LIFE Biorefformed

LIFE BIOREFFORMED
MARKETING BRIEF PACK

SUSTAINABLE FOREST BIOMASS FOR THE REFINERY INDUSTRY

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1 Objective

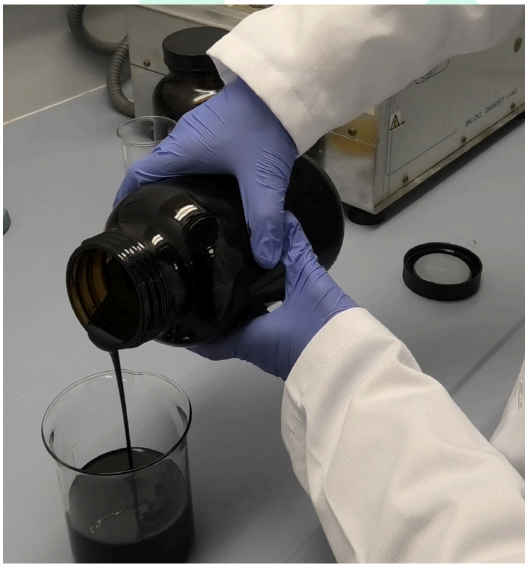
This marketing brief summarises **LIFE BIOREFFORMED's** final **products** obtained from the thermochemical conversion (**pyrolysis** and torrefaction) of wood biomass and their further processing with **biorefinery** technologies. The bioproducts obtained have great interest for several **industries** including **chemical, nutraceutical and pharmaceutical** industries. In this brief the quality of the products obtained will be shown and the current market placement of these **renewable products** will be evaluated with the aim of boosting the replacement in the market of the equivalent fossil-derived products.

The biomass used for the development of value-added products has come from the **sustainable forest management** of the Mediterranean forests in Catalonia. Innovative forest treatments have been applied in the designated stands from where biomass has been harvested. The **socio-environmental effects** of these treatments and the environmental data in relation to other fossil-based products will also be summarised in this brief pack.

This brief's target audience includes **business owners**, managers from the refining and **chemical industry,** as well as **policymakers**, environmental NGOs, the media, **academic institutions,** research centres, and **forest owners** at all levels. The goal is to demonstrate the strategic advantages of investing in wood biomass technologies such as pyrolysis and biorefineries and how they align with both environmental **sustainability** and **business profitability.**

Key takeaways:

- **Mediterranean forest biomass** can be transformed by **pyrolysis** into useful products like **biochar** and **bio-oil**.
- **Biochar** can be used as a biofuel, as a **biostimulant** source, as a **soil structuring** agent and for **water retention** purposes, enhancing soil health and helping businesses to meet **carbon reduction** targets.
- **Bio-oil** can be used in the synthesis of **phenolic resins** or further processed into value-added chemicals like **antioxidants, sugars, acids and aromas.**



2 Business Opportunity

Global Shift to Renewable Energy:

- The demand for **renewable chemicals** and **energy** is growing rapidly as governments and industries face pressure to reduce greenhouse gas emissions. **Biochar** and **bio-oil** could play a key role.

Forest Biomass as a Feedstock:

- Forest biomass is **abundant** and often considered waste (e.g., sawdust, forest residues).
- Utilising forest biomass from the sustainable management of forests could tackle two problems in one: boosting and giving **economic profitability** to the necessary **management of forests**, preventing fire risk, enhancing forest health and preserving biodiversity and obtaining bioproducts from a renewable source.

Key Markets for Bio-Oil and Biochar-derived products:

- **Bio-oil**: **Antioxidants, sugars, acids** and **resins** can be obtained from bio-oil, with great interest for chemical, nutraceutical and pharmaceutical industry.
- **Biochar**: It has great interest for the agricultural sector thanks to its uses as a **soil structuring agent** and as a source for **biostimulants** with a lot of interest for fertilizing. It also has a lot of interest for the **energy industry.**

3 Final products obtained

The final products are derived from the thermochemical conversion of forest biomass from the Mediterranean sustainable forest management. Seven different types of wood have been employed: **Aleppo pine with and without leaves, Stone pine, Oak, Strawberry tree, Heather, Cork oak with bark and Chestnut tree.**

Biomass has been transformed by pyrolysis into biochar (solid) and bio-oil (liquid).

- **Bio-oil** is further fractionated with an integrated and **multiobjective process** that allows the separation of **value-added compounds** such as antioxidants, sugars, acids and resins. The best pyrolysis temperature to produce these products is between 400 and 500 °C with a maximum yield at 450 °C.
- **Biochar** can be used as a **biostimulant** source through the extraction of **humic amendments**. The best pyrolysis temperature to produce biostimulants is 300 °C. It can also be used as a fuel and has multiple applications, from **soil improvement** (increasing fertility and moisture retention) to **carbon storage** (maintaining CO_2 sequestered).

What products can be obtained and with which quality?

Table 1 provides a summary of the final products obtained, including the highest quality (defined as the purity or maximum substitution, or better properties) that have been achieved independently of the type of biomass.

Fraction	Bioproducts	Obtained quality	Composition	Market placement
Liquid fraction (Bio-oil)	Antioxidants	100 % purity (Sum of all phenolic species)	Contains a mixture of phenolic compounds such as catechol, guaiacol, vanillin, phenol, among others	Cosmetic, dermocosmetic, natural health ingredients and nutraceutical industries
	Phenolic resins	30% substitution	Phenol-formaldehyde resins synthesized from pyrolytic lignin	Wood adhesive
	Sugars	44.5 % purity	Mainly composed by levoglucosan	Chemical, pharmaceutical and food industries
	Acids	72.2 % purity	Mainly composed by acetic acid and small amounts of formic acid	Chemical, pharmaceutical, textile and metallurgical industries
Solid fraction (Biochar)	Biostimulants	4.9 g of humic compound per 100ml	Composed by humic and fulvic acids	Chemical, pharmaceutical and food industries
	Biochar	HCV from 17.6 to 30.6 MJ/kg		Bioenergy

From **bio-oil**, it has been possible to obtain a **pure mixture of antioxidants**, a fraction that is rich in **acetic acid** and a **sugar**-rich fraction. Phenolic resins have been synthesised and tested with good results. From **biochar, biostimulants** have been extracted with very promising extraction yields when comparing them to other common renewable sources such as compost. Its calorific value indicates that it is also a good material for energy purposes.

What type of biomass is suitable for the obtention of these products?

In Table 2 the product yields obtained when using different tree species as feedstocks can be seen. Eight different types of biomasses have been used including softwoods, hardwoods and shrub wood species: *Pinus Pinea* (*Pp*), *Pinus halepensis* with leaf (*Ph leaf*), *Pinus halepensis* (*Ph*), *Quercus ilex* (*Qi*), *Arbutus unedo* (*Au*), *Erica arborea* (*Ea*), *Quercus suber* with bark (*Qs bark*) and *Castanea sativa* (*Cs*).

Table 2. Final product yield at 400 ºC.

Fraction	Bioproducts	Yield (g/kg biomass)							
		Pp	***Ph leaf***	***Ph***	***Qi***	***Au***	***Ea***	***Qs bark***	***Cs***
Liquid fraction (Bio-oil)	Antioxidants	4.0	4.4	4.6	2.5	0.6	2.3	1.1	0.7
	Phenolic resins	3.33	2.38	1.43	2.01	1.67	2.01	1.34	2.33
	Sugars	6.9	8.3	9.5	5.9	2.9	9.6	2.7	5.9
	Acids	16	21.1	17.6	19.8	11.9	25.6	17.6	11.5
	Aldehydes and ketones	3.8	6.4	5.4	6.0	2.4	5.4	2.9	2.1
Solid fraction (Biochar)	Biostimulants (g/100 ml) produced at 300 ºC	1.5	1.4	1.2	1.6	1.6	1.4	2.3	2.4
	Biochar (MJ/kg)	29.9	25.8	26.2	24.2	22.1	23.1	16.6	22.7

Similar amounts of compounds of interest have been obtained from the different types of forest biomass processed in the project. Therefore, it can be concluded that there are no important differences between hardwood, softwood and shrub wood species. This suggests the **feasibility** of using **all** the tested **forest species** in this type of biorefinery and the possibility of using biomass with a **difficult market placement**, such as small trees with bark and leaves, cork coming from **aged trees,** or **mixed wood** of different species and characteristics, coming from **post-disturbance actions**.

Some specific values can be highlighted:

- Among the tree species studied, pines and especially ***Pinus halepensis*** (*Ph*) have been the best to produce **antioxidant** compounds (such as guaiacol, catechol, phenol and vanillin, among others).
- ***Castanea sativa*** (Cs) and ***Quercus suber*** (*Qs bark)* are the ones that have given the best results for the production of **humic extracts** as **biostimulants** of soil microbial activity and plant growth.
- ***Erica arborea*** *(Ea*) gave very good results in the obtention of **acids**, especially acetic acid.
- To produce phenolic resins used as **adhesives** for wood, plywood and particleboard, the pine species and ***Castanea sativa*** (Cs) are the most interesting due to the good results and abundance of these trees in the Mediterranean regions.

4 Products' placement in the market

The bioproducts obtained could have different placements in the current industry market. In this brief some of the main applications are summarized.

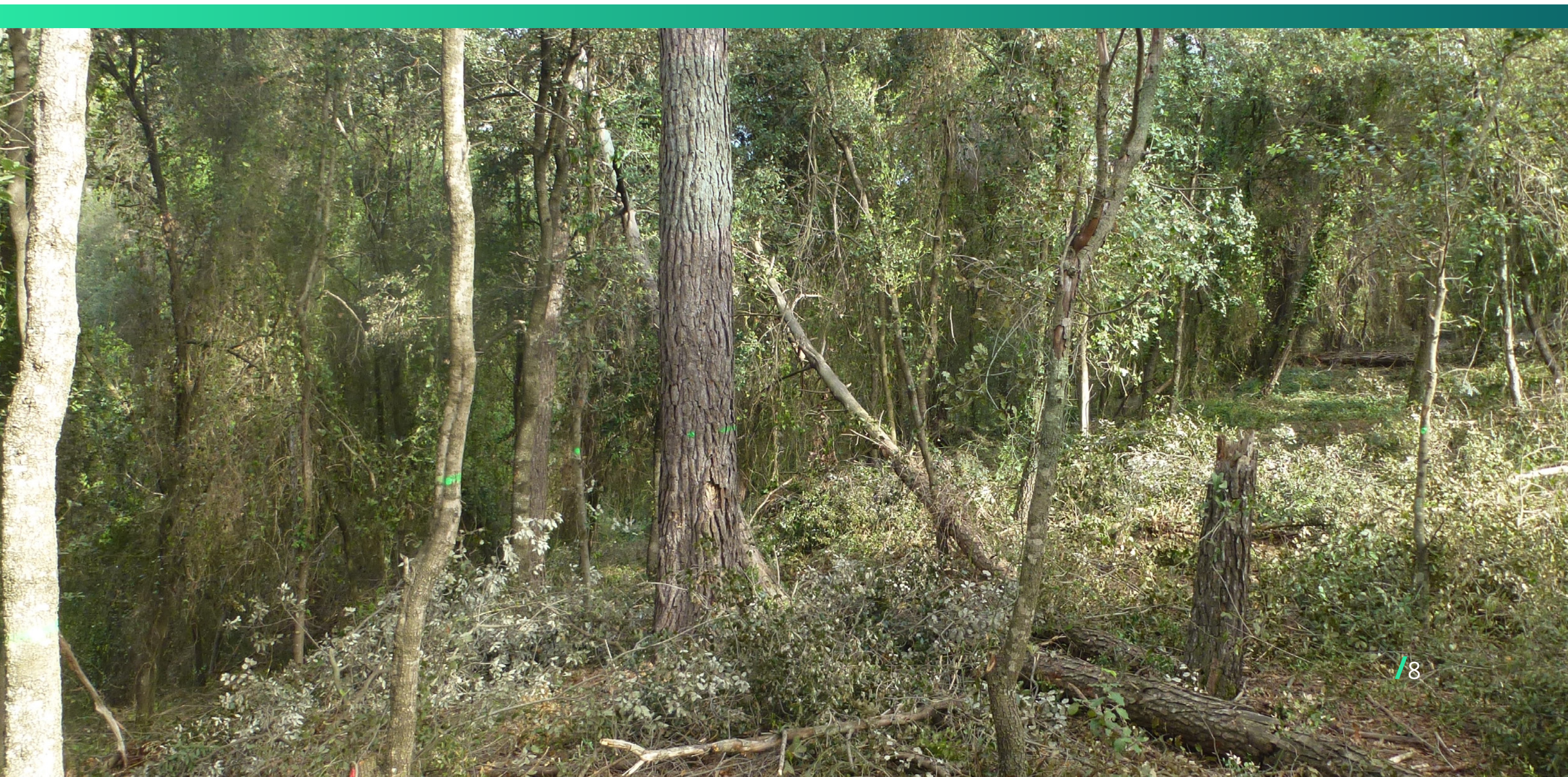
- **Antioxidants:** these compounds have a lot of interest in the cosmetic, pharmaceutical, nutraceutical, chemical and food industries due to their use as antioxidants, flavouring and fragrance agents, reagents for the synthesis of phenolic resins, etc. Phenolic compounds comprise a wide variety of chemicals: phenol, polyphenols like catechol, methoxyphenols like guaiacol, aromatic aldehydes like vanillin, etc.
- **Phenolic resins:** phenol-formaldehyde adhesives are the most thermosetting resin for the manufacture of wood-based panels such as plywood, particle board and fiberboard. These adhesives are characterised by their high strength and moisture resistance, which prevents delamination and gives excellent temperature stability.
- **Sugars**: levoglucosan is considered a chemical platform. It can be used to produce biodegradable plastics, and in the synthesis of high-value speciality chemicals such as pharmaceuticals using chiral catalysts incorporating levoglucosan-based ligands.
- **Acids**: acetic acid is used in the fabrication of numerous industrial and pharmaceutical products (for example, in the synthesis of vinyl acetate and cellulose acetate, as a food additive, as an antiseptic for medical applications, etc.). Formic acid is used as a preservative and antibacterial agent in livestock feed. It can also be used in fuel cells for energy purposes, for soldering due to its capacity to reduce oxide layers, in chemistry laboratories as a solvent typically used in chromatography. Other uses include tanning, cleaning products, dyeing textiles, and coagulant to produce rubber. The typical process to produce acetic acid is the carbonylation of methanol, a procedure that requires the use of fossil fuels, such as natural gas, coal and light products of petroleum.
- **Biochar and humic amendments:** biochar, besides its characterization as a fuel, was also used to produce humic amendments, which are considered biostimulants for plant growth. They were applied directly on soil, to test their effect on soil activity, since they are considered a soil structuring and a biostimulant agent.

5 Socio-environmental impact of the forest treatments proposed

The LIFE BIOREFFORMED project has worked on three priority types of forests:

- **Post-wildfire Aleppo pine forests**, with satisfactory regeneration without previous action since the disturbance, with very high densities and high vulnerability to fire. Forest management is necessary to reduce the risk of fire and restore the main ecosystem services that the forests may offer in the future. This type of action is not economically profitable given that the product obtained does not currently have a commercial value, which in turn conditions its management. If silvicultural treatments are not applied, the future regeneration of the tree is compromised in case of recurrent fire.
- The regeneration of **cork oak forests** is economically unprofitable, making it difficult to ensure the stands' sustainability, which are suffering the effects of climate change. Obtaining value from the products that can be removed from cork oak forests would provide an economic incentive to guarantee their continuity and adaptation to the new climate scenario, helping to prevent the effects of future disturbances such as droughts or fires. It is considered that currently, 2/3 of the Catalan corks in production are located in areas that will be outside their ecological range in 2050.
- Forests affected by a recent **natural disturbance** other than fire. The increase of water stress weakens the vegetation and makes it more vulnerable to abiotic disturbances (wind, snowfall, hail, etc.), which are becoming increasingly frequent and biotic damage (pests and diseases). This is particularly relevant in dense monospecific pine forests. The disturbances are cyclical, and with a degree and mortality that is difficult to predict. After forest management, the forest is supposed to be well structured and therefore increase its future resilience; this is a phase that requires a significant economic effort.

The use of these types of biomasses in biorefineries can **boost economically** their extraction and help to finance these **adaptation/restoration treatments**, which are essential to maintain and improve the **local economy** of the territory and the **sustainability** of the **ecosystems**.



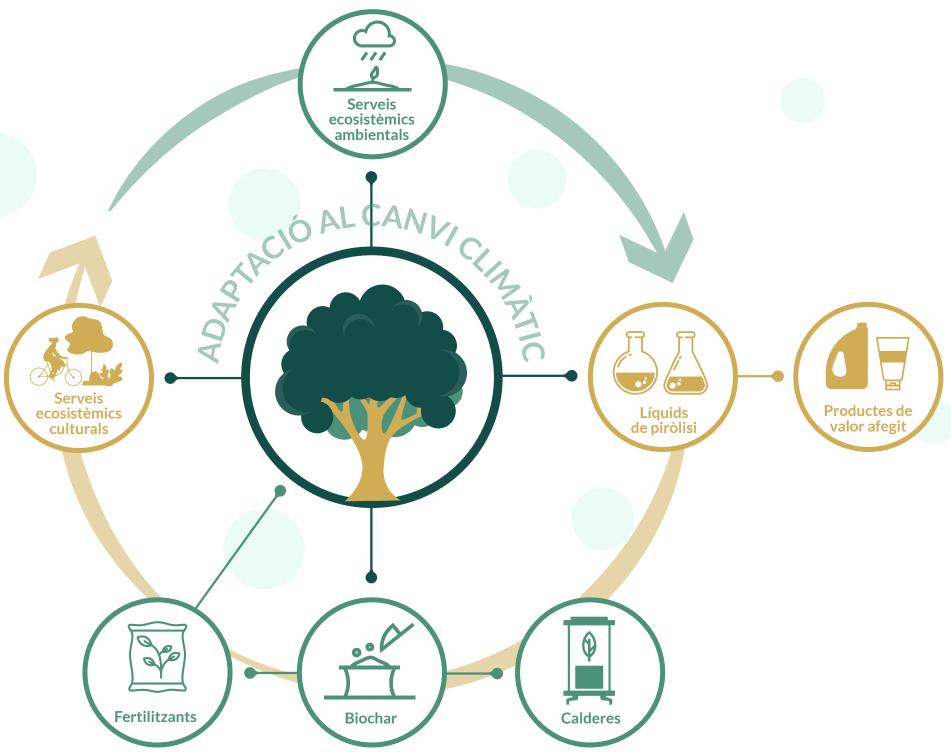
6 Value Proposition for Businesses

Sustainability & Carbon Footprint Reduction:

- The biorefinery processing of 1 kg of non-commercial biomass to produce **solid components (biochar) and liquid components**—yielding valuable extracts such as acids, sugars, and antioxidants—yields an **average overall impact of 0.56 kg CO_2 equivalents**.
- Considering the potential extraction of liquid components, **this process has 3.7 times less environmental impact than the combined production of the same products** through today's conventional industry.
- **Biochar** offers long-term carbon sequestration by trapping carbon in soil, helping businesses meet **carbon neutrality targets.**
- **Biostimulants** produced from biochar can **replace** the current commercial **fossil-based source**: leonardite, offering companies a more sustainable solution.
- **Biochar** and **bioproducts** can be sold to industries as a **renewable** alternative to petroleum-based products.

Circular Economy Integration:

- Using local, renewable feedstock such as forest residues or wood waste creates a **closed-loop system**.
- Companies can integrate the conversion of biomass into their own operations or partner with biomass processing facilities to create **synergies.**



7 Investment Considerations

Costs:

- Initial capital investment is required for **pyrolysis plants**, but there are scalable options available from small modular mobile units to larger industrial plants.
- Funding opportunities exist through **green bonds, government incentives**, and **carbon credits** for renewable energy projects and carbon sequestration initiatives.

Return on Investment (ROI):

- Revenue can be generated from **bio-oil-derived product** sales to industrial sectors and **biochar** and **biostimulant** sales in the agricultural sector.
- **Long-term value** is derived from **reduced energy costs**, enhanced **sustainability** credentials, and potential **carbon offset credits**.

8 Conclusion

Forest biomass and **biorefineries** offers a promising and sustainable alternative to the conventional production of **fuels** and **chemicals.** Furthermore, it presents a **significant opportunity** for businesses to lead in sustainability, reduce costs, and create new revenue streams. The transformation of biomass into bioproducts aligns with global trends toward **green energy** and offers long-term benefits for businesses, the environment, and society.

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