepts and definitions for the management of waste and develops a principle called “Extended Producer Responsibility” (EPR).

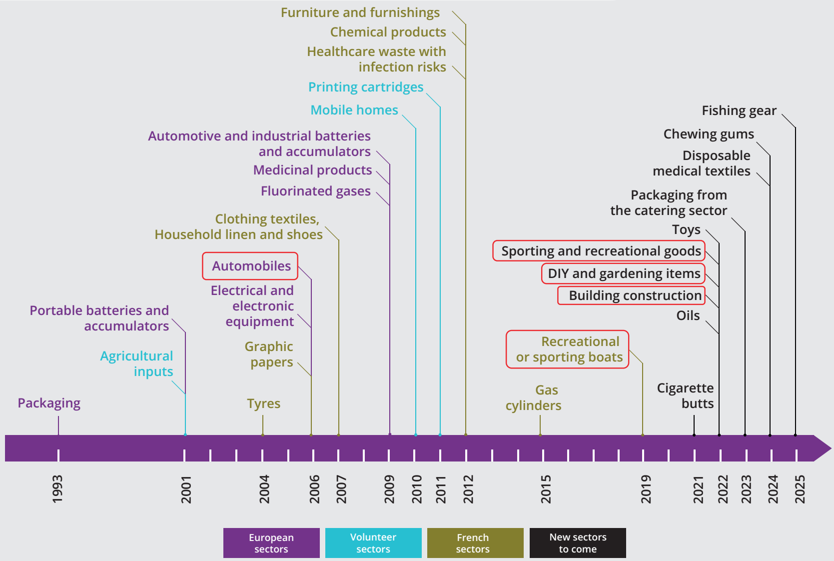
In France, more and more industrial sectors using composites are subject to EPRs. Undertakings placing products on the markets are considered responsible for the entire life cycle of a product, from its design to its end of life. In France, the AGEC law (anti-waste law for a circular economy) (2020) initiates an acceleration of the change in the production and consumption model in order to limit waste and preserve resources. It deeply transforms the organisation system of EPR channels: the purpose is no longer solely to handle the generated waste but first to prevent it.

Waste management regulatory hierarchy [2]

The objectives set for the different EPRs are as follows:

- Save resources by **developing the recycling** of some types of waste and increase the recycling performance of this waste
- Relieve local authorities of all or part of the waste management costs and **transfer financing from tax payers to consumers**
- Include in the selling price of a new product the costs of managing this product once used, in order to encourage manufacturers to **commit to an ecodesign approach**
- **Extend the lifetime of a product**, by promoting product ecodesign, repair and reuse

French EPR channel and date of operational implementation
In red, the sectors where composites are present [10]



TECHNICAL SOLUTIONS

CASE STUDIES

TECHNICAL SOLUTIONS

Here, by “technical solution”, we mean a technology available on the market for the recycling of composites.

The case studies will allow you to assess the different technical solutions adopted and to see what the following terms precisely mean, with regard to the legislation:

> **REUSE**

> **REPURPOSING**

> **RECYCLING**

- Mechanical recycling
- Thermal recycling
- Chemical recycling

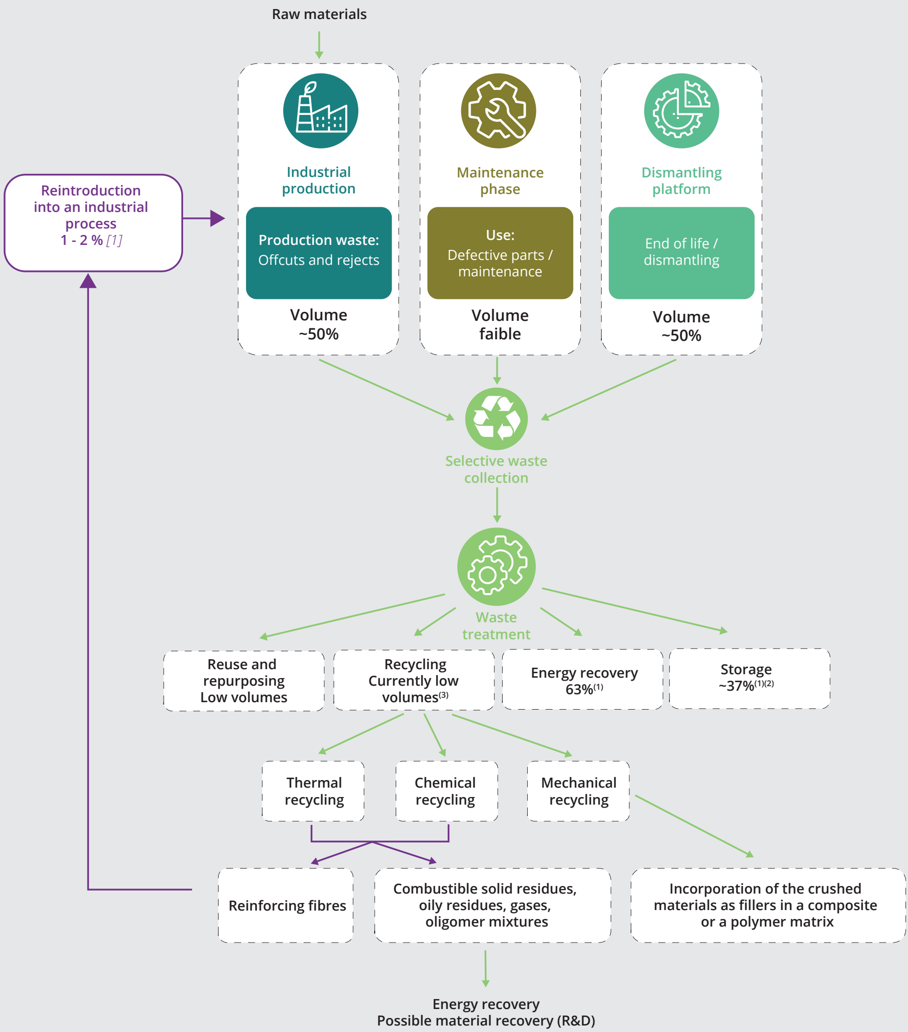
> **ENERGY RECOVERY**

- Solid Recovered Fuel (SRF)
- Incineration

> **STORAGE**




The life cycle of composites



(1) Based on the feedback from the leisure marine sector
(2) The gradual cessation of storage will progressively make landfilling of composites impossible
(3) Recycling: The volumes are low but the potential for development is high, driven by changes in the legislation

3.1 TECHNICAL SOLUTION REUSE

WHAT THE LAW SAYS

Article L. 541-1-1 of the French Environmental Code states that reuse refers to “any operation by which substances, materials or products that are not waste are used again for a purpose identical to that for which they were designed”.

Reuse is undoubtedly the most virtuous solution to allow a product to keep a similar use and avoid reclassification as waste. This is the first and simplest solution for the end-of-life management of composites.

For example, the reuse of wind turbines is now very common practice, in particular when structures are replaced for economic reasons (end of the subsidy scheme, end of the operating licence, maintenance cost, etc.). Thus, after many quality and safety checks, the life of wind turbine blades can be extended with a new period of service on a second-hand market.

The concept of reuse can also be applied in the context of the use of joint products which may stem from production offcuts or rejects. In this context, various French companies, such as Lavoisier Composites, reuse composite co-products that come from the European aerospace sector to manufacture new materials for various sectors, among which the luxury watchmaking industry. Similarly, to manufacture sport blades, the Hopper start-up reuses carbon fibre-based semi-finished products that come from the A350 aircraft production lines and were initially intended to be scrapped.

Examples of reuse of composite semi-finished products by Lavoisier Composites (right) and Hopper (left)

CASE STUDY

COMPANY: APPLY CARBON	MATERIALS: CFRP
Market(s): Automobile, coating, renfort cimentaire, impression 3D, textiles techniques	**Maturity:** Industrial scale TRL 9 **Production:** Up to 2,000 metric tons of fibres per year
Concept: Apply Carbon specialises in precision cutting and milling of technical fibres (carbon and aramid) but also offers a range of oversized fibres used as reinforcement material in thermoplastics. **Processed input materials:** Dry carbon/aramid fibres. Apply Carbon directly collects carbon residues from manufacturers and users of materials and fabrics. **Products sold:** Milled fibres (75 to 300 µm), cut fibres (300 µm to 120 mm), oversized and cut fibres (6 mm).	APPLY CARBON by Procotex

Business model: Apply Carbon's business model is based on the collection of raw materials and industrial waste and their reclamation by milling and cutting. With a production capacity of more than 1,000 metric tons of milled carbon per year, Apply Carbon remains extremely competitive thanks to controlled production costs.

Environmental impact reduction: Les techniques de broyage et découpe permettent de proposer des solutions en matière de déchets industriels et de déchets de carbone en fin de vie. Par ailleurs, l'utilisation de fibres de carbone recyclées vis-à-vis de fibres de premier choix tend à diminuer l'empreinte carbone des matériaux.

Contact: contact@apply-carbon.fr, +33 (0)2 97 65 10 89

CASE STUDY

COMPANY: HOPPER

MATERIALS: CFRP / GFRP

Market(s): Disability sports

Maturity: Commercial TRL 9

Reused volume: Currently 350 kg per year

Concept: Hopper reuses carbon fibre-based semi-finished products from the A350 aircraft production lines that were initially intended to be scrapped, to manufacture sport blades.

Processed input materials: Ends of carbon fibre-based and glass fibre-based (to a lesser extent) thermosetting prepreg rolls.

Products sold: Sport blades, available by spring 2022.

Business model: Hopper's objective is to promote innovation and sustainability by offering low-cost high-performance solutions to make sports and mobility accessible to everyone.

Environmental impact reduction: By reusing pre-impregnated semi-finished products, Hopper limits the disposal and storage of high value-added materials whose potential for use as composite structures remains intact.

Contact: direction@hopper-accessibility.com

CASE STUDY

COMPANY: LAVOISIER COMPOSITES

MATERIALS: CFRP

Market(s): Appearance parts (luxury, hi fi, automobile, aerospace) and structural parts.

Maturity: Available technology

Production capacity: Series > 15,000 pcs as from 2022

Concept: Lavoisier Composites develops composite parts from by-products of the composites sector. Lavoisier Composites controls the whole manufacturing chain: design, process and implementation for the supply of moulded parts.

Processed materials: By-products of thermoset prepregs (not cross-linked) and thermoplastics with traceability.

Products sold: Development and manufacture of composite parts with high mechanical properties and environmental performance for appearance and structural applications.

Business model: Lavoisier Composites creates value by selecting and transforming by-products into high value-added parts. The acquisition of production equipment suited to intermediate-sized series will allow Lavoisier Composites to remain competitive with titanium and aluminium machining processes.

Environmental impact reduction: The use of by-product based materials such as Carbonium® allows for an environmental impact reduction of 40 to 50% compared to equivalent materials made from virgin raw materials.

Contact: bonjour@lavoisier-composites.com, +33 (0)4 81 68 11 67

3.2 TECHNICAL SOLUTION
REPURPOSING

WHAT THE LAW SAYS

From a regulatory standpoint, repurposing is identified as “any operation by which substances, materials or products that have become waste are used again”.

Repurposing is also one of the most virtuous ways of reclaiming materials classified as waste.

In this context, it is thus possible to find various materials and composites made from end-of-life parts whose structure can be readapted for other applications.

CASE STUDY

COMPANY: BATHÔ

MATERIALS: GFRP

Market(s): Tourism, private individuals, companies, shops, communities

Maturity: 25 boats/year; 100 boats in 2023

Concept: Circular economy of composite waste through reuse, with the ability to create an ecosystem of partners (communities, industrial manufacturers, etc.).

Processed input materials: Boats, 6 to 16 meters long, made of fibre-reinforced polyester.

Products sold: Unusual land-based lodges and accommodations called "Bathôs" (boat hotels), business meeting rooms, children's playgrounds.

Business model: 70% of labour costs (in combination with a training activity). Social and Solidarity Economy status (Économie Sociale et Solidaire). Business model based on the sale of Bathôs, with work in progress to sell a use (functional economy).

Environmental impact reduction: Saving of resources for the manufacture of unusual accommodations whose walls, roofs and functions already exist. Avoids the destruction of a non-recyclable material. No impact of construction on the ground.

Contact: contact@batho.fr, +33 (0)2 40 40 20 12

CASE STUDY

COMPANY: RECYCLING-CARBON

MATERIALS: CFRP

Market(s): All markets – focused on carbon fibre

Maturity: Variable, depending on the maturity of the customer's project

Concept: The offered solutions are technical and economic feasibility analyses that are specific to each customer and are based on one of the 4 following pillars: ecodesign; repair; upcycling and recycling.

Processed materials: The materials proposed as input are customer products which have reached their end of life, production scraps or after-sales returns, made of carbon fibres only.

Products sold: Feasibility analysis, for example:

- Reuse for the structure of a drone
- Cargo bike made from production scraps

Business model: Recycling-Carbon is a non-profit association. It also offers consulting services. Several consultants are active in Recycling-Carbon's ecosystem.

Environmental impact reduction: The reduction of the environmental impact is at the heart of Recycling-Carbon's action. The 4 pillars of the association are all geared towards circular economy.

Contact: contact@recycling-carbon.org

3.3 TECHNICAL SOLUTION
RECYCLING

WHAT THE LAW SAYS

Article L. 541-1-1 of the French Environmental Code defines recycling by "any recovery operations by which waste, including organic waste, is reprocessed into substances, materials or products for the purposes of its initial function or for other purposes. Waste energy recovery operations, waste-to-fuel operations and landfilling operations cannot be qualified as recycling operations".

The recycling of fibre-reinforced composites can be achieved in different ways, particularly in terms of processes and technologies.

Therefore, several treatment channels are accessible, among which the mechanical, thermal and chemical processes are the most advanced in terms of technological maturity.

The choice of the recycling method will thus depend on the nature of the different components of the composite, whether the matrix (thermoplastic or thermoset), the reinforcement (glass, carbon or other fibres) or the targeted application for the use of the recyclate.

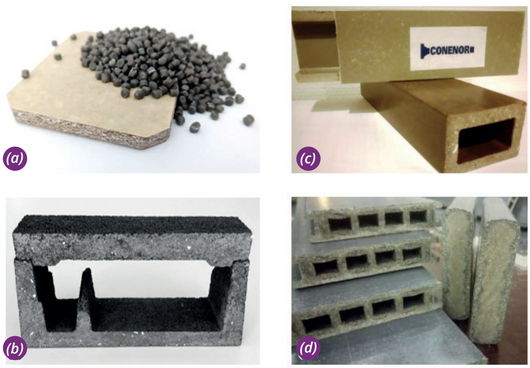
MECHANICAL RECYCLING

Mechanical recycling is potentially the most economical method of treatment of composites because it makes it possible to recycle the whole treated composite. The treatment process usually involves an initial phase to reduce the size of the composite waste. The main phase is then carried out in a high speed mill in which the composite is chopped into smaller pieces typically ranging from 10 mm to micronized particles less than 50 µm in size.

This phase is most often followed by two additional steps: the first one is aimed at recovering large-sized pieces while the second step is aimed at refining the particle size according to the intended use. A final sieving operation then allows the obtained recyclate to be broken down into batches of different sizes. Various studies have shown that the recyclates obtained from composites (glass fibres and polyester resin) could be used in thermoplastic composites that had final mechanical properties comparable to those of a virgin glass fibre reinforcement *[11]*, *[12]*.

Similarly, recyclates in the form of shreds have been used in open loop in the building construction and civil engineering sectors, but also in the automotive industry in the form of fillers in non-structural parts *[13]*.

Several European companies, such as Reprocover (Belgium) and Conenor (Finland), as well as the US-based company Global Fiberglass Solutions, have specialised in the recycling of glass fibre-reinforced composites, mainly using a technique which consists in grinding then reincorporating the material into a thermoset or thermoplastic polymer matrix.



Example of products containing waste from glass fibre-reinforced thermoset composites.

Credits: (a) Global Fiberglass solutions ; (b) Reprocover ; (c-d) Conenor.

CASE STUDY

COMPANY: FAIRMAT	MATERIALS: CFRP
Market(s): New mobilities, office furniture and layout, electronic consumer goods	**Maturity:** Technology available in March 2022 with a capacity of 5,000 metric tons/year

Concept: Fairmat uses a mechanical process for recycling thermoset or thermoplastic carbon fibre composites. The waste is transformed into chips and then consolidated in the form of laminates with a polymer binder. The process is energy efficient and preserves at least 55% of the performance of the recycled composite.

Processed input materials: Carbon fibre-based composites in the form of raw or baked prepregs, consolidated semi-finished products or finished parts.

Products sold: Sale of products containing recycled composite material in the form of laminates and sale of chips.

Business model: Fairmat's business model is based on the collection of composite waste and its recovery through mechanical cutting and reincorporation to manufacture laminates.

Environmental impact reduction: Fairmat's recycling process has a limited impact estimated to less than 41 kg of CO2 per kg of recycled material. Fairmat wishes to use as little energy as possible in order to reduce the environmental impact of the products placed on the market.

Contact: sales@fairmat.tech

THERMAL RECYCLING

The purpose of the pyrolysis-based **thermal treatment** method is to retrieve the reinforcing fibres by thermally breaking down and degrading the polymer chains of the organic matrix in an anoxic chamber, at temperatures of 300 to 800°C for several hours.

At the end of the treatment, the matrix is usually recovered in the form of oil, gas or solid carbon products. These components can then be reused as input materials for other chemical processes or simply as an energy source.

In the case of the treatment of glass fibre-reinforced composites, losses of tensile strength of approximately 50% have been noticed after treatment *[14]*. Conversely, in the case of the treatment of carbon fibres, various studies have shown that the mechanical properties of the recycled fibres could, under optimum conditions, retain up to more than 95% of the tensile strength and feature a surface condition without resin residues *[15]*.

CHEMICAL RECYCLING

Chemical recycling, also called “solvolysis”, is mainly used with thermoset composites. Its principle consists in breaking down the organic portion of the composite by depolymerisation and thus releasing the fibres from their polymer matrix. In this recycling channel, water appears as the most widely used solvent (usually at the supercritical point). Other solvents with lower temperature and critical pressure, such as ethanol, methanol, propanol or acetone, can also be used either alone or in a mixture with water in order to moderate the operating conditions.

Glass fibres have a low commercial value and appear to be fragile when exposed to thermal, acid and alkaline conditions. As a consequence, few studies have focused on the processing of glass fibres. However, the literature tends to demonstrate that the chemical treatment method seems to significantly affect the mechanical properties of the glass fibres, with decreases in tensile strength ranging between 35 and 65% depending on the applied temperature *[16]*. For these materials, R&D work is currently underway to develop a chemical recycling process under “soft” conditions, such as the CETEC project steered by Vestas or the ZEBRA project steered by IRT Jules Verne. Regarding carbon fibre, chemical recycling makes it possible to retrieve fibres of variable length with a surface topology almost identical to that of virgin fibres.

Many studies have shown that post-treatment carbon fibres retain approximately 95% of their mechanical properties compared to those of a virgin fibre *[17]*.

CASE STUDY

COMPANY: EXTRACTHIVE

MATERIALS: CFRP

Market(s): Sports and leisure – Transport

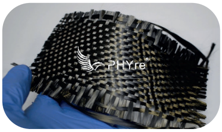
Maturity: Pilot TRL 6 / TRL 8-9 in 2023

Treatment capacity: 340 metric tons per year in late 2023

Concept: Extracthive offers a technology for the treatment of thermoset and thermoplastic composite materials based on the solvolysis process. This technology, named PHYre, is an innovative solution which relies on the use of solvents at moderate temperature (typically below 200°C). The combined action of solvents in "vapour phase" makes it possible to recover carbon fibres without altering their mechanical properties.

Processed input materials: Thermoset composite materials and a few thermoplastic composite materials, reinforced with carbon fibres of any size (long or short fibres, etc.).

Products sold: Extracthive is actively working with many partners on the development of a range of products in order to prepare the introduction on the market of its recycled fibres, scheduled for 2023.



Business model: Extracthive intends to market its recycled carbon fibres between € 6 and 10 per kg.

Environmental impact reduction: The PHYre recycling technology has a low environmental impact, especially with a CO_2 footprint ten times smaller than that of the production of virgin fibres. As a matter of fact, thanks to a solvent regeneration system, PHYre makes it possible to recycle up to 90% of the chemicals used during the process.

Contact: info@extracthive.eu, +33 (0)7 48 88 26 90

CASE STUDY

COMPANY: ALPHA RECYCLAGE COMPOSITES (ARC)

MATERIALS: CFRP

Market(s): Leisure marine, automobile, aerospace, wind turbines, sports and leisure

Maturity: Industrial pilot TRL8-9

Treatment capacity: 1 metric ton per day

Concept: ARC specialises in the recovery of recycled carbon fibres thanks to the steam thermolysis technology. This process makes it possible to retrieve clean carbon fibres, with final properties almost equivalent to those of virgin fibres, without the need to use chemicals.

Processed input materials: From sized dry fibres to thermoset composites (machining waste, manufacturing scrap, end-of-life items, dismantling).

Products sold: Bulk fibres: ground fibres, short fibres and long fibres. Semi-finished products: mats, 200 to 500 gsm, made of recycled carbon fibres, possibly commingled.

Business model: ARC offers services ranging from the preliminary treatment study in laboratory to the marketing of semi-finished products. ARC intends to be competitive with respect to the treatment solutions and to remain competitive with respect to products reinforced with virgin carbon fibres.

Environmental impact reduction: The manufacture of 1 kg of recycled carbon fibres consumes less energy (by a factor of 6 to 15) than the manufacture of virgin carbon fibres and generates smaller amounts of greenhouse gases.

Contact: l.pech@alpharecyclage.com, +33 (0)5 62 16 72 82

3.4 TECHNICAL SOLUTION
ENERGY RECOVERY

WHAT THE LAW SAYS

Article L. 541-1-1 of the French Environmental Code defines energy recovery as: “any operation whose main result is that waste is used for a useful purpose in substitution for other substances, materials or products which would have been used for a particular purpose, or that waste is prepared to be used for that purpose, including by the waste producer”.

SOLID RECOVERED FUEL (SRF)

Solid Recovered Fuel (SRF) is a generic term which covers any type of non hazardous solid waste, not made up of biomass only, and whose heating value is sufficiently high to be of interest for recovery by combustion, as a substitute for fossil fuels.

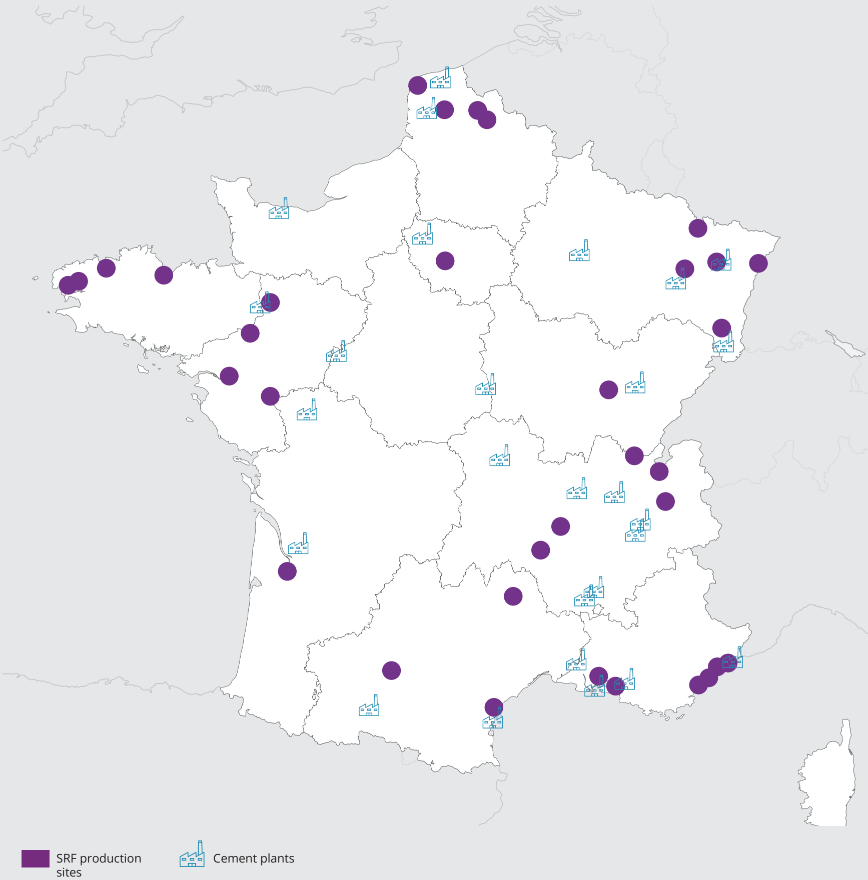
The main difference between SRFs and incineration is the quality of the product generated in order to meet customer requirements which require sorting/quality control during production (e.g.: a preliminary sorting phase to remove any PVC still present, in order to maintain stable production in terms of Lower heating Value (LHV)).

France is currently producing 400,000 metric tons of SRF per year and aims at a national production capacity of 2.5 million metric tons by 2025.

Holders of composite waste, if they wish to recover their waste in a cement plant, must contact an SRF processor (see the table extracted from *[18]*). This SRF processor is in charge of generating a fuel whose final purpose is mainly to be used in cement plants.

Map of players of the French SRF sector

Credit: IPC



REGION	DEP.	ADDRESS	NAME	COMPANY / OPERATOR
AURA	1	Dortan	SERRAND site	SERRAND
AURA	42	Ricamarie	SERMACO activity platform	SERMACO
AURA	43	Polignac	ALTRIOM eco-hub	3WAYSTE
AURA	73	Chamoux sur Gelon	BIOVAL (formerly SIBUET site)	BIOVAL
AURA	74	Villy-le-Pelloux	Excoffier high-performance sorting centre	EXCOFFIER
BFC	21	Ruffey les Beaume	Beaune site	BOURGOGNE RECYCLAGE
Bretagne	22	Ploufragan	Material sorting, recovery and energy unit	KERVAL
Bretagne	29	Guipavas	St Thudon high-performance sorting centre	RECYCLEURS BRETONS
Bretagne	29	Saint-Martin des-Champs	St Martin site	GUYOT ENVIRONNEMENT
Bretagne	29	Brest	Brest site	GUYOT ENVIRONNEMENT
Grand Est	54	Ludres	Ludres high-performance sorting centre	VEOLIA
Grand Est	57	Heming	Platform integrated to the Heming cement plant	EQIOM
Grand Est	57	Longeville-lès-Saint-Avold	Longeville site	VTB
Grand Est	67	Strasbourg	Bluepaper	Bluepaper
Grand Est	68	Cernay	Cernay Environnement	Cernay Environnement
Haut de France	59	Blaringhem	Material Preparation Centre and SRF manu-facturing	BAUDELET
Haut de France	62	Evin Malmaison	Material sorting, recovery and energy unit	SYMEVAD
Haut de France	62	Calais	Calais sorting centre	OPALE ENVIRONNEMENT (Séché)
Haut de France	62	Billy Berclau	VANHEEDE site	VANHEEDE ENVIRONNEMENT SAS
Ile de France	91	Echarcon	SEMAVAL	SEMARDEL
Normandie	27	Alizay	Alizay unit	NPC
Normandie	76	Oissel	Propreté Nord Normandie (VEOLIA)	VEOLIA
Nouvelle aquitaine	33	Mérignac	CORIS	GROUPE PENA
Occitanie	11	Narbonne	Narbonne eco-hub	GRAND NARBONNE
Occitanie	31	Bruguières	PAPREC Bruières site	PAPREC
Occitanie	48	Mende	Environnement Massif Central site	ENVIRONNEMENT MASSIF CENTRAL
PACA	6	Nice	VALAZUR high-performance sorting centre	VEOLIA
PACA	6	Villeuneuve-Loubet	Villeneuve-Loubet sorting centre	VEOLIA
PACA	6	Cannes la bocca	Organic recovery centre	SMED06
PACA	13	Istres	Provence Valorisation	SUEZ PROVENCE VALORISATION
PACA	13	Gignac-La-Nerthe	Gignac-La-Nerthe plant	EPUR
PACA	83	Fréjus	SOFOVAR DND eco-hub	SCLAVO ENVIRONNEMENT
Pays de la Loire	44	Coueron	High-performance sorting centre of the Arc en Ciel site	NANTES METROPOLE
Pays de la Loire	44	Chateaubriant	Tri OUEST site	BARBAZANGES TRI OUEST
Pays de la Loire	49	Cholet	Cholet sorting centre	BRANGEON RECYCLAGE
Pays de la Loire	53	Changé	Changé multisector hub	SECHE

CASE STUDY

COMPANY: VANHEEDE ENVIRONNEMENT SAS

MATERIALS: GFRP

Market(s): High LHV SRF

Maturity: Production of 140,000 metric tons per year

Concept: Vanheede manages the waste logistic chain as well as the preparation and shipment operations at the customer's.

Processed input materials: Industrial waste generated by economic activities, mainly complex, non-recyclable flexible textile and plastic waste. Preferably flexible products with limited glass fibre content (max. 10%).

Products sold: SRF of cement plant quality with high LHV, in the form of fluff and pellets, for heat production and material recovery (fraction of mineral filler in the cement).

ALTERCOAL®
THE ALTERNATIVE FUEL FOR THE FUTURE

VANHEEDE.COM ENVIRONNEMENT

Business model: The waste collection service is invoiced to the waste generator. Vanheede is charged by the cement producer for reincorporating the SRF. All the waste treatment costs are borne by the waste generator.

Environmental impact reduction: SRF avoids landfilling of non-recyclable industrial waste that meets stringent requirements. In cement plants, high BTU SRF reduces the use of fossil fuels such as carbon or petroleum coke, and makes it possible to recover materials from mineral residues generated during combustion.

Contact: offre.fr@vanheede.com, +33 (0)3 21 18 17 62

INCINERATION

Besides the transformation of materials into SRF, composite waste can be used as substitute fuel in conventional incineration units for energy recovery purposes, as is the case in the management of non-recoverable household waste.

Unlike for SRF, previous waste sorting is not mandatory, thus involving possible variations in the quality of the sources in terms of LHV and composition. As a result, incineration plants must be equipped with filters to capture organic pollutants generated during the combustion of waste, unlike those plants which use SRF.

3.5 TECHNICAL SOLUTION
STORAGE

WHAT THE LAW SAYS

From a regulatory standpoint, in accordance with Article L. 541-1-1 of the French Environmental Code, storage corresponds to: “any operation that is not recovery, even when said operation has as a secondary consequence the retrieval of substances, materials or products or energy”.

Therefore, **storage** is undoubtedly the most unfavourable solution in the waste treatment cycle. If the majority of composite production waste could be stored in Non-Hazardous Waste Storage Facilities (NHWSF), formerly known as “engineered landfills”, these facilities have been authorised, since 2002, to only receive ultimate waste, defined as follows: “resulting or not from the treatment of waste which is no longer likely to be treated under the current technical and economic conditions, in particular by extraction of the recoverable fraction or by the reduction of its polluting or hazardous nature”.

All in all, it has been observed that storage facilities are becoming saturated and that the cost of burial is increasing *[19]*. Moreover, the French AGEC law (anti-waste law for a circular economy) imposes a reduction in the quantity of household and similar waste accepted in storage facilities to 10% in 2035.

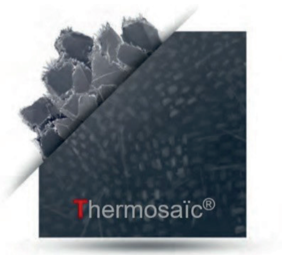
4 INNOVATION: EMERGING TECHNOLOGIES

As opposed to “technical solutions”, technologies still in the process of maturing (under development or close to be placed on the market) may foreshadow the future of composite recycling in Europe.

PROCESSES FOR RECYCLING PRODUCTION OFFCUTS

In response to the manufacturing processes which generate large quantities of waste for which high-performance recovery channels are difficult to find, Cetim Grand Est has developed two green processes for the recovery of plastic and thermoplastic composite waste: the Thermosaïc® and ThermoPRIME® processes.

The Thermosaïc® process makes it possible to agglomerate waste, after sorting and shredding steps, in order to make highly formable panels. Similarly, the ThermoPRIME® process converts the same production waste into high value-added semi-finished products by adding a long or continuous fibre reinforcement.



Semi-finished products (panels) obtained with the Thermosaïc® and ThermoPRIME® processes

LIQUID THERMOPLASTIC RESINS

TO UNDERSTAND

Elium® is an acrylic resin developed by Arkema and placed on the market in 2014. It is a two-component reactive thermoplastic resin whose viscosity at room temperature, approximately 100 to 500 cP, is compatible with the Liquid Composite Moulding (LCM) processes. After curing, this resin has a mechanical behaviour that is very similar to that of PMMA. The low initial viscosity and the thermoplastic nature of this material currently allow the Elium® resin to compete with thermosetting resins in terms of recyclability, implementation and properties.

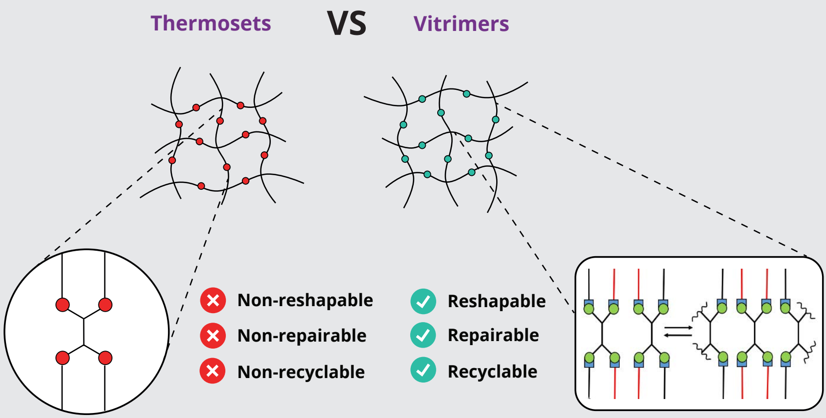
TOWARDS RECYCLABLE THERMOSETTING RESINS

TO UNDERSTAND

The three-dimensional networks formed during the curing of thermoset matrices are usually qualified as permanent; that is to say that the systems obtained can neither be melted nor solubilised. It is this particular characteristic of thermoset matrices which makes composites so difficult to recycle. In order to solve this problem, a new class of polymers has been developed, named "vitrimers". Therefore, during the curing phase, these systems have the particularity of forming crosslinks which, unlike conventional thermoset structures, have the ability to dissociate and recombine under the effect of a simple increase in temperature.

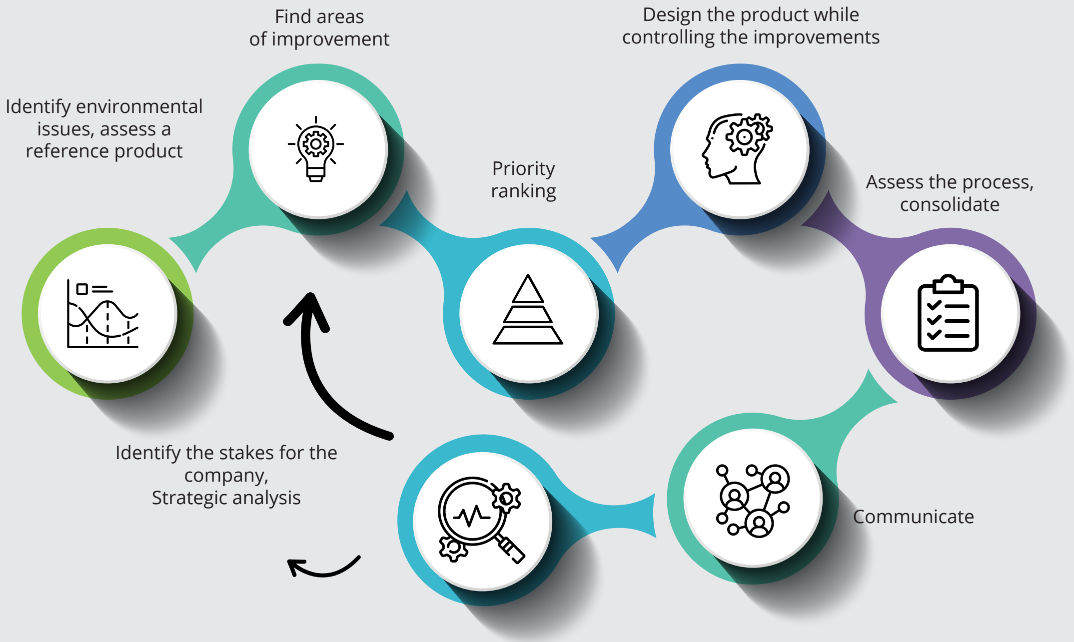
This reversible feature allows vitrimers to significantly decrease their viscosity when they are subjected to a temperature rise and, therefore, to have properties similar to those of thermoplastic polymers. Thus, vitrimers feature the strength and resistance properties specific to thermoset matrices as well as the reshapability potential specific to thermoplastics, thereby allowing a certain level of material recyclability.

Illustration of the difference between crosslinks obtained from a conventional thermoset matrix and a vitrimer matrix [20]



Similarly, one can note the rise of new commercially available thermosetting resins in which the chemical composition of the hardeners has been changed to facilitate chemical recycling with an energy-efficient process. Technical solutions currently exist on an industrial scale and they are offered by international companies such as Aditya Birla/Connora Technologies or Adesso Materials.

General course of
an eco-design approach



5 INITIATING A COMPOSITES ECODESIGN PROCESS

Ecodesign is an approach which consists in taking into account the environmental criteria in the design and development of new or existing products, for the purpose of reducing negative environmental impacts throughout the product's life cycle. It is governed by standard ISO 14006:2020.

This approach must be:

- **Multi-criteria:** Integration of all potential environmental impact.
- **Multi-stage:** Integration of all the steps of the product's life cycle, from the extraction of raw materials ("cradle") to the end of the product's life ("grave"), and including the manufacturing stage (factory "exit"), distribution and use.
- **Multi-player:** Raising the awareness of the whole product development team to ecodesign in order to apply all its principles.

The integration of ecodesign allows companies to meet the increasingly stringent regulatory and market requirements and can also generate economic gains through an increase in the perceived value of the product or through optimised design.

RELYING ON LCAs OR SIMPLIFIED LCAs

The Life Cycle Assessment (LCA) makes it possible, based on quantitative criteria, to assess the environmental impacts of a process. It relies on the following steps:

- Definition of the scope of the study (functional unit) and the extent of the life cycle (boundaries)
- Inventory of the necessary inputs (energies, raw materials, etc.) and outputs ($CO2$, water, heat, etc.) over the entire life cycle
- Assessment of impacts via recognised and quantified environmental indicators (global warming, acid rain, resource depletion, etc.)

The results are then analysed in order to identify recommendations for improvement, and they are finally subjected to external critical review.
This approach can be iterative to assess the environmental impact caused by a product modification, with the risk of transferring an impact to another.

A simplified LCA can be used as a first approach to evaluate processes more easily. It is a lighter and faster version of the LCA; it is based on the results of other LCAs, which can lead to biases in the assumptions. These tools must be used with a concern for transparency regarding the results obtained.

	ADVANTAGES	LIMITS
Complete LCA	• The most robust method • Exhaustive analysis: components, life cycle phases • Can be used for regulatory documents • Possibility of communication	• Used by experts and for experts • Complex data collection task • Tedious data process • Complicated analysis
Simplified LCA	• Easier data collection task • Process accessible to beginners, therefore with a lower level of expertise • Easier analysis • Allows the major trends to be identified	• Requires thorough knowledge of the product and its design • Cannot be used for regulatory documents • The use of impact data does not allow the customisation of data sets (specific features of the process, for example); the data is averaged • Involves more uncertainties in the results

Table of comparison between a complete LCA and a simplified LCA

EXAMPLE OF LCA RESULTS

As an example, the impacts of the fibres and matrices commonly used in the composition of petroleum-sourced and biosourced composites have been studied and are presented below, namely:

> **For reinforcements:** Glass and carbon fibres, natural fibres and a polyester fibre

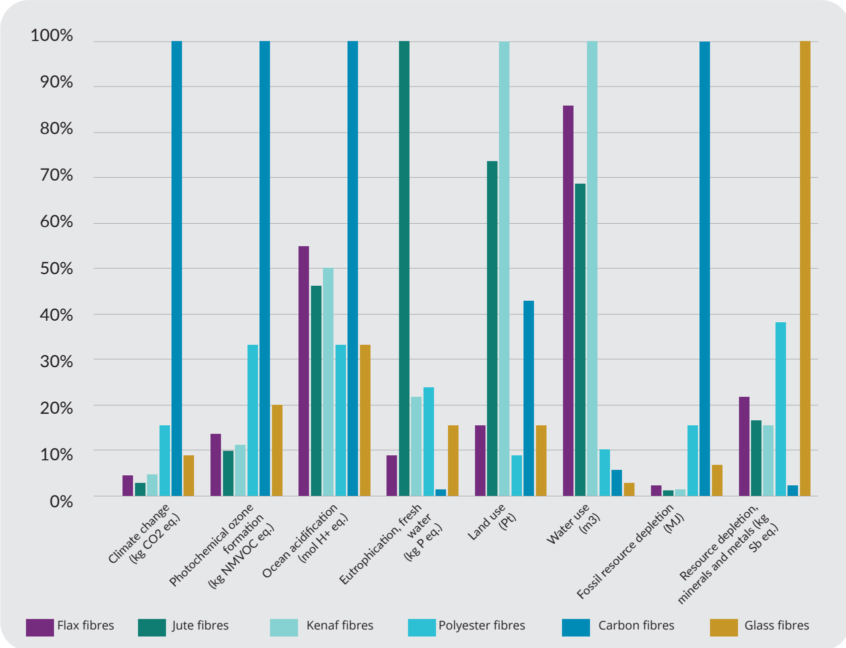
> **For matrices:** PA 6.6, PA 6, PC, PPS, PP, PLA (biosourced and hardly biodegradable plastic), ABS, polyester resin and epoxy resin

The impacts used are indicators which are commonly used in LCAs:

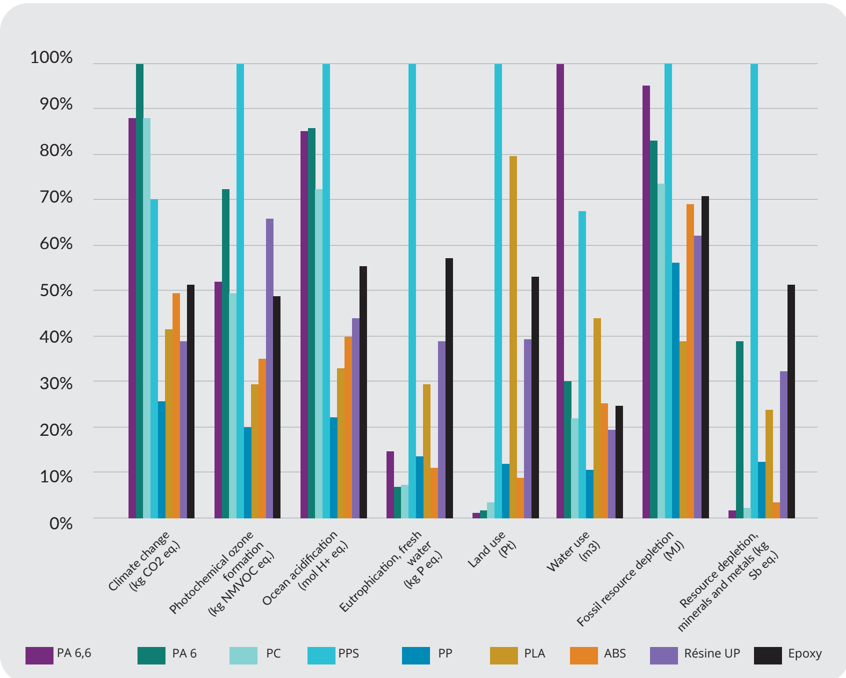
> Global warming, ocean acidification and photochemical ozone formation;

> Use of fossil, mining and metallic resources and natural resources (water, soils).

The impacts are calculated from the time they are placed on the market, that is to say from extraction to production and transport.



Comparative LCA of different fibers, isomass (1 kg), Ecoinvent data, Simapro software and EF 3.0 method, upon placing on the market



Comparative LCA of different matrices, isomass (1 kg), Ecoinvent data, Simapro software and EF 3.0 method, upon placing on the market

REFERENCE MARKS: COMPARING SOLUTIONS

When examining orders of magnitude and comparisons on the impacts of composites (matrices and reinforcements), the following points should be kept in mind:

> Impact analyses are usually complex, as they contain many parameters: life cycle extent, impacts taken into account, reference solutions, etc. The results of these analyses must be read with full knowledge of the modelling assumptions and the limits of the analysis.

> The production of synthetic fibres has a greater impact than that of natural fibres in terms of use of non-renewable resources and climate change (for an equivalent mass). The production of carbon fibre has a markedly higher impact than that of glass fibre, with the exception of its impact on rare mineral resources.

> Natural fibres, on the other hand, have a more significant impact, at equivalent mass, on agricultural resources than synthetic fibres.

> A biosourced polymer does not automatically imply smaller environmental impacts. The production and transport of raw materials as well as the transfer of impacts can affect a balance sheet which seemed attractive at first glance. Some petroleum-sourced polymers are recyclable or biodegradable, while biosourced polymers are not necessarily so.

> As a general rule, the production of thermoplastic matrices has a higher impact than that of thermoset matrices, however thermoplastic matrices have the advantage of being recyclable.

> A PLA / flax biosourced and biodegradable composite has a markedly smaller impact than a glass fibre / polyester resin composite over a complete life cycle.

> The use of recycled thermoplastics drastically reduces the environmental impacts (nearly 75% found in this study).

> These analyses only rarely take into account the benefits achieved on the operation of products by the use of composites: weight reduction and chemical resistance. It would be appropriate to take these advantages into consideration in the case of comparative analyses with other materials.

CONCLUSIONS

Thermoplastic (TP) or thermosetting (TS) polymer resin-based composites offer very interesting opportunities. The combination of their excellent mechanical properties and unique lightness makes these materials particularly useful for the design of vehicles (trains, aircraft, cars, boats), devices for the production of renewable energy (wind turbines, marine energy), buildings (panels, tubes, shells), sporting and recreational goods and consumer goods. However, the environmental benefits of composites conflict with the impact of their end-of-life management, which mainly leads to energy recovery or landfilling. The recycling rate is currently very low, this being mainly due to the technical difficulties involved by the separation of the polymer matrix and the reinforcing fibres. The end of life of composites must therefore be reconsidered.

Concerning the recycling of composites, the main lessons taught by this study are as follows:

> It is recommended to dissociate the recycling of carbon fibre-reinforced composites (high value-added material) and that of glass fibre reinforced composites (volume material).

> On a national scale, the recycling of carbon fibre-reinforced composites relies on various players such as Tarmac Aerosave (dismantling of aircraft), recyclers and upcyclers of recycled carbon fibres such as Apply Carbon, Alpha Recyclage Composites and Extracthive, and transformers such as Lavoisier Composites, Fairmat or Hopper.

> The examples of companies such as ABVAL or APV show that it is more difficult to achieve economic equilibrium for the recycling of glass fibre-reinforced composites. However, although more difficult, this economic equilibrium is possible as shown by the examples of European or US companies such as Conenor, Reprover or Glassfiber Solutions Inc. The common point between these companies is the use of technologies for grinding and reincorporating GFRPs into thermoset or thermoplastic matrices.

> In order to promote the emergence of a complete recycling channel, more accurate economic data will be required. This data will make it possible to assess the economic viability of the recycling solutions that are the most suited to each territory (nature and size of the source of composites) by including in particular the concept of critical size of the sources of composites.

Regarding the ecodesign of composites, the main lessons taught by this study are as follows:

- Ecodesign of composites should strongly develop in the years to come, driven by the regulatory context (in particular EPRs) and the CSR polices of companies, which increasingly become environmentally aware.
- The development of ecodesign will require reliable tools and databases in order to offer alternatives with real effect. The collection of this data regarding composites is a major challenge for the composites industry.
- One of the most promising main areas for the reduction of the impact of composites is the use of recycled materials. Currently, the recycling potential focuses on thermoplastics, but their production usually involves higher impacts. The use of biosourced materials may be of interest but it is not a guarantee for lower impacts.
- The composite structures that are currently dismantled are often between 20 and 40 years of age, and their end of life was often not integrated into their design. These structures include, among others, bonded assemblies of heterogenous materials (foam / composite and/or composite / wood) which involve difficulties when they reach their end of life. Moreover, the thermosetting resins used for their good properties (mechanical, chemical, durability) also cause difficulties at the end of their life. Therefore, it is recommended to reconsider the design of composite structures to make their recycling easier. This work also requires to integrate the suppliers of materials into the future developments (resins, reinforcements, joining solutions).

It would seem appropriate, when applicable, to consider changes in the business models in order to integrate more functional economy (sale of a use and no longer of a product).

The ability to provide updated data relating to the recycling and ecodesign of composites is also important. As a matter of fact, a momentum is building on this subject and it seems important to have the ability to share the good practices and know-hows between the different sectors which use composites but also throughout the value chain, from the material manufacturer to the recycler.

Partners

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GLOSSARY

ACRONYM	DESCRIPTION
ADEME	*Agence de l'Environnement et de la Maîtrise de l'Énergie* (French environment and energy management agency)
AGEC	*Loi Anti-Gaspillage pour une Économie Circulaire* (French anti-waste law for a circular economy)
APER	*Association pour la Plaisance Éco-Responsable* (French association for eco-friendly boating)
CETIM	*Centre technique des industries mécaniques* (Technical centre for the mechanical industries)
CFRP	Composite Fibre-Reinforced Polymer
CSR	Corporate Social Responsibility
EPR	Extended Producer Responsibility
FEE	*France Énergie Éolienne* (French wind energy association)
FIN	*Fédération des Industries Nautiques* (French federation of leisure marine industries)
GFRP	Glass Fibre-Reinforced Plastic
GREC	Guide for the Recycling and Ecodesign of Composites
IFTH	*Institut Français du Textile et de l'Habillement* (French textile and clothing institute)
IPC	*Centre Technique Industriel de la Plasturgie et des Composites* (Industrial technical centre for plastic engineering and composites)
LCA	Life Cycle Assessment
LHV	Lower Heating Value
SLCA	Simplified Life Cycle Assessment
SRF	Solid Recovered Fuel
SRG	Sporting and Recreational Goods
TGAP	*Taxe générale sur les activités polluantes* (General tax on polluting activities)
TP	Thermoplastic
TRL	Technology Readiness Level
TS	Thermosetting

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ADEME in a few words:

At ADEME – the French agency for ecological transition – we are resolutely committed to the fight against global warming and the degradation of resources. We are working on all fronts to mobilise citizens, economic players and territories, and we give them the means to move towards a resource-efficient, low-carbon, fairer and more harmonious society.

In all fields (energy, air, circular economy, food, waste, soils, etc.), we provide advice and assistance in the funding of many projects, from research to sharing of solutions.

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