

I am CELISE

Sustainable production of Cellulose-based products and additives to be used in SMEs and rural areas

D1.3. Production of cellulose fibres, biochar, biofuels and energy to be used in SMEs and rural areas



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CELISE: Sustainable production of Cellulose-based products and additives to be used in SMEs and rural areas

Deliverable D1.3. Production of cellulose fibres, biochar, biofuels and energy to be used in SMEs and rural areas

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Executive Summary

Table 1. Document information

Document information			
Document	D1.3. Production of cellulose fibres, biochar, biofuels and energy to be used in SMEs and rural areas		
Executive Summary:	<p>This deliverable (D1.3) presents an integrated assessment of biomass valorisation routes for the sustainable production of cellulose fibres, biochar, biofuels and energy in SMEs and rural areas. It builds on the results of D1.1 (biomass characterisation), D1.2 (pre-treatments), and D2.1 (business models and socio-economic context), while incorporating new results obtained by CELISE partners and scientific communications presented in international meetings.</p> <p>The study focused on representative biomass feedstocks from both EU countries (Spain, Czech Republic, Greece, Poland) and associated third countries (Argentina).</p> <p>In conclusion, D1.3 demonstrates the technical feasibility and socio-economic relevance of integrating cellulose fibres, biofuels, biochar and biogas production into rural SME contexts. These valorisation pathways strengthen local resilience, close material and energy cycles, and support the transition towards a circular bioeconomy.</p>		
Keywords	Biochar, bioethanol, fibers, lignocellulosic biomass, rural areas, hydrolysis		
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4. LIST OF ABBREVIATIONS

Table 2. List of abbreviations

Acronym	Definition
CA	Consortium Agreement
CT	Coordination Team
D	Deliverable
SMEs	Small Medium Enterprises

5. INTRODUCTION

5.1. General purpose of the document

The purpose of this deliverable is to analyse biomass valorisation pathways that can be implemented in SMEs and rural areas, with particular focus on cellulose fibres, biochar, ethanol, biodiesel and biogas. The document connects the technical processes of biomass conversion with their socio-economic implications, including opportunities for small enterprises and vulnerable communities to participate in the bioeconomy.

5.2. Role and contribution from partners

This deliverable is part of WP1 and integrates contributions from partners responsible for biomass characterisation (D1.1), pre-treatment (D1.2), and socio-economic modelling (D2.1). It also incorporates results presented by CELISE partners in scientific meetings and theses, ensuring that both technological and social aspects are considered.

6. PRODUCTION OF CELLULOSE FIBRES, BIOCHAR, BIOFUELS AND ENERGY

6.1. Cellulose fibres

Representative feedstocks included soybean hulls, brewery spent grains (BSG), olive tree prunings, and *Cortaderia selloana*. Table 3 summarises their structural composition.

Table 3. Comparative composition of biomass feedstocks.

Biomass	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Other (%)
Soybean hulls (Argentina)	32	28	18	22
Brewery spent grains (Spain)	12	47	21	20
Olive tree prunings (Greece)	28	22	32	18
<i>Cortaderia selloana</i> (Spain & Argentina)	35	25	20	20

Soybean hulls were tested in thermochemical pre-treatment studies [1], [2]. Results showed that dilute acid pre-treatment maximised glucose release but generated inhibitors, while combined strategies offered more balanced performance. Multi-response optimisation confirmed that controlled acid concentration and temperature improved hydrolysis yields and reduced inhibitor formation. Olive pruning residues were subjected to steam explosion [3]. XRD analysis revealed a crystallinity increase from 34.1% to >50%, while particle size distribution shifted towards smaller fractions. These changes enhanced enzymatic accessibility, confirming the suitability of steam explosion for fibre and ethanol production. Brewery spent grains were analysed at pilot scale through Aspen Plus simulation [4].

Table 4. Simulation results for 2G ethanol plant using BSG.

Parameter	Value
Feedstock	Brewer's spent grains (BSG)
Moisture content	78 %
Daily input	110 kg/day (wet basis)
Process	Dilute acid hydrolysis + enzymatic hydrolysis + fermentation
Ethanol yield	6.5 kg ethanol/day
Ethanol purity	99.95 %

6.2. Cellulose fibre final materials

Rural lignocellulosic biomass (such as agricultural residues, straw, husks, and other rural plant-based residues) represents an unused raw material for producing cellulosic fibres as an intermediate product to create cellulose fibre-based materials, e.g., fibre boards, insulation, and filter materials [5]. By converting rural lignocellulosic biomass into value-added products, not only is agricultural waste reduced, but also the principles of a circular economy and rural development are promoted. The typical cellulose fibre processing pathway [6] consists of (1) mechanical or chemical pulping, (2) refining and bonding, and (3) pressing and curing. Mechanical pulping is recognised as the key processing step that influences product quality [7]. Fibre dimensions affect how well the fibres bond during pressing and determine the mechanical properties of the final product.

Student Science, s.r.o. and Cellulose Laboratory, Latvian State Institute of Wood Chemistry have developed functionalized pH-sensitive hemp nanofiber membrane and paper with repellent properties. Novel material is prepared only from natural and biodegradable materials. The pH-sensitive material for possible applications in the food industry was obtained from red cabbage and successfully tested. This material is planned as a smart novel generation of packaging material. Prepared samples of hemp/PCL/oregano oil paper and control samples (hemp paper) are currently under further development for practical testing.

6.2.1. Mechanical pulping

Properly extracted cellulosic fibres provide strength and flexibility to cellulose-based composite materials, as demonstrated during a CTU-BESARTE research stay within the CELISE project. The pretreatment by the Pulveriser, shown in Fig. 1, relies on intense shear forces generated in a rotor-stator system, where a rotating roll interacts with a stationary gap. Key process parameters such as roll revolutions, gap distance, temperature, solid-to-liquid ratio, and processing time are precisely monitored and controlled to optimise defibring efficiency and preserve fibre quality [8]. For bean pods, see Fig. 2, a biomass-water suspension with 0.5–5 wt% solids ensures proper flow, while the rotor operates at a peripheral speed of 3–5 m·s⁻¹ with the stator gap in contact. Processing typically lasts 30–60 minutes, providing sufficient shear to separate the tougher fibres without excessive shortening. *Sambucus nigra*, being softer and less lignified, requires gentler conditions: similar solid-to-liquid ratios but shorter durations (20–40 minutes) and slightly lower peripheral speeds (2.5–4 m·s⁻¹) to maintain fibre integrity. Both processes operate at ambient to moderate temperatures and monitor energy demand (0.3–0.6 kWh·kg⁻¹ biomass) and pH to support efficiency and chemical stability, enabling scale-up and sustainability assessments.

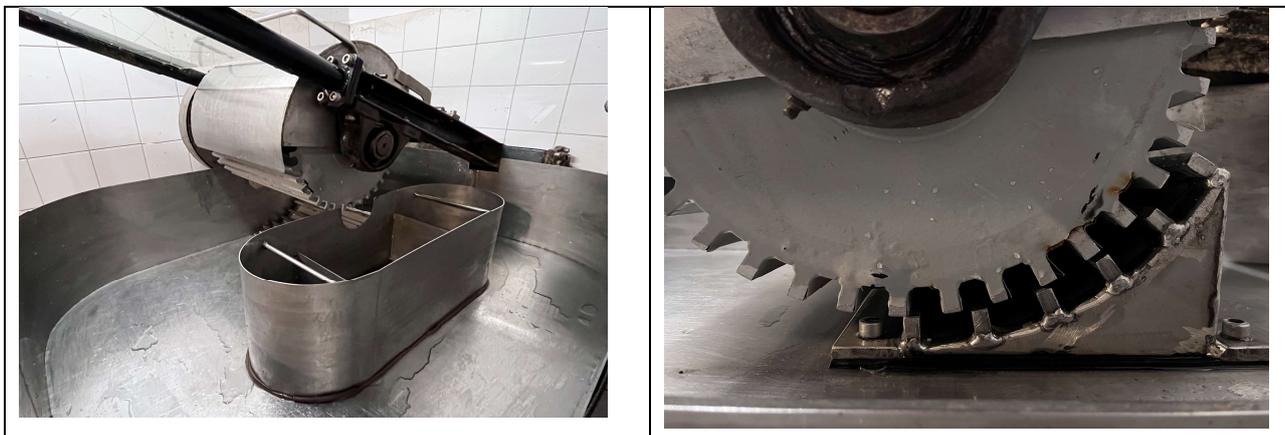


Figure 1. BESARTE Pulveriser for mechanical pulping of biomass.



Figure 2. Raw (left) and defibred (right) bean pods by Pulveriser.

6.2.2. Refining, Bonding, and Pressing in Fiberboard Production

After mechanical pulping, the refining and bonding stage prepares fibres for consolidation by adjusting particle size and enhancing inter-fibre adhesion. A comprehensive review of fibreboard production from diverse lignocellulosic sources—such as sugarcane residues, cereal straws, and woody or non-woody biomass—highlights the importance of pretreatment and bonding chemistry [9]. Alkaline treatments (e.g., NaOH, Na₂SO₃) improve bonding strength by removing lignin and hemicellulose, exposing cellulose surfaces, while acid treatments and steam explosion can also enhance performance [10]. Optimal particle sizes typically range from <0.5 mm to 2 mm, with moisture contents adjusted to 2–13 wt%. Pressing and curing, then consolidating the mat into boards, commonly sized 300 × 300 mm with thicknesses of 5–10 mm [11]. Hot-pressing temperatures span 130–280 °C, with a dominant range of 180–200 °C, and pressures range from 1–18 MPa (most often 5–12 MPa) [9]. Pressing times vary from 5 to 120 minutes, typically 10–20 minutes, with shorter times for thin, high-temperature boards and longer times for low-temperature or thick boards [12]. Natural additives such as citric acid, sucrose, or polyester may be incorporated to enhance bonding without synthetic resins. High holocellulose, lignin, starch, and sugar contents are generally required for effective self-bonding [13].



Figure 3. Appearance of the binderless boards. (a) Binderless board made from whole particles. (b) Binderless board made from whole powder [14].

6.3. Biofuels

Different strategies for biofuel production were tested. Ethanol was obtained through alcoholic fermentation mediated by *Saccharomyces* non-conventional yeasts (*Spathaspora passalidarum* and *Scheffersomyces stipitis*) [15-16]. Mixed inocula demonstrated complementary behaviour, with *Saccharomyces* consuming glucose first and *Spathaspora* subsequently fermenting xylose, increasing overall ethanol yield. Lipid-accumulating yeasts were evaluated for biodiesel production through lipid extraction and transesterification. In parallel, lactic acid bacteria (LAB) were assessed for lactic acid production, with applications in animal feed, food preservation, and as precursors for bioplastics (PLA).

Within the CELISE framework and in previous contributions, the feasibility of using agro-industrial residues and liquid effluents as substrates for ethanol production has been demonstrated. Agro-industrial residues (soybean hull hydrolysates, BSG, whey permeate, olive prunings) were confirmed as suitable substrates [1], [4], [16]. Optimised pre-treatment improved sugar release, with soybean hulls reaching up to 75% glucose recovery [2].

Following distillation, the residual yeast biomass (spent fermentation broth) contains dead cells, proteins, vitamins, minerals and non-fermentable sugars. Instead of being discarded, this biomass can be valorised as:

- Animal feed additive for poultry, ruminants and pigs, improving gut health and productivity.
- Protein-rich supplement in mixed feeds.
- Composting material contributing to soil fertility.

This reuse pathway increases the circularity of ethanol production processes by transforming microbial residues into inputs for livestock and agriculture.

Ethanol produced from waste valorisation is primarily considered a biofuel (liquid renewable fuel compatible with internal combustion engines and blending with gasoline). However, its versatility offers additional community-level applications:

- Sanitisation of hands, utensils, and surfaces, providing a low-cost solution to improve hygiene standards in rural and vulnerable communities.
- Disinfection of healthcare environments, enabling better first-line medical care.
- Ingredient for beverages and fermentation industries, when purity standards are achieved.

These alternative uses reinforce ethanol's role not only as an energy carrier, but also as a socially valuable product that directly contributes to public health, hygiene, and wellbeing in rural settings. Thus, even if biofuel markets are not prioritised, ethanol retains a strong relevance as a sanitiser and versatile bioproduct.

6.4. Biochar, biogas and other products

Biochar was obtained from lignin-rich residues and olive pruning via pyrolysis. Fernández-Ferreras et al. [17] demonstrated that pyrolysis temperature influences yield and porosity, with potential applications as soil amendment, adsorbent, and carbon sequestration agent.

Biogas was evaluated using cheese whey and whey permeate as substrates [18-19]. Two-stage digestion and co-digestion with manures improved stability and methane yield. Studies reported methane productivity increases up to 79% when whey was co-digested with cattle slurry [20]. His work on low-tech digesters and MCA tools supports decision-making for rural anaerobic digestion plants [21].

In parallel, the cultivation of **lactic acid bacteria (LABs)** on agro-industrial liquid effluents has been evaluated as a strategy to obtain both lactic acid and microbial biomass. Lactic acid has well-established uses as a natural preservative, in the ripening of fruits, and in fermented

foods and pickles, while LAB fermentation of effluents contributes to waste detoxification. Furthermore, LAB biomass presents potential applications as animal feed supplement (particularly when strains display probiotic properties, such as *Lactobacillus plantarum*) and as biological agents for crop protection (bioinsecticides and biocontrol). These multifunctional roles reinforce the importance of LAB cultivation on low-cost substrates, integrating food safety, animal nutrition and sustainable agriculture into circular bioeconomy strategies [22-23].

6.5. Fermentation processes of recycled wood-based materials

During the CELISE research fellowship, investigations were undertaken on the potential utilization of the dust fraction derived from the recycling of wood-based materials. The principal objective was to assess the suitability of this raw material for biotechnological processing through the application of enzymatic treatments and fermentation processes.

6.5.1. Scope of the research

Enzymatic processing of the dust fraction was performed in order to decompose lignocellulosic components.

Fermentation processes were carried out with the participation of various strains of microorganisms (bacteria and fungi), with the aim of verifying their capacity to efficiently utilize the decomposed components of the raw material.

Chemical analyses of the resulting research materials were conducted using high-performance liquid chromatography (HPLC), enabling the determination of the composition of products obtained at successive stages of the study.

6.5.2. Results and observations

The chemical composition of the samples exhibited considerable variability, attributable to the heterogeneous origin of the raw material. Repeated chemical analyses were required in order to achieve results of sufficient reliability and reproducibility.

The application of diverse bacterial and fungal strains facilitated a comparison of bioconversion efficiency and provided insights into potential directions for further research.

6.5.3. Conclusions

The dust fraction obtained from recycled wood-based materials represents a valuable, though challenging to standardize, research substrate. Enzymatic and fermentation processes hold promise for the production of useful chemical compounds; however, they necessitate optimization of process conditions and the careful selection of suitable microorganisms.

The results generated during the fellowship will constitute a foundation for further studies concerning the utilization of lignocellulosic waste in biotechnology and biorefinery applications.

6.5.4. Additional outcomes

Advancement of knowledge and expertise in biomass conversion methodologies and HPLC analysis. Establishment of collaborative ties with the research team at the Universidad Nacional del Litoral.

Such research methods hold great potential, as they have proven highly effective for the recycling of lignocellulosic materials. Naturally, their efficiency depends on the composition of the raw material subjected to microbiological processes; nevertheless, previous studies confirm that these are effective approaches with considerable potential. Agricultural residues such as straw, husks, and bagasse are generated in large quantities worldwide and are often regarded as waste. However, these residues can be transformed into a wide range of value-added products through biotechnological processes, offering both environmental and economic advantages. For

instance, agricultural residues can be converted into biofuels such as bioethanol and biodiesel through fermentation and transesterification [24-25]. In addition, lignocellulosic feedstocks can serve as substrates for the production of high-value biochemicals, including lactic acid, amino acids, and other platform chemicals [24,26-27]; biopolymers and bioplastics, thereby contributing to sustainable material development [24,28]; and industrial enzymes such as lipases produced through microbial fermentation [29]. Furthermore, thermochemical treatments such as pyrolysis and gasification enable the production of biochar, which improves soil health and functions as a carbon sink [25,30]. Residues rich in bioactive compounds can also be utilized for nutraceuticals and functional ingredients, including antioxidants, dietary fibers, and other health-promoting compounds relevant to the food and pharmaceutical industries [24]. For example, recent studies have shown that thermochemical pretreatment of soybean hulls significantly improves the efficiency of second-generation bioethanol production [31], while investigations into xylose metabolism by non-conventional yeasts provide valuable insights into microbial conversion of pentose-rich hydrolysates [32]. However, despite the extensive research on agricultural residues, recycled wood dust fractions remain poorly explored as substrates for enzymatic hydrolysis and microbial fermentation. Therefore, the objective of this study was to evaluate the potential of wood dust fractions from recycled materials for biotechnological applications, including enzymatic treatment and microbial fermentation processes.

6.6. Social and circular economy impacts

The valorisation routes described in this deliverable were designed under a circular bioeconomy framework, where by-products are systematically reintegrated as new resources (animal feed, soil amendments, bioenergy). This approach ensures not only environmental benefits, but also social and economic impacts that are particularly relevant for SMEs and rural areas.

6.6.1. Improved quality of life and public health.

By generating local ethanol from agricultural residues, communities gain access to a low-cost product with multiple uses: as a fuel, but also as a sanitiser for hands, utensils, and surfaces. This is particularly valuable in rural healthcare centres, where disinfectants may not always be available. The local production of sanitising ethanol therefore supports hygiene, infection control and public health resilience in vulnerable populations.

6.6.2. Job creation and local entrepreneurship.

Decentralised biorefineries based on residues (soybean hulls, brewery spent grains, olive prunings, whey) enable new business opportunities for SMEs, cooperatives and local producers. Jobs are generated across the value chain:

- Collection and pre-treatment of residues.
- Operation of fermentation and digestion facilities.
- Distribution of bio-based products (bioethanol, biochar, biogas, animal feed, biofertilizers).

These activities foster local entrepreneurship and contribute to rural development, counteracting migration to urban areas.

6.6.3. Reduction of inequalities and empowerment of rural communities.

Circular valorisation processes promote self-sufficiency by reducing dependence on fossil fuels and external chemical inputs. Farmers and SMEs gain access to low-cost fertilisers, bioenergy, and sanitising agents, strengthening their autonomy. Furthermore, training and capacity-

7. CONCLUSIONS

Deliverable D1.3 demonstrates the technical feasibility and socio-economic relevance of integrating cellulose fibres, ethanol, biodiesel, biochar, and biogas into SMEs and rural settings. Results highlight advances in pre-treatment, fermentation, pyrolysis and anaerobic digestion, supported by case studies (soybean hulls, BSG, olive pruning, whey).

Beyond energy, ethanol provides public health benefits as sanitiser, while biochar, biodiesel and biogas contribute to soil fertility and energy security. The integrated approach enhances resilience and supports the transition to a circular rural bioeconomy.

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