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State Research Programme
"Research and Sustainable Use of Local Resources for the Development of Latvia 2023-2025"

Project No. VPP-ZM-VRIIILA-2024/2-0002
"Innovation in Forest Management and Value Chain for Latvia's Growth: New Forest Services, Products and Technologies (Forest4LV)"

WP 3 "Wood products and technologies"
Task 3.1-3.4

Recommendation for practise
"Wood processing residues to produce added-value biobased materials"

Riga, 2025

SRP
State Research
Programme

FOREST4LV

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Content

1. Introduction

Latvia's forest sector generates a wide spectrum of wood processing residues - bark, sawdust, veneer cores, plywood residues, recycled particleboard, and other by-products - that remain significantly underutilised despite their high potential for conversion into biobased materials. The Forest4LV WP3 has demonstrated that Latvia's wood processing residues - bark, sawdust, veneer cores, juvenile wood, recycled particleboard, and other by-products - represent a substantial, underutilised resource base capable of supporting a new generation of high-value biobased materials. These residues, traditionally directed toward low-value energy use, can be transformed through biorefinery, chemical modification, polymer processing, and biotechnology into advanced materials for construction, furniture, insulation, composites, medical applications, and biological plant protection.

In total five activities were implemented – Wood as material (T.3.1.); Biorefinery (T.3.2); Polymers and insulation (T.3.3); Innovative products from wood residues (T.3.4) and Efficiency of the use of wood resources (T.3.5), which can be seen in the Figure 1.

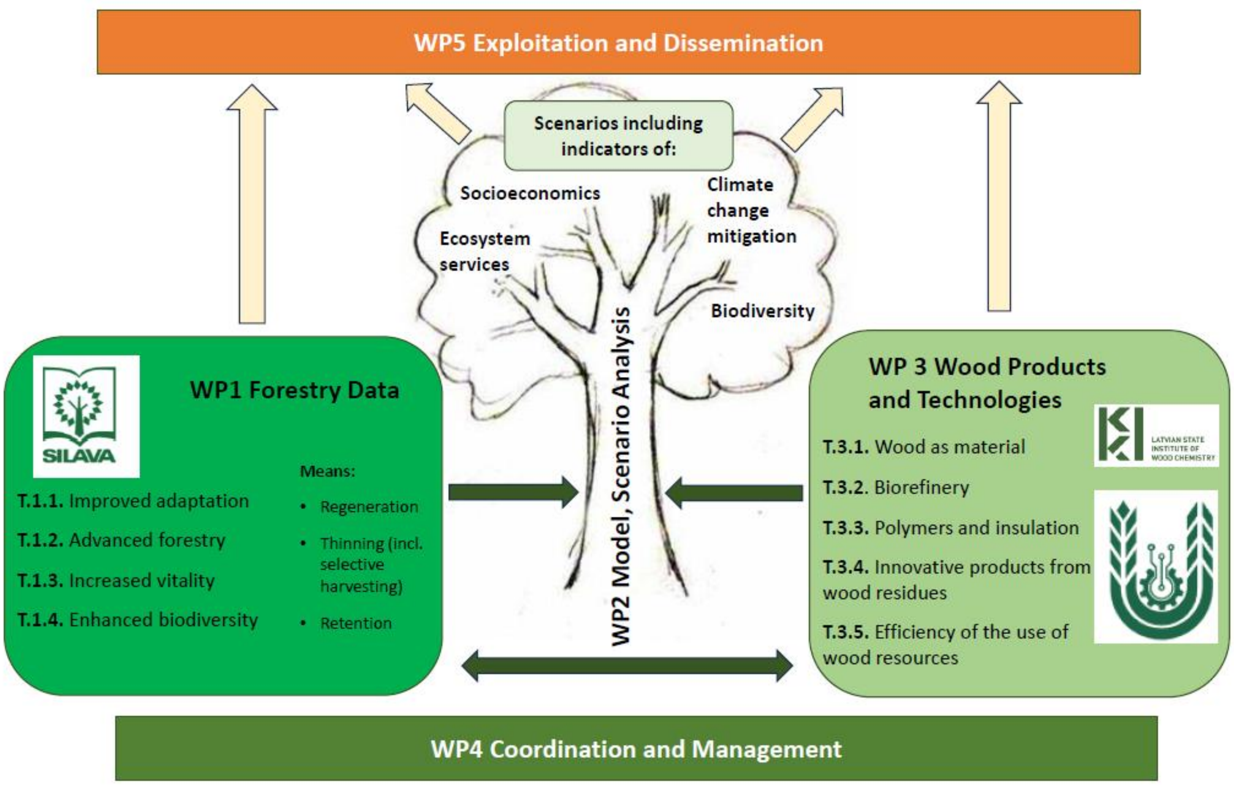

Figure 1. Total scheme of Forest4LV work packages and tasks.

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The present recommendation document consolidates the scientific evidence generated within Tasks 3.1-3.4 and related WP3 activities, providing guidance for industry, policymakers, and public authorities on the sustainable utilisation of wood processing residues. The document outlines the technological potential of these residues, describes the material properties achieved through innovative processing routes, and identifies appropriate application areas. It also highlights environmental and regulatory considerations relevant to the adoption of these materials in Latvian and European markets.

The dominant wood species in Latvia – birch and pine – form the foundation for both traditional wood processing and the emerging bioeconomy. Their full-value utilization enables the creation of high added-value products while simultaneously reducing the use of fossil resources and lowering CO_2 emissions. The circular bioeconomy cycle demonstrates how primary wood and its by-products are transformed into construction materials, furniture, polymers, and medical and chemical products, thereby strengthening Latvia's national economy.

The recommendations presented here complement those of Deliverable D.3.3, which focused on wood-based materials for construction and furniture. While D.3.3 addressed the utilisation of primary wood resources and engineered wood products, **the present document expands the scope to include a broader spectrum of biorefinery-derived outputs and residue-based materials**. These encompass **ecological binders** obtained from suberinic acids, **bio-polyols** for rigid polyurethane foams, wood-polymer composites incorporating **functionalised sawdust**, and a range of **platform chemicals** such as furfural, acetic acid and cellulose-derived intermediates. The document also integrates the **valorisation of bark extractives rich in phenolic**, **catechol-type and antioxidant compounds,** which support applications in medical, cosmetic and bioprotective formulations. In addition, it covers lignin-rich fractions suitable for renewable binders and carbon materials, as well as **biological control agents produced through solid-state fermentation of forestry residues**. High-performance **densified wood** derived from veneer cores further broadens the portfolio of advanced materials. Together**, these technologies complete the WP3 vision of a circular, resource-efficient wood value chain in which residues and by-products are transformed into high-value materials, chemicals and biotechnological products that complement traditional wood-based applications.**

2. Scientific basis and context

The scientific results obtained in WP3 demonstrate that wood processing residues can be transformed into high-performance materials through a combination of chemical, thermal, mechanical, and biotechnological processes. These processes enable the extraction of functional compounds, the modification of lignocellulosic structures, and the creation of composite systems with enhanced mechanical, thermal, and environmental performance.

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2.1. Biorefinery of bark and lignocellulosic residues

Birch and pine bark contain significant quantities of extractives, including polyphenols, catechol-type compounds, and suberinic acids. Through hydrolytic depolymerisation, pressurised water extraction, and oxypropylation, these components can be converted into:

- **Suberinic acid binders**, suitable for particleboards, fibreboards, plywood, and wood coatings.
- **Bio-polyols**, which serve as precursors for rigid polyurethane foams with improved thermal stability and reduced flammability.
- **Bioactive extractives**, applicable in wound-healing materials, antimicrobial formulations, and biological plant protection.

The scientific studies conducted within WP3 show that suberinic acid-based binders exhibit strong adhesion, high thermal resistance, and favourable environmental profiles, while bio-polyols derived from bark extractives can replace fossil-based polyols in insulation foams without compromising performance.

2.2. Polymer composites from wood residues

Wood-plastic composites (WPCs) produced from recycled polypropylene and **alkaline-treated pine sawdust** demonstrate improved mechanical properties, reduced melt viscosity, and lower energy consumption when **suberinic acids are incorporated as internal lubricants**. The alkaline treatment enhances fibre-matrix compatibility by removing extractives and increasing surface hydroxyl groups, while suberinic acids facilitate homogenisation during extrusion.

The resulting composites exhibit increased bending strength, tensile modulus, and dimensional stability, making them suitable for interior finishing elements, decorative components, and non-load-bearing building applications.

2.3. Densified wood for high-performance applications

Birch wood subjected to controlled **alkaline pretreatment, extraction, impregnation with citric acid or chitosan, and stepwise thermal densification** achieves densities approaching 1300 kg/m^3 and mechanical properties exceeding those of many engineering polymers. The densified material retains significant stiffness and strength under harsh climatic conditions and demonstrates favourable biocompatibility, enabling its use in conceptual **osteosynthesis implant prototypes** and other high-performance applications.

2.4. Biological control agents from wood residues

Solid-state fermentation of pine shavings supplemented with wheat bran enables the production of high-viability oidia of ***Phlebiopsis gigantea*****, a biological agent used for stump protection against *****Heterobasidion*** **spp**. The process developed within WP3 achieves spore yields significantly higher than previously reported in the literature, demonstrating the feasibility of producing biological control agents using forestry residues as substrate.

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2.5. Integration with construction and furniture materials

Biorefinery products such as **suberinic acid binders and bio-polyols directly support the development of sustainable construction materials**. Particleboards bonded with suberinic acids meet the requirements for interior fitments, while bio-polyol-based polyurethane foams provide thermal insulation with reduced flammability. These materials complement the engineered wood products described in D.3.3, enabling a fully integrated, circular material system.

2.6 Biorefinery conversion of veneer residues into furfural and 5-HMF

The birch veneer residues generated in plywood production can be transformed into **high-value platform chemicals through a two-stage biorefinery process**. In the first stage, orthophosphoric-acid-catalysed hydrothermal pretreatment selectively converts hemicellulose into furfural and acetic acid while preserving the majority of cellulose. This represents a significant technological improvement over conventional sulfuric-acid-based furfural production, which typically causes extensive cellulose degradation and generates problematic sulfur-containing waste streams. The use of orthophosphoric acid reduces corrosion, simplifies effluent treatment and enables the use of standard industrial equipment.

The second stage focuses on the valorisation of the cellulose-rich lignocellulosic residue. Experimental results confirm that this residue can be further processed into 5-hydroxymethylfurfural (5-HMF), a high-value platform chemical used in the production of bio-based plastics, solvents and fuels. Although the achieved 5-HMF yields remain modest, the study demonstrates the technical feasibility of converting veneer-derived cellulose into 5-HMF using acid-catalysed dehydration in organic solvent systems. The preservation of cellulose during the furfural stage is therefore a critical enabler for downstream valorisation, supporting the development of a fully integrated biorefinery concept.

Together, these findings confirm **that veneer residues** - traditionally treated as low-value fuel - **can serve as a feedstock for the production of furfural, acetic acid, 5-HMF and lignin-derived materials**, significantly increasing the added value of plywood manufacturing by-products.

3. Material-specific recommendations

The valorisation of wood-processing residues into added-value biobased materials requires a clear understanding of the functional properties, processing requirements, and application potential of each material class developed within WP3. The following recommendations synthesise the scientific evidence generated across Tasks 3.1-3.4 and related deliverables, translating laboratory-scale findings into guidance for industrial uptake.

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3.1 Suberinic-acid-based binders and wood composites

Suberinic acids derived from birch outer bark represent a robust, formaldehyde-free adhesive system suitable for particleboards, fibreboards, coatings and impregnation treatments. Their chemical composition, dominated by long-chain fatty acids, phenolic fragments and ester-linked oligomers, provides inherent hydrophobicity, thermal stability and strong adhesion to lignocellulosic substrates. Particleboards bonded with suberinic acids demonstrated compliance with EN 312 Type P2 requirements for interior fitments, particularly when binder content, pressing temperature and particle fractionation were optimised. The boards exhibited favourable internal bond strength, reduced thickness swelling and acceptable bending properties, with performance strongly influenced by density and pressing regime.

Industrial stakeholders are encouraged to adopt suberinic-acid binders in applications where formaldehyde emissions must be minimised, including furniture carcasses, interior panels and decorative elements. The binder's compatibility with recycled particleboard fractions and sawdust from cellular wood material production supports circular-economy objectives and reduces dependence on fossil-based resins. For large-scale implementation, attention should be given to binder viscosity control, moisture content of furnish, and pressing cycles that ensure complete polymerisation.

3.2 Bio-polyols and rigid polyurethane foams

Polyols synthesised from suberinic acids and tall-oil fatty acids provide a renewable alternative to petrochemical polyols in rigid polyurethane foams. Their hydroxyl functionality, viscosity profile and thermal behaviour can be tuned through depolymerisation conditions, catalyst selection and reactant ratios. The resulting foams exhibit high closed-cell content, low thermal conductivity and improved fire resistance when formulated with ammonium polyphosphate or other halogen-free flame retardants.

These foams are recommended for prefabricated insulation panels, sandwich structures and technical insulation systems where thermal stability and reduced flammability are required. Their compatibility with existing industrial foaming equipment facilitates rapid adoption. **Manufacturers should consider the influence of polyol composition on foaming kinetics**, cell morphology and mechanical performance, ensuring that NCO/OH ratios are adjusted to maintain consistent reactivity.

3.3 Wood-polymer composites

Wood-polymer composites incorporating alkaline-treated pine sawdust and recycled polypropylene demonstrate enhanced mechanical properties, reduced melt viscosity and improved processing efficiency when suberinic acids are used as internal lubricants. The alkaline treatment increases fibre surface area and reduces extractives, improving interfacial adhesion with the polymer matrix. Suberinic acids further facilitate homogenisation of the melt, reduce torque during extrusion and contribute to improved bending strength and dimensional stability.

These composites are suitable for interior building components, trims, mouldings and furniture elements where moisture resistance and mechanical robustness are required. Their reliance on recycled polymers and wood residues aligns with sustainability targets and reduces the carbon footprint of composite production. **Industrial users should optimise fibre loading, compatibiliser content and extrusion parameters to achieve consistent product quality**.

3.4 Extractives and bioactive compounds

Pressurised-water extraction of pine, alder and birch bark yields carbohydrate-rich and phenolic-rich fractions with potential applications in medical, cosmetic and bioprotective formulations. Catechol-bearing extractives exhibit antioxidant, antimicrobial and wound-healing properties, supporting their use in dressings, skin-repair formulations and biological plant-protection agents. The extraction residues can be further valorised into polyols or used as fillers in polymer composites, ensuring full utilisation of bark biomass.

Stakeholders in the pharmaceutical, cosmetic and agricultural sectors should consider these extractives as renewable alternatives to synthetic additives. Standardisation of extraction conditions, purification protocols and quality-control parameters will be essential for regulatory compliance and market acceptance.

3.5 Densified wood for high-performance applications

Chemically pretreated and thermally densified birch wood achieves densities approaching 1300 kg/m³ and mechanical properties exceeding those of cortical bone in dry conditions. Impregnation with citric acid or chitosan-based systems significantly improves dimensional stability and mechanical retention under wet or humid conditions. The resulting material demonstrates potential for osteosynthesis implants, precision components and high-performance structural elements.

Industrial adoption should focus on applications where high stiffness-to-weight ratios, biocompatibility and renewable sourcing are valued. Further development is required to optimise machining, thread formation and long-term durability under physiological conditions.

3.6 Biological agents from wood residues

Solid-state fermentation of pine shavings supplemented with wheat bran enables efficient production of Phlebiopsis gigantea spores for biological stump protection. The process achieves high spore yields and viability, offering a locally produced alternative to imported biocontrol agents. The use of forestry residues as substrate reduces production costs and supports circular use of biomass.

Forestry operators and plant-protection companies should consider integrating this technology into stump-treatment operations to reduce Heterobasidion root-rot incidence. Scaling requires attention to substrate sterilisation, moisture control and contamination management.

3.7 Furfural, acetic acid and 5-HMF from veneer residues

The integrated conversion of birch veneer residues into furfural, acetic acid and 5-HMF offers a new valorisation pathway for plywood by-products. Furfural produced using orthophosphoric acid as a catalyst meets the purity requirements for established industrial applications, including furfuryl alcohol synthesis, resin production, solvent systems and refining processes. The process achieves high theoretical yields while avoiding the formation of sulfur-containing wastes, making it more compatible with modern environmental regulations.

Acetic acid, obtained as a co-product, can be recovered at significant quantities and directed toward chemical synthesis, food-grade applications or internal process loops depending on purity. Its recovery contributes meaningfully to the economic viability of the process.

The cellulose-rich residue remaining after furfural extraction is recommended as a feedstock for 5-HMF production. Although current yields are below industrial benchmarks, the results confirm that veneer-derived cellulose can be converted into 5-HMF through catalytic dehydration. Continued optimisation of catalysts, solvent systems and reaction conditions is expected to improve yields. In the interim, the residue can be flexibly allocated to alternative cellulose valorisation routes, ensuring full utilisation of the biomass.

These three product streams - **furfural, acetic acid and 5-HMF** - form the basis of a multiproduct biorefinery model that **can be integrated into plywood manufacturing operations, transforming low-value residues into high-value chemical intermediates**.

4. Integrated biorefinery pathways

The products developed within WP3 collectively demonstrate the feasibility of an integrated biorefinery model in which wood processing residues are transformed into a spectrum of

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high-value products. Birch and pine bark, sawdust, veneer cores and chips, and recycled particleboard fractions can be channelled into parallel processing streams that maximise resource efficiency and enable the production of chemicals, polymers, composites and advanced materials within a single value chain.

Within this integrated system, bark-derived suberinic acids serve as adhesives, polyol precursors and lubricants in composites, linking biorefinery outputs directly to construction and furniture applications. Pressurised-water extraction of bark yields bioactive compounds suitable for medical and agricultural use, while extraction residues can be further upgraded into polyols or incorporated into composite formulations. In parallel, glycerol-based extraction of pine and birch bark provides a complementary route for isolating phenolic-rich bioactive compounds with antioxidant, antimicrobial and dermal-healing properties. These glycerolic extracts can be used directly in wound-care and cosmetic formulations, while the remaining solid residues - depleted in low-molecular-weight phenolics but enriched in carbohydrates and hydroxyl-bearing structures - represent a valuable feedstock for the synthesis of “green” bio-polyols. This creates a closed-loop valorisation pathway in which both the extract and the extraction residue contribute to high-value product streams.

Sawdust and recycled wood particles form the basis of particleboards and wood-polymer composites, while densified-wood technologies valorise veneer cores and small-diameter logs into high-performance structural and biomedical materials. These material-based pathways operate in parallel with chemical and extractive routes, ensuring that each biomass fraction is directed toward the most suitable and highest-value application.

The veneer residues from plywood production can also be integrated into this biorefinery model through the production of furfural, acetic acid and 5-hydroxymethylfurfural (5-HMF). Using orthophosphoric-acid-catalysed hydrothermal pretreatment, hemicellulose in veneer chips is selectively converted into furfural and acetic acid while preserving the cellulose fraction. This approach avoids the formation of sulfur-containing wastes typical of conventional furfural technologies and enables the use of standard industrial equipment. The resulting furfural can be directed toward resin production, solvent systems and other established industrial applications, while acetic acid provides an additional revenue stream. The preserved cellulose-rich residue can be further processed into 5-HMF, a recognised platform chemical for bio-based polymers, fuels and specialty chemicals. Although current yields remain modest, the results confirm that veneer-derived cellulose is chemically suitable for 5-HMF production and that further optimisation of catalysts and solvent systems can significantly improve conversion efficiency. The remaining lignin fraction retains high aromaticity and thermal stability, supporting its use in phenolic resin substitution, carbon materials or energy recovery.

Together, these pathways demonstrate how different residue streams - bark, sawdust, veneer cores, and plywood by-products - can be integrated into a coherent biorefinery system that produces adhesives, polyols, foams, composites, bioactive compounds, platform chemicals and high-performance materials. This integrated approach reduces waste, diversifies product portfolios and strengthens the resilience of the wood-processing sector. It also aligns with European Green Deal objectives by reducing reliance on fossil-based chemicals, lowering emissions and promoting circularity across the entire wood value chain.

5. Environmental and regulatory considerations

The transition to biobased materials requires careful evaluation of environmental impacts, chemical safety and end-of-life management. Suberinic-acid binders eliminate formaldehyde emissions, contributing to improved indoor air quality and compliance with increasingly stringent emission standards. Bio-polyols and foams reduce the use of halogenated flame retardants, lowering toxicity risks during production and disposal. Glycerol-based bark extracts, which rely on a non-volatile, non-toxic solvent, further support safe material development by avoiding hazardous organic solvents and enabling direct incorporation into cosmetic and biomedical formulations without solvent removal.

Combustion of wood products containing adhesives, coatings or flame retardants must be regulated to prevent harmful emissions. **National authorities should establish guidelines defining permissible chemical loads for products intended for energy recovery**, enabling manufacturers to design materials that remain safe throughout their life cycle. Such guidelines are particularly important as new biobased additives, including polyols, extractives and compatibilisers, enter the market and may influence combustion behaviour. Clear regulatory thresholds would allow manufacturers to select formulations that ensure safe disposal while maintaining wood’s status as a clean, renewable fuel.

Biorefinery processes also introduce new regulatory considerations. The production of furfural, acetic acid and cellulose-derived intermediates requires compliance with chemical safety legislation, including REACH registration, classification and labelling requirements. Effluent streams containing phosphorus or organic residues must be managed in accordance with water and waste regulations. At the same time, the use of orthophosphoric acid instead of sulfuric acid significantly reduces the formation of corrosive or hazardous by-products, simplifying wastewater treatment and lowering environmental risk.

Life-cycle assessments should assume regional production of chemicals to avoid inflated transport emissions and to reflect realistic supply-chain conditions. For emerging materials such as glycerolic extracts, green polyols, lignin-derived fillers and biological control agents, environmental assessments should consider the full cascade of valorisation steps, including the reuse of extraction residues and the integration of process heat. These assessments will support transparent communication of environmental benefits and help position biobased materials within eco-label and green-procurement frameworks.

Certification pathways for emerging materials, including biobased foams, WPCs, suberinic-acid-bonded boards and bark-derived extractives, should be developed to facilitate market entry and ensure compliance with construction, furniture, cosmetic and biomedical standards. For biological agents such as *Phlebiopsis gigantea* spores, regulatory approval must address biosafety, efficacy and environmental compatibility. Establishing harmonised testing protocols and performance benchmarks will accelerate industrial adoption and ensure that new materials meet the safety and durability requirements of their respective sectors.

Overall, **the regulatory environment should evolve in parallel with technological development**, ensuring that biobased materials are introduced safely, transparently and in a manner that supports long-term sustainability objectives. By aligning environmental regulation, certification frameworks and industrial practice, Latvia can create favourable conditions for the deployment of innovative biobased materials and strengthen its position within the European circular bioeconomy.

6. Sector-specific guidance

6.1 Construction and building materials

Construction stakeholders should prioritise materials with low embodied carbon, high durability and reduced chemical emissions. Suberinic-acid-bonded boards, biobased insulation foams and WPCs offer viable alternatives to conventional materials in interior partitions, wall modules, insulation systems and decorative elements. Thermally modified veneers and lightweight stabilised blockboards provide dimensionally stable solutions for large-area applications.

The integrated biorefinery pathway developed in WP3 further strengthens the construction sector's transition toward renewable materials. Furfural produced from veneer residues can serve as a precursor for bio-based resins and binders used in engineered wood products, enabling partial substitution of fossil-derived phenolic and furan resins. In the longer term, 5-HMF and its derivatives, such as FDCA, may support the development of new bio-based polymers and coatings with improved environmental profiles. These emerging chemical intermediates expand the portfolio of renewable construction materials and reinforce the sector's alignment with European Green Deal objectives.

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6.2 Furniture and interior materials

Furniture manufacturers can adopt suberinic-acid-bonded particleboards to eliminate formaldehyde emissions and incorporate recycled wood fractions. Thermally modified veneers and densified wood components offer high-quality surfaces and structural elements with enhanced stability. WPCs provide moisture-resistant options for interior trims and functional components.

The biorefinery outputs from veneer residues also offer opportunities for the furniture sector. Furfural-derived resins can be used in moulded components, coatings and adhesives, providing renewable alternatives to petrochemical systems. As 5-HMF technologies mature, they may support the development of bio-based lacquer systems, polymer coatings and interior surface treatments with reduced VOC emissions. Integrating these renewable chemical intermediates into furniture manufacturing strengthens the sector’s sustainability profile and supports compliance with increasingly stringent indoor-air-quality requirements.

6.3 Chemical and polymer industries

Chemical producers can integrate bark-derived extractives, suberinic acids and bio-polyols into polymer formulations, adhesives and coatings. These materials support the development of renewable, low-toxicity products aligned with regulatory trends and consumer demand for sustainable materials.

The furfural and 5-HMF pathways developed in Activity 3.2.1 provide additional strategic feedstocks for the chemical industry. Furfural from veneer residues can be upgraded into furfuryl alcohol, furan resins, solvents and intermediates for bio-based polymers. Acetic acid recovered as a co-product can be directed toward acetylation processes or used as a platform for chemical synthesis. The cellulose-derived 5-HMF stream, although still under development, represents a key precursor for FDCA, DMF and other high-value chemicals central to the emerging bio-polymer sector. These integrated pathways diversify raw-material supply, reduce dependence on imported furfural and support the development of regional bio-based chemical production.

6.4 Medical and biotechnology sectors

Densified birch wood and bark extractives offer opportunities for medical devices, wound-care products and bioprotective agents. Collaboration with regulatory bodies and clinical researchers will be essential to advance these materials toward certification and market deployment.

The biorefinery process contributes additional opportunities for the medical and biotechnology sectors. Furfural-derived intermediates are used in pharmaceutical synthesis, antimicrobial

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formulations and specialty solvents, while 5-HMF exhibits antioxidant and bioactive properties relevant to biomedical research. The ability to produce these compounds from veneer residues strengthens Latvia's capacity to supply renewable chemical intermediates for medical applications and supports the development of high-value bioproducts with reduced environmental impact.

6.5 Forestry and wood-processing industries

Forestry operators can valorise residues through biorefinery pathways, reducing waste and generating new revenue streams. The production of biological stump-protection agents and the use of veneer cores in densified wood technologies exemplify high-value applications for materials traditionally considered low-grade.

The integration of furfural and 5-HMF production into plywood and veneer operations represents a major opportunity for the wood-processing sector. Veneer residues, which are typically used for low-value energy production, can be transformed into platform chemicals with established global markets. This shift enables plywood plants to evolve into multiproduct biorefineries, increasing economic resilience and reducing exposure to fluctuations in timber and panel markets. The approach also supports regional development by creating new industrial activities linked to chemical production, purification and downstream processing.

7. Implementation considerations

Successful industrial adoption of the materials and technologies developed within WP3 requires coordinated efforts across research institutions, manufacturers and policymakers. The transition from laboratory-scale demonstrations to industrial practice depends on the establishment of stable supply chains for wood-processing residues, the development of appropriate processing infrastructure and the creation of regulatory and market conditions that support investment in biobased technologies.

Scaling biorefinery processes demands targeted investment in extraction, depolymerisation and catalytic conversion equipment, as well as in the supporting utilities required for heat integration, solvent recovery and effluent management. For the furfural–5-HMF pathway, particular attention must be given to reactor design, catalyst handling systems and purification units capable of achieving the product quality required for chemical markets. Workforce training is essential to ensure safe and efficient operation, especially in facilities where chemical processing is being introduced alongside traditional wood-processing activities.

Standardisation of raw-material specifications - such as moisture content, particle size, bark content and chemical composition - is critical for ensuring consistent product quality across all WP3 technologies. Veneer residues destined for furfural and 5-HMF production must be collected and stored in a manner that preserves their chemical integrity, while sawdust and recycled wood particles used in composites or particleboards require controlled fractionation and drying. Establishing internal quality-control protocols within wood-processing plants will support reliable feedstock supply for biorefinery operations.

Pilot-scale demonstrations should be prioritised to validate performance under real-world conditions and build confidence among industry stakeholders. For the furfural–5-HMF pathway, pilot units co-located with plywood plants can demonstrate the feasibility of integrating chemical production with existing industrial operations, including the reuse of process heat and the management of effluent streams. Such demonstrations will also provide essential data for techno-economic analysis, life-cycle assessment and regulatory approval.

Public procurement policies can accelerate uptake by prioritising biobased materials in public buildings and infrastructure projects. Demonstration projects using suberinic-acid-bonded boards, biobased insulation foams, WPCs and densified wood components will showcase the performance of these materials in practice. In parallel, the inclusion of furfural-derived resins and, in the longer term, 5-HMF-based polymers in public procurement frameworks can stimulate demand for renewable chemical intermediates and support the development of regional supply chains.

Collaboration with certification bodies will facilitate the development of standards tailored to emerging materials. For biorefinery products, this includes establishing purity requirements for furfural and acetic acid, defining quality parameters for cellulose-derived intermediates such as 5-HMF and ensuring that lignin-based materials meet the performance and safety criteria required for their intended applications. Early engagement with regulatory authorities will streamline permitting processes and ensure that environmental and safety considerations are fully integrated into plant design.

Overall, successful implementation will depend on phased development, beginning with technologies that have reached higher TRLs - such as suberinic-acid binders, WPCs, biopolyols and furfural production - and gradually incorporating more advanced pathways. **By adopting a coordinated, stepwise approach, Latvia can establish a resilient and competitive biorefinery sector that maximises the value of its wood-processing residues and supports long-term industrial transformation.**

8. Summary

The research conducted within WP3 demonstrates that Latvia's wood-processing residues can serve as a foundation for a new generation of biobased materials and chemical intermediates. Across Tasks 3.1–3.4, the project has shown that bark, sawdust, veneer residues, juvenile wood and recycled

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wood particles can be transformed through biorefinery, polymer chemistry and biotechnology into high-value products that complement traditional wood-based materials and expand the technological capabilities of the forest sector.

The biorefinery activities carried out in Task 3.2 confirm that industrial by-products such as birch veneer residues can be converted into platform chemicals including furfural, acetic acid and cellulose-derived intermediates. The use of orthophosphoric-acid-catalysed hydrothermal pretreatment enables selective hemicellulose conversion while preserving cellulose for further upgrading. In parallel, bark-derived extractives provide functional phenolic and catechol-type compounds with antioxidant, antimicrobial and bioprotective properties, supporting applications in medical, cosmetic and agricultural sectors. These results demonstrate that chemical valorisation of wood residues can significantly increase the added value of existing processing streams.

Task 3.3 has shown that bark-derived suberinic acids and bio-polyols can replace fossil-based binders and polyols in particleboards, fibreboards and rigid polyurethane foams. These materials exhibit favourable mechanical properties, reduced emissions and improved environmental profiles. Wood-polymer composites produced from recycled polypropylene and sawdust demonstrate enhanced performance when functionalised with bark-derived components, supporting the development of high-renewable-content composites for interior and exterior applications.

Task 3.4 has demonstrated that densified wood, functional extractives and biological agents derived from wood residues can support advanced applications in materials engineering and forestry. Densified birch wood exhibits exceptional strength-to-weight ratios and biocompatibility, enabling conceptual biomedical uses. Solid-state fermentation of forestry residues enables the production of high-viability *Phlebiopsis gigantea* spores for stump protection, strengthening sustainable forest management practices.

Together, **these developments provide a scientifically validated and technologically mature foundation for expanding the use of Latvian wood resources beyond traditional construction materials**. They demonstrate that residues previously considered low-value can be transformed into adhesives, polyols, foams, composites, extractives, platform chemicals, densified materials and biological agents, **supporting the transition toward a circular, low-carbon bioeconomy**.

To maximise their impact, Latvia should:

- promote the uptake of biobased materials and chemical intermediates across polymer, chemical, medical, forestry and manufacturing sectors;
- support certification and standardisation of emerging products; ensure safe chemical use and end-of-life management;
- encourage industrial deployment through incentives and public procurement; and integrate circular-economy principles by valorising residues and recycled materials.

Strengthened collaboration between research institutions, industry and policymakers will be essential to accelerate market uptake and ensure that emerging technologies reach commercial maturity. By adopting the recommendations outlined in this deliverable, Latvia can significantly enhance the added value of its wood resources, reduce environmental impacts and position itself as a leader in sustainable biobased material innovation. The integration of biorefinery outputs, functional extractives, high-renewable-content composites and biotechnology-based solutions into industrial practice will contribute to a more resilient, resource-efficient and climate-neutral future.

26/01/2026

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