RECYCLABILITY OF BAUMIER BICYCLE RIMS AND FRAMES

BEELIVINU

By Brigitte Blais

August 30th 2024

TABLE OF CONTENTS

INTRODUCTION

In order to manage the entire life cycle of the products developed by the BeelivinU company, I-GES explored the different possibilities of repair, reuse, recycling and recovery (4R) of the rims, frames and fittings of the *Baumier.bike* brand produced by BeelivinU, all with the aim of avoiding the landfilling of end-of-life materials.

In addition, the use of recycled materials for the manufacture of parts was explored. This report proposes companies from Quebec, Ontario and even France that would be useful or potentially useful resources for carrying out the 4R (reduction, reuse, recycling, recovery) or the purchase of recycled materials for the creation of parts.

RECYCLABILITY OF MATERIALS USED FOR THE BAUMIER.BIKE BRAND

At first glance, the "carbon fiber" residue and its composites are relatively new on the residue market. As such, recycling methods are still underdeveloped. The industry is currently looking for solutions, because the use of *virgin carbon fiber* is a significant source of greenhouse gas emissions, and its landfilling means the need to produce other *virgin fibers* from petrochemicals. Furthermore, this very durable material would take hundreds, if not thousands of years to decompose in a landfill site.

So this is where the research and development (R&D) mode and the carbon fiber end-of-life management industry stands.

THERMOSETTING MATERIALS: RIMS (DRY CARBON FIBER + EPOXY)

Baumier.bike rims are made of dry carbon fiber impregnated with epoxy resin. Is this composite material recyclable?

1. If a rim breaks, it is possible that it is only the resin that has broken. If the carbon fiber has broken, it is possible to repair it with unidirectional carbon fiber bandages at the affected areas.
    a. If applicable, the braided tubes of *Baumier.bike wheels* could be:
        i. Reused for parts other than wheels (for example to make handlebars)
        ii. Sold to another industry. See the possible *Digital Resource Exchange Platform* (CDCQ). Also see *Waste Trade* in the section of companies that recover.
2. **In theory, it is possible to recover intact carbon fiber,** unless the wheel breakage has fractured the fiber. Microwave pyrolysis is the most environmentally friendly of the recycling techniques. See the description of this method in the *Recycling Methods section.*
3. The manufacturing process of the fiber at the beginning is important in its recyclability. There are different grades of carbon fiber. The quality goes up to 1400 MPA in traction. If the virgin fiber is 1400 MPA, the recycled fiber will be very good, according to Cynthie Dega, a PhD researcher specializing in carbon fiber recycling through microwave pyrolysis. If *Baumier.bike* makes its high-end wheels with this fiber, it could be recycled and reused for recreational bike parts later on, i.e. lower-quality bikes, slightly heavier, but still very good quality. If there is no breakage in the fiber, in theory, a rim could be remodeled from the same part by adding virgin resin. Of course, before proceeding, tests would have to be done to confirm these hypotheses.
4. According to Ms. Dega, composite products have a performance curve, a cycle, for certain applications. Thus, it is necessary to be able to monitor mechanical performance over time, a

quality control of the product. To do this, we must either ask our engineers to carry out such tests, or entrust the tests to a research center or to students linked to an engineering school.

THERMOPLASTIC MATERIALS: FRAME (NYLON IMPREGNATED CARBON FIBER, PA6CF)

PA6 is a nylon called Polyamide, and CF is carbon fiber. Is PA6 CF recyclable?

Nylon can be recycled, but when it is combined with carbon fiber, the nylon must first be separated from the carbon fiber. Thermoplastics are temperamental materials, according to Ms. Dega. Tests must be done to determine the precise parameters for recycling our frames.

Ms. Dega suggests doing R&D to find out under what conditions (temperature, time, humidity, etc.) they should be recovered and recycled, what quality of materials should come out of them, etc.)

If the company decides to go in this direction, it must define a mandate, objectives, and the steps if it wants to put Polytechnique students on this file.

Nylon will be more recyclable if it does not contain dyes and flame retardants.

Furthermore, to recycle thermoplastic frames, it will be necessary to separate them from the titanium fitting and any other part that is made of a different material.

TO DO: Thus, the *Baumier.bike* manufacturing workshop will have to provide a space, a technique and a human resource that will be able to separate these parts. This could generate dust and residual materials to manage.

TITANIUM

If the fittings that come back with damaged bikes are still in good condition, they should first and foremost be **reused.** Otherwise, titanium is **recyclable.** It is a strong, lightweight metal that is difficult to break.

RESIN

Resin that passes the recycling test cannot be reverted to resin. However, the epoxy that is broken down during *microwave pyrolysis* is broken down into 13 elements derived from petroleum hydrocarbons and could theoretically be recovered, but for formulations other than epoxy. A certain percentage of the gases, oils and other chemicals can be reused in other formulations by other industries, but not to be remade into epoxy.

Thus, an industrial synergy will eventually be possible with industries that use these by-products in their processes. Some of the resins will thus be able to avoid landfill and be part of a circular economy. We are talking about the future because for the moment, this type of recycling is only on the R&D scale, not scaled up or offered by industries. It will be relevant for the aeronautics industry and for managing end-of-life wind turbine blades, which are in phenomenal quantities. The minimal quantities of our bicycles risk posing an obstacle to the interest of recyclers for our products.

RECYCLING METHODS

Pyrolysis, whether microwave or conventional, separates the resin from the carbon fiber. This produces three by-products: a **synthetic gas** (syngas) that can be used as an energy source for the conventional pyrolysis itself, an **oil** that can be used as fuel or chemicals, and finally, **carbon fiber** with properties similar to virgin fiber.

Two forms of pyrolysis are possible:

1) **Microwave pyrolysis** : less energy-intensive, faster (7 min.), but has not yet reached the stage of industrial scaling up of scientific knowledge.

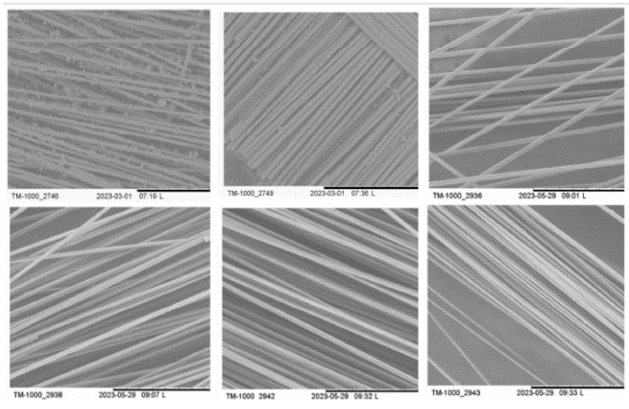
2) Conventional pyrolysis: more energy-intensive, longer (2 to 6 hours).

THERMAL: MICROWAVE PYROLYSIS

This **microwave pyrolysis (PAM)** has demonstrated impressive results in separating carbon fiber from resin. In **about 6 minutes,** the separation is done. The fact that microwaves activate heat from the inside of the material, rather than from the outside (by convection, as is the case with conventional pyrolysis), explains why the process is faster and less damaging.

Microwave pyrolysis must be followed by a **post-pyrolysis treatment** to rid the carbon fibers of remaining black carbon impurities. Among the secondary treatments evaluated, those that have been most successful are:

1. Thermal oxidation by a microwave applicator
2. Chemical dissolution



Thus, with a 6-minute microwave pyrolysis **+ a 10-minute microwave thermal oxidation treatment (total 16 minutes),** the fiber almost entirely retains its properties. This recycling method offers an efficient, energy-efficient and environmentally friendly alternative.

Dega 's thesis describing this new technique was published in July 2024 and received honors (best thesis 2024). She would like a company to scale this technique, but for now, none have done so. Stay tuned.

(**Source** : Dega, C.; Boukhili, R.; Esmaeili, B.; Laviolette, J.-P.; Doucet, J.; Decaens, J. Microwave-Assisted Pyrolysis of Carbon Fiber-Reinforced Polymers and Optimization Using the Box–Behnken Response Surface Methodology Tool. Materials 2024, 17, 3256. https://doi.org/10.3390/ma17133256)

THERMAL : CONVENTIONAL PYROLYSIS

This pyrolysis aims at the decomposition of organic molecules in an inert or oxygen-poor atmosphere, at temperatures **ranging from 400 to 1000 ◦C** for **a few hours.** It is therefore an energy-intensive technique.

The carbon fiber thus recovered is used as (thermal) **fuel** to fuel the combustion necessary for the manufacture of cement.

GASIFICATION

Gasification is the transformation of waste into synthesis gas (syngas), which will be used as biofuel or various chemical products. This technology requires a lot of energy (600 ^{0}C to 2000 ^{0}C) and is expensive.

CHEMICAL

Solvolysis, a reaction of substitution, elimination or fragmentation of a product using a solvent, could be used to separate PA6 from carbon fiber.

Some methods use chemicals to recover polyamide (PA6). This method generates other environmental problems, such as waste chemical management, water management, air emissions, etc. This is not what is preferable in BeelivinU 's vision.

GRANULATION

Granulation is the transformation of matter into granules. The technique consists of crushing composite materials and introducing them into other materials, such as concrete , giving it properties such as durability, strength and permeability. This permeability is sought after during heavy downpours, to let water pass through while maintaining the hardness of the concrete. This way of recovering and recycling carbon fiber requires little energy and avoids landfilling.

Access to a scientific study on the introduction of carbon fiber aggregates in concrete, carried out by the University of Washington here .

NORTH AMERICAN AND EUROPEAN COMPANIES THAT REPAIR, RECOVER AND/OR RECYCLE

Here are companies that are likely to accept our end-of-life materials, **if our quantities meet their acceptability criteria.**

THERMOSETTING MATERIALS: RIMS (DRY CARBON FIBER + EPOXY)

CARBON RECYCLING VARENN ES

Gasification technology from ENERKEM, a Quebec company. This technique does not allow the recovery of carbon fiber, but it allows the creation of energy and chemical products.

The plant is currently under construction in Varennes. It is expected to open in 2025. It will then be possible to register as a supplier of raw materials. The minimum quantities accepted are not yet available on the website.

3R SYNERGY

Thermoselect technology to gasify waste at high temperatures to turn it into syngas and reusable raw materials. It's a technology similar to ENERKEM's.

Although interesting as a last option before burial, the company does not seem to have been able to establish itself in Quebec.

THE QUEBEC COMPOSITES DEVELOPMENT CENTER (CDCQ)

This Center being a "Technology Transfer Center" at the college level, it does R&D. It is therefore not a company that recovers.

The Centre de développement des composites du Québec (CDCQ) offers manufacturing companies a wide range of services adapted to their needs in the composite materials sector: research into materials, processes and equipment, prototyping, characterization, molding and qualification tests.

Some equipment allows for testing. If BeelivinU wants to do recyclability tests on its rims, it could do them there (or at Polytechnique), but the expertise of CDCQ researchers would be necessary. Most of their services are eligible for the tax credit for technological adaptation. Here is an example of equipment that the CDCQ has:

RÉACTEUR DE PYROLYSE

Cet équipement est principalement impliqué dans la chaîne de valeur du recyclage des fibres de carbone, dans le but d'une réutilisation dans un nouveau produit. Le réacteur permet de récupérer des fibres de bonne qualité ainsi qu'une huile de pyrolyse.

THERMOPLASTIC MATERIALS: FRAME (NYLON IMPREGNATED CARBON FIBER)

THE QUEBEC COMPOSITES DEVELOPMENT CENTER (CDCQ)

This Center being a "Technology Transfer Center" at the college level, it does R&D. It is therefore not a company that recovers.

The recycling industry requires an economically attractive quantity of materials to be recycled in order to survive. This is why the CDCQ is setting up **a virtual platform** where recyclers, processors and **producers** can publish their needs and **offers** of materials.

This **platform** does not yet exist, but seems to be in the process of being created. To be continued.

BeelivinU should announce its rims and frames to be recycled there, when the time comes. Thus, our parts could interest recyclers from Quebec.

Link to their website.

PYROWAVE

This innovative Quebec company recycles plastic no. 6 using microwave electrical technology. It is also starting a research project aimed at replacing fossil fuels with microwave energy in the production of Portland cement, with the goal of decarbonizing the cement industry.

Pyrowave was a financial partner in Cynthie 's research project Dega, **but does not yet offer the recycling service of carbon fiber + epoxy** or **carbon fiber + PA6**.

It is possible to dream or influence this company to take the results of Cynthie 's research Dega to scale them up for recycling epoxy-impregnated carbon fiber. It remains to be seen whether BeelivinU is willing and able to influence this venture.

WASTE TRADE

Some companies, such as Waste Trade, recycle PA nylon and then resell it to industries that need it. After checking, **they recover PA6 CF.** Thus, *Baumier.bike* will be able to sell its frames to be recycled in PA6 CF when the necessary quantities are accumulated:

Quantity required : between 3 and 10,000 tonnes.

Since a ton is a weight, and the weight of frames is very light, here is how many frames it would take to consider sending the whole thing for recycling:

3,000,000 grams (3 tons) / 572 grams (frame weight) = 5,245 frames

RYMYC

Although in Italy, this carbon fiber recycling company seemed worthy of mention: https://www.rymyc.it/

TITANIUM

GLOBE METAL

Processing and recycling titanium uses less energy than sourcing and producing components from virgin raw materials, saving money and reducing pollution.

This company can recycle **alloyed and unalloyed titanium** : including chip, powder and **solid forms.**

Web link
Address: 1545 1st Avenue, Sainte-Catherine, QC J5C 1C5

RESIN

No company currently recovers the chemicals and residual oils from the resin to reintegrate them into other products (circular economy). However, the resin can be used as fuel in some industries, such as at RECYCLAGE CARBONE VARENNES. This option is preferable to landfilling.

However, the management of the residual resin will be in the hands of the company that will carry out the separation between the carbon fiber and the epoxy. BeelivinU will therefore have no control over this step.

RAW MATERIALS MADE FROM RECYCLED OR RECYCLABLE MATERIALS

If BeelivinU wishes to test certain materials from the recycling of raw materials, both for its rims and frames as well as for accessories, it can test the materials offered by the following companies.

BeelivinU could also consider creating accessories or derivative products from the recycling of its own rims and frames.

THERMOPLASTIC MATERIALS FROM RECYCLING

REFLOWFILAMENT

This company manufactures rPACF, or **recycled** PA6 + recycled carbon fiber, for 3D printers.

Baumier.bike frames, it could be used to make accessories in a 3D printer, such as bottle holders, cell phone holders, etc.

Web link: S ource
Location: Amsterdam

TITANIUM

In the event that we wanted to use recycled titanium to manufacture certain parts, a Quebec company and a European one were found.

METAL GLOBE

A recycler of several metals, including titanium, this company has an 88,000 square foot materials warehouse located in Montreal. BeelivinU could explore the possibility of purchasing recycled titanium from this location if it finds a way to transform it into a fitting here in Quebec.

Website : https://globemetal.com/fr/achat-fourniture/produits-et-aménagement-de-revert/

ECOTITANIUM

Recycled titanium: Ecotitanium in France. TA6V and TA6V ELI

RESIN

ARKEMA AND ARKEMA CANADA

This French company has a factory in **Bécancour (Qc)** and distributes its products to two addresses in Quebec (and elsewhere in North America).

However, it seems that BeelivinU is too small a company for these distributors.

The company has created a **recyclable thermoplastic liquid resin** that can be used **cold, without the need to heat** the rim, for example, to harden it. This resin is called **Elium.**

Other environmental assets characterize it, as quoted on their website " Elium ® : **no use of cobalt salts,** a classic catalyst to initiate the radical polymerization of resins, but often classified as carcinogenic in Europe (CMR substances), **nor styrene,** toxic for reproduction, also classified among the substances dangerous for human health."

The company has a CSR (Corporate Social Responsibility) Policy with environmental values and objectives. See here .

Nanostructured Acrylic Additive Information Page Nanostrength ® mentioned in the image opposite.

Distributor of their products in Quebec :

- Bostik Canada Limited, 4645 Boulevard Metropolitain E, 66023 MONTREAL QUEBEC
- Arkema Canada , 655 Boulevard Alphonse- Deshaies, Bécancour, Quebec, Canada - G9H 2Y8, (+1) 819 294-3365

R&D POSSIBLE WITH THE ÉCOLE POLYTECHNIQUE

Since the carbon fiber recycling industry is only at the R&D stage, BeelivinU could contribute to this research and development by submitting its products to students so that they can discover the most favorable conditions for recycling our products.

To influence the industrial scaling of academic knowledge achieved on a very small scale, BeelivinU could contact certain companies likely to develop technology on a scale such as Pyrowave, for example.

For now, here are two contacts at Polytechnique for continuing research on our products.

CONTACTS

Cynthie Dega, Consultant, cynthie-ornella.dega-kougoum@polymtl.ca , Tel: 514 588-0423

Rachid Boukhili, Full Professor, rachid.boukhili@polymtl.ca

FEDERAL GRANT FOR RESEARCH AND DEVELOPMENT

BeelivinU can submit a project to the Pole of Excellence in Innovative Materials of the École Polytechnique de Montréal, which can submit a request for a federal grant (to MITACS) to pay two students and their holder. This could be for example $20,000 to $40,000/year. These students could work partly in our premises, as well as in the Polytechnique laboratories. The grant can be up to 80% of the industrial partner's contribution.

The same project could also be submitted to the Quebec Composites Development Center (CDCQ) .

Although the mandate remains to be specified, here are some possible elements:

Description of mandates	Details	No.	Cost breakdown
1) DETERMINING THE RECYCLABILITY OF RIMS MADE OF THERMOSETTING COMPOSITE MATERIALS BY MICROWAVE PYROLYSIS. DETERMINING THE CONDITIONS OF RECYCLING AND THE POSSIBLE RECOVERY RATE OF CARBON FIBER	Activities	#1	
		#2	
		#3	
	Deliverables	#1	
		#2	
2) CONDUCT REUSE TESTS OF FIBERS RECOVERED FOLLOWING PYROLYSIS AND RE-MAKE RECREATIONAL QUALITY RIMS. TEST THEM.	Activities	#1	
		#2	
	Deliverables	#1	
		#2	
3) DETERMINE A RIM QUALITY CONTROL PROTOCOL TO KNOW THE RIM PERFORMANCE CYCLE CURVE OVER TIME.	Activities	#1	
		#2	
		#3	
	Deliverables	#1	
		#2	
		#3	
		Total :	**$X0,000**

SCIENTIFIC AND TECHNOLOGICAL WATCH

Here are some reference sites where you can follow the progress in terms of recyclability of carbon fiber composite materials:

1. Recycling Carbon: https://www.recycling-carbon.org/
2. Engineering techniques: https://www.techniques-ingenieur.fr/ and https://www.techniques-ingenieur.fr/actualite/articles/recycler-les-fibres-de-carbone-des-materiaux-composites-91423/
3. Polytechnique Insights (Paris): https://www.polytechnique-insights.com/dossiers/energie/transition-energetique-recycler-les-materiaux-pour-preserver-les-ressources/

CONCLUSION

In conclusion, **microwave pyrolysis is the fastest, using clean electricity and with the best results of the recycling methods. But no plant exists to recycle them like this.**

While waiting for microwave pyrolysis to be developed on an industrial scale, the rim or frame residues from *Baumier.bike* could be offered to a recovery company (reintroduction into other materials or transformation into fuel), as long as they accept our small quantities.

It is proposed to accumulate the broken frames and rims and to re-communicate with the companies mentioned above when the company has enough material to fill a trip or to meet the minimum quantities required by these companies.