NewWave

Sustainable biobased products for the construction industry

Results booklet

Funded by the European Union

Project funded by

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What is it about?

The NewWave Project, funded by the European Union's Horizon Europe Programme, has been a pioneering initiative to lay the foundations for a sustainable and circular economy by introducing innovative and bio-based raw materials into production lines for the construction sector. The focus lies with the transformation of current fossil-based production lines into new bio-based value chains. Through technological innovation, NewWave aimed to replace toxic and fossil chemicals and reduce the environmental footprint, while ensuring mechanical and physical performance equal to or exceeding that of traditional construction products. This booklet provides a recap of the results achieved after four years of work by the project consortium.

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Discover more on the NewWave Website

The NewWave consortium

The consortium is led by **Biomass Technology Group (B.T.G.)**, specialized in the conversion of biomass into fuels, energy, and biobased raw materials for the past 35 years. The other partners are:

AEP Polymers, an innovation-based company focused on R&D in the field of industrial polymers and intelligent formulations from non-edible biomasses with application in composites, polyurethanes, coatings, and adhesives. **Avecom** is a company with expertize in Microbial Resource Management, wastewater treatment, digestion processes, soil remediation and microbial fermentation. **Foreco** is a family owned firm in the field of timber products with a history of over 30 years. The company is active in the field of wood protection and sustainable development. **Foresa Technologies** is a spin-off of the chemical company FORESA, and deals with innovation, sustainability and industrial property in the field of chemicals, adhesives, wood, and furniture. **Blue Synergy** is a consultancy specialized in supporting the transition towards sustainable operations across multiple fields. **Transfurans Chemicals (TFC)** is a pioneer in Furfural chemicals, active in the production of Furfuryl Alcohol and derivative products. **Innorenew CoE** is a research department at the University of Primorska focusing on renewable materials and sustainable buildings, specifically innovative approaches to wood and its use, with the goal of transferring scientific knowledge into industrial practice.

The **University of Groningen** is a high ranking European University carrying out applied research on multiple sectors. The **University of Applied Sciences of Northwestern Switzerland (FHNW)** is a leading research body comprising 10 schools with different specializations. **ETA Florence Renewable Energies** is a consultancy active in EU-funded research and innovation projects, with expertise in communication, dissemination, exploitation, and project delivery.

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Introduction The NewWave vision

The NewWave project has been a pioneering initiative, funded by **Horizon Europe**, that had the ambition to lay the foundations for a sustainable, circular economy at the heart of the construction industry. The project’s central vision is the **radical transformation** of current fossil-based production lines into new bio-based value chains capable of upcycling biomass residues (such as sawdust) and end-of-life products. Through technological innovation, NewWave aimed to reduce the environmental footprint of **construction materials** while ensuring mechanical and physical performance equal to or greater than that of the traditional products.

The overall concept of the project revolved around **four manufacturing lines** (ML) that developed a series of intermediate and end products. The work in the ML was possible thanks to the technology at the core of NewWave: **Thermo-Chemical Fractionation** (TCF). The scheme below provides you with an overview of the different manufacturing lines and their interlinks.

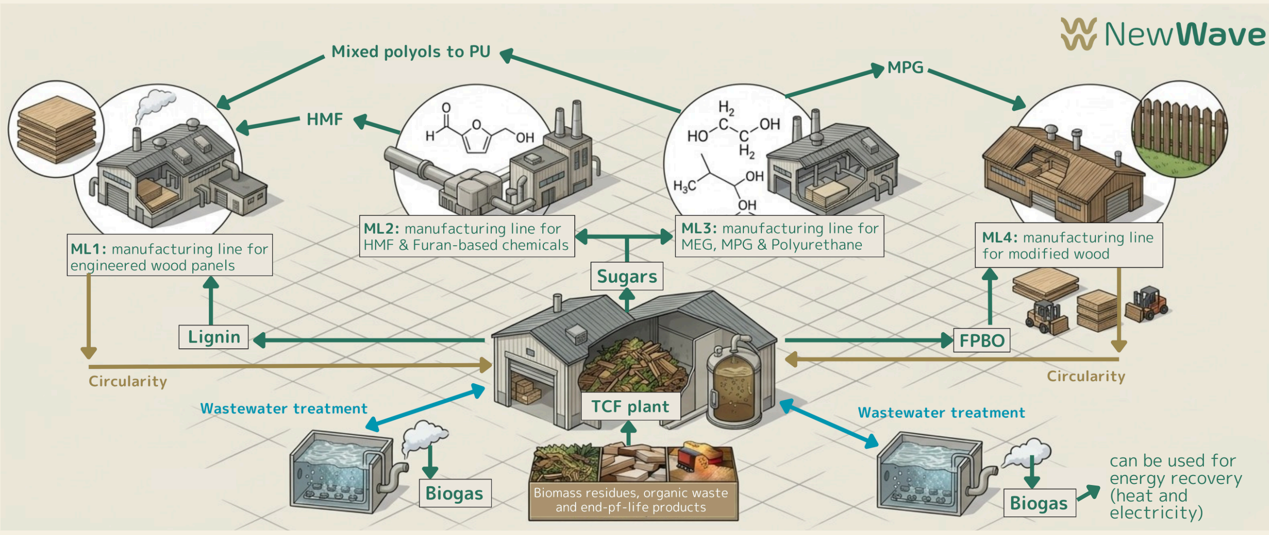


Figure 1: The NewWave concept and its manufacturing lines

A **fundamental pillar** of this mission was the replacement of toxic and hazardous chemicals—including formaldehyde, creosote, and copper salts—with bio-sourced, non-toxic, and fully recyclable alternatives. This approach not only makes materials safer for end-users but also promotes a healthier working environment and reduces air pollution. Driven by a consortium of 11 European partners, bringing together research excellence and industrial leaders, the project has advanced these technologies to a new maturity level (TRL-5/6).

The validity of this vision has been demonstrated concretely through the construction of a real **architectural model** (mock-up) in Slovenia, where the new bio-based materials have been tested for durability and performance in outdoor conditions. This document guides you through the innovation and results made possible by the NewWave partners during 4 years of relentless work.

The consortium wishes that this marks the start of a "**new wave of doing things**” where construction stops consuming finite resources, by becoming more circular and transforming itself into an engine for natural regeneration.

Chapter 1

The Core Technology: Thermo-Chemical Fractionation (TCF)

The beating heart of the NewWave project is Thermo-Chemical Fractionation (TCF), an innovative two-stage process designed to transform biomass residues and end-of-life wood products into high-value, sustainable raw materials. Currently at a TRL 6/7 maturity level, this technology "unlocks" the chemical potential of wood without the use of enzymes or added chemicals, driving a true circular economy.

Figure 2: The TCF pilot-plant at BTG

Phase 1: Fast Pyrolysis – Turning Matter into Energy and Oil

The process begins inside a rotating cone reactor, where biomass (such as sawdust residues from sawmills) is rapidly heated to temperatures between 400°C and 600°C in the absence of oxygen.

- **Energy Efficiency**: The biomass thermally decomposes to produce vapors that, once condensed, form Fast Pyrolysis Bio-Oil (FPBO).
- **Self-Sustaining Process**: The by-products—non-condensable gases and solid charcoal (char)—are burned to generate the heat required to sustain the reaction. This makes the system energetically efficient and drastically reduces CO_2 emissions (by up to 97% compared to fossil-based alternatives).

Phase 2: Fractionation – Separating to Create

The true innovation of NewWave lies in how the bio-oil is processed. Rather than using traditional boiling-point distillation, the project employs liquid-liquid extraction based on chemical functionality. By using water as a solvent, the bio-oil is separated into two primary streams:

- Reactive Pyrolytic Lignin: A viscous liquid fraction that serves as an excellent substitute for fossil-derived phenol in the production of resins and adhesives.
- Pyrolytic Sugars: An aqueous solution rich in C6 sugars, used as a foundation for creating bio-polyols and chemical intermediates like HMF.

Proof of Circularity: Closing the Loop

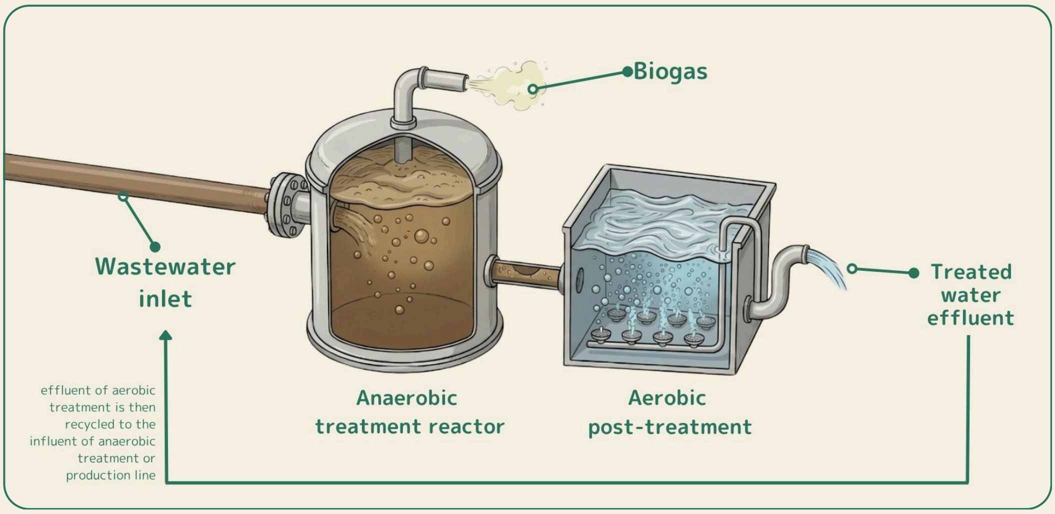
The TCF process is not limited to virgin biomass. NewWave has demonstrated that it is possible to reintroduce end-of-life products back into the cycle, such as the plywood panels and modified wood developed during the project. These materials were ground down and subjected to pyrolysis once more, transforming old construction components into new chemical building blocks.

This approach ensures a virtually waste-free production, where even wastewater is treated to produce biogas and treated water, which can be reused in the production line. TCF is not just a chemical process; it is a "green refinery" system that transforms wood waste into an infinite resource, eliminating oil dependency and reducing the environmental impact of the construction industry.

Chapter 2 **Wastewater treatment**

Wastewater treatment and reuse are central elements of the NewWave project, designed to transform manufacturing processes into essentially waste-free systems. Partner **Avecom** analyzed 16 different samples of **wastewater** generated by the **Thermo-Chemical Fractionation** (TCF) lines and **polyol production** (ML1), successfully defining specific treatment pathways that combine biological and physicochemical processes. The following scheme provides an overview of the overall wastewater treatment train for ML1, while the primary results achieved can be found below.

Figure 3: the wastewatert reatment train of ML1



High-Efficiency Biogas Production: Conversion of TCF wastewaters into biogas was found cost-beneficial when fed as a co-substrate and after pre-treatment with urea. On the other hand, significant potential was identified for producing biogas with high methane content from the hydrotreated wastewater of the ML1 line. This result is considered of extreme scientific and industrial relevance, as there are no previous publications documenting such conversion efficiency for industrial effluents of this complexity; for this reason, the optimization protocols are considered a project trade secret.

Closing the Water Loop: wastewater treatment tests demonstrated that the designed treatment trains allow for the recycling and reuse of purified water both within the TCF process and as dilution water in the treatment system itself. This approach drastically reduces the water footprint and environmental compliance costs.

Biochemical Optimization: since these wastewaters are unique and initially lack essential nutrients for microorganisms, Avecom optimized the dosage of a specific trace element product, named Methanostim Liquide, to maximize biological degradation.

Energy Sustainability: the biogas generated from anaerobic treatment can be used for energy recovery (heat and electricity), decreasing the need for external energy to sustain the plant, or production of hydrogen and further re-use in the hydrotreatment production lines

Technological Maturity: the biogas production process, currently at a TRL 3-4 level, is undergoing further scale-up toward TRL 4-6 through collaboration with the FUEL-UP project.

With these achievements, NewWave has successfully transformed a potential environmental problem (highly concentrated industrial effluents) into an energy and water resource, validating a circular economy model applicable on an industrial scale.

Chapter 3 Polyols and Polyurethanes

Manufacturing Line 1 (ML1) represented a fundamental pillar of the NewWave project, focusing on replacing fossil-based components in polyurethanes with bio-polyols derived from residual biomass. The success of this line is the result of close collaboration between chemical research at **BTG** and the synthetic and formulation expertise of **AEP Polymers**.

From Biomass to Chemical Building Blocks: The Hydrogenation Process

The journey begins with the sugar fraction obtained from the fractionation of Fast Pyrolysis Bio-Oil (FPBO) done through TCF.

- **Advanced Synthesis**: At BTG, pyrolytic sugars undergo a hydrogenation process within pilot-scale hydro-treaters.
- **Innovative Catalysts**: This reaction utilizes the patented nickel-based catalyst PICULA™, which is capable of operating effectively within the complex aqueous and acetic matrix of pyrolytic streams.
- **Polyol Fractionation**: The result is a mixture of small monomeric polyols, such as ethylene glycol (MEG) and propylene glycol (MPG), and larger oligomeric molecules. These are subsequently separated via distillation to be ready for industrial use.

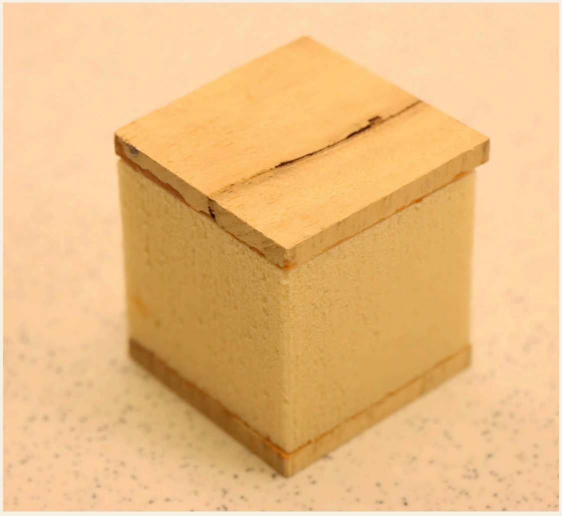


Figure 4: Rigid polyurethane foam core

Innovation in Applications: foams and adhesives

The produced polyols (15 total samples delivered during the project) were validated by AEP Polymers for two key applications in the construction sector:

1. **Rigid Polyurethane Foams**: Used as insulating cores for sandwich panels, demonstrating mechanical properties in line with fossil-based standards.
2. **Bio-based Adhesives**: two systems formulated for bonding Cross-Laminated Timber (CLT) panels, based on two different bio-polyols synthesized using FPBO-derived glycols fully replacing petrochemical polyols.

The Demonstrator: Wood-Polyurethane Composite Panels

The most significant tangible result of ML1 is the creation of 15 "sandwich" composite panels measuring 50x50x5 cm^3.

- **Integrated Structure**: Each panel combines a 3 cm bio-based polyurethane foam core encased between two 1 cm eco-friendly plywood layers (produced in the ML3 line), creating a direct link between the project's various innovations.
- **"Pour-in-Place" Process:** The panels were manufactured by pouring the polyurethane mixture directly between the plywood sheets in a closed mold, custom built to resist the pressure generated by the foam.
- **Technical Precision:** To ensure perfect adhesion, the internal wood surfaces were pre-treated with sandpaper, and each panel was left to cure in the mold for at least three hours.

Validation and outlook

These components are not merely laboratory samples: 8 panels (covering a surface area of 2 m²) were installed in the architectural mock-up at the **InnoRenew** headquarters in Slovenia to test their resistance to weathering under real-world conditions. The remaining 7 panels have been subject to rigorous scientific testing to benchmark their mechanical, acoustic, and thermal properties against petrol-based reference panels. **Results** show that the performance of newly developed bio-based composite panels is comparable to the fossil-based reference.

Currently, the technologies developed in this line have reached a maturity level of **TRL 4-5**, marking a decisive step toward the decarbonization of insulating and structural materials for the construction of the future.

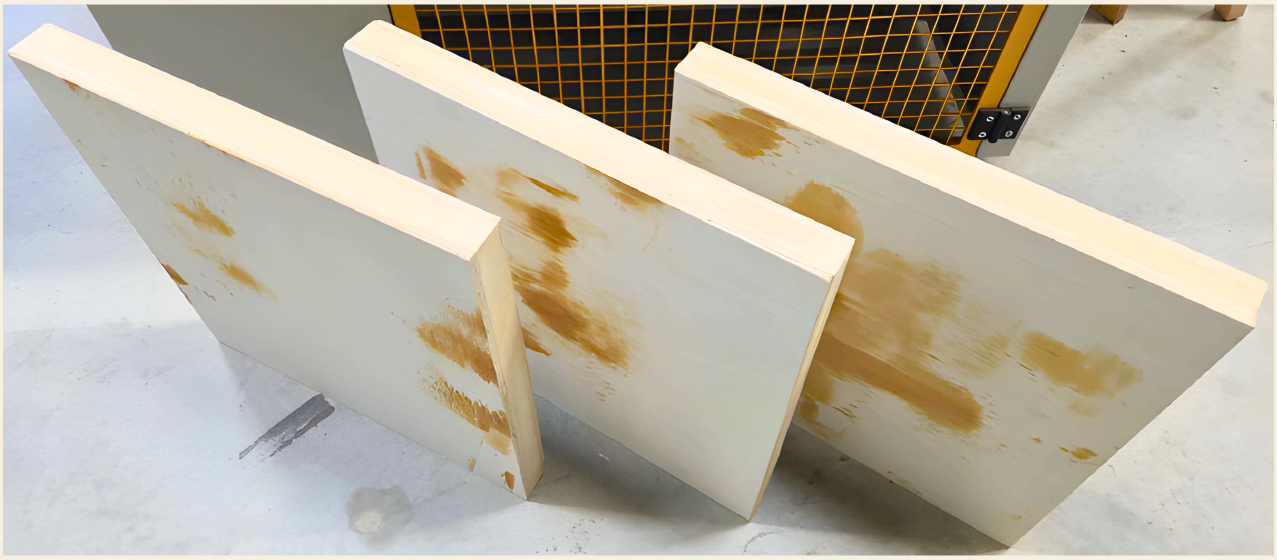


Figure 5: Finished 50x50cm composite PU-plywood panels.

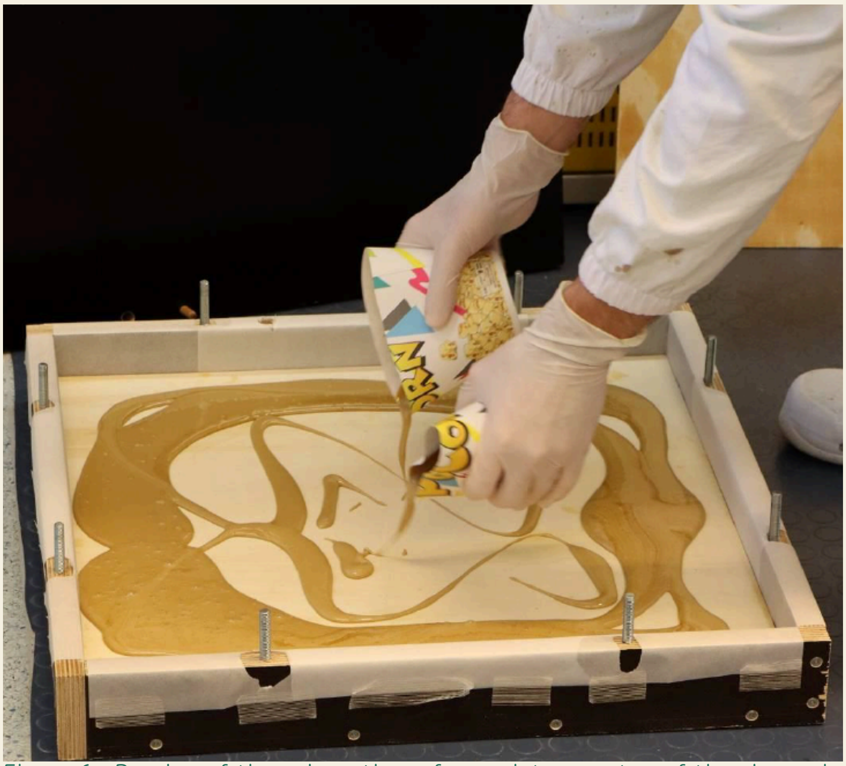


Figure 6: Pouring of the polyurethane foam mixture on top of the plywood

Chapter 4 Furan chemistry

Manufacturing Line 2 (ML2) of the NewWave project harnesses the potential of sugar streams obtained through the **Thermo-Chemical Fractionation** (TCF) of residual biomass. While traditional processes typically rely on C5 sugars for furfural production, NewWave utilizes fractions rich in C6 sugars.

Through acid-catalyzed dehydration, these sugars are converted into 5-hydroxymethylfurfural, or
5-HMF, a versatile platform molecule for a wide range of bio-based chemical products.

Based on the lab-scale development of the fundamental conversion of pyrolytic sugars to 5-HMF by partner **RUG**, a scale-up in a reaction system of 5 liters was achieved by partner **FHNW**. A yield of 0.17 g 5-HMF per g of hexoses in the pyrolytic sugar fraction was obtained. The main challenge was the isolation and purification of the 5-HMF from the biphasic reaction mixture.

Figure 7: Commercial plant with capacity> 4 kton/ year(startup Q12025) TRL4 to 9 during the NewWave project

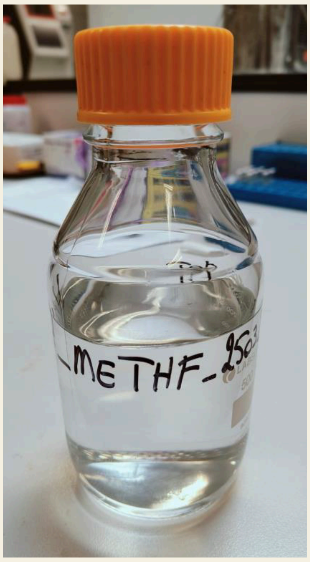


Figure 8: First batch of 2-MeTHF from TFC plant (Q12025)

Innovative Chemical Intermediates and Solvents

The use of 5-HMF paves the way for the production of several substances with crucial industrial applications:

- **Sustainable Solvents:** These include dimethylfuran (DMF), dimethyltetrahydrofuran (DMTHF), 2-methyltetrahydrofuran (2-MeTHF), and tetrahydrofurfuryl alcohol (THFA).
- **Polymer Building Blocks:** Compounds such as bis-hydroxymethylfuran (BHMF) and bis-hydroxymethyltetrahydrofuran (BHMTHF) show high potential for applications in polymer chemistry.

Industrial Success and Scalability (TRL 9)

One of the most significant achievements of ML1 involves the optimization of the furan ring hydrogenation process conducted by partner **TFC**. By utilizing mild reaction conditions and a cost-effective non-noble metal catalyst, the project demonstrated excellent selectivity and recyclability.

This work has successfully:

- **Reached TRL 9**: With the launch of a commercial hydrogenation unit for the production of 2-MeTHF and THFA, the process is now fully market-ready.
- Improved Safety: The developed protocol offers better process control and enhanced thermal safety.
- **Served Established Markets:** 2-MeTHF is already in demand by the pharmaceutical industry for the synthesis of Active Pharmaceutical Ingredients (APIs), while THFA is used in agrochemical formulations, coatings, and cleaning products.

Beyond Solvents: Resins and Polymers

5-HMF also plays a key role in the sustainability of wood panels. It has been used to develop formaldehyde-free resins, where HMF entirely replaces formaldehyde, reducing the toxicity of the final materials. Although the production of 100% HMF-based resins still faces challenges—such as long curing times (up to 6 hours) and high temperatures (95°C)—technical feasibility has been confirmed.
Regarding polymeric materials, the production of BHMTHF from 5-HMF has been validated in a laboratory environment (TRL 4) and is currently being evaluated for polyurethane (PU)-based applications.

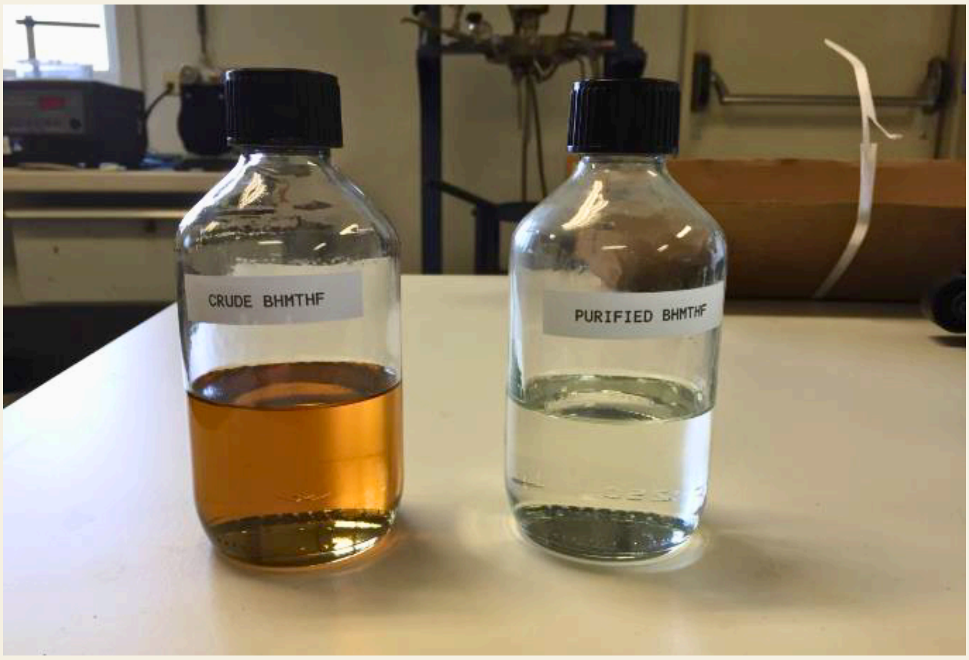


Figure 9: Crude BHMTHF (left) and Purified BHMTHF (right)

Strategic Advantages and Circularity

The furan chemistry developed within NewWave not only reduces petroleum dependency but also fits into a virtually waste-free production model. The hydrogenation processes have proven flexible for various furanic compounds, ensuring credible pathways for industrial adoption and integration into existing value chains.

Chapter 5 New engineered wood products

Manufacturing Line 3 (ML3) had the objective of creating **wood panels**, such as plywood and MDF (Medium Density Fibreboard), using **sustainable resins** produced by partner **Foresa Technologies**. The primary objective was the replacement of fossil-based and toxic chemicals, such as phenol and formaldehyde, with bio-based alternatives derived from the fractionation of pyrolysis oil.

Bio-Resin Innovation: Lignin and HMF

The core of ML3 lies in the development of resins where traditional components are replaced by natural building blocks:

- **Pyrolytic Lignin as a Phenol Substitute:** Lignin extracted via the TCF process has shown superior reactivity compared to natural lignin due to its lower molecular weight (~1000 g/mol). The project successfully tested phenol replacement levels ranging from 25% to 100%, achieving mechanical performance comparable to standard resins.
- **HMF as a Formaldehyde Substitute:** To eliminate harmful emissions, formaldehyde was replaced with hydroxymethylfurfural (5-HMF). This innovation results in final products that are safer for both the environment and human health, aligning with the European Commission's "**Safe and Sustainable by Design**" framework.

Figure 10: Plywood panels produced by FORESA Technologies

Results in plywood production

Tests conducted on plywood production yielded significant results:

- **Class 1 Success:** Panels produced with a 50% phenol replacement fully met European standards (EN 314-2) for use in dry indoor environments.
- **Durability Challenges:** While it was technically possible to reach 100% replacement, panels with extremely high lignin content faced difficulties passing the rigorous Class 3 tests for outdoor use due to delamination phenomena.
- **Process Optimization:** It was identified that Solid Pyrolytic Lignin gave the best results in terms of stability and resistance.

Results in MDF and Particleboard

In parallel, MDF panels were developed using "green" resins:

- **Mechanical Efficiency:** MDF panels with 25% phenol replacement demonstrated excellent dimensional stability and successfully met all industrial standards (EN 622-5).

Figure 11: the sixteen 50x50cm MDF boards produced by FORESA Technologies

- **100% Bio-based Panels:** The technical feasibility of producing particleboards using 0% formaldehyde and 0% fossil phenol was demonstrated, utilizing 100% HMF/Lignin resin and modified wood chips.
- **Current Industrial Limits:** Although the synthesis of a totally bio-based resin (100% HMF) is a scientific success, the process currently requires high temperatures (95°C) and long curing times (up to 6–7 hours), making it less economically competitive than standard fossil systems at this stage.

Sustainability and Real-World Applications

The use of these bio-resins drastically reduces the carbon footprint and the emission of volatile organic compounds (VOCs). To demonstrate the commercial viability of these solutions, **Foresa Technologies** produced and shipped 16 plywood panels and 16 MDF panels (50x50 cm) to be integrated into the facade model (mock-up) at **InnoRenew** in Slovenia.

Chapter 6 New modified wood products

Manufacturing Line 4 (ML4) of the NewWave project addresses one of the most significant challenges in the construction sector: **the replacement of toxic, fossil-based preservation agents** for wood—such as creosote, copper salts, and organic biocides—with fully safe and recyclable bio-based alternatives.

The **objective** was to transform less durable European wood species into high-performance construction materials through a deep impregnation process.

Figure 12: Wood samples at FORECO impregnated with an FPBO derived formulation

The Technology: Impregnation and Stabilization

The developed process is based on passive modification, which does not alter the chemical nature of the wood but instead deposits functional molecules within its cellular structure.

- **Impregnation:** The wood is placed in a reactor where, through vacuum and pressure cycles, the cells are saturated with a formulation derived from Fast Pyrolysis Bio-Oil (FPBO). The low viscosity of these solutions allows for impregnation at room temperature, significantly reducing energy consumption.
- **Drying and curing:** After impregnation, the wood is air- or kiln-dried and then subjected to a thermal curing process in a steam autoclave (up to 130°C). This phase is essential for stabilizing the impregnating agents within the cell walls, ensuring they are not released into the environment (leaching).

Results and Performance: Exceeding Standards

.Pilot-scale tests conducted by partner Foreco have led to excellent results using the formulation based on FPBO.

- **Certified durability:** The modified wood reached Durability class 2 in laboratory settings. This means the material is highly resistant to attacks by fungi (white and brown rot) and mold, making it suitable for outdoor applications without the use of toxic substances.
- **Wood Species:** Tests were performed on Radiata Pine, Scots Pine, and European beech. Radiata Pine was confirmed as the preferred species for this treatment due to its exceptional capacity for uniform absorption.
- **Physical Properties:** The treatment significantly improves dimensional stability (reducing swelling and shrinkage) and resistance to weathering and UV rays.

Figure 13: The mockup structure built in Slovenia

An Infinite Life Cycle

One of the most important successes of ML4 is the demonstration of the product's full circularity. At the end of its useful life, the modified wood does not need to be disposed of as hazardous waste (as is the case with creosote-treated wood). Instead, it can be reintroduced into the Thermo-Chemical Fractionation (TCF) process.

Through a new round of pyrolysis, the old wood is transformed back into bio-oil, which can then be used to create new impregnation formulations or resins. This approach enables a virtually waste-free production cycle.

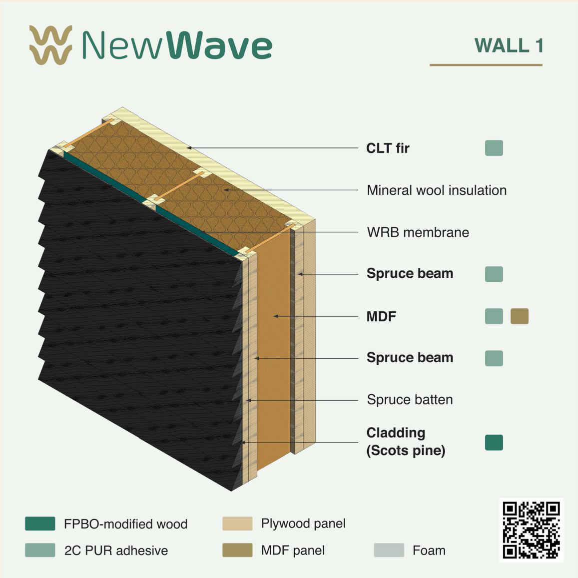
Real-World Applications: Approximately 2 m^3 of wood was treated on a pilot scale to produce real components. Modified wood cladding elements were installed in the architectural mock-up in Slovenia, where their durability and aesthetics will be monitored under real-world exposure conditions.

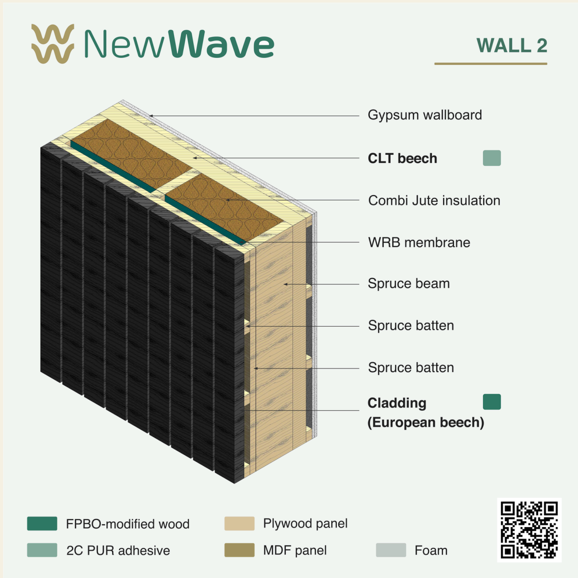
Chapter 7 The NewWave mockups

The mockups presented by **InnoRenew** (located at their headquarters in Izola, Slovenia) consist of an outdoor demonstration structure designed to test and showcase the integration of bio-based materials developed within the NewWave project under real-world conditions. The core of the presentation focuses on the configuration of four wall types **(Wall 1–4)**, each featuring a different combination of innovative technologies

Wall 1: Features external cladding made of Scots pine modified with a formulation based on FPBO. The internal structure includes spruce beams, MDF panels with bio-resin, mineral wool insulation, and spruce CLT components bonded with bio-based PUR adhesives.

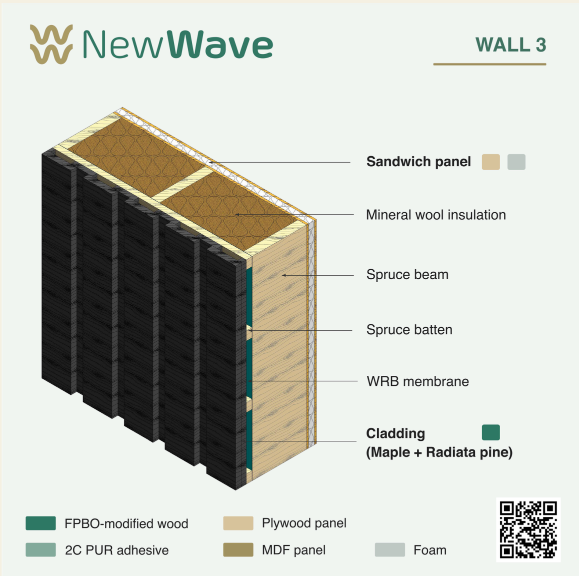
Wall 2: Utilizes modified beech cladding. It includes an internal gypsum plasterboard layer, jute insulation, protective membranes, and beech CLT.

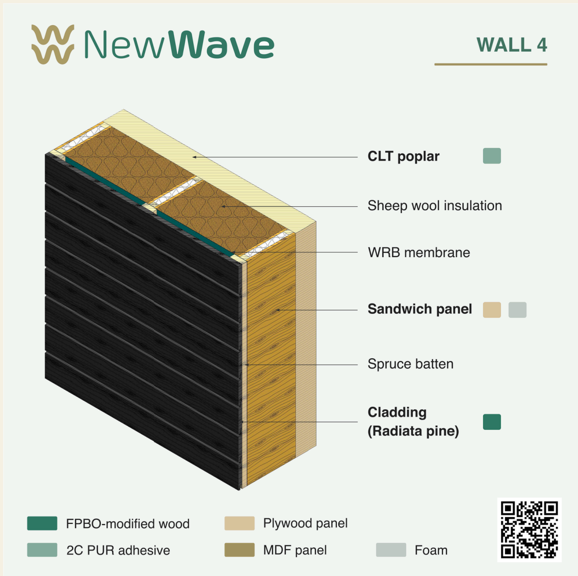




Wall 3: Distinguished by the use of a bio-based sandwich panel (wood-polyurethane) and a mixed external cladding of modified maple and radiata pine.

Wall 4: Integrates poplar CLT, sheep wool insulation, and modified radiata pine cladding, in addition to the bio-based sandwich panels.





Chapter 8 Toward the market and upcoming challenges

The NewWave project has successfully demonstrated that transforming wood waste into high-performance bio-based materials is technically feasible.

However, moving from prototype to industrial production requires a strategic path that combines infrastructure scaling, cost optimization, and long-term validation.

Figure 14: NewWave partners inspecting the mockup structure in Slovenia

Industrial Scalability: Europe's First Bio-Refinery

The cornerstone of the project's commercial future is the scaling up of the Thermo-Chemical Fractionation (TCF) process.

- 2027 Milestone: The construction of the first industrial-scale Fast Pyrolysis Bio-Oil (FPBO) fractionation unit is **planned for 2027** at Biorefinery Twente in the Netherlands. This infrastructure will be essential to ensure a consistent supply of bio-based lignin and sugars at competitive prices.

State of the Art and Technology Readiness Levels (TRL)

Commercial readiness varies across the different manufacturing lines:

- **Green Solvents (ML2):** These are the products closest to the market, having already reached TRL 9. With the launch of a commercial hydrogenation unit, solvents like 2-MeTHF are ready for immediate use in the pharmaceutical and agrochemical industries.
- **Modified Wood (ML4):** Currently at TRL 6. While pilot results are excellent, further field testing (such as EN 252 stake tests) is required to confirm durability over multi-decade periods in ground contact.
- **Polyols and Resins (ML1 & ML3):** These stand between TRL 4 and 6. While partial phenol replacement is already promising, creating 100% bio-based resins (entirely replacing formaldehyde with HMF) requires further research to reduce production times and energy costs, which are currently too high for industrial competitiveness.

Further Research and Required Testing

To reach full market maturity, the NewWave consortium has identified several key areas for future research:

- **Reactivity Optimization**: Chemical formulations for bio-resins must be refined to reduce curing times (currently up to 6–7 hours for 100% green solutions), making them compatible with the speeds of modern industrial pressing lines.
- **Real-World Validation:** The architectural mock-up in Slovenia will be vital for gathering real-time data on the aesthetic and structural degradation of materials, providing potential investors with tangible proof of reliability.
- **Certification and Regulation**: It will be essential to work closely with authorities (such as ECHA) for the approval of new pyrolysis derivatives under REACH regulations, ensuring every product is "Safe and Sustainable by Design."
- **NewWave project results** should serve legislative bodies of EU Member States to categorise the novel industrial (pyrolytic) wastewaters and define their discharge limits.
- **Novel industrial (pyrolytic) wastewaters** should be added to the list of highly suitable resources of renewable energy, biogas (precursor of methane and hydrogen), production.

A Long-Term Vision

NewWave has done more than just create new materials; it has defined realistic exploitation pathways, identifying where bio-based alternatives can already compete today and where regulatory pressure will create new opportunities tomorrow. Ultimate success will depend on the ability to create an integrated value chain, where the waste of one industry becomes the precious raw material for the sustainable construction of the future.

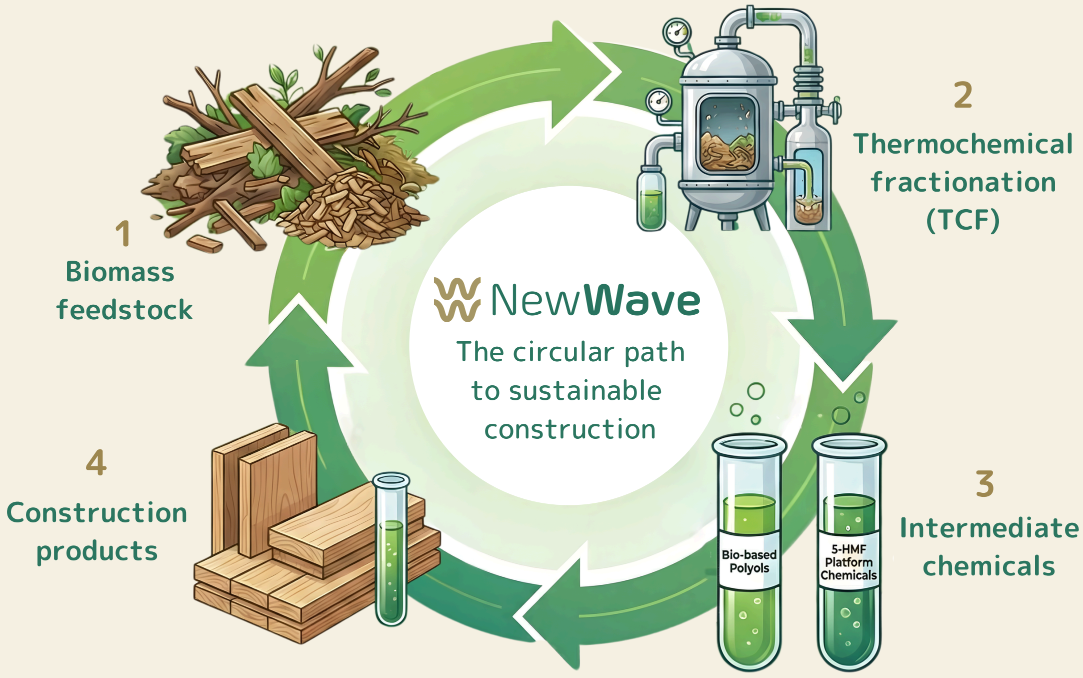


Figure 16: The NewWave approach in a nutshell

Useful links and references

Reports and publications from NewWave

ML 1: New ways to produce Polyols and Polyurethanes

ML 2: Production of Hydroxymethylfurfural (5-HMF) and derivatives

ML 3: New engineered wood products

ML 4: New modified wood products

Results summary #1: New steps in the modification of wood, utilizing sustainable formulations

Results summary #2: Ensuring the circularity of wood products for the construction industry

Results summary #3: Revolutionize construction with green chemistry

Results summary #4: New insights into wood modification

Policy recommendations and project executive summary

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