END OF LIFE SOLUTIONS FOR BIOMATERIALS (ELIOT PROJECT)

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Abstract:

Bio-FRP (fibre-reinforced polymers) that use natural fibres as reinforcement and resins from renewable sources are being increasingly used in sectors like aviation, building & construction, sports, home equipment, as they are a key technology to reduce environmental impact thanks to their favourable combination of mechanical properties and low weight (reducing fuel consumption and CO_2 emissions into the atmosphere). However, the widespread use of FRP and bio-FRP has led to waste management difficulties since the polymer matrices are usually thermosetting resins which have a cross-linked molecular structure that pose a challenge to conventional recycling technologies. Despite all the advantages of these biocomposites, no efficient solutions have been found for End-of-Life (EoL) management when they become waste. This is more pronounced in the case of biocomposites, a new material, which, unlike conventional composites, does not contain carbon fibres with a high market value.

In the search for new solutions for recovering biocomposites, the project ELIOT reviews current composite recycling technologies to analyse the most feasible alternatives with respect to environmental, economic, resource and technical performance. Next, the most promising candidates will be adapted to the characteristics of biocomposites and tested to scale in the laboratory. Finally, the project is expected to demonstrate technical feasibility at pre-industrial scale, thus full-scale demonstration will be provided for 2 EoL methods for 2 target biocomposites, respectively, including their technical validation at pre-industrial scale and their validation in terms of life-cycle sustainability. These EoL methods will be ready to be further scaled up in industrial environments.

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The ELIOT project started the 1st of July 2020, and it will finish the 1st of March 2023.

Key words:

Composites, biocomposites, End-of-Life, recycling, landfield, gasification, pyrolysis, MWs, solvolysis, dissolution, mechanical, TRL.

Introduction:

Composite materials comprise two main constituents, one of which is the matrix phase, and another one could be in particle or fibre form.[1,2] Composites represent an alternative over many traditional materials since they have a significant enhancement in the structural, mechanical, and tribological properties of fibre-reinforced polymers (FRPs) material.[3,4] The utilisation of natural or synthetic fibres in the fabrication of composite materials finds significant applications in the construction, mechanical, automobile, aerospace, biomedical, and marine industries.[5,6]

Biocomposites are often defined as materials in which at least one of the components can be considered as bio-based[7]. Matrices can be bio-based, typically obtained from renewable resources like vegetable oils, furan resins and starch or produced by microorganisms (polyhydroxybutyrate, PHB), although petroleum-based polymers are predominantly used (virgin or recycled, thermoplastic or thermosets). Regarding reinforcements, not only natural fibres from plants such as cotton, flax, hemp, jute, etc. can be used in combination with polymers, but also fibres from recycled wood, paper residues or by-products from plant crops like rice husk. Figure 1 details the source of sustainable reinforcements and fillers that can be used in the different biocomposites formulations.

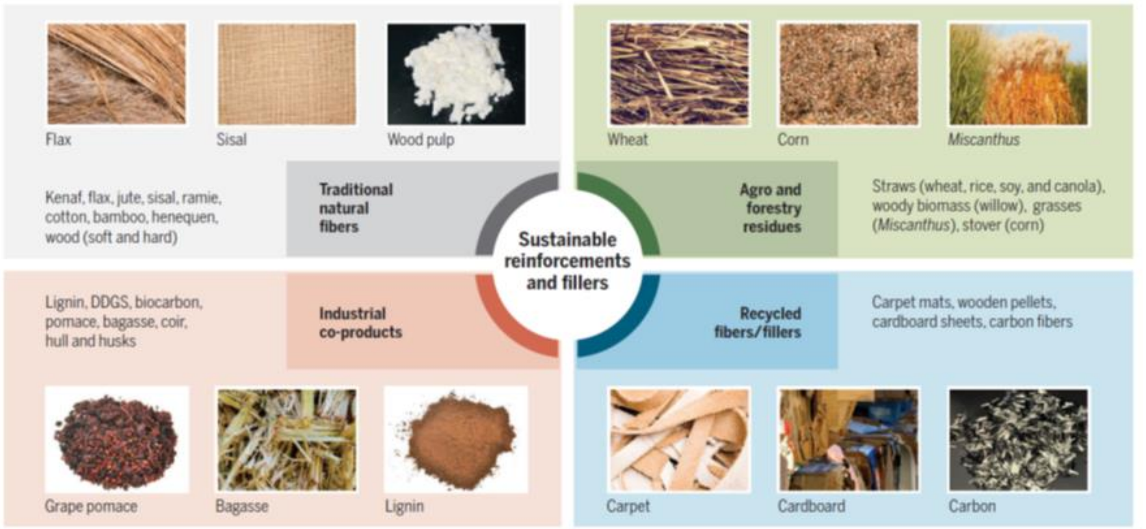

Figure 1. Sustainable reinforcements and fillers that can be used in biocomposites composition (ref 19 – Mohanty et al.)

Results and discussion:

Within the frame of ELIOT project a deep study has been done regarding the End of Life technologies available nowadays in literature and industry for composites and biocomposites in particular. The most important aspects of this study are summarised below:

1) LANDFIELD

Landfill is the oldest and most common form of waste disposal. Landfill is a relatively cheap disposal route, but it is the last option for waste management under the European Union's (EU) Waste Framework Directive. Landfill and incineration processes are regulated at European level.

There is no recuperation of materials from biocomposites through landfill. Part of the biobased content will be transferred into methane; modern landfills capture this gas and use it as a fuel to generate energy but the transfer is limited and not a sustainable option. Landfield technology is set as a Technological Readiness Level (TRL) of 9 as it is very well established.

2) INCINERATION

Incineration is a thermal process which heats the waste in an excess of oxygen. Figure 2 shows the most determinate factor to differentiate between different thermal processes is the amount of oxygen available: without oxygen pyrolysis takes place, with a limited amount of oxygen it becomes gasification, and with an excess of oxygen (more than 100%) it becomes combustion or incineration[8].

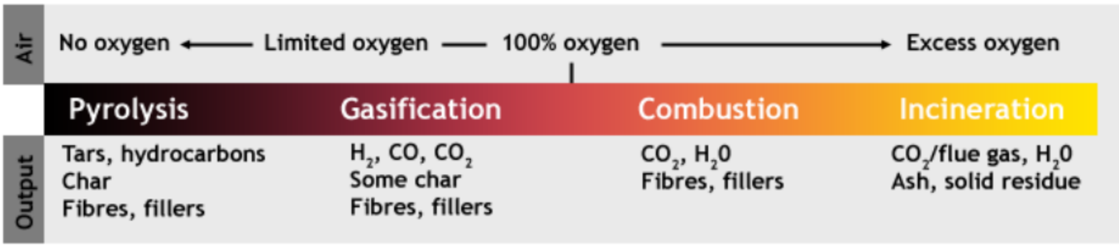

Figure 2. The difference between pyrolysis, gasification, and combustion

The biocomposites products recovered after incineration are gases and solids. Some of the gases can be used as combustible to feed the incineration process and the flue gases must be cleaned before releasing to the atmosphere. The solid discharge consists of ash and residue[9], which is usually moved to landfill (depends on the process, discharge consistency and contents). Incineration of biocomposites is set at a TRL of 9 (Industrial scale).[10]

3) CEMENT KILN

Yearly billions of tons of cement are being produced in cement kilns for the manufacturing of concrete in the building and infrastructure sector[11]. The manufacturing process in the cement kiln is energy intensive and emits large quantities of greenhouse gas emissions due to the consumption of fossil fuels with a high CO_2 footprint, including coal, gas and petroleum coke[12]. Approximately 30% to 40% of total production costs for cement manufacturing comes from energy consumption[13]. To lower energy costs and greenhouse gas emissions, the cement industry has started to replace virgin fossil fuels with waste materials and biomass. The cement kiln co-processes various waste materials, including tires, sewage and paper sludge, and other high volume waste streams[1,3]. Bio composites are suitable for co-processing in a cement kiln.

4) MECHANICAL RECYCLING

With the mechanical recycling process of biocomposite materials, mainly flakes, fibres and fractions rich in powder are obtained. Two types of fractions are normally obtained, a fibre-rich fraction, which is called a coarse fraction, and a matrix-rich fraction, called a fine fraction. These fractions can be identified and separated with the help of elements such as cyclones or through sieving processes. To obtain a purer material, a heat treatment can be applied to the materials, thus achieving a greater separation of the fibres on the one hand and the matrix on the other hand. Mechanical recycling technology is at a TRL 8 level for CFRP and a TRL 7 level for GFRP[14].

5) PYROLYSIS (CONVENTIONAL, FLUIDISED BED AND MW ASSISTED)

The most widespread thermal process to be used as a recycling method of waste is pyrolysis. It operates in the absence of oxygen. In the conventional pyrolysis process, the composite waste is carried through a furnace with controlled temperature (around 400-700 °C), see Figure 3.

The pyrolysis process produces (including the usual proportion of each part):

1) a solid residue including the inorganic fibres and fillers and a char residue (50 wt.% up to 67 wt.%)[15].

2) liquid oil products (10–50 wt.%)

3) a fuel gas (5–15 wt.%)

The technology maturity of conventional pyrolysis is ranked at TRL 7 for GFRP and TRL 8 for CFRP. Some pyrolysis plants have been established for the treatment of carbon fibres reinforced composite waste during the last decade in Europe and North America with a treatment capacity from 1,500 to 2,000 tonnes per year. Regarding biocomposites no literature founded reveals the use of pyrolysis as an end-of-life route for these biomaterials although it is believed it can be a good process due to the lesser thermal stability of the natural fibres compared to the glass or carbon fibre. Then it can be established a TRL of 3 as the technology for composites is well established and the experimental and proof of concept at laboratory scale for biocomposites is well established.

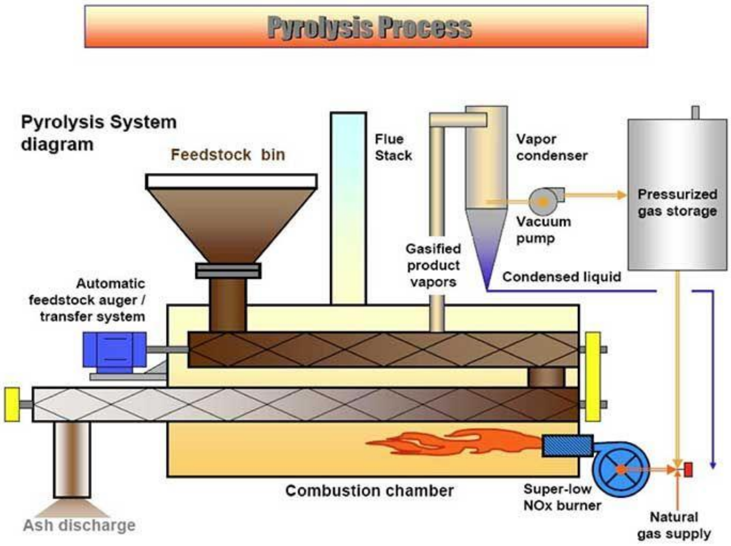

Figure 3. Conventional pyrolysis of composite waste

FLUIDISED-BED PYROLYSIS is is a modification from a traditional pyrolysis process to achieve more rapid heating of materials, it involves passing the size-reduced waste material through a hot bed stream of hot air in the presence of silica sand that keeps floating. Fluidised-bed pyrolysis technology is currently ranked at TRL 4 for FRP composite waste as it has been developed to pilot scale[16]. Regarding biocomposites this technique can be classified as TRL 3.

THE MICROWAVE-ASSISTED PYROLYSIS is a thermal process emerging as a promising technology as it reduces residence time and accelerates chemical reactions, which leads to energy saving. Through this pyrolysis variant the material is heated in its core using microwaves so that thermal transfer is very fast. Micro-wave assisted pyrolysis technology is today classified as TRL 3 for FRP composite waste. Several universities have done trials but so far it has not been successfully piloted and commercialized. Regarding biocomposites this technique can be classified as TRL 2 as nothing have been found for biocomposites, but the technology could apply for them.

6) GASIFICATION

Gasification is a method of thermal treatment that can be applied to treat variety of composite waste types where resin from fibre is separated. This technology applies higher temperatures than pyrolysis (>700 ˚C) in combination with a controlled amount of oxygen and/or steam to make the material react without combustion. The end products can be roughly divided in oil, gas and solids.

7) SOLVOLYSIS

Solvolysis process for biocomposites disintegrates the polymer matrix by dissolving it with temperature into a suitable chemical such as acids, bases and solvents. Solvolysis process has gained increasing interest in the recent past because it can open the door to the recovery of a wide variety of valuable resins and fibres. Solvolysis technology is at lab scale for CFRP and GFRP composite waste and can be classified at TRL 3-4. No major scientific study is reported for lab scale solvolysis of biocomposites, the TRL level is estimated as 3.

8) DISSOLUTION

In the dissolution process concept the solvent solution does not break down the polymer bonds but rather selectively dissolves the polymer matrix through choice of solvent. The key advantage of dissolution process over solvolysis is that the resin is recovered as a polymer and the fibres are also recovered. The dissolution technology is now at early pilot stage for recycling plastic waste streams.[17] However, it is at early lab scale for CFRP and GFP composite waste and can be classified as TRL 3-4. For bio composites with no major scientific study reporting lab scale solvolysis, the TRL level is estimated to be at 2.

9) ENZYMATIC DEGRADATION

Enzymatic degradation refers to the use of biocatalyzers as enzymes to carry out the depolymerization of polymers. For thermoset composites materials, enzymatic degradation process depolymerizes the resins to monomers or oligomers. The enzymatic degradation process has a low impact on the environment due to low process temperatures and low energy requirements and enzymes have been identified as candidates to developed biocatalytic process to recover valuable raw materials [18]. Besides, it does not consume chemicals and solvents like in other technologies such as solvolysis, which means a reduction in the use of toxic chemicals leading to potential reduction in environment impacts. Enzymatic degradation technology is at lab scale for CFRP and GFP composite waste and can be classified as TRL 3. For biocomposites with no major scientific study reporting lab scale enzymatic recycling, the TRL level is estimated to be at 3.

10) COMPOSTING

Composting is an aerobic method of decomposing organic solid waste. The process involves decomposition of organic material into a humus-like material, known as compost, which is a good fertilizer for plants. Composting requires human management, aerobic conditions and development of internal biological heat due to the microorganism's activity. Composting technology is developed at industrial level for organic and biodegradable materials, so it has a TRL 9. However, composting would only work for GFRP and CFRP if they are composed of biodegradable polymeric materials. Therefore, the use of this technology for biocomposites will depend on the resin used. In ELIOT project, epoxy and phenolic resins have been selected, and because of the low biodegradability of these resins the TRL for these materials is 2.

Conclusions:

The key difference between composites and biocomposites recycling technologies is their higher level of maturity for composites. For biocomposites, almost all recycling technologies are either at lab scale or early pilot scale, see Figure 4 as it summarises the TRL of each End-of-Life option for biocomposites. Regarding the circularity potential, where TRL and the quality of products recovered are involved, four technologies seem to have more circularity potential than the others for biocomposites, those are Solvolysis, Dissolution, Mechanical and Pyrolysis.

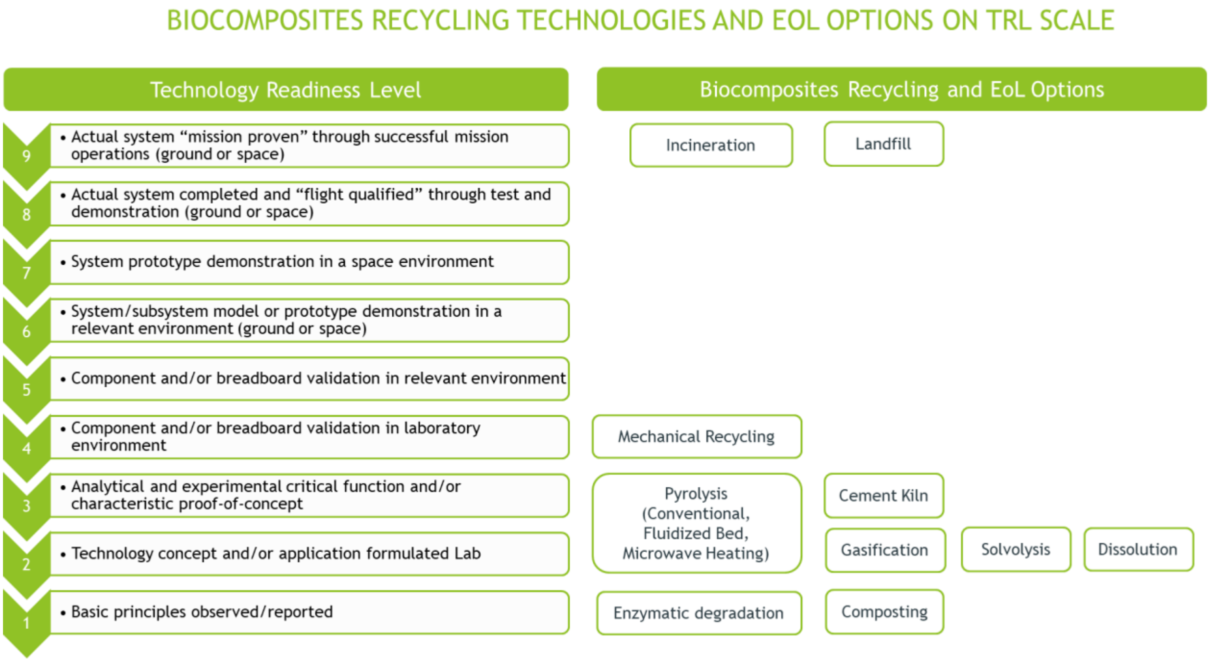

Figure 4: TRL Mapping for Biocomposites Recycling and EoL options

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