signal_name	signal_description	mindmap_maincategory	mindmap_subcategory	degree_of_emergence
Process Simulation Software (Aspen Plus)	Aspen Plus contributes to wood utilization by optimizing thermochemical processes for energy and chemical production. It enhances wood pellet gasification by identifying conditions, such as higher temperatures and steam-to-biomass ratios, that maximize hydrogen yield while minimizing tar formation. For pine woodchips, Aspen Plus determines optimal parameters like particle size, temperature, and steam ratios, achieving efficient gasification and hydrogen production. It also evaluates the economic viability of bio-methanol production from woody resources, highlighting biochar as a cost-effective alternative to other biomass derivatives. By simulating biomass gasification with CaO-Fe materials, Aspen Plus improves hydrogen output and system efficiency through advanced deoxygenation and decarburization techniques. Additionally, it supports the Energreen process, enabling the conversion of biomass into biofuels that replace fossil fuels in industrial applications like cement production, reducing emissions and costs. These innovations position Aspen Plus as a key tool in promoting sustainable wood-based energy and advancing a circular bioeconomy.	Energy, Gas and Ashes Volarisation	Fluidised Bed Gasification	0.525641026
Box Behnken Design	Box Behnken design facilitate advancing wood-based innovations by optimizing processes for material extraction and transformation. It enhances the efficiency of delignification in abies wood, enabling the production of nanofibrillated cellulose with high purity and nanoscale particle sizes, which are essential for advanced material applications. By refining autohydrolysis conditions for eucalyptus woodchips, it facilitates the removal of hemicelluloses, yielding high-purity cellulose suitable for dissolving pulp, a key resource in textiles and bioplastics. Additionally, Box Behnken design supports the development of sustainable solid-fuel pellets from corn stalk rinds by optimizing parameters like density and durability, improving their performance as renewable energy sources. These advancements contribute to reducing reliance on fossil fuels and promoting a circular economy by transforming wood and agricultural residues into high-value products, demonstrating the design's pivotal role in sustainable material science and bioenergy.	Cascade refinement technologies for wood waste upcycling	Composite production	0.28525641
Cross-laminated Bamboo and Timber (CLBT)	Cross-laminated bamboo and timber (CLBT) promotes the use of wood in sustainable construction by combining the strengths of bamboo and timber. This hybrid material enhances construction performance, particularly through improved bonding achieved with phenol resorcinol formaldehyde adhesive, while leveraging wood's natural carbon storage and low thermal expansion properties. CLBT structures reduce primary energy consumption and greenhouse gas emissions compared to conventional materials like concrete, aligning with sustainability goals. Additionally, CLBT's integration into modular and cross-laminated designs maximizes biomass residue utilization, contributing to resource efficiency. By enabling the development of predictive models for screw withdrawal resistance, CLBT supports the optimization of hybrid wood panel performance. Although further research is needed to refine its compressive strength, CLBT demonstrates significant potential for cost-effective, low-moisture-risk construction. Its adoption could accelerate the transition to a circular economy, reduce reliance on fossil fuel-intensive materials, and expand the role of wood in eco-friendly architectural innovation.	Cascade refinement technologies for wood waste upcycling	Validation of new composite products through prototyping	0.28525641
Cellulose Nanocrystals (CNC) Machines	CNC machines enable precise cutting and machining processes that account for wood's non-homogeneity. In hardwood and softwood milling, CNC machines optimize spindle speed and tool selection to reduce vibrations and improve cutting efficiency, particularly in high-speed applications. This precision supports the production of advanced wood-based materials, such as cellulose nanocrystals (CNCs) derived from wood pulp. These CNCs enhance the mechanical properties of various composites, including chitosan-silica aerogels and wood-cement panels, by improving strength, durability, and insulation. Additionally, CNCs contribute to innovations like cellulose nanopaper, which exhibits superior tensile strength and crack resistance. By facilitating the extraction and integration of cellulose nanocrystals into diverse applications, CNC machines enable the development of stronger, more sustainable wood-based materials, advancing both structural performance and environmental goals in construction and manufacturing.	Cascade refinement technologies for wood waste upcycling	CNF treatment	0.28525641
CO2 Uptake	CO2 uptake is important as it enhances material performance and enables sustainable innovations in wood based applications. Bio-based carbon foams derived from wood waste, such as hornbeam sawdust, demonstrate the dual capability of pollutant removal and CO2 capture, showcasing wood's potential in environmental remediation. The carbonation of wood ash compacts improves their structural integrity and CO2 absorption capacity, with operational conditions fine-tuning these properties for optimized performance. Additionally, the co-gasification of wood with materials like rice husk improves furnace porosity, which enhances syngas composition and calorific value, making wood a viable contributor to renewable energy systems. These advancements highlight wood's role in reducing reliance on fossil fuels and promoting a circular economy by transforming waste into functional materials and energy sources. CO2 uptake not only reinforces wood's utility in diverse applications but also aligns its use with global sustainability goals.	Energy, Gas and Ashes Volarisation	Upcycling of H2 and CO2	0.429487179
Glass Fiber Reinforced Polymer (GFRP) Bars	GFRP bars improves the performance and durability of wood-based structures. By reinforcing wooden beams and columns, GFRP bars significantly improve strength, stiffness, ductility, and energy absorption, addressing the inherent limitations of wood under load. For example, strengthened beech wood beams and wood-filled GFRP columns with lattice reinforcements demonstrate superior mechanical properties, including enhanced bonding and load-bearing capacity. In glulam beams, GFRP reinforcement at finger joints increases bending strength and stiffness, ensuring greater structural reliability. Additionally, GFRP materials replace wood in applications like bridge decks and soil substructures, overcoming wood's susceptibility to environmental degradation. The integration of GFRP in wood-cored composites, such as those with balsa cores, further optimizes strength and insulation while maintaining lightweight characteristics. These advancements not only extend the lifespan and functionality of wood-based systems but also promote sustainable construction practices by reducing reliance on traditional materials prone to durability challenges.	Cascade refinement technologies for wood waste upcycling	Validation of new composite products through prototyping	0.28525641
Internet of Things (IoT) Devices	IoT devices can optimize energy efficiency in IoT routing systems in wood based applications. For instance, a hybrid woodpecker and flamingo optimization algorithm enhances energy use, reduces delays, and improves delivery ratios in IoT networks. These advancements can indirectly support sustainable forestry operations, such as monitoring wood supply chains or optimizing resource allocation in timber processing. By improving energy efficiency and operational precision, IoT devices contribute to reducing environmental impacts and fostering a more sustainable approach to wood utilization.	Digital tools for improving circular flows	Supply chain optimisation for secondary materials	0.615384615
Near-Infrared Spectroscopy	NIR spectroscopy contributes to wood science and applications by enabling precise, non-destructive analysis. It enhances the prediction of wood density, a critical quality parameter, through optimized spectral analysis and advanced calibration techniques, improving accuracy across species and grain angles. This capability supports efficient quality control in renewable energy production, where woodchips are assessed in real-time for energy content, promoting sustainable energy solutions. Additionally, NIR spectroscopy aids in the conservation of waterlogged archaeological wood by accurately evaluating its hardness, ensuring effective preservation strategies. By integrating chemometric methods, it further refines wood property predictions, accommodating variations across species and locations. These innovations not only optimize wood utilization but also contribute to broader goals such as renewable energy advancement and cultural heritage preservation, reinforcing the role of wood in a sustainable and circular economy.	Separation and sorting of CDW	An advanced multilayer sorting system	0.525641026
Polylactic Acid (PLA) Composites	PLA composite play a role in wood industry by integrating wood fibers into bioplastics, creating materials with enhanced strength, durability, and eco-friendly properties. Functionalized wood fibers improve the mechanical performance and UV resistance of PLA composites, making them suitable for sustainable packaging and durable applications. Thermal modification of wood-filled PLA filaments enhances extrusion and tensile strength, enabling their use in 3D printing processes. This innovation allows for the creation of complex, high-performance products like car spoilers, demonstrating the material's versatility. By incorporating natural fillers such as wood and buckwheat husk, PLA composites achieve improved crystallization and biodegradation resistance, aligning with circular economy goals. These advancements reduce reliance on fossil fuels and expand the potential of wood-based materials in modern manufacturing, bridging the gap between traditional wood applications and cutting-edge bioplastic technologies.	Cascade refinement technologies for wood waste upcycling	Composite production	0.28525641
Sustainable Aviation Fuel	Sustainable aviation fuels support wood industry by leveraging its potential as a renewable feedstock. Wood residues, such as softwood and urban wood waste, are increasingly utilized in biorefineries to produce aviation fuels, achieving significant greenhouse gas reductions—up to 86% in some cases. Processes like Fischer-Tropsch technology and torrefaction enhance the efficiency and cost-effectiveness of converting woody biomass into fuel, while also addressing supply chain challenges. Additionally, poplar wood and other fast-growing species are integrated into biofuel production systems, maximizing both economic and environmental benefits. By repurposing wood waste and residues, these innovations reduce reliance on fossil fuels, promote carbon storage, and contribute to a circular economy, positioning wood as a cornerstone of sustainable energy transitions.	Energy, Gas and Ashes Volarisation	Fluidised Bed Gasification	0.615384615
Trametes Versicolor	Trametes versicolor plays a pivotal role in advancing wood by enhancing its applications in bioremediation, material innovation, and enzyme production. Through solid-state fermentation on wood chips, this fungus enables the effective degradation of diesel and pesticides, leveraging wood as a support medium to overcome microbial contamination in polluted environments. In fungal bioreactors, pine wood chips facilitate pollutant removal by stabilizing Trametes versicolor, which excels in breaking down harmful compounds like bentazone. Additionally, its treatment of bamboo-plastic composites improves material toughness and mold resistance, creating durable, eco-friendly options for outdoor structures. The fungus's interaction with wood, particularly when supplemented with oak sawdust and copper, significantly increases laccase production, a key enzyme for lignin degradation and pollutant breakdown. These advancements highlight Trametes versicolor's ability to transform wood into a versatile platform for environmental cleanup and sustainable material development, contributing to reduced reliance on fossil fuels and promoting a circular economy.	Chemical and Bioremediation	Bioremediation wood treatment	0.429487179
Ultraviolet (UV) Aging	UV aging properties advances wood-based materials by enhancing their durability, functionality, and sustainability across diverse applications. In wood-plastic composites, UV resistance is improved through the integration of wood flour and treated wood fibers, which also bolster biodegradability and mechanical strength. These innovations make such materials suitable for construction and packaging, where durability under environmental stress is essential. Additionally, cellulose nanocrystals derived from wood enhance UV stability, thermal performance, and mechanical strength in polymer composites, expanding their use in advanced manufacturing. In 3D printing, wood flour-PLA filaments demonstrate challenges under UV exposure, such as reduced strength and increased water absorption, highlighting areas for further optimization. By addressing UV aging, wood-based materials not only achieve greater longevity and performance but also contribute to sustainable alternatives in industries like healthcare and construction, supporting the transition to eco-friendly solutions and reducing reliance on synthetic, non-renewable materials.	Cascade refinement technologies for wood waste upcycling	Composite production	0.28525641
Ultraviolet (UV) Blocking	UV blocking capability enhances wood functionality for sustainable and energy-efficient applications. Innovations in wood-based materials, such as transparent films and lignocellulosic nanofibrils, leverage UV blocking to improve durability, transparency, and light management. For example, bamboo-based films with high lignin content provide eco-friendly solar protection, while poplar sawdust is transformed into flexible nanopapers with UV-blocking properties. Additionally, preserving natural wood components and fiber alignment enables the creation of recyclable, transparent wood films that combine strength with UV protection. These advancements contribute to energy-efficient construction by reducing thermal conductivity, managing light, and protecting against harmful UV radiation. By integrating UV blocking into wood-based materials, these innovations support sustainable building practices, reduce reliance on synthetic materials, and promote a circular economy.	Cascade refinement technologies for wood waste upcycling	Composite production	0.653846154
You Only Look Once (YOLO) Detection Model	The YOLOv5s model improves detection and monitoring processes. It improves grasping robot object detection for wooden blocks, achieving high precision in identifying wood knots, which has practical applications in sawmill operations to optimize wood processing. By leveraging deep learning, the model enables rapid and accurate identification of defects, streamlining production workflows. Additionally, similar models like YOLOv8 have been applied to detect and count eucalyptus timber, demonstrating the effectiveness of video analysis for managing stacked wood inventories. UAV-based deep learning, informed by such models, also facilitates the detection of pine wilt disease in forests, enabling efficient monitoring and control of infected trees. These innovations contribute to sustainable forestry practices, improved resource utilization, and reduced waste, supporting broader goals like environmental conservation and the circular economy within the wood industry.	Digital tools for improving circular flows	Material volume estimation	0.615384615
Accoustic Metamaterials	Acoustic metamaterials support wood acoustic and structural performance. Lightweight acoustic metamaterials are used in wooden floors of high-speed trains to significantly reduce low-frequency noise and vibration, improving passenger comfort. Inspired by wood's natural porous structure, biomimetic designs incorporating acoustic metamaterials optimize multi-layer architectures for superior sound absorption and noise control. Additionally, graded-stiffness metamaterials and multiscale optimization methods enable the creation of mechanical cloaks for wood, enhancing its structural integrity and adaptability in engineered applications. These innovations contribute to the development of quieter, more efficient, and sustainable wood-based solutions in modern engineering and design.	Cascade refinement technologies for wood waste upcycling	Validation of new composite products through prototyping	0.782051282
Acrylonitril Butadiene Styrene (ABS)	Acrylonitrile butadiene styrene (ABS) contributes to advancements in wood applications by enabling innovative composite materials in additive manufacturing. When reinforced with wood dust, recycled ABS filaments enhance flexural strength, making them suitable for non-structural uses. This integration of wood dust into ABS filaments optimizes material performance while promoting sustainability by repurposing waste materials. Although the resulting composites exhibit reduced heat resistance, they provide a viable solution for lightweight and rigid components in 3D printing. By merging ABS with wood-based additives, these innovations reduce reliance on virgin polymers, supporting a circular economy and fostering environmentally conscious material development.	Cascade refinement technologies for wood waste upcycling	Composite production	0.28525641

Adaptive Algorithms	Adaptive algorithms optimize processes and enabling innovative designs in wood based application. In the wood industry, an adaptive framework enhances production planning by integrating models that address diverse challenges, improving efficiency and resource management. This adaptability extends to material science, where wood flour-filled polylactic acid (WPLA) is combined with 3D printing to create moisture-responsive bio-hygromorphs, showcasing the potential for smart, sustainable materials. By refining such processes, adaptive algorithms contribute to the development of advanced wood-based technologies, supporting broader goals like sustainability and the circular economy.	Digital tools for improving circular flows	Supply chain optimisation for secondary materials	0.576923077
Advanced Oxidation Processes	Advanced oxidation processes imporve wood properties, enabling sustainable applications, and enhancing its functionality. Oxidizing oak wood with ammonium persulfate increases porosity, gas permeability, and sound absorption, making it more effective for acoustic applications. In biochar production from wood waste, oxidation enhances photocatalyst efficiency for environmental applications like dye degradation, promoting sustainability and cost reduction. Additionally, oxidation accelerates wood pyrolysis and combustion, influencing decomposition rates, density, and mass loss, which are crucial for optimizing energy recovery and material performance. These processes also contribute to innovative uses such as 3D-printed wood-PLA composites, although challenges remain in reaction efficiency. By transforming wood waste into high-value materials and improving wood's functional properties, advanced oxidation processes support a circular economy, reduce reliance on fossil fuels, and expand wood's role in sustainable technologies.	Cascade refinement technologies for wood waste upcycling	Composite production	0.28525641
Biocompatible Materials	Biocompatible materials enhance wood functionality and expanding its applications. Modified plant materials, such as cellulose, improve wood's biostability and compatibility with binders like casein and polyurethane, enabling the creation of durable composites. Wood-derived lignin enhances nanocellulose membranes, increasing tensile strength and gas permeability while maintaining thermal stability, which supports advanced material engineering. Additionally, wood's porous structure makes it a promising biocompatible material for bone implants, offering excellent osteoconductivity for medical applications. Innovations like cellulose nanofiber-based actuators showcase wood's potential in biodegradable and responsive 3D transformations for biomedical and robotic uses. These advancements highlight wood's versatility as a sustainable, renewable resource, contributing to eco-friendly technologies and reducing reliance on fossil-based materials. By leveraging its natural properties and integrating biocompatible enhancements, wood supports a circular economy and fosters sustainable development across multiple industries.	Cascade refinement technologies for wood waste upcycling	Composite production	0.721153846
Biological Resistance	Biological resistance imporves woods durability and performance against environmental and biological threats. Innovations such as integrating silver nanoparticles into wooden surfaces improve resistance to bacteria and mold, safeguarding wood in hygienic and structural applications. Similarly, wood-plastic composites demonstrate exceptional termite resistance, achieving complete termite mortality and reducing wear, making them ideal for long-lasting construction materials. The use of boron-nitrogen compounds further enhances wood's fire resistance and bio-protection while maintaining its structural integrity, expanding its utility in safety-critical environments. Research on eucalyptus wood waste particleboards highlights the importance of fungal and termite resistance in optimizing mechanical properties for sustainable building materials. By improving wood fiber processing through chemical treatments, cellulase efficiency and pulp quality are enhanced, contributing to better resource utilization. These advancements in biological resistance not only extend wood's lifespan but also support sustainable practices, reducing reliance on non-renewable materials and fostering a circular economy.	Chemical and Bioremediation	Bioremediation wood treatment	0.28525641
Biowastes	Biowastes unlock wood potential for energy production, material innovation, and environmental sustainability. Technologies like pyrolysis transform wood biowastes into fuels, contributing to renewable energy generation while reducing reliance on fossil fuels. As a lignocellulosic residue, wood serves as a precursor for porous carbon materials, which are essential for energy storage and pollutant sorption. Grapevine wood waste demonstrates high energy potential, offering cleaner combustion with lower emissions. Additionally, wood chips and bark are utilized in biofilters to purify waste air during composting, showcasing their role in environmental management. Wood's classification as an agriculturally derived biowaste also opens pathways for additive manufacturing, though further research is needed to optimize its industrial applications. By valorizing wood biowastes, these innovations support a circular economy, reduce environmental impact, and enhance the sustainable use of natural resources.	Energy, Gas and Ashes Volarisation	Hydrothermal carbonisation through microwaves	0.849358974
Building Envelopes	Building envelopes play a critical role in advancing wood by leveraging its natural properties and enhancing its applications in sustainable construction. Wooden windows and timber cladding, integral to building envelopes, capitalize on wood's renewable and CO2-neutral characteristics, offering superior thermal regulation and reduced life-cycle impacts compared to alternative materials. Innovations such as thermally anisotropic systems in wood-framed walls significantly improve energy efficiency in residential buildings, while wood sawdust and wood fiber insulation demonstrate the material's versatility in enhancing thermal performance and sustainability. By integrating wood into steel systems and exploring combinations like wooden frames with hemp-lime composites, building envelopes reduce CO2 emissions and address thermal bridging challenges. These advancements position wood as a cornerstone of energy-efficient, eco-friendly construction, aligning with broader goals of reducing fossil fuel dependency and fostering a circular economy.	Cascade refinement technologies for wood waste upcycling	Validation of new composite products through prototyping	0.615384615
Sustainable Construction	The building sector promote wood as a sustainable material for reducing environmental impact. By incorporating wood into retrofits and construction, it significantly lowers carbon emissions and supports carbon neutrality. Cross-laminated timber (CLT) exemplifies this potential, offering a low-emission alternative to concrete that reduces greenhouse gas emissions and energy consumption, aiding decarbonization efforts. Innovations such as reinforcing lightweight plaster with wood fibers improve material strength and versatility, while integrating wood with phase change materials (PCM) enhances thermal regulation, though it necessitates careful optimization to maintain structural integrity. These advancements position wood as a key material for carbon-negative buildings, leveraging its natural carbon storage capacity and adaptability through engineering and chemical modifications. By prioritizing wood in construction, the building sector drives progress toward sustainable development, reducing reliance on fossil-intensive materials and contributing to a circular economy.	Cascade refinement technologies for wood waste upcycling	Validation of new composite products through prototyping	0.429487179
Modeling Chemical Structures	Studying chemical structure of wood enables targeted modifications and optimizing its applications. Understanding lignin's molecular structure has improved wood adhesives, with low molar mass lignin fractions enhancing bonding strength and performance. Thermal and hydrothermal treatments alter the microstructure of wood and agricultural residues, such as bamboo and cotton stalk, improving their mechanical properties and enabling the production of valuable byproducts like wood vinegar containing phenols and ketones. Modeling hardwood lignin's structure and pyrolysis supports advancements in biomass conversion and biorefineries, addressing challenges in lignin's complex composition. These innovations contribute to sustainable wood protection methods, enhancing durability, carbon sequestration, and environmental benefits. By leveraging chemical structure, wood science drives resource efficiency, reduces reliance on fossil fuels, and supports a circular economy.	Cascade refinement technologies for wood waste upcycling	Lignin treatment	0.541666667
Composite Filaments	Composite filaments support integrating wood-derived materials into sustainable 3D printing technologies. By combining wood fibers with polymers like PLA and ABS, these filaments reduce reliance on plastics, addressing pollution and global warming. Innovations such as teak wood-PLA composites enhance adhesion, strength, and printability, particularly with finer wood particles, while walnut shell-based composites improve mechanical performance and reduce printing errors through optimized parameters. The incorporation of wood dust into recycled ABS filaments boosts mechanical properties and recyclability, though heat resistance remains a challenge for non-structural applications. Thermal modification of wood-filled PLA filaments further enhances extrusion and tensile strength, demonstrating the potential for improved material performance. These advancements not only expand the functional applications of wood in additive manufacturing but also promote a circular economy by utilizing waste materials and reducing fossil fuel dependency, paving the way for more sustainable production practices.	Cascade refinement technologies for wood waste upcycling	Composite production	0.881410256
Composite Properties	Reinforcing mixed plastics with wood flour (WF) improves material upcycling, reducing environmental impact and dependence on fossil-based resources. Innovations like combining basswood with Sn-Bi alloy result in composites with superior conductivity, toughness, and electromagnetic shielding, broadening wood's applications in advanced industries. Small-diameter round timber, traditionally non-structural, is repurposed for light frame construction, optimizing resource efficiency and lowering costs. Additionally, wood-based laminated composites, such as those made from bamboo and poplar, exhibit enhanced density, water resistance, and strength, making them ideal for outdoor applications. Processes like particle orientation in wood particle boards further refine composite properties, tailoring density and performance for specific uses. These advancements not only expand wood's versatility but also support sustainable practices, contributing to reduced reliance on non-renewable materials and fostering a circular economy.	Cascade refinement technologies for wood waste upcycling	Composite production	0.541666667
Core Materials	Core materials play a pivotal role in advancing wood by enhancing its structural and functional applications. Balsa wood, a key core material, is integral to lightweight sandwich panels, offering exceptional strength-to-weight ratios for industries like wind energy. Its use in wind turbine blades, however, introduces challenges in pyrolysis recycling due to the production of diverse hydrocarbons, highlighting the need for innovative recycling methods. Structural advancements include layering balsa veneers with varied grain orientations, significantly improving strength and suitability for load-bearing applications. Additionally, wood-plastic composites benefit from enhanced bonding and mechanical properties through innovative designs like trapezoidal mortise and tenon structures, increasing stability and resistance to deformation. Inspired by natural systems, sandwich beams incorporating wood with steel cores optimize impact resistance, broadening their utility in demanding environments. These innovations in core material applications not only expand wood's versatility but also support sustainable development by reducing reliance on non-renewable materials.	Cascade refinement technologies for wood waste upcycling	Validation of new composite products through prototyping	0.618589744
Creep Deformation	Creep deformation influencing the structural performance and longevity of wood-based materials. In wood-plastic composites (WPCs), factors such as wood-plastic ratio and molding conditions affect creep behavior, while reinforcement with GFRP sheets or rebars reduces deformation and enhances strength. This enables WPCs to perform better under sustained loads, expanding their use in structural applications. Studies of wood and composite cantilever beams focus on analyzing creep behavior to optimize long-term performance in construction. Additionally, the shear-creep properties of wood, such as Norway spruce, are essential for designing durable structures, with compression testing providing valuable insights. In tropical climates, materials like Chengal wood in transmission tower cross arms degrade over time due to creep, prompting the development of improved testing and material alternatives. By addressing creep deformation, innovations in wood and composite materials contribute to more reliable, lightweight, and sustainable structural solutions.	Cascade refinement technologies for wood waste upcycling	Validation of new composite products through prototyping	0.28525641
Cycling Stability	Cycling stability influence wood-based technologies by enhancing performance and durability in energy storage and insulation applications. Nitrogen-doped wood carbons improve the cycling stability of iron oxide electrodes, making them more effective for energy storage. Wood's natural porous structure enhances hydrogel stability, reducing swelling and enabling flexible supercapacitors with high conductivity and long-lasting performance. Retaining lignin in bamboo improves wood's mechanical properties, enabling its use in thermochromic phase change materials for advanced insulation systems. Additionally, wood-derived carbon electrodes, when combined with graphene, optimize conductivity and wettability, achieving superior energy storage stability. Functionalized wood biochar serves as a base for MoS2 nanocomposites, further improving supercapacitor cycling performance. Inspired by wood's vertical channels, a carbon matrix design stabilizes potassium-metal batteries by mitigating dendrite growth and volume changes. These innovations position wood as a sustainable material for energy systems, supporting renewable energy adoption and reducing reliance on fossil fuels.	Energy, Gas and Ashes Volarisation	Hydrothermal carbonisation through microwaves	0.881410256
Economic Viability Assessments	Economic viability drives sustainable practices and innovations that balance profitability with ecological benefits. Mixed-species tropical plantations demonstrate how diverse forestry can meet wood demand while enhancing biodiversity and competing economically with monocultures like Teak. Wood-based biomass gasification, a key process for sustainable energy, becomes more feasible with advancements in cost-effective tar-reducing catalysts, improving gas quality and investment returns. Additionally, integrating wood production with complementary industries, such as honey production in Acacia nilotica plantations, ensures financial sustainability and supports environmental goals. The use of mass timber in construction exemplifies how economic viability fosters the adoption of wood-based materials, offering cost-competitive and carbon-efficient solutions for taller buildings. By enabling innovations that reduce deforestation, lower emissions, and provide alternative revenue streams, economic viability strengthens wood's role in sustainable energy, construction, and the circular economy, contributing to long-term environmental and economic resilience.	Digital tools for improving circular flows	Life cycle sustainability assessment	0.28525641
Empty Fruit Bunch (EFB)	Empty fruit bunch (EFB) serves as a sustainable alternative for wood-based applications. Through processes like pyrolysis and torrefaction, EFB can be transformed into bio-coal and biochar, reducing waste while generating renewable energy and enhancing biomass properties such as heating value and stability. EFB also enables the production of nanocrystalline cellulose, offering a sustainable substitute for wood pulp in bio-based materials. Additionally, composites combining EFB-derived fibers with materials like rice husk achieve optimal strength, presenting viable replacements for traditional wood products. Innovations such as hybrid plywood, reinforced with palm oil ash nanoparticles, further demonstrate EFB's potential to enhance durability and structural performance. By integrating EFB into these processes, industries reduce reliance on wood, address agricultural waste challenges, and contribute to a circular economy, promoting sustainable resource use and mitigating the environmental impact of traditional wood production.	Cascade refinement technologies for wood waste upcycling	Composite production	0.28525641

Flame Resistance	Flame resistance improves safety, durability, and versatility in various applications of weed. Innovations such as treating wood with tannin-based composite gels or MgAl-LDH nanoflakes improve its flame resistance while enabling its use in sustainable building materials. Modified treatments, including boron solutions for bamboo and ammonium phosphite for kraft paper, significantly enhance fire resistance, extending the material's lifespan and safety in construction and manufacturing. Additionally, combining wood fiberboards with stone wool increases fire resistance, though it requires balancing mechanical properties. These advancements not only improve the performance of wood and wood-based composites but also enable the replacement of less sustainable materials, such as fossil-fuel-based plastics, with natural alternatives. By integrating flame retardants into wood products, the industry supports safer, more durable, and eco-friendly materials, contributing to broader goals like reducing environmental impact and promoting a circular economy.	Chemical and Bioremediation	Upcycled wood validation	0.615384615
Flexible Sensors	Flexible sensors play a critical role in advancing wood by transforming it into a multifunctional material for innovative applications. Porous wood sponges have been used to create dual-parameter sensors with high sensitivity and stability, enabling advancements in healthcare monitoring. Broadleaf wood fibers have facilitated the development of stretchable strain sensors, which combine durability and sensitivity for use in soft robotics. Wood's role in sustainable construction is enhanced by iSens technology, which improves sensor integration and monitoring without compromising structural integrity. Additionally, wood substrates have been utilized to produce laser-induced graphene sensors, offering scalable and flexible solutions for diverse applications. Chir wood sawdust has been repurposed into lightweight thermal sensors with excellent thermal stability and sensitivity, while woodpile structures have been engineered to enhance sensor performance for flexible electronics. These innovations position wood as a sustainable, versatile platform for cutting-edge sensor technologies, contributing to advancements in healthcare, robotics, and environmental monitoring.	Digital tools for improving circular flows	Material volume estimation	0.929487179
Flexible Thermochromic Composites	Flexible thermochromic composites integrate energy-saving and adaptive functionalities into wood-based materials. By modifying porous bamboo through delignification, these composites enhance thermochromic and energy storage properties, enabling visual thermoregulation and improved flame retardancy for building applications. Wood aerogels serve as flexible, lightweight support structures, increasing temperature sensitivity and light absorption, while reversible thermochromism in flexible wood films facilitates energy storage and dynamic thermal management. Delignified eucalyptus composites stabilize phase change materials, offering color-changing capabilities and efficient thermal regulation for sustainable building design. Transparent wood with thermochromic enhancements provides a renewable, energy-efficient alternative to glass, ideal for smart windows that adapt to environmental conditions. These innovations reduce reliance on fossil fuels, improve energy efficiency, and position wood as a key material in the circular economy, though further research is required to optimize practical applications.	Cascade refinement technologies for wood waste upcycling	Composite production	0.721153846
Freshwater Resource Management	Freshwater resources enable innovative applications that enhance sustainability and resource efficiency. Wood-based solar evaporators, crafted from cellulose, leverage their renewable and porous structures to produce freshwater through solar desalination, addressing global water scarcity. Recycled wood waste, such as sawdust, is carbonized to create antibacterial solar steam generators, further optimizing seawater desalination processes. Additionally, wood sponges serve as nanoplatforms for purifying water by effectively removing heavy metals like mercury, demonstrating wood's potential in environmental remediation. These advancements not only utilize freshwater resources to unlock wood's functional properties but also contribute to sustainable water management and the circular economy by repurposing wood waste and reducing reliance on non-renewable materials.	Chemical and Bioremediation	Bioremediation wood treatment	0.625
Frictional Energy	Frictional energy improve wood functionality and expanding its applications. In briquette production, optimizing frictional forces during oak sawdust compaction improves energy efficiency and product quality. In engineering, frictional energy is harnessed in red willow wood composites infused with nano-MoS2 and epoxy, reducing vibration, noise, and wear, which enhances performance in mechanical systems. Frictional interactions also enable wood's use in earthquake-resistant designs, where it transfers loads effectively when combined with materials like glass. Furthermore, the study of wood's high friction with black wheat grains informs the design of efficient handling and storage equipment. These innovations demonstrate wood's versatility as a natural material with unique viscoelastic and deformation properties. By leveraging frictional energy, wood contributes to sustainable engineering, eco-friendly materials, and energy-efficient processes, aligning with broader goals of reducing reliance on fossil fuels and advancing the circular economy.	Cascade refinement technologies for wood waste upcycling	Validation of new composite products through prototyping	0.28525641
Fungal Bioremediation	Fungal bioremediation supports advancing wood by leveraging its properties as a support medium for environmental and industrial applications. Wood chips, such as those from Quercus ilex and pine, serve as effective platforms for immobilizing fungi, enabling the biodegradation of pesticides like bentazone and imidacloprid in wastewater and stormwater treatment systems. In rotating drum bioreactors, wood enhances fungal stability and adsorption capacity, improving the efficiency of pesticide removal. Additionally, wood-based cultivation, enriched with additives like oak sawdust and copper, significantly increases laccase enzyme production in fungi such as *Trametes versicolor*, further expanding its bioremediation potential. Beyond remediation, fungal bio-composites derived from wood are being explored for sustainable construction, including extraterrestrial applications. By integrating fungal bioremediation with wood, these innovations contribute to cleaner water systems, reduced reliance on fossil fuels, and the development of circular, sustainable materials for diverse environmental and structural uses.	Chemical and Bioremediation	Bioremediation wood treatment	0.625
Glycerol Pretreatment	Glycerol pretreatment strengthen wood chemical and structural properties for diverse applications. By improving cellulose content, crystallinity, and thermal stability, glycerol pretreatment enables more efficient conversion of wood and biomass into high-value chemicals, such as levoglucosan. This process supports innovations in bio-based materials, such as sustainable bio-polyols derived from wood lignins, which are essential for producing eco-friendly polyurethanes. Additionally, glycerol pretreatment contributes to optimizing feedstock for thermochemical processes, ensuring higher yields and better performance in applications like bio-oil production and biochar enhancement. These advancements reduce reliance on fossil fuels, minimize waste, and promote the circular economy by transforming wood and forestry residues into sustainable, high-performance materials.	Chemical and Bioremediation	Liquefaction of mixed wood waste and green adhesives based on polyols	0.525641026
Green Energy	Green energy transforms wood waste and residues into sustainable energy solutions. Wood waste from the pulp and paper industry can be converted into green energy and valuable byproducts, reducing environmental impact. Through co-gasification, wood-based biomass can be combined with plastic waste to produce eco-friendly energy, addressing both energy demands and waste management challenges. Thermochemical conversion processes enable the transformation of wood from food court waste into renewable energy, showcasing its versatility in green energy applications. Additionally, biomass fly ash, a byproduct of wood combustion, can be repurposed in cement production, enhancing material strength and sustainability. With forest residues generating 4.12 PJ/yr of energy, wood contributes significantly to bioenergy development, particularly in regions like Nigeria. These innovations reduce reliance on fossil fuels, promote circular economy practices, and position wood as a cornerstone of sustainable energy systems.	Energy, Gas and Ashes Volarisation	Fluidised Bed Gasification	0.525641026
Green Technology	Green technology transform wood into a more sustainable and versatile resource. Innovations like the laccase-based process enhance cellulose availability in Melia dubia wood by efficiently removing lignin, enabling the production of valuable chemicals while reducing waste. In thermal energy applications, biochar derived from date seeds is combined with wood to create high-capacity, leakage-resistant energy storage materials, promoting renewable energy solutions. Additive manufacturing techniques, such as fused filament fabrication, optimize energy use and precision in wood-based production, minimizing material waste and improving sustainability. Additionally, silica fume coatings enhance plywood's fire resistance, offering eco-friendly fireproofing alternatives. Wood-based biopanels outperform traditional materials in strength and flexibility, providing sustainable options for construction. These advancements reduce reliance on fossil fuels, address construction waste challenges, and support a circular economy, positioning wood as a cornerstone of green technology and sustainable development.	Cascade refinement technologies for wood waste upcycling	Validation of new composite products through prototyping	0.28525641
Homogenization Methods	The homogenization method significantly advances the field of wood by enabling precise modeling and optimization of wood-based composites. It facilitates the analysis of transport phenomena in porous wood media, improving the estimation of diffusivity and accounting for molecular memory effects. By applying homogenization principles, researchers enhance the understanding of elastic properties in wood-polymer composites, particularly in additive manufacturing processes like FDM, where wood content, shape, and porosity critically influence performance. Additionally, the method supports the development of accurate analytical models for bending behavior in wood-based sandwich panels and corrugated core composites, addressing shear deformation and boundary conditions. These advancements enable the design of stronger, more thermally efficient, and structurally reliable wood products. By improving material performance and resource efficiency, the homogenization method contributes to sustainable innovations in wood applications, aligning with goals of reducing reliance on non-renewable materials and fostering a circular economy.	Cascade refinement technologies for wood waste upcycling	Validation of new composite products through prototyping	0.28525641
Hydroxyapatite Adsorbent	Hydroxyapatite adsorbent creates wood as a versatile material for environmental and regenerative applications. By combining wood powder with nano-hydroxyapatite, researchers have developed composites with enhanced metal adsorption efficiency, particularly for wastewater treatment, addressing critical environmental challenges. The porous structure of wood charcoal serves as an effective base for synthesizing fluoride adsorbents, demonstrating high capacity and reusability. Additionally, wood's anisotropic properties and natural liquid transport mechanisms inspire the creation of bone-like materials for tissue regeneration, bridging the gap between biomaterials and sustainable resources. These innovations not only expand wood's functional applications but also contribute to reducing reliance on non-renewable materials, supporting a circular economy.	Chemical and Bioremediation	Bioremediation wood treatment	0.525641026
Hygrothermal Conditions	Hygrothermal conditions influences wood structural performance, durability, and applications. In composite materials like wood-plastic composites, exposure to water and temperature reveals low deformation and strong recovery, enhancing their potential for structural use. Hygrothermal treatment at elevated temperatures, such as 180°C, improves the crystallinity and mechanical properties of materials like Moso bamboo, reducing porosity and increasing elasticity and hardness. In bio-based construction, wood pellets enhance the hygrothermal properties and durability of earth materials, supporting sustainable building practices. Additionally, advanced models now predict moisture risks in wood by assessing mold growth under varying temperature and humidity conditions, improving long-term performance and safety. These innovations reduce reliance on fossil fuels, expand wood's utility in demanding environments, and support the circular economy by optimizing renewable materials for diverse applications.	Cascade refinement technologies for wood waste upcycling	Composite production	0.28525641
Impact Behavior	Impact behavior drives innovations in wood material design and structural applications. Research into plywood as a core layer in protective structures highlights its capacity for energy absorption and impact resistance, making it a valuable component in safety-focused designs. Inspired by natural systems, such as the woodpecker, layered composite panels with optimized cores mimic wood's resilience, enhancing impact performance in engineered materials. These advancements not only improve the functionality of wood-based products but also support sustainable practices by extending the material's utility in high-stress environments. By leveraging wood's inherent properties and refining its impact behavior, industries can reduce reliance on non-renewable materials, contributing to a circular economy and fostering environmental resilience.	Cascade refinement technologies for wood waste upcycling	Validation of new composite products through prototyping	0.721153846
Impedance Matching	Impedance matching contributes to wood-based materials by optimizing their electromagnetic properties for innovative applications. In the development of wood carbon aerogels, precise impedance matching enhances the absorption of electromagnetic waves, resulting in lightweight and efficient shielding materials. Similarly, wood shavings and bamboo-derived biochar are transformed into magnetic carbon composites and biochar-based materials, respectively, where impedance matching improves wave absorption and material performance. These processes leverage the natural structure of wood and agroforestry waste, creating sustainable solutions for electromagnetic shielding in smart devices. By enabling superior wave absorption and material efficiency, impedance matching contributes to reducing reliance on non-renewable resources and supports the circular economy through the valorization of wood and biomass waste.	Cascade refinement technologies for wood waste upcycling	Composite production	0.28525641
Interfacial Interaction	Interfacial interaction supports wood mechanical properties, durability, and functionality. Modifying fast-growing poplar wood with melamine-urea-formaldehyde improves interfacial bonding, resulting in stronger and more resilient materials. In wood polymer composites, silica Janus nanosheets strengthen interfacial interactions, reducing water absorption and increasing structural stability, making these materials more suitable for demanding applications. Similarly, grafting methacryl groups onto wood enhances interfacial cohesion through copolymerization, significantly improving water resistance, hardness, and anti-swelling efficiency. In biomass gasification, interfacial dynamics during processes like pyrolysis and char conversion optimize energy extraction from wood pellets. Additionally, nanocellulose derived from wood leverages its amphiphilic interfacial properties to create sustainable alternatives to petroleum-based products, adding value to forest by-products. These advancements not only improve wood's performance but also support broader goals such as reducing reliance on fossil fuels, promoting renewable materials, and contributing to a circular economy.	Cascade refinement technologies for wood waste upcycling	Composite production	0.28525641

Iron Oxide Nanoparticles	Iron oxide nanoparticles enhances wood-based material performance and expanding their applications. Incorporating these nanoparticles into medium-density fiberboard (MDF) significantly improves water resistance, thickness stability, and thermal properties, making the material more durable and suitable for demanding environments. In wood-plastic composites, iron oxide nanoparticles enhance durability, UV resistance, and thermal stability while reducing weathering effects and flammability, increasing their lifespan and safety. Additionally, wood-derived carbon combined with iron oxide nanoparticles creates effective composites for environmental applications, such as removing arsenic and toxic dyes from water through adsorption. These innovations contribute to the development of wood-based materials with superior functionality, supporting sustainable practices by extending product lifespans, reducing reliance on synthetic materials, and enabling environmental remediation.	Cascade refinement technologies for wood waste upcycling	Validation of new composite products through prototyping	0.28525641
Laminated Flattened Bamboo (LFB)	Laminated flattened bamboo (LFB) offers a sustainable, high-performance alternative to traditional timber. Its strong mechanical properties make it ideal for construction, where it enhances strength and ductility, particularly in BFRP-reinforced bamboo wood columns optimized at a 2.3% cloth ratio. The dowel-bearing strength of LFB is influenced by factors such as panel arrangement, bolt diameter, and grain direction, enabling tailored applications in structural design. Cross-laminated bamboo demonstrates bending performance comparable to or exceeding that of traditional timber beams, expanding its utility in load-bearing structures. Additionally, laminated Petung bamboo, with 0° fiber alignment, shows promise in shipbuilding due to its strength and eco-friendliness. LFB materials like glubam also outperform SPF wood in sound insulation, with performance influenced by moisture and thickness. These innovations position LFB as a versatile, sustainable material that reduces reliance on conventional timber, supporting eco-conscious construction and material efficiency.	Cascade refinement technologies for wood waste upcycling	Validation of new composite products through prototyping	0.525641026
Lignin Depolymerization	Lignin depolymerization enables the efficient breakdown of lignin into valuable compounds and improving wood processing techniques. Optimized depolymerization methods, such as using Ru/C catalysts, convert birch wood lignin into low molecular weight aromatic compounds, enhancing its utility in fine chemical production. Maleic acid processing further improves lignin conversion, facilitates saccharification, and simplifies acid recovery, making wood biomass more accessible for bio-based applications. Deep eutectic solvent (DES) pretreatment tailors lignin properties, expanding its potential for specialized applications. Additionally, smectitic clays like montmorillonite offer a cost-effective solution for catalyzing lignin transformation into aromatic compounds, while hydrogen peroxide pretreatment enhances pyrolysis by increasing cellulose content and bio-oil yields. These innovations reduce reliance on fossil fuels, promote sustainable wood utilization, and contribute to a circular economy by transforming lignin, a traditionally underutilized component, into a valuable resource.	Cascade refinement technologies for wood waste upcycling	Lignin treatment	0.525641026
Logistics Systems	A logistics system is essential for indicating wood's role in renewable energy and sustainable practices. By optimizing the layout of logistics outlets, it minimizes transportation costs, addressing challenges like urban sprawl and seasonal demand for wood biofuel. Advanced models and spatial tools improve the efficiency of energy biomass supply chains, ensuring the sustainable use of wood resources. Reverse logistics innovations, such as recovering wooden pallets, enhance resource reuse, reducing waste and promoting circular economy principles. These advancements position wood as a viable alternative to fossil fuels, supporting energy transitions and environmental sustainability.	Digital tools for improving circular flows	Tool functions	0.28525641
Low Carbon Construction	Low carbon construction supports wood as a sustainable building material by leveraging its natural properties and integrating innovative techniques. Replacing concrete and steel with mass timber reduces emissions by 69%, positioning wood as a cornerstone of climate-conscious construction. Structural wood combined with recycled materials minimizes embodied carbon, while wood-concrete hybrid systems, such as those using glulam timber, enhance sustainability and acoustic performance in specialized spaces. Innovations like wood fiber insulation in steel systems and porous wood-based materials for indoor humidity regulation further demonstrate wood's versatility in reducing CO2 emissions and energy use. Additionally, research into combining wood and agricultural biomass ashes with CO2 to create hardened materials highlights wood's potential in circular, low-carbon solutions. By optimizing land use to preserve woodland and adapting policies across Europe, wood's role in low carbon construction supports global climate goals and fosters a shift toward energy-efficient, eco-friendly building practices.	Cascade refinement technologies for wood waste upcycling	Validation of new composite products through prototyping	0.28525641
Magnesium Oxychloride Cement (MOC)	Magnesium oxychloride cement (MOC) creates opportunities for durable, eco-friendly composites and adhesives. When combined with waste timber, MOC forms wood-MOC boards with superior durability, low emissions, and enhanced environmental performance compared to traditional materials. By incorporating plant fibers and wood sawdust, MOC-based composites reduce the need for raw wood while achieving high compressive strength and strong bonding. A formaldehyde-free adhesive using MOC enhances wood products with improved water resistance, flame retardancy, and sustainability. Additionally, reusing wood waste with MOC minimizes pollution and greenhouse gas emissions, contributing to circular economy goals. Innovations like lightweight concretes made with wheat husk and hemp hurd further demonstrate MOC's versatility in creating sustainable materials. While challenges such as water resistance remain, modifiers like citric acid improve MOC's performance, making it a viable alternative to conventional binders and supporting the development of greener, more efficient wood-based applications.	Cascade refinement technologies for wood waste upcycling	Validation of new composite products through prototyping	0.541666667
Metal-Organic Frameworks	Metal-organic frameworks (MOFs) advances wood-based technologies by enhancing its functional properties for diverse applications. By integrating MOFs like UiO-66-NH2 into wood membranes, heavy metal ions can be removed from water with over 90% efficiency, offering a reusable and sustainable solution for water purification. MOFs also improve wood's performance in energy storage, as wood-based composites exhibit superior capacitance, energy density, and durability in supercapacitors. Additionally, MOF-infused wood materials support environmental remediation, such as creating aerogel composites that effectively capture microplastics from water. The porous structure of wood, combined with MOFs, enables advanced separation and adsorption processes, including selective molecular imprinting for precise filtration. These innovations not only enhance wood's utility in energy, water treatment, and environmental sustainability but also contribute to broader goals like reducing reliance on fossil fuels and promoting circular economy practices through renewable and multifunctional materials.	Chemical and Bioremediation	Bioremediation wood treatment	0.522435897
Methyl Orange	Methyl orange improves wood applications by serving as a model dye to evaluate wood-derived materials' efficiency in water purification. Wood-based biochar, derived from wood waste, enhances photocatalytic processes for degrading organic contaminants like methyl orange, demonstrating its potential for sustainable wastewater treatment. By supporting Cu_2O nanoparticles or acting as a template for TiO_2-coated composites, wood biochar significantly improves dye removal through adsorption and photocatalysis, offering high efficiency and reusability. Innovations such as sawdust-based bio-beads and N-doped biochar derived from poplar wood further enhance adsorption capacity and cost-effectiveness, addressing environmental challenges. These advancements not only showcase wood's versatility in creating functional materials but also contribute to reducing reliance on fossil fuel-derived products and promoting a circular economy through the valorization of wood waste.	Chemical and Bioremediation	Bioremediation wood treatment	0.653846154
Mixed Mode Loading	Mixed mode loading assists in understanding and application of wood by improving the prediction of fractures and crack growth in wood and wood-like orthotropic materials. By examining fracture behavior under combined stress conditions, it enables the development of advanced fracture criteria, such as the extended Hashin and ReiSED models, which account for the anisotropic and fiber-reinforced nature of wood. These models enhance the accuracy of predicting crack propagation and fracture toughness properties in species like Scots pine, red spruce, and Norway spruce. Cohesive zone modeling further refines these predictions by addressing the complexities of mixed mode stress conditions, offering better insights into cohesive laws and crack behavior. These advancements not only improve the structural reliability of wood-based materials but also expand their potential applications in engineering and construction, contributing to more efficient use of renewable resources and fostering innovation in sustainable material design.	Cascade refinement technologies for wood waste upcycling	Validation of new composite products through prototyping	0.525641026
Multifunctional Materials	Multifunctional materials contributes to the wood performance and expanding its applications. Wood-derived cellulose nanofibers (CNF), produced without pulping, create strong, sustainable materials for electronics and composites. Innovations include reinforcing wood with aramid fibers and steel, which improves impact resistance and mechanical strength under diverse conditions. Additionally, wood-inspired mechanical interlocking techniques enable the joining of composites and aluminum without adhesives, increasing structural integrity while reducing chemical reliance. Carbonized wood-based materials infused with nickel nanoparticles further extend wood's functionality, offering efficient electromagnetic interference (EMI) shielding and electrothermal capabilities. These advancements position wood as a versatile, high-performance material, supporting sustainability and reducing dependence on fossil fuel-based alternatives.	Cascade refinement technologies for wood waste upcycling	CNF treatment	0.28525641
Nano-SiO2	Nano-SiO2 significantly enhances wood performance and sustainability in various applications. Its incorporation into wood-polymer and wood-plastic composites improves thermal stability, flame retardancy, and mechanical strength while reducing heat and smoke production, making these materials safer and more durable. In coatings, nano-SiO2 enhances plywood's resistance to fire, water, stains, and wear, extending its lifespan and functionality. Impregnating woods like ganitri and rubber wood with nano-SiO2 increases density, stability, hardness, and flame resistance while reducing hygroscopicity, resulting in more durable and eco-friendly materials. Additionally, modifying wood with nano-SiO2-based compounds, such as SiO2-TiO2, improves hydrophobicity, aging resistance, and photocatalytic properties without compromising structural integrity. These advancements contribute to the development of stronger, safer, and more sustainable wood products, supporting reduced reliance on non-renewable materials and fostering a circular economy.	Cascade refinement technologies for wood waste upcycling	Validation of new composite products through prototyping	0.28525641
Non-destructive Testing Methods	Non-destructive testing enables efficient and accurate assessment of material properties and structural integrity. Techniques such as ultrasonic testing and acoustic velocity testing are used to detect defects in timber-concrete glued connections and predict wood stiffness in species like lodgepole pine, ensuring optimal use in construction and utility applications. For example, non-destructive methods help monitor the condition of wooden utility poles, reducing premature replacements and failures. In engineered wood products, such as bamboo-wood composites and cross-laminated timber (CLT) made from radiata pine, these methods allow for precise property prediction, enhancing quality control and material performance. The development of affordable devices for testing wood beams further democratizes access to these technologies, supporting broader adoption. By improving the efficiency and sustainability of wood utilization, non-destructive testing contributes to extending the lifespan of wooden structures and advancing the use of renewable materials in construction.	Chemical and Bioremediation	Upcycled wood validation	0.525641026
Oil Spill Remediation	Oil spill remediation leverages wood-derived and wood-inspired materials for efficient and sustainable cleanup solutions. Modified balsa wood sponges achieve 99% efficiency in separating oil from water, demonstrating wood's potential for high-performance pollution control. Wood-based NFC/PVA aerogels with superhydrophobic properties enable reusable oil absorption, while PDMS-coated wood aerogels function as solar-heated, hydrophobic adsorbents, enhancing crude oil recovery and recycling. Additionally, biochars like Cinnamon Wood Biochar (CWBC) offer cost-effective alternatives for oil spill cleanup in challenging environments. These innovations not only improve remediation efficiency but also highlight wood's versatility in addressing environmental challenges. By integrating wood-derived materials into oil spill solutions, remediation efforts contribute to reducing reliance on fossil-based products and promoting a circular economy.	Chemical and Bioremediation	Bioremediation wood treatment	0.576923077
Optical Performance	Optical performance support wood transformation into innovative and sustainable materials. Enhancing the optical and mechanical properties of transparent wood through KH550 improves its compatibility with resin while preserving its natural texture, making it suitable for advanced lighting applications such as laser-driven diffusers. Additionally, wood residues are repurposed to produce fluorescent carbon quantum dots, which improve the optical properties of coating films, showcasing a circular approach to material use. Transparent bamboo emerges as a sustainable alternative to transparent wood, addressing resource limitations while expanding possibilities for smart materials in high-end applications. Optical advancements also optimize combustion processes by analyzing wood biomass fuel sprays, improving energy efficiency. Furthermore, photochromic films integrated with wood enable energy-saving smart windows, reducing cooling costs in buildings. These innovations not only enhance wood's functionality but also contribute to sustainability, energy efficiency, and the development of eco-friendly technologies.	Cascade refinement technologies for wood waste upcycling	Composite production	0.525641026
Oxygen Evolution Reaction	Oxygen evolution reaction are important in wood sector given transforming its natural porosity and structure into high-performance electrocatalysts for sustainable energy applications. The porous framework of basswood and balsa wood-derived carbons is leveraged to create durable catalysts, such as NiFe/carbon and ruthenium-cobalt nanoparticle composites, which outperform traditional materials in oxygen evolution efficiency. Carbonized wood serves as a stable substrate for advanced electrocatalysts, including molybdenum-doped and NiFe hydroxide-enhanced systems, optimizing water-splitting processes and hydrogen production. By utilizing wood's inherent micro-channels and carbon structure, these innovations not only improve reaction stability and efficiency but also highlight the potential of renewable materials in energy technologies. This integration of wood-derived carbon into electrocatalysis supports the transition to sustainable energy systems, reducing reliance on fossil fuels and promoting a circular economy.	Energy, Gas and Ashes Volarisation	Upcycling of H2 and CO2	0.653846154

Phenol Removal	Phenol removal transforms wood-based materials into effective solutions for environmental challenges. Acacia mangium wood is converted into activated carbon, achieving a 73% phenol removal efficiency from wastewater, demonstrating its potential for sustainable water treatment. Similarly, wood apple fruit shell waste and red pine biochar provide low-cost, efficient methods for toxic phenol removal, with the latter enhancing persulfate-based processes through its catalytic and reusable properties. Optimization of wood-based activated carbon further improves adsorption efficiency, making it a cost-effective approach for industrial applications. Beyond wastewater treatment, phenol removal innovations align with broader sustainability goals, as seen in oil palm waste substituting wood in particleboard production, reducing reliance on virgin wood resources. These advancements underscore the role of phenol removal in promoting circular economy practices, enhancing wood's value in environmental remediation, and reducing dependence on fossil fuel-derived materials.	Chemical and Bioremediation	Bioremediation wood treatment	0.849358974
Plastic Pollution	Plastic pollution drives advancements in wood-based materials by encouraging the development of sustainable alternatives and composites. The integration of wood fibers into FDM filaments and bamboo fiber tableware provides biodegradable, durable solutions that reduce reliance on plastics, mitigating pollution and carbon emissions. Recycling waste plastics into wood-plastic composites (WPCs) combines wood particles with plastics to create durable, eco-friendly materials, offering a sustainable and cost-effective alternative to traditional wood products. Innovations like chitosan-enhanced WPCs improve strength, durability, thermal conductivity, and antibacterial properties, expanding their applications while addressing environmental concerns. These advancements reduce dependence on fossil fuels and promote a circular economy by transforming plastic waste into valuable wood-based materials.	Cascade refinement technologies for wood waste upcycling	Composite production	0.429487179
Poplar Veneer	Through heat treatment, poplar plywood achieves greater strength, water resistance, and durability, making it more versatile for structural applications. Its use in wooden tubes demonstrates exceptional energy absorption and eco-friendliness, positioning it as a cost-effective alternative for crash-resistant materials. Innovations like delignifying poplar veneer and infusing it with epoxy resin create transparent, flexible wood with superior optical and thermal properties, expanding its potential in design and engineering. Additionally, alkali and silane treatments improve adhesive bonding and water resistance in plywood, though careful optimization is required to balance shear strength. By integrating flame-retardant additives like alpha-ZrP, poplar veneer reduces fire hazards, enhancing safety in construction. These advancements contribute to reducing reliance on synthetic materials, promoting eco-friendly solutions, and driving the wood industry toward greater efficiency and sustainability within a circular economy framework.	Cascade refinement technologies for wood waste upcycling	Composite production	0.525641026
Pre-processing Techniques	Pre-processing techniques improve the efficiency and sustainability of biofuel production from woody biomass, while wood-based waste is transformed into activated carbon, a valuable material for pollution control and industrial uses. Innovations in monitoring woodworking tool wear, such as filtering combined with neural networks, enhance precision in furniture manufacturing, reducing waste and improving product quality. Deep learning methods for segmenting wood cells accelerate tree species identification, supporting forestry management and conservation efforts. UAV-LiDAR technology, optimized with the watershed algorithm, refines the measurement and monitoring of Eucalyptus trees, ensuring better resource management. Additionally, wood's unique structure positions it as a key cellulose precursor for advanced materials like microwave absorbers. These processing advancements not only expand wood's applications but also contribute to sustainability, resource efficiency, and the development of a circular economy.	Cascade refinement technologies for wood waste upcycling	Composite production	0.541666667
Robotic Sorting	Robotic sorting enhances the processing of wood-related construction waste by leveraging advanced technologies like deep learning and augmented reality. By employing models such as YOLOv7, robotic systems achieve high accuracy and speed in detecting and sorting wood materials from mixed construction debris. This dynamic grasping capability ensures efficient separation of wood, reducing contamination and improving recycling outcomes. Augmented reality further facilitates human-robot collaboration, enhancing safety and operational efficiency during wood sorting tasks. These advancements contribute to sustainable waste management practices, promoting resource recovery and supporting circular economy goals by minimizing wood waste in landfills.	Separation and sorting of CDW	Separation of wood and metallic components by human-robot collaboration	0.525641026
Sawing Techniques	The sawing process is pivotal in wood utilization by enhancing efficiency, precision, and material yield. Innovations such as optimized cutting parameters for frozen wood reduce tool wear and extend saw blade lifespan, improving operational efficiency. In regions like the Amazon, where wood yield is influenced by factors such as stem conicity and species variability, the use of cutting templates significantly boosts efficiency. Advanced techniques like 3D scanning and flexible cutting methods further refine the sawing process, enabling higher yield and superior product quality. For instance, studies on oak lamellae production reveal that addressing dimensional inaccuracies in outer layers can improve overall precision. Additionally, research on beech wood demonstrates that cant sawing maximizes material quantity (84%), while quarter sawing enhances quality, offering tailored solutions for diverse applications. These advancements in sawing processes not only optimize resource use but also contribute to sustainable practices and higher-value wood products.	Cascade refinement technologies for wood waste upcycling	Composite production	0.576923077
Selective Laser Sintering (SLS)	Selective laser sintering (SLS) improves the utilization of wood by enabling the development of innovative wood-based composites and eco-friendly manufacturing solutions. By incorporating materials like rice husk, peanut husk powder, and Prosopis chilensis, SLS enhances the strength, surface quality, and precision of wood-plastic composites while reducing ash and agricultural waste. Optimized SLS parameters and postprocessing techniques, such as waxing, improve the performance of wood composites, making them suitable for high-quality construction and furniture applications. Additionally, the creation of a 3D bionic balsa wood structure through SLS enhances energy harvesting efficiency, showcasing the potential for advanced material design. These innovations contribute to reducing waste pollution, promoting cost-effective production, and supporting sustainable practices. By integrating wood-based materials into SLS processes, this technology fosters a circular economy and reduces reliance on fossil fuel-intensive manufacturing, positioning wood as a versatile and eco-conscious resource in modern engineering and design.	Cascade refinement technologies for wood waste upcycling	Composite production	0.429487179
Silver Nanowires	Silver nanowires enables multifunctional materials with enhanced properties. Integrating silver nanowires into wood-derived cellulose matrices creates strong, conductive films with exceptional electromagnetic interference (EMI) shielding, hydrophobicity, and antibacterial capabilities. Transparent wood coated with silver nanowires achieves high light transmittance, tensile strength, and effective EMI shielding, making it suitable for flexible, durable applications in lighting and electronics. Additionally, wood substrates in silver nanowire-based heaters demonstrate superior thermal resistance and rapid response times, optimizing energy efficiency. By combining the natural strength and sustainability of wood with the advanced conductivity and shielding properties of silver nanowires, these innovations contribute to the development of eco-friendly, high-performance materials for electronics, intelligent devices, and protective coatings. This synergy between wood and nanotechnology supports sustainable design and reduces reliance on non-renewable materials, aligning with broader goals of environmental sustainability and technological advancement.	Cascade refinement technologies for wood waste upcycling	Validation of new composite products through prototyping	0.625
Solid State Fermentation	Solid state fermentation enhances the value and utility of wood by enabling innovative biotechnological applications. Using wood chips as a substrate, it supports fungal processes like laccase production, which aids in wood decomposition and bioremediation of diesel-contaminated soils. This approach not only cleans the environment but also leverages wood's natural properties for sustainability. Additionally, wood chips facilitate the production of natural pigments, such as orange pigments from Pycnoporus sanguineus, showcasing their potential in eco-friendly manufacturing. When combined with materials like beer draff, wood chips improve fungal conidia production in reactors, advancing industrial fermentation efficiency. Furthermore, microbial pretreatment of wood residues, such as camelina straw and switchgrass, enhances their strength, digestibility, and versatility for broader applications. By transforming wood and its byproducts into valuable resources, solid state fermentation contributes to waste reduction, environmental remediation, and the circular economy, positioning wood as a cornerstone of sustainable innovation.	Chemical and Bioremediation	Bioremediation wood treatment	0.525641026
Sustainable Bioeconomy	A sustainable bioeconomy transform wood into a versatile resource for clean energy, innovative materials, and environmental solutions. Salix wood, with its rapid growth and genetic diversity, exemplifies sustainability by enabling biofuel production and enhancing carbon sequestration. Waste wood biomass has been utilized to develop aluminium-biochar composites, demonstrating wood's potential in catalytic applications that reduce reliance on non-renewable resources. Lignin, a complex wood component, offers promise for creating sustainable bioproducts, though its conversion remains a technical challenge. Additionally, bioashes and biochar derived from wood contribute to environmental protection and biomass waste management, despite hurdles like toxicity and regulatory gaps. By leveraging biomass conversion technologies, such as those in Canada's forests, wood is increasingly integrated into clean energy and chemical production. These innovations position wood as a cornerstone of the circular economy, reducing fossil fuel dependency and fostering sustainable economic and environmental development.	Energy, Gas and Ashes Volarisation	Valorisation of Ashes	0.429487179
Topology Optimization	Topology optimization improves the use of wood by enhancing its structural efficiency and sustainability. Through multiscale optimization methods, it enables the design of advanced engineered wood products like GLULAM and CLT, which are tailored for reduced material use and improved performance in construction. By integrating graded-stiffness metamaterials, topology optimization facilitates the creation of mechanical cloaks for wood-based solids, expanding their applications in innovative architectural and structural designs. These advancements contribute to more sustainable construction practices, minimizing resource consumption while maximizing the mechanical potential of wood, aligning with broader goals of environmental stewardship and the circular economy.	Cascade refinement technologies for wood waste upcycling	Composite production	0.721153846
Weathering Resistance	Co-extruded wood plastic composites (WPCs) achieve superior weathering resistance through protective cap layers, making them more durable than uncapped alternatives. Innovations like eco-friendly coatings and soybean-based adhesives improve UV resistance, hydrophobicity, and water resistance, ensuring long-lasting performance while maintaining wood's natural aesthetics. Impregnating coconut trunk lumber with black liquor and resin not only increases weathering resistance but also inhibits fungal growth and strengthens mechanical properties. Transparent wood, engineered with advanced polymers such as ETW and PTW, demonstrates improved resilience to outdoor conditions, expanding its potential applications. Additionally, silanized wood pulp fibers enhance the weathering resistance of PLA biocomposites, with ENR further boosting UV protection and durability. These advancements reduce material degradation, extend product lifespans, and support sustainable practices, contributing to a circular economy and reducing reliance on non-renewable resources.	Cascade refinement technologies for wood waste upcycling	Composite production	0.576923077
Wood Extractives	Wood extractives bioactive properties, such as antioxidant and antimicrobial effects, make them valuable for developing natural preservatives, extending the lifespan of wood products. Innovations in extraction methods, including horse-based techniques, optimize the recovery of extractives like lignans from Norway spruce stumps, though their composition is influenced by storage conditions. Industrial processes benefit from advancements in solvent purification, where recyclable ethanolamines restore solvent efficiency compromised by wood extractive contamination, improving overall productivity. Additionally, the integration of automated, lightweight felling machines enhances wood harvesting by increasing precision, reducing soil compaction, and minimizing worker risks. These developments not only maximize the functional potential of wood extractives but also contribute to sustainable forest management and the circular economy by reducing reliance on synthetic chemicals and improving resource efficiency.	Cascade refinement technologies for wood waste upcycling	Extraction of wood and lignin from wood waste	0.817307692
Wood Heat Treatment	Through thermal modification, wood becomes more resistant to environmental factors, while higher treatment temperatures reduce milling energy and cutting power requirements, making processing more efficient. Heat-treated wood also exhibits improved mechanical properties and reduced water absorption, optimizing its performance in various applications. Additionally, the minimal impact of substrate temperature on bonding strength allows adhesives to be used effectively at lower temperatures, broadening the scope of wood's utility. These advancements contribute to more sustainable wood usage, reducing energy demands and supporting environmentally friendly practices in construction and manufacturing.	Chemical and Bioremediation	Bioremediation wood treatment	0.576923077
Wood Moisture	Wood moisture impacts wood preservation, durability, and processing efficiency. Innovations like the portable UMR sensor enable non-destructive measurement of moisture distribution, optimizing drying processes and ensuring structural integrity. Superhydrophobic treatments, created through one-step or eco-friendly polymer coatings, significantly enhance water resistance and durability, protecting wood from environmental damage. For waterlogged archaeological wood, green methods using wax, nanotubes, and silane treatments improve preservation, strength, and conservation, while NIR spectroscopy provides accurate, non-destructive hardness assessments. Pre-freezing and supercritical CO_2 drying techniques refine wood's physical properties, such as color and wettability, while reducing drying time and structural collapse. Additionally, denser eucalyptus plantations equalize moisture levels, improving drying rates and wood quality. By addressing moisture management, these advancements reduce resource waste, enhance wood's longevity, and support sustainable practices, contributing to a circular economy and reducing dependence on less renewable materials.	Chemical and Bioremediation	Bioremediation wood treatment	0.721153846
Wood Preservation	Wood preservation plays a critical topic as it's related to the durability, functionality, and sustainability. Innovations such as cellulose acetate-based coatings with ZnO and TiO_2 improve wood's hydrophobicity and resistance to degradation, extending its lifespan. Eco-friendly solutions like beta CD-AITC and lignin nanoparticles infused with essential oils offer natural protection against decay and fungi, reducing reliance on harmful chemical treatments. Additionally, bio-based curing agents have enabled the development of sustainable coatings with enhanced flame retardancy and performance. Advanced preservation techniques, such as PVB nanocomposite coatings with ZnO and CNCs, provide superior UV and moisture protection, further increasing wood's resilience. These methods not only improve wood's structural integrity but also open new applications, such as transparent and conductive wood for electronic sensors and displays. By prioritizing natural durability and innovative treatments, wood preservation contributes to carbon sequestration, reduced environmental impact, and the integration of wood into a circular economy.	Cascade refinement technologies for wood waste upcycling	Validation of new composite products through prototyping	0.28525641

Wood Substrate	Wood substrate are important as it enables innovative materials and sustainable applications. Co-extruded wood plastic composites (WPCs) utilize protective cap layers to enhance weather resistance, extending the durability of wood-based materials. Integrating bimetallic metal-organic frameworks (MOFs) into wood improves flame retardancy, thermal stability, and dye removal efficiency, creating eco-friendly building materials. Additionally, charged nanoparticles enhance wood's flame resistance, stability, and transparency, expanding its potential for modern construction. Substituting wood with agricultural residues like sunflower husks in particleboard production reduces reliance on traditional wood sources while maintaining strength and water resistance through optimized adhesive use. Bamboo boards offer a versatile alternative to wood, with customizable properties based on pressure application, supporting sustainable construction. These innovations not only improve wood's performance but also promote resource efficiency and environmental sustainability, aligning with circular economy principles and reducing dependence on fossil-based materials.	Cascade refinement technologies for wood waste upcycling	Validation of new composite products through prototyping	0.541666667