



Novel fibre value chains & ecosystem services from
sustainable feedstocks

Deliverable 3.1 Analysis of the current value chain activities for the
pilot validation trials

28/11/2024

GENERAL DATA

Project acronym: FIBSUN

Project title: Novel fibre value chains & ecosystem services from sustainable feedstocks

Grant Agreement: Project 101112318

Project lead: Natural Resources Institute Finland (LUKE)

Call and topic identifier: HORIZON-JU-CBE-2022-R-05 (RIA): Sustainable fibres biorefineries feedstock

Type of action: Research and Innovation Actions

Project duration: 48 months (June 1st 2023 - 31st May 2027)

Document Information			
WP	3	Task	3.1
Due date	30/11/2024		
Version	V1	Status	Final
Dissemination level	PU		
Deliverable leader	MANF		
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Document History		
Version	Publication date	Change
V1	28/11/2024	

DISCLAIMER

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The present Deliverable 3.1 (D3.1) analyzes the current value chain activities for the five pilot validation trials (PVTs) conducted on an industrial scale within the FIBSUN project. It summarizes the information collected so far through questionnaires and interviews with the involved partners, but also thanks to the several contributions from the literature. This information is in some cases partial and not final, as it evolves in parallel with the progress of the PVTs.



ABSTRACT

FIBSUN supports the development of resilient and competitive production systems and enhanced provision of ecosystem services from degraded and marginal soils, by facilitating sustainable fibre value chains in European industries, via a series of five Pilot Validation Trials (PVT). Its work package on value chain development (WP3) evaluates the economic viability and environmental performance of the novel value chains and develops business strategies to enhance the utilization of biomass from marginal lands in industrial applications and focuses on three key factors for each PVT: technological, market, and economic factors.

This report examines the current value chain aspects and activities relating to the PVTs and processes, considering input processes (suppliers and suppliers of suppliers), throughput processes (manufacturers), output processes (distributors, customers), and return/circular processes. This analysis represents the first of the two deliverables in which Task 3.1 – Analysing technological & value-chain aspects of PVTs is structured.

This report is organized as follows:

- Chapter 1 is an introduction to the analysis of the current value chain activities for the PVTs;
- Chapter 2 describes the methodology adopted to collect information and data on the progress of the PVTs;
- Chapter 3 presents the analysis of the current value chain activities for the PVTs, focusing on existing technologies, PVT's progress and first results, and a preliminary assessment of their technological advancements;
- Chapter 4 provides a preview of the forthcoming evaluations about the PVTs' technological advancements, especially concerning the Technology Watch;
- Chapter 5 gives a brief conclusion and outlines the next steps.

This report summarises the current progress of the PVTs and forecasts their future scenarios. It is the basis for the next evaluations included in the WP3, especially for the next deliverable Synthesis report on technological advances (Technology Watch), market opportunities & economic feasibility (D3.2), whose results will depend on the developments in the work packages about biomass production (WP1) and industrial processes (WP2).



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1. INTRODUCTION

This report provides a comprehensive synthesis of the current value chain activities for the Pilot Validation Trials (PVTs) of FIBSUN project. It investigates the economic feasibility of the novel value chains and formulates business strategies that facilitate improved use of biomass from marginal land in industrial applications.

Focusing on input processes (suppliers and suppliers of suppliers), throughput processes (manufacturers), output processes (distributors, customers), and return/circular processes of the five PVTs, this analysis is part of the Task 3.1 – Analysing technological & value-chain aspects of PVTs, which includes two main Deliverables: the Deliverable 3.1 (D3.1) - Analysis of the current value chain activities for the pilot validation trials and the Deliverable 3.2 (D3.2) - Synthesis report on technological advances (Technology Watch), market opportunities & economic feasibility. Through them, each PVT is examined on the basis of some key factors (technological, circularity, market and economic), which act as a reference and a common thread throughout all activities in WP3.

Due to their nature and the sector they belong to, each of the partners occupies a different position within the new value chains created for the five PVTs of the FIBSUN project. Based on this premise, they were able to provide an interesting overview of technologies, processes, and materials currently existing in the established value chains related to each pilot, highlighting strengths and weaknesses and identifying key trends and recent developments.

The Analysis of the current value chain activities for each PVT mainly starts from the crop processing stage, while the cultivation and harvesting phases are extensively covered in the Deliverables related to WP1 and WP2, to which reference is made. Complete value chains will be, however, included in the technological and economic analyses of the D3.2.

The five PVTs implemented in the project by the research and industrial partners are (see Figure 1):

- **PVT1: Non-Woven Insulation Materials from Hemp Fines**, which focuses on transforming hemp fines, an underutilized agricultural by-product, into sustainable non-woven insulation materials;
- **PVT2: Composites from MFC-Improved Hemp Fibres for Automotive Applications**, which aims to enhance the mechanical properties of hemp fibres for use in automotive composites;

- **PVT3: Concrete with Fibres from Underutilized Trees on Contaminated Soils**, which explores the use of fibres extracted from trees grown on contaminated sites as a partial replacement for aggregates in concrete;
- **PVT4: Textile Yarn from Cardoon Fibres**, which aims to capitalize on fibres sourced from cardoon stalks, integrating them with cotton fibres to foster a new generation of sustainable textiles;
- **PVT5: Flexible Insulation Boards with Fibres from Tall Aquatic Grasses**
In PVT5, the focus is on validating the use of cattail and common reed fibres for flexible insulation boards.

They are currently in progress with the aim to verify the industrial and economic feasibility of the new bio-based solutions.

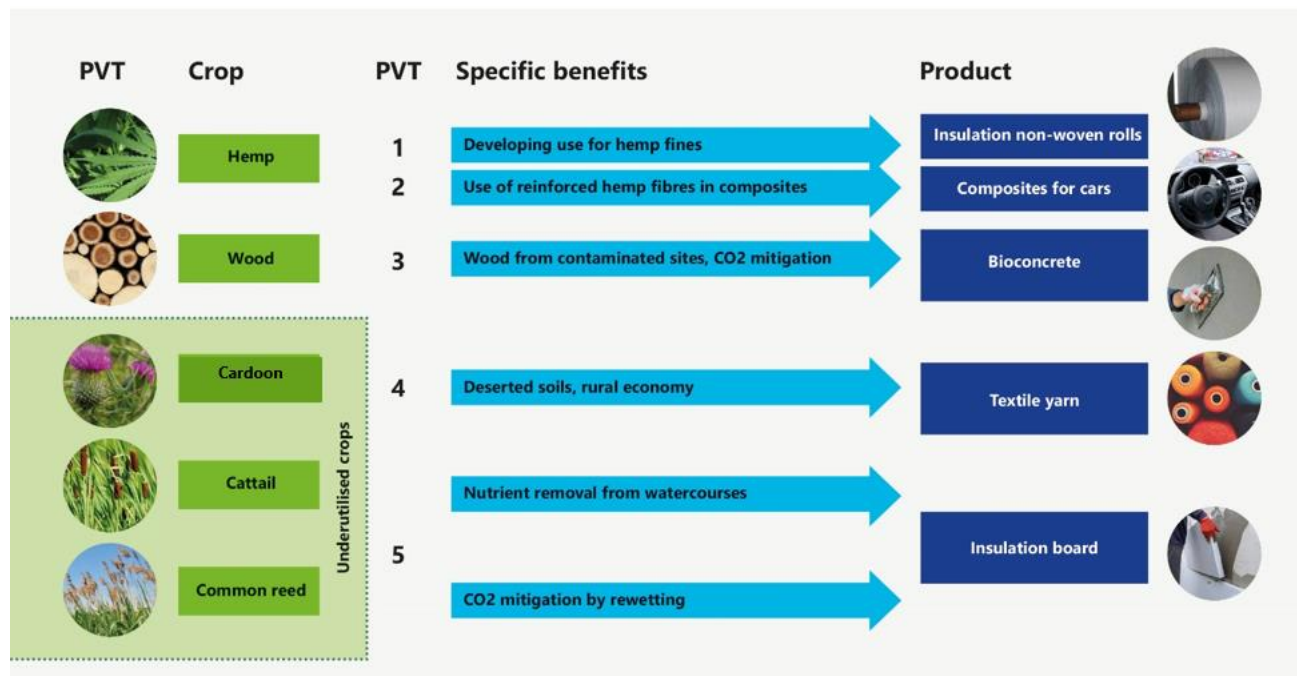


Figure 1. Crops, pilot-specific benefits and final products in FIBSUN's PVTs.

2. METHODOLOGY

In order to analyse the current value chain aspects and activities relating to the PVTs and processes, Manifaktura (MANF) and Steinbeis (SEZ) collaborated in gathering qualitative and quantitative information on each of the five pilots conducted in the project (see Table 1).

The first and main tool used for collecting information and data is the **Value-chain Questionnaire** (see Figure 2), designed by Steinbeis and administered to the industrial partners of each PVT. The questionnaire opens with a simplified overview of the five PVTs and the related value chains, and it is structured into 3 sections, each containing 3 open-ended questions: the first section (1. Overview of current technologies) asks for a general description of the existing technologies, processes and materials currently used in the established value chain; the second one (2. Presentation of the pilot) regards the presentation of the pilot(s) in which the partner is involved; and the third section (3. Analysis of technological advances of the pilot) aims to investigate the technological advancements of the pilot(s).

Table 1. Overview of the value chains related to the PVTs. Industrial partners are coloured to set them apart from academic and consulting partners.

Value chain	Fibre crop	Origin	Field site operations (WP1)	PVT - Product	Industrial process development (WP2)	Established product/competitor
A	Hemp <i>Cannabis sativa</i>	Germany	BAFA	PVT1 - Non-woven insulation materials	CORM, SOPR, LUKE	Rock wool Glass wool Recycled cotton-based insulation materials
B	Hemp <i>Cannabis sativa</i>	Germany	BAFA	PVT2 - Composites from microfibrillated cellulose for automotive application	CORM, HP, FTL	Fibreglass Natural fibres such as jute, sisal, coconut
C	Wood e.g. <i>Populus</i> spp.	France	FCBA	PVT3 - Concrete reinforced with fibres from underutilised trees cultivated on contaminated soil	FCBA, Vicat	Steel fibres Basalt fibres Rebar (reinforcement steel)
D	Cardoon (Thistle/Artichoke) <i>Cynara cardunculus</i>	Portugal	F4S	PVT4 - Textile yarn	TEFI	Cotton Flax Wool Polyester
E.1	Cattail <i>Typha</i> spp.	Netherlands	SRU	PVT5 - Flexible insulation boards	LUKE, ÅAU, SOPR, GRA	Wood Cork Silica-based insulations Plastic-based insulation such as polyurethane, polystyrene and other composites
E.2	Common reed <i>Phragmites australis</i>	Finland	LUKE			

Questionnaire	
Participant (dropdown list) Wählen Sie ein Element aus.	Value chain/Product/Crop:
1. Overview of current technologies 1.1. Describe the existing technologies, processes and materials currently used in the established value chain: 1.2. Analyse the strengths and limitations of current technologies, processes and materials: 1.3. Identify key trends and recent developments of current technologies, processes and materials: 2. Presentation of the pilot 2.1. Describe the specific pilot considered in the new value chain: 2.2. Explain the distinctive features of the pilot and the technologies adopted: 2.3. Discuss the reasons for selecting the pilots for comparison with current technologies: 3. Analysis of technological advances of the pilot 3.1. Evaluate the performance and characteristics of the pilots compared with current technologies: 3.2. Identify the strengths and aeras for improvement of the pilots compared to current technologies: 3.3. Present the results of quantitative and qualitative analysis of the technological advances of the pilots: 	

Figure 2 The Value-chain Questionnaire.

Once the requested information was received through the questionnaire, it was further explored through one-on-one interviews with the industrial partners.

As shown in the next chapter, the contributions provided by the partners in each of the 3 sections of the Value-Chain Questionnaire have been integrated with some useful insights. For the first section, universities and research centers involved in each PVT were asked to provide research documents, such as papers, reports, references, or any other relevant content, in order to analyze the state of the

art in the literature regarding the existing technologies, processes, and materials currently used in the established value chain. The documents have been then organized into a Literature Index (see Figure 3) to facilitate the access and the consultation of their contents by the partners. The Index is currently shared and available for the project partners on the FIBSUN channel on Teams.

LITERATURE INDEX - PVT1					
TITLE	YEAR	AUTHORS	TYPE OF DOCUMENT	ABSTRACT	LINK
"Traditional, state-of-the-art and renewable thermal building insulation materials: An overview".	2019	Basim Abu-Jdayil, Abdel-Hamid Mourad, Waseem Hittini, Muzamil Hassan, Suhaib Hameedi	Paper	Energy saving has become a strategic goal in the whole world, that will lead to protect the environment and conserve natural resources. The energy consumption in buildings for heating and cooling is considered as one of the major sources of energy consumption in a lot of countries. Therefore, there is an ongoing search for finding the proper alternatives to preserve energy and minimize energy losses. Subsequently, heat insulators, part of building materials, are steadily getting their importance as a means of saving energy. Although, a lot of insulation materials are used commercially, this part of building construction still faces different difficulties and challenges such as the cost, thermal and mechanical properties, health problems, etc. Current insulation materials used in construction industry are generally polymer based materials such as polystyrene and polyurethane foam. Although these materials have a high performance in thermal insulation, but the environmental impacts in their production processes are significant. Consequently, the researchers find that there is a necessity to develop and come up with insulating materials that possess excellent properties and at the same time, they have less environmental impacts, and are relatively cheap. In this review paper, the researches carried out in the formulation and development of different kinds of thermal insulation in the last decades are presented. The focus was placed on researches utilized of renewable resources and wastes in thermal insulations development. In addition, the light was shed on the composites materials which was developed as a construction material with high thermal insulation capacity.	1-s2.0-S0950061819309845-main.pdf
"A framework for sustainable and circular system design: Development and application on thermal insulation materials".	2019	Maja Wiprichtiger, Melanie Haupt, Niko Heeren, Eliane Waser, Stefanie Hellweg	Paper	Circular economy is increasingly promoted as a solution to decouple economic growth and environmental impacts. To design a circular and sustainable system, a structured approach is needed. In this study, we suggest to follow a 3-step approach. First, the status quo is evaluated using environmental assessment methods. We determine current circularity (share of assessed product and material retained and further used in the system), environmental impacts, the most impactful products and processes, and assess contaminants and impurities. Second, scenarios favoring circularity strategies are developed and their environmental impacts evaluated. Third, the scenarios are compared and measures for environmental impact mitigation derived. The suggested approach was applied to the case study of thermal insulation in residential buildings in Switzerland. Coupling dynamic, prospective material flow analysis with life cycle impact assessment enabled to determine current and future environmental impacts. Current material circularity is low due to lacking incentives for recycling and legally required incineration of flame retardant containing oil-based materials. The most impact-intensive processes were the production of insulation materials and the incineration of oil-based materials including their adhering residues. The investigated scenarios include (i) increased recycling, (ii) augmented use of biogenic materials, and (iii) a combination thereof. All scenarios lead to reduced climate change and human toxicity impacts. The second and third scenario showed increased impacts for land use, ozone depletion, and ecotoxicity. Taking into consideration end-of-life already in the design process, phasing out toxic materials, and increasing usage of renewable materials are crucial for sustainable, circular system design.	1-s2.0-S0921344919305373-main.pdf
		LiFang Liu,		Thermal insulations have begun to play an increasing important role in realizing building energy saving in the past years. Thermal insulations made of biomasses like agro-residues, forest residues, etc., are developing very fast recently, although their research and development history is relatively short. In order to help researchers to achieve a global viewpoint of the research on this topic and to improve the research and application progress, a systematic review is presented in this study. After review and screening, 144 original research journal papers were selected as samples and analyzed to investigate the following topics: Historical development of bio-insulations from 1974 up to April 2016, from viewpoint of number of	

Figure 3. The Literature Index.

For the second section, the presentations of the PVTs have been enhanced with updates from WP2 on the most recent progress of each pilot and the first results achieved.

For the third section, the industrial partners of each PVT were asked to give further information for assessing the technological advancements of the pilot(s). In particular they were asked to answer some open-ended questions about the technical and regulatory standards they use or know for the evaluation of the quality of raw materials, production processes and end products.

In conclusion, the methodology employed for collecting information and data on the five PVTs revolves around the key tool of the Value-Chain Questionnaire. Indeed, through a series of open-ended questions

organized in 3 sections, it facilitated the gathering of qualitative and quantitative information on each pilot.

The contributions obtained through interviews, literature and updates represent the starting point, not only for the analysis of the current value chain aspects and activities related to the pilots discussed in the next chapter, but they also form the basis of the knowledge necessary for the implementation of the Technology Watch's methodology (Chapter 4), grounded in a systematic collection and evaluation of information and data regarding the technological advancements of the PVTs.



3. ANALYSIS OF THE CURRENT VALUE CHAIN ASPECTS AND ACTIVITIES FOR THE PVTs

In the following paragraphs, the current value chain aspects of the five PVTs will be analyzed based on the information and contributions provided by the partners involved in each pilot. First, technologies, processes, and materials currently existing in the value chains related to each PVT will be examined. Then, the PVTs will be described in detail along with their progress status and the first results achieved, focusing on the input, throughput and output processes, as well as on the circularity aspects. Finally, preliminary evaluations of the technological advancements for each PVT will be presented. The results of this analysis represent the basis for the next evaluations included in the WP3, especially concerning the Technology Watch.

3.1 Overview of existing technologies, processes and materials in the established value chains

In this paragraph, the information provided by the partners for each PVT is further developed through the integration of the most relevant contributions currently available in the literature.

- **PVT1: Non-woven insulation materials with hemp fines**

In the PVT1, where the hemp fines are used for the production of non-woven insulation materials, BAFA operates upstream of a well-established value chain that encompasses several key technologies and processes. At the forefront are cultivation and harvesting techniques specifically tailored for industrial hemp. Following this, the mechanical processing of hemp fibres involves fibre decortication, a crucial step that separates the valuable fibres from the plant material. The value chain is further enriched by a variety of fibre qualities, each suited to different industrial applications.

One of the significant strengths of these current technologies is the ability to adapt and modify natural fibres throughout the harvesting, retting, and decortication stages. This flexibility allows for the production of diverse fibre qualities tailored to various industrial needs: technical fibres for insulation and automotive applications, short fibres for the paper industry, and ultra-short fibres for use in brake pads.

However, there are some challenges to consider, indeed weather conditions during cultivation and harvesting can impact fibre quality, while the natural variability of raw materials poses limitations on

standardization. A potential solution lies in raising customer awareness about the nature of these products, emphasizing that while technical specifications must be met, cosmetic aspects like color should not determine quality.

Additionally, the current technologies do not support the production of long hemp fibres suitable for textile applications. Addressing this gap may require investment in new technologies, which could be feasible if new markets emerge. Another constraint is the limited production capacity within the existing framework. To overcome this, investing in technologies that enhance throughput could be beneficial, particularly as sales begin to increase.

In terms of key trends and recent developments, there is a growing focus on modifying processing parameters to better align with the needs of new applications and on expanding production capacity to meet rising demand. These advancements reflect an ongoing commitment to innovation and adaptability within the hemp industry.

Besides BAFA, the other two industrial partners involved in the PVT1 are CORMATEX and SOPREMA. As regards CORMATEX, its forming process primarily utilizes a carding machine, which creates a parallel-laid web of fibres. In this method, the fibres are oriented mainly in the direction of the machine, a technique that has its roots in traditional non-woven textile machinery. After carding, the process may continue with a lapping stage, such as cross-lapping, to further refine the material. The main goal of carding is to disentangle and comb the fibres, resulting in a homogeneous web with a uniform weight across its surface. One of the key advantages of this technology is its ability to maintain consistent weight distribution, even for very lightweight products. The precise fibre orientation achieved during carding can be beneficial for certain applications, but it can also present challenges for others that require a random orientation of fibres in both machine and cross directions.

However, carding technology has some limitations. It can only process fibres that meet specific minimum length requirements, and it is restricted to using fibrous raw materials. Additionally, there is a maximum weight and loftiness that this technology can achieve, which can pose challenges for applications such as thermal insulation panels in buildings.

In terms of recent trends and developments, the Airlay forming system offers a distinctly different approach compared to the carding machine. This system employs an airstream to guide both fibrous and non-fibrous materials toward a permeable screen or conveyor. Here, the air is separated, allowing the fibres to be randomly deposited, creating a unique web structure. This innovative method opens up new possibilities in material formation within the textile industry.

The other industrial partner in this PVT is SOPREMA, which harnesses an innovative technology centered around pMDI binders, which are pivotal in the dry process used to manufacture wood fibre panels. At the heart of this process lies a sophisticated matformer, shaping the wood material into panels that boast impressive strength and versatility. One of the standout features of this technology is its wide array of applications for thermal insulation in buildings, with panel densities ranging from 80 to 200 kg/m³. This adaptability makes it an attractive option for various construction needs. However, there are limitations to consider: the current development stage of the bio-based binder presents challenges that render it less suitable for some applications; good mechanical performance can be achieved always on a wood base and the product is intended for professionals with complex applications on-site (ETICS, roofing). Moreover, according to SOPREMA, key trends are emerging in this field, notably the integration of bio-based glues and the introduction of new fibres, which allow for a substitution rate of 10% to 50%, while maintaining a wood base. These developments signify a progressive shift towards more sustainable practices in insulation technology, reflecting the industry's ongoing evolution.

Relevant literature

In the "*Traditional, State-of-the-Art, and Renewable Thermal Building Insulation Materials: An Overview*" (Basim Abu-Jdayil *et al.*, 2019) the authors offer a comprehensive examination of various thermal insulation materials used in building construction, categorizing them into three main groups: traditional, state-of-the-art, and renewable. They examine traditional insulation materials like fibreglass, mineral wool, and polystyrene, discussing their thermal performance, cost-effectiveness, and installation techniques, while also noting their environmental impact and limitations. Basim Abu-Jdayil *et al.* (2019) explore state-of-the-art options such as vacuum insulation panels and aerogels, which offer superior thermal performance but may have higher costs and specific installation challenges. The authors also highlight the growing importance of renewable materials like cellulose, sheep's wool, and hemp, which provide effective insulation and reduce environmental impact, supporting sustainable building practices. The authors conclude by emphasizing the need for continued research and development to improve insulation performance and sustainability in energy-efficient construction.

Another interesting contribution from the literature on this topic is "*A Framework for Sustainable and Circular System Design: Development and Application on Thermal Insulation Materials*" (Maja Wiprächtiger *et al.*, 2019), which introduces a framework aimed at enhancing sustainability and circularity in the design of thermal insulation materials. It emphasizes principles of the circular economy, focusing on resource efficiency, waste reduction, and the use of sustainable materials throughout the product lifecycle. They propose specific criteria and indicators to evaluate the sustainability and

circularity of insulation materials, facilitating informed decision-making for stakeholders. Through case studies, they illustrate the practical application of the framework, demonstrating how it can guide the selection and design of insulation that supports sustainable building practices. The authors conclude by highlighting the need for collaboration among industry, researchers, and policymakers to promote circular system design in thermal insulation, ultimately contributing to more sustainable construction. Finally, an analysis of possible future scenarios is provided in the "*The Development History and Prospects of Biomass-Based Insulation Materials for Buildings*" (LiFang Liu *et al.*, 2016), which examines the evolution and future potential of insulation materials made from biomass. It traces the historical context of these materials, noting their traditional uses and growing popularity in sustainable building practices. They discuss various biomass materials, such as wood fibres, straw, and cellulose, highlighting their thermal performance and environmental benefits. They also address challenges like moisture absorption and fire resistance but note advancements in technology that improve these materials' performance. Looking forward, the authors emphasize the increasing market demand for sustainable construction materials and suggests that biomass insulation can significantly contribute to this trend. They advocate for ongoing research and innovation to enhance the properties of biomass-based insulation and encourage its adoption in the building industry.

- **PVT2: Composites from MFC improved hemp fibres for automotive applications**

The PVT2 focuses on developing composites made from MFC-improved hemp fibres to enhance their mechanical properties for use in automotive applications. In this pilot BAFA and CORMATEX implement the same activities as PVT1, while FIBERLEAN and HP Composites are involved, respectively, in the application of FIBERLEAN® MFC on non-woven rolls to improve their mechanical performance and in the use of these materials for the production of composites for automotive applications.

In particular, according to FIBERLEAN, the current value chain in the automotive sector relies on established technologies, processes, and materials, particularly fibreglass laminates impregnated with resin used for composite production. These materials have both strengths and limitations: on one hand, they provide high performance, on the other, the final product is extremely difficult to recycle. Recent trends and developments in technology and materials are increasingly focusing on the incorporation of biobased materials. This innovation aims to achieve similar performance levels to traditional products without the use of petrochemical-derived substances, paving the way for more sustainable solutions in the industry.

For HP Composites, in today's automotive industry, high-performance components are predominantly crafted from synthetic, fossil-based composite materials. These materials can be categorized into two main groups: body components and chassis components. Exterior body components, such as hoods and door panels, demand high stiffness and damage tolerance, along with a "Class A" surface finish for aesthetic appeal. For these applications, composite materials like E-glass or carbon fibre-reinforced composites are utilized, featuring either continuous or discontinuous fibres impregnated with resin systems such as epoxy, polyester or vinylester.

While glass fibre-reinforced polymers are the most commonly used composites in modern vehicles, there is a growing recognition that substantial weight reduction, critical for improving fuel efficiency, can only be achieved with Carbon Fiber Reinforced Polymers (CFRP). These materials offer significantly higher strength-to-weight and modulus-to-weight ratios compared to their glass fibre counterparts.

The manufacturing processes for these Fiber Reinforced Polymer (FRP) parts typically include autoclave or compression molding.

A primary design requirement for many exterior panels is the attainment of a "Class A" surface finish, which can be challenging for certain materials and technologies. However, many components located under the body or hood do not prioritize external appearance, allowing for greater flexibility in material choice.

Strengths and limitations of current technologies composite materials are increasingly recognized as essential for weight reduction across various automotive applications. The growing emphasis on developing more efficient vehicles, particularly high-range Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs), has prompted manufacturers to embrace these innovative materials to counterbalance the heavy batteries used in these vehicles.

Composites offer exceptional performance at a notably low weight. However, the European market, along with many international markets, is governed by stringent and evolving environmental regulations. Although CFRPs are advantageous for reducing weight and, consequently, the fuel consumption and emissions associated with transportation, they are not free from these regulatory challenges. On one hand, using composite materials in EVs can lower energy consumption during operation. On the other hand, the transition from traditional materials like steel and aluminum to composites often results in increased energy consumption during the manufacturing phase, generating higher environmental impacts and posing challenges for recyclability. It is estimated that the production of raw materials (fibres and matrices) accounts for over 90% of the total environmental impacts of CFRPs (Vita *et al.*, 2019). Regarding the key trends and recent developments to address these concerns, there is a pressing need

to identify alternative and sustainable materials to replace synthetic, fossil-based composites. Innovative solutions that leverage natural materials, which are both cost-effective and biodegradable, as well as recycled materials, are increasingly being explored to mitigate the environmental footprint of current solutions that are intensive in CO₂ emissions and energy consumption. For instance, natural fibre composites hold significant potential as alternatives to synthetic fibre composites in automotive applications, offering a more sustainable path forward.

Relevant literature

The "*Bioepoxy based advanced lightweight hybrid composites from hemp fibers: Towards greener production*" (Krittirash Yorseng *et al.*, 2024) explores the development of sustainable and lightweight composites utilizing bioepoxy resins and hemp fibres. They emphasize the environmental benefits of using hemp, a renewable and biodegradable resource, as a reinforcement material. Bioepoxy resins, derived from renewable sources, are highlighted for their comparable performance to traditional synthetic materials while significantly reducing ecological footprints. The authors detail various production methods that prioritize eco-friendly processes, ensuring a greener approach to composite manufacturing. Mechanical property analyses demonstrate that these bio-based composites can compete effectively with conventional materials, making them suitable for a variety of applications, particularly in sectors such as automotive and construction where lightness and sustainability are paramount. Furthermore, the authors propose future research directions aimed at optimizing composite formulations and exploring additional biomaterial sources. Overall, they promote the adoption of bio-based materials to address environmental challenges, offering innovative solutions for lightweight composite production.

In the the "*Bio-based treatment of hemp fiber for use as reinforcement of a composite: An effort towards development of green and sustainable polybenzoxazine brake pad*" (Ibrahim Lawan *et al.*, 2024) the authors investigate the treatment of hemp fibres to enhance their effectiveness as reinforcement materials in eco-friendly brake pads made from polybenzoxazine. In particular they present various bio-based treatment methods aimed at improving the mechanical properties and compatibility of hemp fibres with the polybenzoxazine matrix. A key focus is on sustainability, highlighting the need for brake pads that reduce reliance on synthetic materials, thereby minimizing environmental impact. The study shows that treated hemp fibre-reinforced composites exhibit superior mechanical performance compared to untreated fibres, making them suitable for automotive applications, particularly in brake systems where both performance and sustainability are critical. Ibrahim Lawan *et al.* also suggest future research

directions to optimize the treatment processes and explore additional bio-based fibres, ultimately aiming to enhance the performance and environmental benefits of brake pads.

Finally, particularly relevant to the themes and activities of the PVT2 is the study "*A Review on Natural Fiber Composite Materials in Automotive Applications*" (Venkatesh Naik *et al.*, 2022), which provides a comprehensive overview of the use of natural fibre composites in the automotive industry. The authors discuss the growing interest in these materials due to their lightweight, biodegradable nature, and renewable sourcing, which align with sustainability goals in automotive manufacturing. Key topics include the various types of natural fibres, such as hemp, jute, and flax, and their mechanical properties, which are crucial for automotive applications. The review highlights the benefits of using natural fibres, including reduced weight, improved fuel efficiency, and lower environmental impact compared to traditional materials like fibreglass and carbon fibre. The authors also address challenges associated with natural fibre composites, such as moisture absorption, compatibility with matrices, and variability in fibre properties. They emphasize the importance of proper treatment and processing techniques to enhance performance and durability. Furthermore, this review outlines current and potential applications in automotive components, such as interior panels, door trims, and structural parts, showcasing successful case studies. Venkatesh Naik *et al.* call for more research and development to overcome existing challenges and fully leverage the advantages of natural fibre composites in the automotive sector.

- **PVT3: Concrete with fibres from underutilised trees on contaminated soils**

In the PVT3 the two main partners involved are Institut Technologique FCBA and VICAT, whose activities aim to investigate the incorporation of fibres from trees cultivated on contaminated land as a partial substitute for aggregates in concrete.

VICAT describes how bio-based materials are integrated into concrete production. In this process, indeed, bio-based materials are mechanically crushed into particles ranging from 2 mm to 4 cm, which are then mixed with cement to create a bio-based concrete that boasts enhanced thermal and acoustic properties. Various bio-based materials can be incorporated, with examples from France including hemp, wood (sawdust and shavings), flax, beetroot pulp, miscanthus, lavender, and rapeseed.

The specific material currently developed by VICAT consists of cement and hemp shives derived from conventional hemp production, paired with cement from VICAT's own manufacturing. The strengths of this approach include a reliable supply chain for both cement and hemp shives, which allows for

sufficient production volumes. The addition of plant particles not only reduces the density and carbon footprint of the concrete (T. P. L. Siqueira *et al.*, 2022; Barbhuiya *et al.*, 2024) but also enhances its acoustic and thermal performance.

However, there are notable limitations. The ratio of plant particles to cement must be carefully controlled to mitigate issues related to wood acidity, which can affect the bond between wood and concrete. Pre-treatment solutions may be required to address these challenges, potentially involving the use of mineral binders like specific cements, lime, pozzolans, or silica fume to improve compatibility. Additionally, the hemp sector is experiencing increased price pressures, which could affect material costs.

Since concrete is often mixed on-site, sourcing wood particles close to construction locations is essential. Furthermore, wood-based concrete tends to be 15% to 20% more expensive than conventional precast concrete.

The introduction of bio-based materials can also alter mechanical properties, depending on the concrete mix and binder type. Recent trends in technology emphasize the development of ready-to-use bricks that enhance acoustic insulation. As a result, concrete manufacturers must refine the size and shape of wood particles to ensure compatibility with prefabrication processes. The type and quantity of binders are critical for achieving desired mechanical properties, necessitating ongoing optimization of formulations. It is also important to diversify the sources of plant materials to avoid reliance on a single supply chain. Finally, the potential implementation of CO₂ pricing could positively impact the industry by promoting the use of more sustainable materials.

Relevant literature

The "*State of the Art Review of Attributes and Mechanical Properties of Hempcrete*" (Nima Asghari and Ali M. Memari, 2024) presents a detailed examination of hempcrete, a sustainable building material composed of hemp hurds and lime. The authors explore its mechanical properties, highlighting key attributes such as compressive and tensile strength, as well as excellent thermal performance, which make it suitable for construction applications. The review points out the environmental benefits of hempcrete, including its ability to sequester carbon and its low energy consumption during production, aligning with green building practices. However, the authors also address challenges such as variability in material properties, moisture sensitivity, and the need for standardization in building codes. They suggest future research directions to enhance durability, investigate alternative binders, and optimize production processes.

More focused on the potential of wood-based concrete as a sustainable building material, is the study *"How to Build More Sustainably: Could Wood-based Concrete Be the Answer?"* (Camille Rustici, 2022), which discusses the environmental advantages of incorporating wood fibres into concrete, such as reducing carbon emissions and improving thermal and acoustic properties. Rustici highlights the benefits of using renewable resources, addressing the increasing demand for eco-friendly construction materials. However, the author also identifies challenges, including the higher cost of wood-based concrete compared to traditional precast options and the need for careful management of wood particle ratios to maintain structural integrity. The study emphasizes the importance of ongoing research and development to optimize the formulation and production processes, aiming to enhance the performance and affordability of wood-based concrete.

Another useful comprehensive analysis on the topic of bio-based building material is contained in the *"Overview on Bio-based Building Material Made with Plant Aggregate"* (Sofiane Amziane and Mohammed Sonebi, 2016). Here the authors explore various types of plant materials, such as hemp, flax, and straw, highlighting their properties and benefits in construction. The review discusses the mechanical and thermal performance of these bio-based materials, pointing out their potential to enhance energy efficiency and sustainability in building applications. The authors also address the challenges of using plant aggregates, including variability in material properties and durability concerns, while advocating for further research to optimize formulations and processing techniques.

- **PVT4: Textile yarn with cardoon fibres**

The PVT4 revolves around utilizing fibres from cardoon stalks and blending them with hemp and cotton fibres to create a new generation of sustainable textiles. Besides FOOD4SUSTAINABILITY, responsible for delivering cardoon biomass, TEARFIL is the industrial partner involved in carrying out the pilot's activities.

TEARFIL is currently specialized in processing hemp and cotton fibres for textile applications, while cardoon represents for them a raw material that has never been processed before. The functionalisation of the cardoon fibres is one of the challenges for TEARFIL.

In the value chain of mixed yarns that combine hemp and cotton, the production methods for hemp yarn are well-established and predominantly applied in automotive applications. The production processes along the entire value chain of the textile industry are fully defined and are considered "conventional," currently serving a wide range of applications, from the fashion industry to home textiles and various

technical uses. All spinning technologies can be utilized for the production of yarn made from cotton and hemp fibres, including conventional methods such as ring spinning, open-end spinning, compact spinning and other less common techniques. Initially, the fibres can be dyed or left in their natural state, depending on the intended use. The next steps involve heating and carding the fibres, which pass through a varying number of stages on the drawing frame, resulting in the creation of roving. Subsequent processes include spinning and winding.

All these steps, carried out with different types of equipment, aim to transform the fibres into yarn through mixing, diameter reduction, fibre alignment and uniformity. This ensures the final product meets the necessary quality standards for specific applications. Hemp yarn is recognized for its strong physical properties, including resistance to abrasion and water, making it a valuable material in various contexts. Hemp and cotton are both fibres that are already quite intensive, particularly cotton in the textile sector. For the different applications and types of fibre, there are no significant limitations. The purchase of hemp and cotton fibres is primarily based on their quality of origin, as well as their price. Recently, there has been a trend toward enhancing these fibres through functionalization with metal ions, aiming to improve their performance and expand their applications. Today the main trends are emerging in the context of sustainability, focusing on reducing waste and promoting a circular economy. This movement has notably evolved, especially regarding cellulosic fibres like hemp and cotton.

Relevant literature

The study "*Cynara cardunculus L. as a biomass and multi-purpose crop: A review of 30 years of research*" (Jorge Gominho *et al.*, 2018) proposes a thorough evaluation of the potential of cardoon (*Cynara cardunculus L.*) as a versatile biomass crop. The authors summarize three decades of research highlighting its adaptability to various climates and soils, making it a sustainable option for biomass production. The review discusses the multiple applications of cardoon, including its use in bioenergy, fibre production, and as a raw material in the food and pharmaceutical industries. The authors also examine the crop's environmental benefits, such as carbon sequestration and soil improvement. Challenges in cultivation, such as pest management and yield optimization, are addressed, along with future research directions aimed at enhancing its economic viability.

Other two interesting contributions from literature about the use of biomass for textile applications are the following: "Utilization of agricultural biomass for textile applications: Opportunities and challenges" (K. S. R. Gupta, R. N. Singh, 2018) and "Sustainable textile materials from biomass: Recent developments and future perspectives" (A. S. Ramakrishna, M. A. S. M. Noor, 2019).

The first study examines the potential of agricultural biomass as a sustainable resource for textile applications, highlighting its significance in addressing environmental challenges within the industry. Various agricultural residues, such as cotton stalks, hemp, and jute, are explored for their suitability as textile fibres. The study discusses the environmental benefits of utilizing these renewable materials, including reduced dependency on synthetic fibres and minimized waste. Different processing techniques for converting biomass into textile fibres are reviewed, alongside the challenges posed by variability in fibre quality and processing costs. The authors advocate for continued research and innovation to improve extraction methods and processing efficiency, while emphasizing the need for collaboration among academia, industry, and policymakers. Ultimately, the study calls for a strategic shift towards integrating agricultural biomass into the textile sector, promoting a sustainable and eco-friendly approach to textile production.

The second article provides a comprehensive overview of recent advancements in the development of sustainable textile materials derived from biomass. The authors discuss various sources of biomass, including agricultural residues and plant-based materials, and their potential for producing eco-friendly textiles. Key developments in processing technologies, such as extraction and transformation methods, are examined to highlight improvements in fibre quality and functionality. The article also addresses the environmental benefits of utilizing biomass, emphasizing its role in reducing dependency on conventional synthetic fibres and minimizing waste. Additionally, the authors explore future perspectives, identifying challenges and opportunities for innovation in the field of sustainable textiles. By fostering interdisciplinary collaboration and encouraging further research, the study promotes the broader adoption of biomass-based materials in the textile industry, ultimately aiming for a more sustainable and circular economy.

- **PVT5: Flexible insulation boards with fibres from tall aquatic grasses**

The PVT5 concentrates on evaluating the effectiveness of using fibres from cattail and common reed in the production of flexible insulation boards. In this pilot GRASSA and SOPREMA represent the two key partners.

As regards the established technologies utilized in the value chain for processing tall aquatic grasses and other grasses into fibres GRASSA explains that the current machinery is designed to efficiently extract fibres from grass-like biomass. In addition, this process can be expanded to produce also protein

roughage from the juice extracted from the biomass. One of the notable strengths of these technologies is their role in landscape preservation. By employing paludiculture, the processes help prevent peatland oxidation and soil compaction while simultaneously providing feedstock for biobased industries processing fibres (and supplementing livestock feed). The process of converting roughage into energy from feed in the rumen of livestock is currently carried out on an industrial scale.

However, the fibres produced are often seen as byproducts rather than primary products.

Recent trends indicate a growing interest in finding high volume feed sources of constant quality for biobased value chains, which further emphasizes the importance of these technologies in sustainable agricultural practices, particularly within the context of landscape preservation.

As for SOPREMA, it utilizes a bi-component fibres binder technology that employs airlaid technology in its processes. The primary materials involved include wood, cellulose wadding, and cotton. One of the key strengths of this approach is its versatility, allowing for a wide range of materials to be used. This flexibility is particularly beneficial given the relatively low mechanical performance of the products when compared to rigid boards. Additionally, SOPREMA offers improved thermal conductivity and has successfully established a mainstream product in the French market, making it accessible for various applications.

However, there are some limitations to consider. The application range is restricted primarily to internal insulation and between rafters, which narrows its usability compared to more rigid board options. In terms of innovation, current trends highlight the exploration of new fibres and binders (finer, shorter, other composition), reflecting ongoing developments in technology, processes, and materials.

Relevant literature

The study "*Development of Various Building Materials Based on Paludiculture Cattail*" (M. Krus *et al.*, 2023) investigates the potential of cattail, a plant cultivated in wetland environments, as a sustainable resource for building materials. It emphasizes the benefits of using cattail in construction, highlighting its environmental advantages, such as reducing reliance on traditional materials and promoting biodiversity. The authors present various applications of cattail fibres in building materials, discussing their mechanical and thermal properties. They also examine the processes involved in transforming cattail into viable construction products, including insulation materials. This research emphasizes the importance of integrating sustainable practices in the construction industry and the potential economic benefits of utilizing local, renewable resources like cattail.

Another relevant contribution about cattail in literature is "*A Feasibility Study on the Usage of Cattail (Typha spp.) for the Production of Insulation Materials and Bio-Adhesives*" (Colbers et al., 2017), which delves into the viability of using cattail as a sustainable source for insulation materials and bio-adhesives. The study outlines the properties of cattail, emphasizing its availability, renewability, and environmental benefits. The authors conduct a comprehensive analysis of the technical processes required to convert cattail into effective insulation products and bio-adhesives, assessing factors such as material performance, cost-effectiveness, and market potential. They highlight the competitive advantages of cattail, particularly in terms of thermal insulation and eco-friendliness, compared to traditional materials. The findings suggest that cattail can be a promising alternative in the construction industry, supporting sustainable practices while also potentially enhancing local economies.

Regarding common reed, the article "*Common Reed (Phragmites australis) as an Insulation Material - Views on Sustainability for Stakeholder Acceptance*" (Kazi Farzana Karim Baly, 2023) examines the potential of common reed as a sustainable insulation material. It explores the environmental benefits of using this readily available plant, emphasizing its role in promoting sustainability in the construction sector. The study describes the thermal and acoustic properties of common reed, making it an effective alternative to traditional insulation materials. It also addresses the importance of stakeholder acceptance, discussing the perceptions and attitudes of various parties involved in the construction industry, including builders, architects, and consumers. Through a detailed analysis, the study presents barriers to the adoption of common reed, such as market awareness and perceived performance issues. The author concludes with recommendations for enhancing stakeholder engagement and education, promoting policy support to facilitate the integration of common reed into mainstream building practices, thus promoting a more sustainable and eco-friendly approach to insulation.

Finally, another useful reference for common reed is the article "*Can Common Reed Fiber Become an Effective Construction Material? Physical, Mechanical, and Thermal Properties of Mortar Mixture Containing Common Reed Fiber*" (Chang-Seon Shon et al., 2019), which analyzes the viability of incorporating common reed fibres into mortar mixtures to enhance construction materials. The study focuses on evaluating the physical, mechanical, and thermal properties of these modified mortars. The authors conduct experiments to assess how varying amounts of common reed fibres affect the mortar's strength, durability, and insulation properties. The results indicate that the addition of reed fibres can improve thermal insulation and reduce weight without significantly compromising mechanical strength.

The findings suggest that common reed can be a sustainable alternative in construction, offering both ecological benefits and functional performance.

3.2 Presentation of the progress of PVTs and first results

Below are described the activities carried out by each partner for the implementation of the PVTs in which they are involved, considering input, throughput, and output processes, as well as circularity aspects. Moreover, the current progress of the PVTs is presented along with the initial results achieved.

- **PVT1: Non-woven insulation materials with hemp fines**

In this pilot BAFA supplies hemp fibres as the key input for producing insulation materials. The distinctive features of the pilot and the technologies adopted are aimed at optimizing throughput by meeting specific fibre requirements for new applications, such as length, thickness, and color.

According to BAFA, the decision to select this pilot for comparison with current technologies is driven by the potential to serve broader markets and explore diversification opportunities.

CORMATEX utilizes a specialized airway machine, the Lap Formair H, which employs aerodynamic web formation to ensure a perfect and homogeneous distribution of fibres across horizontal layers.

The production of non-woven materials, ranging from 1,000 to over 6,000 gsm, undergoes a validation process that starts in the lab (TRL4) and continues at the pilot scale (TRL5). The process begins with the input of secondary hemp fines (a mix of hemp dust, shives, and fibre) processed in a tumbler sieving machine to obtain specific fractions, delivered in compressed bales (0.5 ton dry). To enhance the efficiency of the process, a cyclone is integrated into the production line at the condenser, while a heating chamber introduces hot air (~140 °C) to the mix. Binders, either synthetic (epoxy) or biobased (PLA/PBS blends), are sprayed into the material on the transversal collecting belt or in the multimixer, with concentrations ranging from 2% to 75%. The cutting phase for non-woven rolls is optimized to ensure a high-quality output. In terms of output, the fibres are pneumatically transported to the machine's feeding section, which features a volumetric loader that forms a uniformly distributed fibre mat. The material proceeds through an opening section feeding into the forming chamber, where distributor cylinders and suction through a perforated belt ensure uniform distribution and horizontal stratification of the fibres. Continuous weighing systems at both the inlet and outlet of the formation chamber regulate the weight of the output product, which is then prepared for thermal or mechanical bonding. A powder

dosing machine at the top of the forming chamber can introduce various powders or resins to enhance the mat's properties, such as flame retardancy.

The pilot's unique technology allows for the processing of both fibrous and non-fibrous materials without limitations on the length or shape of the input. This means it can effectively handle not only hemp fibre but also shives and dust, maximizing the utilization of all plant materials and minimizing production waste. The random disposition of fibres in horizontal layers enhances the tensile strength of the final product, which can weigh up to 6,000 gsm.

SOPREMA operates at the laboratory scale to produce small rigid panels measuring 250 x 250 mm, employing a process that closely mirrors its industrial product line, with densities ranging from 40 kg/m³ to 200 kg/m³.

The production involves several key steps, beginning with the mixing of hemp fibres and the application of a binder (glue for rigid boards) to create the initial blend (input). This mixture is then transferred to the feeding and blowing station, where fibre mixing is further optimized before being blown into a mold, ensuring uniform fibre orientation within it. Once in the mold, the hemp fibre mix undergoes pre-pressing before moving to the cooking station (throughput). Here, the mold experiences a final pressing to achieve the targeted density, followed by a cooking phase that activates the binder with hot steam. After cooking, the rigid insulation board prototypes are cooled and removed from the mold (output).

The technology utilized in this pilot aligns with that of the industrial line, facilitating the production of rigid boards. A distinctive feature of the pilot is its capacity to produce prototypes in batches (the industrial line is a continuous board production line) and allowing for the testing of various material and binder combinations on a small scale without requiring large quantities of materials. This pilot was chosen for comparison with current technologies because it enables the production of representative rigid boards while maintaining the same parameters as the industrial line, including cooking processes and the types and rates of materials and binders used. Furthermore, the pilot emphasizes circularity by minimizing material waste and enabling the exploration of different binder options, thereby promoting more sustainable practices in the production of rigid insulation boards.

Current progress and first results

BAFA has successfully harvested and processed hemp fibres, including super short fibres and fibre fines, which have been delivered to SOPREMA for the production of non-woven insulation materials. SOPREMA has manufactured semi-rigid (55 kg/m³ – 10 panels/condition) insulation boards, each measuring 40 mm in thickness. These boards incorporate different rates of hemp fibres: 25%, 50% and

100% incorporation rate with hemp short fibres; 25% and 50% with hemp super short fibres, while 100% incorporation rate is not acceptable (see Figure 4).

The mix of fibres have been complemented with SOPREMA reference wood fibre, in particular softwood spruce fibres, with a binder made of PP/PE bicomponent fibres at a 4% rate.

Semi-rigid 100% hemp short fibres



Semi-rigid 100% hemp very short fibres



Figure 4. The semi-rigid insulation boards manufactured by SOPREMA.

The analysis of the products has started and tests related to some performance metrics, such as tensile resistance, fire reaction and dust content, have already been done. Remaining assessments include

thermal conductivity (conducted by SOPREMA), along with acoustic properties and traction validation (conducted by SLU - Swedish University of Agricultural Sciences).

- **PVT2: Composites from MFC improved hemp fibres for automotive applications**

Within the PVT2, BAFA and CORMATEX implement the same activities and processes carried out in PVT1, therefore regarding their roles in this pilot, it is possible to refer to the description provided above. The role of FIBERLEAN in this pilot involves applying a thin layer of MFC to a hemp substrate to enhance its strength. The inputs for this process include the hemp substrate and microfibrillated cellulose. The throughput processes involve the careful application of MFC into the hemp substrate, with a key emphasis on managing the water balance throughout the production. This management is essential to ensure that the final product can be adequately dried, maintaining its quality. The output processes yield a biobased product that demonstrates significantly improved quality compared to untreated hemp, making it suitable for high-end applications and achieving performance levels comparable to conventional technologies.

For HP Composites, the pilot consists in producing automotive composites for both interior and exterior applications using non-woven rolls composed of at least 80% hemp fibres, with grammages ranging from 300 to over 1,000 gsm. The inputs for this process include hemp fibres, MFC at a 1–3% loading, and epoxy resin.

The process begins by improving the mechanical properties of the hemp fibres through the application of MFC, followed by thermo-bonding to create enhanced non-woven sheets. These sheets are then integrated into glass fibre laminate products utilizing epoxy resin in either autoclave or compression molding processes, aiming for at least 85% compliance with technical specifications during large-scale prototype testing. The throughput processes involve the treatment of hemp fibres with MFC, the thermo-bonding to form non-woven sheets, and the integration of these sheets into glass fibre laminates. Two specific components are under investigation: an exterior bodywork panel and an interior panel, both designed to utilize the non-woven hemp fibre with an epoxy resin system. Achieving a "Class A" surface finish, especially for the exterior panel, presents challenges that the pilot seeks to address. The output processes consist of producing these panels while ensuring compliance with performance and aesthetic standards.

The pilot employs innovative technologies to enhance the mechanical properties of hemp fibres, considering hybrid solutions that incorporate synthetic fibres. As regards the circularity aspects, the biobased composites produced are lightweight and have a significantly lower energy footprint compared to traditional materials, emitting only 0.5–0.7 tonnes of CO₂-equivalent per tonne of fibre, as opposed to 1.7–2.2 tonnes for glass fibres. Moreover, these composites can be repurposed into second-life products. This includes lower carbon emissions during production and the potential for recycling or reuse of materials. This pilot envisions practical applications of hemp fibres in hemp-glass fibre laminate composites, which offer improved mechanical and acoustic properties. Non-woven hemp fibre rolls serve as external or internal layers in hybrid structures, employing flexible layer arrangements to meet diverse end-user needs through thermo-bonding.

To ensure optimal performance, the pilot emphasizes the selection of crop varieties for consistent hemp fibre quality and the innovative biotechnological enhancement of non-woven rolls through FIBERLEAN® MFC treatment, which increases the bonding area. The reasons for selecting the pilot for comparison with current technologies are related to the expected mechanical performance of non-woven hemp. Considering that only non-structural applications can be deemed suitable, aesthetic or low-performance components have been chosen to demonstrate the feasibility of the developed solution. This approach aims to highlight the versatility and suitability of the material in specific contexts, showcasing its potential for use.

Current progress and first results

The pilot involves several key verification and testing processes in order to assess the quality and performance of hemp non-woven fabric (see Figure 5). Initial evaluations indicate that T2 and T3 are the best-performing options. An impregnation test is conducted for each batch, with verification through micrography: an RC of 60% is acceptable, while an optimal RC of 70% is targeted. Additionally, the pilot includes the production of sandwich structures that incorporate both carbon and glass materials. Specimens are produced for manual peeling tests to evaluate adhesion with the non-woven fabric, and the peeling test is currently in progress.

To further assess the mechanical properties, flexural testing is performed on the produced sandwiches. The density verification for each batch is being conducted using a gas pycnometer and is currently in progress. Lastly, thermogravimetric analysis (TG) will be carried out for all impregnated batches as a next step. The cooperation between HP Composites and FIBERLEAN is very important for the trial of the coating.

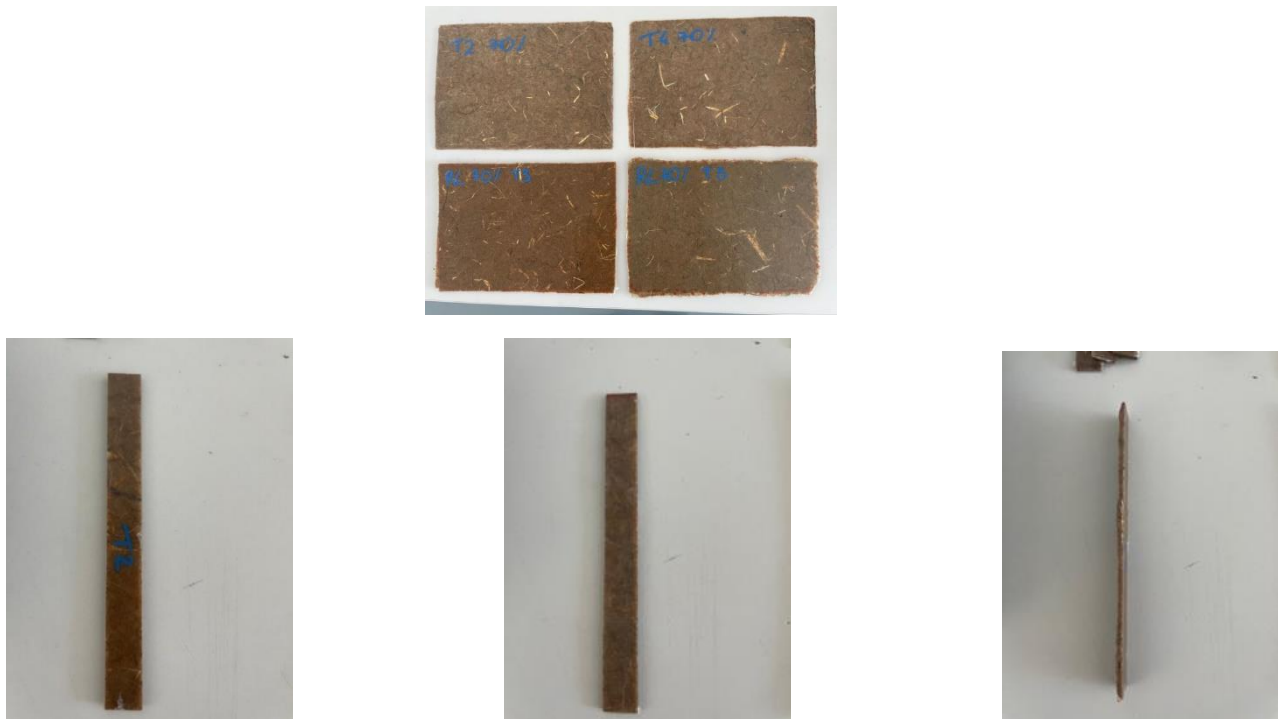


Figure 5. Hemp non-woven fabrics manufactured by CORMATEX.

- **PVT3: Concrete with fibres from underutilised trees on contaminated soils**

According to VICAT, the aim of the PVT3 is to analyze the impact of using wood sourced from trees growing on contaminated soil to produce bio-based concrete. The pilot explores not only the use of wood shavings or sawdust, but also investigates the influence of the material shape factor, utilizing particles ranging from 2 mm to 4 cm, including wood fibres.

Inputs for this process include contaminated wood, cement and water. The bio-based concrete will be produced using a specially developed pilot system that consists of an industrial mixer and a block press, allowing for the production of 4 insulated concrete blocks in a single mixing step. The throughput processes involve grinding the bio-based material using standard industrial grinders, followed by coating with mineral charges. The mixture is then combined in the mixers with cement and water, poured into molds, partially dried, unmolded, and fully dried, with a possible finishing step to clean the surfaces. The output processes result in bio-based concrete blocks that are not only lightweight but also designed to reduce the carbon footprint of traditional concrete, as an important circularity aspect. These blocks aim to improve acoustic and thermal properties, but they are not in competition with the traditional structural concretes (e.g. heavy-duty concrete or steel-reinforced concrete). Other significant circularity aspects of this pilot regard its aim to utilize contaminated wood, thereby addressing environmental concerns related to soil contamination.

Institut Technologique FCBA is responsible for the preparation of the wood, ensuring it meets the necessary specifications for the process. The target market for the product is single-family homes.

The PVT3 incorporates distinctive features and technologies that enhance its effectiveness. It utilizes a 12-inch defibrator powered by a 45kW electric motor, capable of operating at both high and low consistency (from 1 to 5% dry matter up to 20-25%). This defibrator can function under atmospheric conditions or steam pressure, allowing for the defibration and refinement of materials, transforming wood fibres into wood chips. Various types of grinders and sorters are employed to process different particle sizes.

In terms of bio-based concrete, the technologies adopted in the pilot effectively replicate the industrial process while requiring fewer materials and being easier to use. A notable aspect of this pilot is its use of contaminated wood. This pilot was selected for comparison with current technologies due to the limitations of existing methods, which primarily rely on mechanical grinders that produce wood chips, with little or no testing of other types of shape, including fibres.

The PVT3 has the potential to improve the homogenization of the wood-concrete mixture, enhance ease of use and elevate the properties of intermediate products. Additionally, few studies have explored

methods to regulate soil contamination by using plants that sequester contaminants into concrete, making this pilot a significant step forward.

Current progress and first results

Institut Technologique FCBA has produced concrete cylindrical samples measuring 11 cm in diameter and 22 cm in height, with each sample consisting of a 1:3 ratio of wood particles to cement (see Figure 6). These samples are being compared with hemp products to assess their relative performance.



Figure 6. The concrete cylindrical samples with a 1:3 ratio of wood particles to cement, produced by Institut Technologique FCBA.

Ongoing testing will evaluate the properties of the final product, including potential leaching of contaminants. To determine the affinity of the samples with concrete, mechanical and microscopic analyses will be conducted by VICAT. The study will focus on various parameters, including the effect of particle size, wood species, incorporation of fibres mixed with particles and impact of mineral charges on the biomass's affinity with cement. Through these analyses, the pilot aims to provide insights on the viability of using wood particles in concrete production and its implications for sustainable construction.

- **PVT4: Textile yarn with cardoon fibres**

In the PVT4 TEARFIL focuses, in collaboration with FOOD4SUSTAINABILITY, on the characterization of cardoon fibre yarn, the production of yarn made from mixtures of cardoon, cotton and hemp fibres, and the establishment of yarn production processes specifically for cardoon fibre.

Inputs for these processes are cardoon, hemp and cotton fibres, which serve as the raw materials for yarn production. The throughput processes involve the characterization of cardoon fibre properties to optimize the spinning and production methods for cardoon fibre yarn. This includes analyzing the mechanical and physical attributes of the fibres to ensure quality and performance. The output processes result in the production of high-quality yarns made from both cardoon, hemp and cotton fibres, which can be utilized in various textile applications.

The reason for selecting the pilot for comparison with current technologies is related to some ecological advantages, including a better ecological footprint, reduced water requirements, but also lower production costs compared to traditional fibre sources. By focusing on sustainable materials and processes, the pilot not only aims to enhance the performance of yarns but also to demonstrate the viability of cardoon-based fibres as an alternative in the textile industry.

Current progress and first results

TEARFIL and FOOD4SUSTAINABILITY collaborated on an experiment involving cardoon to investigate the potential substitution of cotton with cardoon yarn. This study aims to explore the viability of cardoon as a sustainable alternative to traditional cotton fibres. FOOD4SUSTAINABILITY has successfully delivered cardoon biomass to TEARFIL. Utilizing this biomass, TEARFIL produced yarns with a linear density of 10 tex (i.e., 1000 meters of the fibre or yarn weighs 10 g) with incorporation rate of 10% Cardoon into the mix (see Figure 7).



Figure 7. The yarns with incorporation rate of 10% Cardoon, produced by TEARFIL

- **PVT5: Flexible insulation boards with fibres from tall aquatic grasses**

According to GRASSA, the PVT5 focuses on optimizing the harvest timing for cattail utilization to achieve the maximum yield in terms of fibre. GRASSA is involved in cattail fibre generation with a novel biorefinery concept, the mobile biorefinery, and in the selection of the best performing fibre generation configurations for cattail, to provide SOPREMA with necessary quality and quantities of fibres. The pilot explores if the process used for fodder grasses (e.g. rye grass) can be applied to cattail (*Typha latifolia*) to extract fibres. Using a mobile refinery represents a central innovation within this pilot, indeed, thanks to the adaptation of the mobile refinery to high aquatic grasses, it is able to release the plant's moisture in the field and allow for the processing of proteins and other metabolites in addition to fibres, rapidly increasing the economic profitability of using these novel biomass types.

Cattail plants represent the inputs for this pilot and the harvesting is strategically scheduled before seed formation to ensure both good quality fibres and high protein content in the biomass. The throughput processes, which involve harvesting the cattail plants, are conducted by Radboud University. The output processes aim to produce good quality fibres.

The distinctive features of the PVT5 are the connection between climate adaptation and water storage, and biobased product chains including both fibres and proteins. The reason for selecting this pilot for comparison with current technologies (according to GRASSA there are well-established technologies for grass) lies in the challenge of using fibre bales or pulp as a raw material for the fibre industry, targeting applications in insulation, MDF, and paper production. By focusing on innovative uses for cattail in the construction industry, the pilot promotes the cascade use of resources and contributes to sustainable land management practices.

In the PVT5 SOPREMA produces, at a laboratory scale, small semi-rigid panels measuring 250 x 250 mm, utilizing a representative process that mirrors its industrial product line. The panels can be manufactured with densities ranging from 40 kg/m³ to 200 kg/m³.

Inputs for this process include fibres from tall aquatic grasses, cattail and common reed, and a bicomponent binder specifically formulated for flexible boards. The throughput processes consist of several key steps: first, the fibres are thoroughly mixed, and the binder is applied. Next, the mixture is transferred to a feeding and blowing station, where the fibre blend is further optimized before being blown into a mold. This step ensures a uniform fibre orientation within the mold. Subsequently, the mold is moved to the final stage, where the fibre mix is pressed to achieve the targeted density and cooked. During this cooking process, hot air is used to melt the bicomponent fibres into the fibres, enhancing the

final product's properties. Finally, the flexible insulation board prototypes are cooled and removed from the mold (output).

The technology adopted for this pilot is consistent with that used in the industrial line, allowing to produce flexible boards while offering the flexibility to create prototypes in batch form. The distinctive features of the pilot are that it enables to produce prototypes by batch (the industrial line is a continuous board production line) and to test a matter/binder at small scale (without engaging tons of matter on industrial line).

The reason for selecting the pilot for comparison with current technologies is that it allows to produce representative flexible boards using the same parameters as the industrial line, including cooking conditions and the type and ratio of materials and binders. This approach not only facilitates the development of prototypes but also supports the exploration of more sustainable practices within the industry, aligning with circularity principles by optimizing resource use and minimizing waste.

Current progress and first results

Cattail harvesting has been done by Radboud University, and reed was bought from a commercial supplier in Finland as the studied field site did not yet produce enough biomass. LUKE - Natural Resources Institute Finland, Åbo Akademi University and Institut Technologique FCBA were responsible for Reed harvesting/processing.

Both cattail and reed are being studied for their application in insulation boards manufactured by SOPREMA. SOPREMA has produced insulation boards incorporating different rates and fibres harvested at various times (see Figure 8). The boards come in two types: semi-rigid (**55 kg/m³** – 10 panels/condition) and rigid low-density (**120 kg/m³** – 12 panels/condition). The different incorporation rates are:

- Cattail-autumn harvest: 25%, 50% incorporation rates (100% incorporation rate is not acceptable);
- Cattail-winter harvest: 25%, 50% incorporation rates (100% incorporation rate is not acceptable);
- Cattail-spring harvest: 25%, 50%, 100% incorporation rates;
- Reed - airgap 100µm: 25%, 50%, 100% incorporation rates.

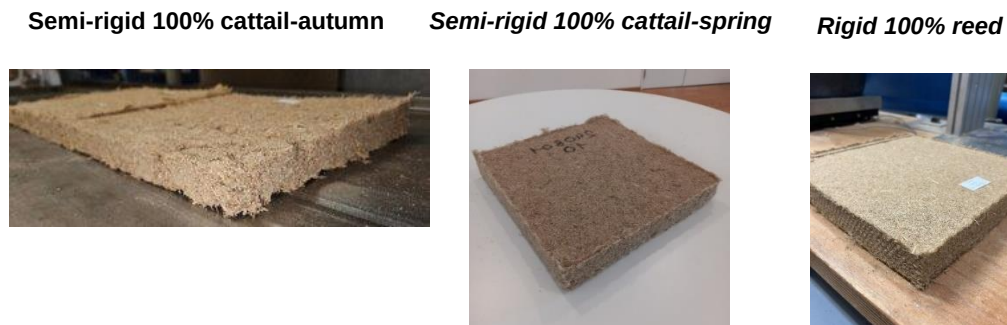


Figure 8. The insulation boards incorporating different rates and fibres harvested at various times, produced by SOPREMA.

The analysis of products has started focusing on several performance metrics, including tensile resistance, compressive strength, fire reaction, thermal conductivity (which requires the longest testing time), dust content, water sorption (conducted by SOPREMA), acoustic properties and validation of traction (conducted by SLU - Swedish University of Agricultural Sciences). SOPREMA has also performed morphological analysis on reed samples provided by Institut Technologique FCBA, selecting 3 qualities of defibrated samples with air gaps of 50 µm, 100 µm, and 200 µm.

3.3 Preliminary evaluation of the technological advances of the PVTs

In order to receive a preliminary evaluation of the technological advancements of each PVT, the partners were asked first to analyse in qualitative and quantitative terms performance, characteristics, strengths and areas of improvement of the pilots in comparison with the current technologies; then to provide useful technical and regulatory standards as references for this first evaluation.

- **PVT1: Non-woven insulation materials with hemp fines**

According to BAFA, the use of natural fibres could significantly enhance the durability and stability of materials compared to conventional options. In examining the results of quantitative and qualitative analyses of the pilot's technological advancements, it is important to consider how the current processes in the 4 stages (cultivation, harvesting, retting, and decortication) should be changed if these fibres were employed in the production of non-woven insulation materials. To meet the needs of partners developing these non-woven materials, BAFA faces several challenges, particularly in scaling up its processes. The company anticipates a minimum production increase of 5% and intends to invest in higher throughput

machinery as sales grow. Additionally, BAFA will need to enhance the capacity of its cultivation land and harvesting equipment. If the fibres do not meet the required technical and physical specifications, adjustments may be necessary in the retting process and in specific parameters of the decortication line, particularly concerning the length and fineness of the materials. BAFA employs various technical and regulatory standards to evaluate the characteristics and quality of raw materials and products from suppliers, focusing on moisture levels and the retting stage of hemp straw. For its own production processes, BAFA conducts sensory testing on intermediate products in accordance with ISO standards, which is also applied to the evaluation of finished products. According to BAFA, these technical and regulatory standards are appropriate for assessing the technological advancements of the pilot.

The CORMATEX technology system is flexible and well-suited for processing various materials, so no significant difficulties are expected in implementing PVT1. However, some challenges have emerged in processing very short hemp fibres. In this pilot, indeed, the management of very short hemp fibres presents a challenge due to the loss of material as dust within the filters. To mitigate this issue, a highly refined cyclone was integrated into the process, effectively retaining most of the processed fibre and preventing it from being lost or expelled as dust. This necessitates specialized air-fibre filtration and separation systems, as processing short fibres generates more dust than long fibres. Both pre-filtration and post-filtration systems are essential: the former removes most of the generated dust before evacuation, while the latter measures and quantifies the dust produced for effective management. Together, these systems help reduce the dust sent to centralized filtration. Within PVT1, another complication arises from the lower permeability of short hemp fibres to air, which poses a challenge for thermal bonding, as it results in less heat distribution throughout the material. This was addressed by incorporating a heating chamber that allows heat to penetrate the entire thickness of the material. Additionally, slowing down the production line can provide more time for thorough heating. In terms of energy consumption, there is an estimated increase of 20-30% in the thermal and electrical energy required to heat the material effectively.

According to SOPREMA, the traditional industrial line can be used as a reference to assess the performance of the pilot. One potential improvement for the pilot compared to current technologies is enhancing the fibre mix by acquiring a fibre opener. For rigid boards, wood fibres and other natural fibres are mixed before gluing.

In terms of quantitative and qualitative analysis of technological advances, SOPREMA internally compares the pilot with its flagship products (PAVATHERM 40 mm, ISOLAIR 30 mm, PAVAFLEX 40 mm), noting that the prototypes from the pilot line are representative of the industrial line in terms of appearance and performance, as detailed in the technical data sheets of the products mentioned above.

Regarding the technical and regulatory standards that SOPREMA uses to evaluate the characteristics and quality of raw materials and products from suppliers, adhesives (glue) and additives are not controlled by the quality laboratory, as these materials are validated online through R&D tests.

For wood, moisture content and chip morphology are measured. In particular, wood chips are controlled by an internal standard on receipt to ensure consistent quality for the defibration stage, which includes particle size analysis, moisture content checks, and the presence of blue wood. These parameters significantly influence the morphology of the produced fibre and, consequently, the performance of wood fibre panels.

The wood used for insulation panels is PEFC certified. In evaluating the quality and performance of its own production processes, SOPREMA monitors particle and VOC emissions in external air. For its end products, SOPREMA adheres to standards such as EN13171 and other relevant tests. The end products are certified by natureplus e.V., which promotes climate- and health-friendly construction with sustainable materials and methods. Additionally, all end products are KEYMARK and/or ACERMI certified, with quality control conducted by the laboratory post-production. Various physical, mechanical, and thermal performances are tested: water sorption at 24 hours, humidity content, fire behavior (Euroclass E); compressive strength at 10%, tensile resistance, bending strength; thermal conductivity. Each characterization test follows specific standards, and the dimensions of the panels are regularly checked online at the end of the line to ensure compliance with declared thickness, length, and width according to defined tolerances.

SOPREMA emphasizes that to evaluate the technological advancements of the pilot, it is essential to improve methods for regularly controlling the adhesives and additives used in the industrial line, as simply monitoring the end products is insufficient. Furthermore, the raw material used in the pilot (hemp) differs significantly from wood chips, and integrating hemp into the industrial line, particularly for rigid boards, will require technical adjustments.

- **PVT2: Composites from MFC improved hemp fibres for automotive applications**

For the PVT2, BAFA provided overall the same information as for PVT1. The only additional information reported, regarding the areas for improvement of the pilot compared to current technologies, is the need for the automotive composites for a lower weight and a safer breakage behavior of the parts.

As regards CORMATEX, its technology system is flexible and well-suited for processing various materials. For the PVT2, where long hemp fibres are processed, the abrasive nature of hemp becomes

a key consideration, emphasizing the need for careful design of the processing plant, especially regarding piping, which should be constructed from abrasion-resistant materials.

According to FIBERLEAN, the performance and characteristics of the pilot are designed to achieve properties similar to those of current technologies. The areas for improvement of the pilot include reaching strength targets and ensuring compatibility with the resin system. The results of the quantitative and qualitative analysis of the technological advancements of the pilot will be available after the completion of the technical work. For HP Composites the performance and characteristics of the pilot compared to current technologies show that biobased composites made with hemp fibres are lightweight and have a less energy-intensive production process than conventional materials, emitting 0.5–0.7 tonnes of CO₂-equivalent per tonne of fibre, compared to 1.7–2.2 tonnes for glass fibres. Additionally, these composites can be easily transformed into second-life products.

Regarding the strengths and areas for improvement of the pilot, the substitution of conventional materials with green composites offers several attractive features, including low cost (Khalid *et al.*, 2021), low density, high specific properties, eco-friendliness, processing advantages, and reduced CO₂ emissions throughout their lifecycle (Maiti *et al.*, 2022; Koronis *et al.*, 2013). However, despite these benefits, certain challenges hinder the wider adoption of these materials. These include difficulties in strength prediction during structural loading, uncertainties about long-term performance, moisture absorption, lower fire resistance, reduced mechanical properties and durability, property variations, sensitivity to temperature and UV radiation, limited processing temperatures, greater variability in cost and properties compared to synthetic composites, and challenges in employing well-established fabrication processes. Some of these limitations contribute to their typically short lifespan in outdoor applications, which has restricted their use in mass car production.

In terms of technical and regulatory standards used by HP Composites to evaluate the characteristics and quality of raw materials and products from suppliers, they include Dry Reinforcement Areal Weight (ISO 3374), Weave (ISO 2113), Width (ISO 22198), Thickness (ISO 5084), DSC, Volatiles content and Resin flow.

For evaluating the quality and performance of its own production processes, HP Composites uses standards such as Voids content (ASTM D2734), DSC (ASTM D3418), DMA (ASTM D7028), and Quality Management System (ISO 9001).

To assess the quality and performance of its end products, HP Composites employs, in addition to the standards mentioned above, also Tensile test (ASTM D3039), Compressive test (ASTM D6641), Flexural test (ASTM D790), and ILSS (ASTM D2344).

According to HP Composites, these technical and regulatory standards are suitable for evaluating the technological advances of the pilot.

- **PVT3: Concrete with fibres from underutilised trees on contaminated soils**

According to VICAT, the performance and characteristics of the pilot compared to current technologies involve the use of plant materials that cannot be utilized elsewhere. This approach could enable the storage of pollutant elements in constructions, thereby serving as an effective depollution tool.

However, while the sequestration of contaminants in concrete has not yet been demonstrated, it is known that plants can store elements they do not need, such as heavy metals.

Optimizing the shape factor for the bio-based material may impact product properties and incorporation rates, allowing for the optimization of material requirements to achieve equivalent product properties.

In terms of strengths and areas for improvement of the pilot compared to current technologies, the strengths include the use of wood from trees cultivated on contaminated soils, which allows for the sequestration of soil contaminants, such as heavy metals, captured by the trees during their growth.

Additionally, since hemp is expensive for use in insulation concrete, transitioning to underutilized wood sourced closer to factories (100-200 km) offers significant advantages.

This approach could help regulate contaminant levels in soils and utilize wood that is currently underused. If this solution proves viable, it may also enable the reuse of heavily treated wood (e.g., electricity and telephone poles, railway sleepers, wood for outdoor use) instead of burning it.

Areas for improvement include the development of a block that serves both as an insulating and load-bearing material while ensuring an adequate supply of raw material. There are also research needs regarding the interaction of wood within cement and the influence of pollutants present in wood from contaminated sites.

Regarding the technical and regulatory standards used by VICAT to evaluate the characteristics and quality of raw materials and products purchased from suppliers, they include the professional rules "Construire en Chanvre," pre-standard methodologies for biobased plant aggregates, technical appraisals, and RILEM TC 236-BBM, which focuses on characterizing hemp shiv to determine initial water content, water absorption, dry density, particle size distribution, and thermal conductivity.

For evaluating the quality and performance of its own end products, VICAT employs a quality assurance plan. According to VICAT, the technical and regulatory standards mentioned above are suitable for assessing the technological advances of the pilot.

- **PVT4: Textile yarn with cardoon fibres**

For this pilot, TEARFIL indicates that the performance of cardoon yarn still needs to be properly evaluated. The strengths of the pilot include some ecological advantages, such as a better ecological footprint, reduced water requirements, but also lower production costs compared to traditional fibre sources. The results of the quantitative and qualitative analysis of the technological advances of the pilot are not yet available, since tests on physical characterization, costs and ecological footprint are in progress. Regarding the technical and regulatory standards used by TEARFIL to evaluate the characteristics and quality of raw materials and products purchased from suppliers, they include Oeko-Tex® Standard 100, Global Organic Textile Standard (GOTS), Fairtrade Cotton FLO ID 4080, and Forest Stewardship Council (FSC). According to TEARFIL, the technical and regulatory standards mentioned above are suitable for evaluating the technological advances of the pilot.

- **PVT5: Flexible insulation boards with fibres from tall aquatic grasses**

GRASSA aims at developing the mobile biorefinery towards a facility enabling processing of cattail, yielding fibres for insulation boards. To assess the feasibility of a functional plant, quantitative experiments concerning fibre yield are in progress. According to GRASSA, the performance and characteristics of the biorefinery pilot compared to current technologies involve a comparison with grass silage and wood as raw materials.

For SOPREMA, the traditional industrial line can be used as a reference to assess the performance of the pilot, as for the PVT1. A potential improvement for the pilot compared to current technologies lies in enhancing the fibre mix by acquiring a fibre opener. For flexible boards, natural fibres are combined with bicomponent fibres. Furthermore, the raw materials used in the pilot (cattail and reed) are completely different from wood chips, necessitating technical adjustments for their integration into the industrial line. The information provided by SOPREMA for the PVT1 is also valid for the PVT5, so it is possible to refer to that for all the other aspects analysed in this section.

4. CONCLUSION

This report on Deliverable 3.1 (D3.1) has provided a comprehensive analysis of the current value chain activities for the five pilot validation trials (PVTs) conducted at an industrial scale within the FIBSUN project.

By focusing on input, throughput, output, and return/circular processes, this analysis is a crucial initial evaluation within WP3, whose aim is to assess the economic viability of innovative value chains and to develop strategic business approaches for the efficient use of biomass sourced from marginal lands in industrial applications. The progress of the PVTs is focused on demonstrating the industrial and economic feasibility of these innovative bio-based solutions and the examination of data gathered from questionnaires and interviews with involved partners, along with relevant contributions from the literature, has led to a clearer understanding of the ongoing dynamics, even though the information remains partial and continues to evolve.

In conclusion, investments in machines, technical adjustments and changes in processes are needed as well as securing the supply chains of the novel raw materials are needed to upscale the presented value chains. This analysis represents a starting point for advancing the PVTs and its findings will guide the next phases of WP3, especially the Deliverable 3.2 in which the Technology Watch approach will be implemented, while contributing to the overall objectives of the FIBSUN project. These results will significantly depend on developments of the work packages regarding biomass production (WP1) and industrial processes (WP2), highlighting the necessity of ongoing monitoring and the adaptation of strategies based on emerging findings.

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