

Review

Green and Efficient Processing of Wood with Supercritical CO₂: A Review

Jingwen Zhang ¹, Lin Yang ^{1,2,3} and Honghai Liu ^{1,*} 

¹ College of Furnishings and Industrial Design, Nanjing Forestry University, Nanjing 210037, China; Wennyzhang96@njfu.edu.cn (J.Z.); yanglin@njfu.edu.cn (L.Y.)

² Key Laboratory of Bio-Based Material Science & Technology, Ministry of Education, Northeast Forestry University, Harbin 150040, China

³ Co-Innovation Center of Efficient Processing and Utilization of Forest Resources, Nanjing Forestry University, Nanjing 210037, China

* Correspondence: liuhonghai2020@njfu.edu.cn

Abstract: Wood processing is a crucial step of wood utilization, but the adding of environmentally hazardous feedstocks and the use of unreasonable technology allow it to harm the environment and human health. Supercritical CO₂ (scCO₂) is a non-toxic, odorless, and safe solvent, which is widely used in studies and industrial production, but there is no review summarizing wood processing with scCO₂. The unique structure and chemical properties of wood combined with scCO₂ technology produce positive results. In this paper, wood processing with scCO₂ is summarized, including wood impregnation, wood drying, wood thermochemical conversion, and wood extraction. The green and efficient characteristics of wood processing with scCO₂ are explained in detail for researchers, engineers, and investors to provide a clean wood processing method. Further study is needed to reduce its energy consumption and commercialize it eventually.

Keywords: supercritical CO₂; green wood processing; wood extraction; wood impregnation; wood drying



Citation: Zhang, J.; Yang, L.; Liu, H. Green and Efficient Processing of Wood with Supercritical CO₂: A Review. *Appl. Sci.* **2021**, *11*, 3929. <https://doi.org/10.3390/app11093929>

Academic Editor:
Manuela Romagnoli

Received: 26 March 2021
Accepted: 22 April 2021
Published: 26 April 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Wood processing enhances the physical property [1], water resistance property [2], and flame-retardancy [3] of wood, and then transforms it into valuable finished products [4], including functional wood-based panels [5], furniture [6], construction materials [7], biomass energy [8], medicine [9], and paper [10].

The use of toxic organic feedstocks and underdeveloped technology in wood processing causes serious pollution to the environment and increases risk of human diseases. The chemical methods (such as acetylation [11], silanization [12], and etherification [13]) improve the dimensional stability of wood by reducing the number of hydroxyl groups. The dimensional stability and strength property are improved after treatment with thermosetting resin as chemical modifiers [14,15]. However, the use of such fossil-based chemical modifiers contradicts environmental protection and causes environmental degradation in the process of use and production [16]. Heat treatment can improve the stability of wood, but the primary organic aerosols (POA) released during the treatment, due to the high treatment temperature, and POA exposure in the atmosphere cause unhealthy effects on people, such as cardiopulmonary diseases [17]. At the same time, volatile organic compounds (VOCs) are discharged from the wood and released directly into the air. VOCs can react with nitrogen oxides in the air to produce ozone, which can increase the risk of respiratory diseases in humans [18]. The organic solvents used in wood extraction and impregnation include ethanol [19], diethyl ether [20], chloroform [21], and hexane [21]. These solvents result in a negative influence on the environment and humans [22].

Green wood processing is expected. Wood processing pollution can be mitigated by reducing the use of toxic organic feedstocks and improving technology. Many wood

processing technologies suffer from low efficiency [23–25]. The wood processing yield improved using scCO₂, a green solvent, by increasing pressure [26,27]. These are the two most important advantages of scCO₂ in wood processing: efficiency and environmentally friendly.

ScCO₂ is a recognized green and clean solvent and is easy to reuse. The technique with scCO₂ takes advantage of excellent solubility to promote the efficiency of wood processing; however, the application in wood processing with scCO₂ has not been summarized. In this paper, the application in wood processing with scCO₂ is summarized in detail, including wood impregnation, wood drying, wood thermochemical conversion, and wood extraction. Combined with the properties of scCO₂, the green and efficiency advantages in wood processing are explained. This paper aims to provide an efficient and green wood processing technology which treats wood using a green solvent of scCO₂ to researchers, engineers, and investors, and to strengthen the clean wood production and to achieve sustainability.

2. Characteristics of Supercritical CO₂

CO₂ is an emission by large-scale industrial sources including fossil-fuel power stations [28], building cement [29], steelworks [30], etc. and a by-product that is generated during the production of ammonia, ethanol, and natural gas in refineries, making it easily sourced [31].

ScCO₂ is used due to its low critical temperature (31.1 °C) and pressure (7.39 MPa) [32]. Figure 1 [32] shows CO₂ reaches a supercritical state by heating above its critical temperature and pressurizing above its critical pressure. In the supercritical state, the density is like that of a liquid and the viscosity like that of a gas, which gives it good solubility and transfer performance [33–35]. ScCO₂ has been used as a medium and solvent in petrochemical engineering [36], the food industry [37], the pharmaceutical industry [38], and cellular material [39]. These studies have shown that using scCO₂ as the transfer medium can effectively improve the extraction rate compared with conventional process, and the temperature and pressure are easy to achieve [40].

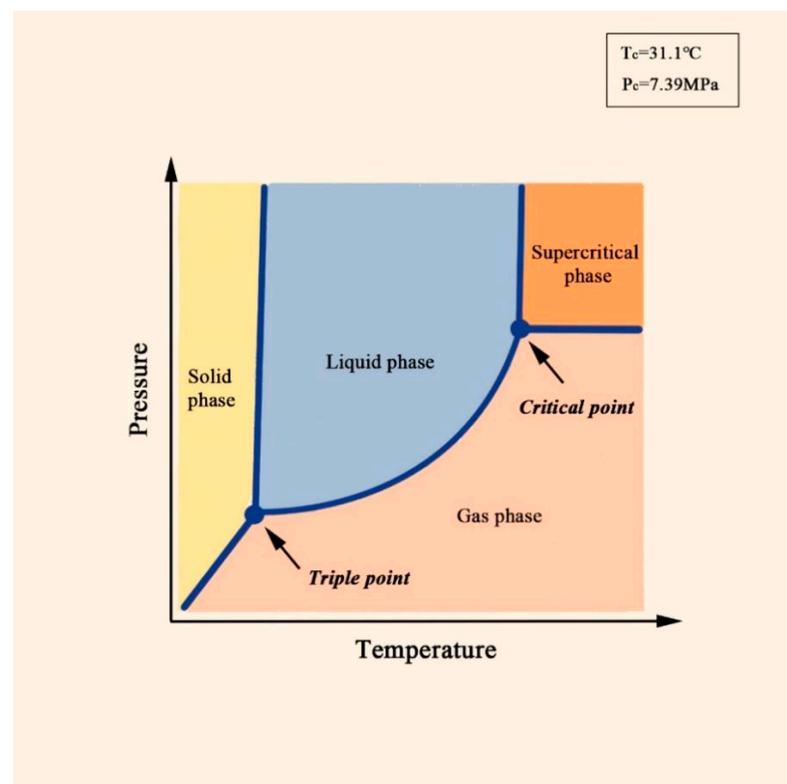


Figure 1. Supercritical CO₂ p-T diagram.

scCO₂ is susceptible to pressure near the critical point, allowing its density to be easily changed by changing the pressure of the control system, which affects its solubility [41]. CO₂ experiences significant thermal physical fluctuations near its supercritical point, which also helps enhance convection and heat transfer [42,43]. Table 1 [44,45] shows the dissolving capacity and transfer characteristics of supercritical fluids relative to liquids and gases. These characteristics indicate that scCO₂ can be of great use for various wood processing applications.

Table 1. The dissolving and transfer characteristics of supercritical fluid compared with liquid and gas.

Characteristics	Liquid	Gas	Supercritical Fluid
Density/g·cm ⁻³	0.6~1.6	0.006~0.02	0.2~0.5
Viscosity/10 ⁻⁴ g·cm ⁻³ ·s ⁻¹	20~300	1~3	1~3
Diffusivity/cm ² ·s ⁻¹	(0.2~2) × 10 ⁻³	0.1~0.4	0.7 × 10 ⁻³

Furthermore, scCO₂, a low polar solvent, is easy to recover as a low polarity molecule without additional cleaning steps [46]. The polarity of scCO₂ can be adjusted by adding a co-solvent, such as ethyl lactate, ethyl acetate, or ethanol [47], thus improving the yield of the polar compounds [48].

3. Wood Impregnation

Wood impregnation is a process to force wood modifying agents—preservatives, fire retardant, and dye—into wood structures by increasing pressure in the vessel [49]. Wood impregnation with scCO₂ is more efficient compared with conventional wood impregnation [50–53]. Applications of wood impregnation with scCO₂ that are summarized in this section include wood preservation with biocides, wood inflaming retarding, wood dyeing, and wood acetylation. An overview of wood impregnation application with scCO₂ shows in Table 2.

The liquid permeability of wood can be improved with scCO₂ treatment, which is one of reasons for impregnation efficiency improving under this method. Wood liquid permeability is a physical property that describes the fluid through the connected voids of wood structure under a static or capillary pressure gradient [54]. The high permeability of wood can increase the migration rate of liquid in wood [50]. This was first demonstrated in 1995 using scCO₂—either alone or with entrainment (methanol)—and was used to improve the permeability of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) heartwood samples [55]. The high-pressure difference of scCO₂ treatment will destroy the wood structure and form new water and other liquid transfer channels, thus increasing the liquid flow in the wood. Matsunaga et al. [56] pretreated sugi (*Cryptomeria japonica* D. Don) with scCO₂ and showed that pits were broken in the pretreated sample with a scanning electron microscope (SEM), which created new water and other liquid transfer channels.

Table 2. An overview of wood impregnation application with scCO₂.

Application	Environment Benefits with scCO ₂	Efficiency with scCO ₂	References
Wood preservation with biocide		The higher insecticide retention value Better protection Fast treatment	[50,57–59]
Flame retardancy of wood	No VOCs emission No metal components Non-toxic solvent	Fire-resistant additives (non-polar compound) have appreciable solubility in scCO ₂ Facilitating dye uptake at moderate temperatures	[60]
Wood dyeing		Improving recycling rates of both CO ₂ and dyes	[25,61]
Wood acetylation		Acetylation reagent penetrate into the core of wood	[62]

3.1. Wood Preservation with Biocides

Wood easily decays and discolors in humid environments. Wood preservation is used to improve its antibacterial capacity and its resistance to wood-decaying fungi, wood-blighting fungi, molds, and wood-damaging insects, which extends the service life of wood products [63–65]. The one of primary wood preservation methods is to add preservatives in the wood through impregnation [66]. However, it is difficult to impregnate the inner part of the wood with preservatives by conventional impregnation due to the large fluid resistance and poor permeability of wood [67]. At present, wood impregnation is treated by water-based or hydrocarbon solvents [57]. The uses of water-based solvents in wood impregnation leads to volume expansion of wood and dimensional stability cannot be restored immediately [57]. The use of hydrocarbon solvents has a negative effect on the environment due to VOCs emission.

The idea of wood preservation with scCO₂ was carried out due to properties of CO₂ in a supercritical state that was mentioned before. Cookson et al. [57] exploited the timber impregnation with the sufficient solubility (2.32 g/L~5.07 g/L) of the insecticide permethrin using scCO₂ in 50 °C and 15 MPa. Even though the maximum solubility (30.07 g/L) was achieved at 30 MPa, the lowest effective pressure is always adopted in the business, which can reduce the cost. A methanol co-solvent improves the solubility of permethrin in scCO₂. After decompression, the insecticide loses its solubility and deposits within the wood, thus protecting wood. There is a higher insecticide retention value and better protection under scCO₂ compared to a light organic solvent. Kjellow et al. [50] used organic fungicides (tebuconazole, propiconazole, and IPBC) for wood impregnation using different pressures and temperatures of scCO₂. They concluded that the proportion of fungicide in the wood and CO₂ had a significant effect on the fungicide deposition. The fungicide solubility increased with the density of the CO₂. Fungicide deposition occurred due to the loss of fungicide solubility during decompression and because a large amount of fungicide was adsorbed by the wood during impregnation.

There are vast differences in impregnation efficiency between softwood and hardwood due to large differences in wood structure. Moreover, artificial boards also have particular impregnation characteristics under scCO₂ treatment. Muin et al. [68] and Muin and Tsunoda [58] studied five kinds of wood-based composite materials (medium-density fiberboard (MDF), hardwood plywood, softwood plywood, particleboard, and oriented strand board) with 3-iodo-2-propynyl butylcarbamate (IPBC) preservative under scCO₂ treatment. The results showed that IPBC improved the preservation of these wood-based composite materials. Furthermore, the treatment largely depended on the temperature, pressure, fungicide dosage, and wood-based composite material [69]. Particleboard, MDF, and hardwood plywood achieved the best preservation at 55 °C and 11.7 MPa, while softwood, plywood, and OSB showed the best performance at 35 °C and 9.81 MPa.

Kang et al. [70] treated Douglas-fir and radiata pine (*Pinus radiata* D. Don) with cyproconazole using scCO₂ impregnation, and the results showed that treatment conditions led to different distributions of fungicides. Most studies indicate fungicide can move in the wood structure by decompression in the vessel, because pressure gradient force preservatives loaded the water to flow. However, decompression can easily lead to water passage blockage, which results in the uneven deposition of fungicides, making it difficult to process wood [55,71]. In the study [70], they adopted temperature-induced biocide deposition at the end of the cycle, and the results showed that this method reduced the consumption of fungicide and more efficiently retained fungicides with minimal line clogging. Kang et al. [59] studied radiata (*Pinus radiata* D. Don) pine lumber specimen impregnation with subcritical CO₂ and scCO₂. The results showed that compared with scCO₂, subcritical CO₂ treatment produces a higher retention rate and more uniform distribution. Besides, subcritical CO₂ treatment has economic advantages over scCO₂, such as lower investment costs due to low pressure and lower energy consumption due to feedstock heating at low temperature.

3.2. Flame Retardancy of Wood

Wood is a porous biomass material that is composed of cellulose, hemicellulose, and lignin, as well as a large number of polar groups containing oxygen atom, such as hydroxyl and methoxyl [72]. These components of wood indicate that it is flammable. For safety purposes, wood is commonly treated with flame retardants by impregnation of the flame retardants into the porous wood structure using a vacuum compression technique or by coating onto the wood surface [73]. The flame retardancy of wood is not only related to the characters of flame retardants, but also the distribution of flame retardants in wood [74]. Eastman et al. [60] prepared poplar–silicone resin composite materials through scCO₂ extraction, using ethanol as an auxiliary solvent. The results showed that the addition of silicone improved the refractory properties, mechanical properties, because silicon resin has a high solubility in scCO₂ [60]. Tsiptsias and Panayiotou [75] added silicon-based polymer coatings to spruce (*Picea abies* (L.) Karst) and beech (*Fagus sylvatica* L.) samples that were impregnated with scCO₂ and the results showed that the flame retardancy of the treated wood was improved.

3.3. Wood Dyeing

Wood dyeing can eliminate color differences and improve defects in timber such as uneven color, tarnish, and color changes [76]. Wood dyeing methods include coloring matter dyeing, chemical dyeing, biological dyeing, hot chemical dyeing, and structural color [77]. It is challenging for conventional hydrothermal dyeing techniques to achieve satisfactory dyeing results due to poor permeability of some parts of wood. However, the use of scCO₂, especially when a co-solvent is added, can significantly improve the dyeing effect. Jaxel et al. [61] used scCO₂ as the dyeing carrier to impregnate different tree species with the dye Blue 134. Lipophilic dyes are easily solubilized in scCO₂. They also added the commonly used paper sizing agent AKD to improve the dispersive capacity of the dye, which helped the dye permeate through the wood using scCO₂. An anthraquinone derivative was also synthesized to improve the solubility of DB 134 in scCO₂ and achieved a significant dyeing effect. Jaxel et al. [62] studied wood dyeing without the addition of an organic co-solvent, and the water-saturated scCO₂ better accessibility of cell wall by expansion.

3.4. Wood Acetylation

Wood acetylation is a wood modification method used to improve its dimensional stability and durability by reducing the content of –OH groups. It is accomplished by esterifying hydroxyl groups of wood with an acetylation reagent [78]. Treating wood with scCO₂ improves the permeability of the wood, allowing acetylation agents to penetrate the wood better.

Matsunaga et al. [79] acetylated Japanese cedar using scCO₂ fluid by acetic anhydride. The results showed that, compared to treatment without the use of CO₂, using scCO₂ in the acetylation had a higher bulking effect which increased the stability of wood. Acetic anhydride becomes a uniphase when in scCO₂ above 90 °C and responds rapidly in the wood to speed up acetylation. In a subsequent study, Matsunaga et al. acetylated four species of wood of *Paraserianthes falcata* (*Albizia falcataria* Linn. Fosberg.), *Alstonia macrophylla* (*Alstonia macrophylla* wall. ex G. Don), *Pinus caribaea* (*Pinus caribaea* Morelet), and *Hevea brasiliensis* (*Hevea brasiliensis* (Willd. ex A. Juss) Muell. Arg.) with acetic anhydride in scCO₂. After 8 h of treatment, anti-swelling efficiency values increased by more than 60%, and the effect of *macrophylla* was the best.

4. Wood Drying

The conventional kiln drying with a heating device is the most common drying method in the wood drying industry, which is commonly carried out by boilers powered with fossil fuel [80]. This results in excessive greenhouse gas and POA emissions, which have a negative impact on the environment [17]. Compared with conventional drying,

scCO₂ drying reduces the harm of greenhouse gases emission to the environment because CO₂ is a feedstock instead of a fossil fuel. However, the high pressure of scCO₂ increases power consumption.

Several researchers have studied wood dewatering using scCO₂ [80–83]. CO₂ is circulated between the supercritical state and the gas phase in wood by changing the scCO₂ pressure. The large pressure difference increases the liquid permeability of wood and the CO₂ bubbles carry the water out of the wood [81]. The water removal without changing the microstructure of the wood during scCO₂ treatment due to its excellent solubility and transfer characteristics [81,82].

Wood drying with scCO₂ has a high rate of dewatering. Franich et al. [81] cycled CO₂ between the gas phase and supercritical state to dewater radiata pine sapwood samples with sizes of 18 mm × 18 mm × 100 mm under different pressures and temperatures. The longest drying time in one cycle lasted for 16 min and the shortest was for 2 min. The results showed that the moisture content of lumber was quickly reduced in this drying method. Compared with the conventional drying method, the wood drying rate was increased with scCO₂ due to the pressure difference in several cycles of pressurization–depressurization. Gabitov et al. [84] dried wood with scCO₂, and 87% of the water was removed in the first drying cycle. Dawson et al. [83] dried radiata pine sapwood using scCO₂, and after seven cycles the moisture content decreased from 174% to 39%.

Collapse is an abnormal shrinkage occurring above the fiber saturation point (FSP), which is caused by the capillary forces in the cell due to the rapid removal of free water from the lumen. Collapse is accompanied with an internal crack and surface cracking, thus wood strength is decreased [84]. The collapse of wood can be reduced by using scCO₂ drying due to fact that the water is pushed out from the cell lumen directly [85]. Additionally, the negative capillary pressure of the wood cell wall decreased in a supercritical state, which has little liquid–gas interfacial tension [62]. Dawson et al. [85] studied the collapse of *Eucalyptus nitens* (Deane and Maiden) with scCO₂ pretreatment compared to conventional drying, and the results showed that this pre-drying method reduced the collapse rate by 75%. Dawson and Pearson [23] dried softwood and hardwood samples with scCO₂ and found that the shrinkage of wood after scCO₂ drying was much smaller compared with conventional drying, and wood cracks were significantly reduced.

Moisture distribution and migration are fundamental processes that occur during wood drying. Behr et al. [86] studied the distribution of CO₂ and water with scCO₂ in green radiata pine (*Pinus radiata* D. Don) sapwood by ¹³C nuclear magnetic resonance (NMR) spectroscopy and proton magnetic resonance imaging (MRI). The results showed that CO₂ first entered the latewood and then diffused into the adjacent earlywood, while less CO₂ entered the earlywood directly. Meder et al. [87] observed the wood drying process using scCO₂ combined with forced ventilation through MRI and found that after scCO₂ drying the ¹H MRI signal intensity was weakened, indicating the removal of water. Newman et al. [88] used NMR to study wood drying with scCO₂, and the experimental results showed that the scCO₂ soluble extractives were removed to open new water pathways in earlywood and the water removal by diffusing into scCO₂ only occurred when the volume of scCO₂ was larger than the volume of wood. As the pressure drops, the CO₂ bubbles expand to help with wood dewatering. Franich et al. [89] observed the wood scCO₂ drying process in real-time using MRI and ¹³C NMR. CO₂ diffused and bound to free water when the pressure increased during drying. The way in which water combines with CO₂ is different when the pressures changed.

However, the development of wood drying with scCO₂ remains an ongoing challenge due to the final moisture content near the FSP, which means the dewatered wood using scCO₂ cannot be utilized directly. The scCO₂ technology combined with other drying technology is more suitable for actual wood drying.

5. Wood Thermochemical Conversion

Bio-fuels are a sustainable and effective alternative to fossil fuels, and reduce environmental pollution compared to fossil fuels [90]. Biomass fuels include biomass ethanol, bio-oil, etc. Bio-oil can be produced by thermochemical conversion of wood, residual crops, and pulp mill fertilizers. Wood thermochemical processes include liquefaction, pyrolysis, and gasification [91]. Wood gasification uses a gasification agent to convert raw wood materials into a product of gas under the condition of low oxygen content and high temperature (800 °C–1400 °C). The wood gasification product of gas mainly contains H₂, CO, and CH₄ and is used for fuel and power generation [92,93]. Wood pyrolysis and liquefaction techniques are similar, but the processes are different. Pyrolysis is the thermal degradation of wood under the condition of 400–700 °C without oxygen, and the pyrolysis temperature is usually lower than the gasification. Bio-oil and Bio-crude are the wood pyrolysis products [94]. Wood liquefaction is performed on wood under the conditions of low temperature (250 °C–400 °C), high pressure, and with a solvent. The wood liquefaction products can produce polyurethane, epoxy resin, adhesives, etc. [95].

5.1. Wood Gasification

Currently, there are many studies using CO₂ gas as the gasification atmosphere of wood [93,96–98]. CO₂ gas is a kind of a clean medium and it also has the following advantages: control of the ratio of H₂/CO through the input of CO₂, save on the cost of steam and oxygen, and increase the production of syngas [91,99,100]. It can be seen that compared with scCO₂, CO₂ gas is a lower cost choice as a wood gasification medium. This is because gasification operation can be realized without high pressure (critical pressure of CO₂ is 7.39 MPa) only under the condition of a catalyst [98], and the high pressure increases the operation cost. At present, the most commonly used supercritical fluid medium for wood gasification is supercritical water [22,101–104] for economic reasons. A few scholars are still studying scCO₂ wood gasification [105], and the specific value of syngas conversion rates are shown in Table 3. It can be seen from the table that compared with the gasification agent gas CO₂ and supercritical water, wood gasification using scCO₂ has a higher syngas conversion rate without catalyst addition, but the operation cost is higher.

Table 3. Wood synthesis gas conversion rates by using different gasification agent.

References	Wood Species	Gasification Agent	Catalyst	Conditions	Syngas	Conversion
[21]	<i>Eucalyptus grandis</i>	Supercritical water	— NiFe ₂ O ₄	400 °C–450 °C	Gas mixture of H ₂ and CH ₄	64–73% 83–95.5%
[100]	Wood chips oak and beech (supplied by J. Rettenmaier & Sohne GmbH)	CO ₂	dolomitic limestone	850 °C	Gas mixture of CO and CH ₄	89%
[101]	The wood residues of the pine tree	Supercritical water	— K ₂ CO ₃	500–600 °C; 19.8 MPa–43 MPa	Gas mixture of H ₂ , CH ₄ and CO ₂	46.9–73.2% 59.1–80.9%
[104]	<i>Populus alba</i> L.	Supercritical water	— K ₂ CO ₃	400–600 °C	Gas mixture of H ₂ and CH ₄	45.2–70.4% 47.6–81.0%
[106]	The wood residues of the fir tree	ScCO ₂	— K ₂ CO ₃	650 °C–800 °C; 30 MPa	CO	43.2–65.8% 56.7–77.5%

5.2. Wood Liquefaction

Hydrothermal liquefaction is a common method of wood liquefaction, which is carried out with water under a subcritical state [103]. The hydrothermal is attractive when operating conditions are near the critical point of water, this is because: the mass transfer resistance is greatly reduced under supercritical state, there is no need for a drying process, energy is saved, and the change to temperature and pressure of water significantly promotes the physical properties changes, thereby improving the effective separation of products and by-products [103]. However, hydrothermal liquefaction needs to reach high temperatures, resulting in specialized materials to deal with this. Moreover, catalysts for hydrothermal liquefaction are necessary, which can possibly cause blockage of the reactor [104].

As a green solvent, when compared with supercritical water, the critical temperature of scCO_2 is much lower, thereby the expensive high temperature equipment is avoided. ScCO_2 can not only be directly used as a liquefaction solvent, but also can be used as a liquefaction catalyst. Chan et al. [105] added scCO_2 to the solvent water of a biomass hydrothermal reaction, which can promote the in situ formation and dissociation of carbonic acid in the reaction of water and CO_2 under high temperature and pressure. This forms a natural catalyst, thus avoiding harmful inorganic acids (hydrochloric acid and sulfuric acid) that harm the environment [107–109]. The results showed that the yield of bio-oil was improved with scCO_2 as a catalyst at 300 °C. Additionally, in a liquefaction reaction at 300–330 °C, the property of the liquefaction medium can be changed by adding scCO_2 due to the generation and dissociation of carbonic acid in water. Wang et al. [110] liquefied pine using different solvents at 300 °C, including scCO_2 , acetone, ethanol, and H_2O . Under the help of catalysis of K_2CO_3 , the results showed that scCO_2 and organic solvents had a similar bio-oil yield, while the bio-oil yield using H_2O as the solvent was relatively low. Table 4 shows the detailed yield of wood liquefaction in different liquefaction media. However, tree species influence the results to some extent because of the differences in their internal structure.

Table 4. Wood liquefaction yield by using different liquefaction media.

References	Wood Species	Liquefaction Media	Catalyst	Conditions	Bio-Oil Yield
[109]	Palm kernel (<i>Elaeis guineensis</i> Jacq.) shell	H_2O	—	300 °C; 30 MPa	3.00–6.59 wt%
		ScCO_2	ScCO_2	300 °C; 25 MPa	12.03 wt%
			—		8 wt%
[110]	White pine (<i>Pinus strobus</i> L.) sawdust	Acetone	K_2CO_3	300 °C; 11 MPa	29.3 wt%
		Ethanol	K_2CO_3	300 °C; 4.5 MPa	27.9 wt%
		H_2O	K_2CO_3	300 °C; 7.3 MPa	30.8 wt%
			K_2CO_3	300 °C; 7.9 MPa	17.3 wt%
[111]	Oak wood (<i>Quercus pubescens</i>)	H_2O	K_2CO_3	320 °C	27 wt%
			Fe		32 wt%
[112]	Aspen wood (<i>Populus tremula</i> L.)	H_2O	—	350 °C; 15 MPa	17 wt%
			NiMo		70.3 wt%
			—		19 wt%
[113]	Silver birch (<i>Betula</i> sp.)	Supercritical ethanol	5 wt% iron modified beta zeolite	234 °C	25 wt%

5.3. Bio-Oil Purification

Bio-oil can be obtained by pyrolysis and liquefaction of biomass. Bio-oil is a complex mixture of more than 400 different compounds containing 25% water [114]. Large amounts of oxygen-containing compounds need to be removed to increase their volatility and thermal stability for bio-oil used as fuel [115]. Compared with expensive organic solvents, scCO_2 is a good medium for extracting heat-sensitive components such as bio-oil [116] because of its lower critical value. Moreover, different types of compounds can be selectively extracted by changing the pressure, so that there are no chemical residues after extraction [117]. Higher purity and better quality fuels of biomass thermal conversion can be extracted with scCO_2 .

Naik et al. [118] used scCO_2 to separate water from wheat–hemlock bio-oil, which was easily dissolved in scCO_2 . The high percentage of water (45.0 wt%) was separated at 10–30 MPa and 40 °C. Feng and Meier [119] extracted pine wood (from North America) bio-oil with scCO_2 , and reached the maximum extract yield of 14.3 wt% at 80 °C and 30 MPa, the water content of bio-oil was 25.4 wt%–28.0 wt%, and the extraction rate was 26.5% at 20 MPa and 60 °C with activated carbon as the catalyst. Rout et al. [120] conducted scCO_2 extraction from wheat–sawdust bio-oil, and the first three fractions were tested at 45 °C and 25 MPa, then pressure was increased to 30 MPa for the fourth fraction. This method separates water from bio-oil with higher moisture content and low calorific value. The calorific value increased to 30.0–44.5 KJ/Kg. In the first three fractions, the value of pyrenoids and oxygenated benzenoids were high, while the values of fatty acids and high molecular mass alcohols were high in the fourth fraction.

6. Wood Extraction

6.1. Natural Component of Wood

Wood extraction with scCO₂ is an effective method to obtain various high-value chemical products. ScCO₂ extraction has a simple process, fast mass transfer rate, high extraction efficiency, and is a green separation technology [121]. ScCO₂ is a low-polar solvent, in which the solubility of polar compound is very low, and the extraction efficiency can be improved by adding a polar co-solvent, such as ethanol or ethyl acetate [48]. However, excessive addition of organic solvents will affect the environment. A brief overview of wood extraction with scCO₂ is shown in Table 5.

Candeia (*Eremanthus erythropappus*) wood is a Brazilian tree species with a high commercial value, and the chemical components of its oil can be used to make cosmetics and drugs, especially the active ingredient, *s*-bisabolol, which has sedative, anti-allergy, and anti-bacterial characteristics [122]. Santos et al. [123] used scCO₂ to extract candeia wood oil at different temperatures and pressures. The results showed that the highest extraction rate of mahogany oil was 1.42% and the residue was 0.41% at 70 °C and 240 bar. Queiroz and Cajaiba [124] extracted chemical substances from candeia wood using scCO₂ with ethanol. The extraction rate of this method was higher than steam distillation. Souza et al. [125] conducted dynamic scCO₂ extraction of candeia wood, and the kinetic curve showed that supercritical extraction and phase behavior were the main factors influencing the extraction efficiency.

Pine extract is important in the fields of food, medicine, and health [126]. Sarikaki et al. [127] extracted *Pinus brutia* bark under different scCO₂ extraction conditions by adding 3% ethanol and performing ultrasonication. The results showed that 46.8% (-)-catechin was extracted, and almost 100% (-)-catechin gallate and (-)-epicatechin were extracted. Conde et al. [128] extracted low-molar-mass phenolics and lipophilic compounds from maritime pine (*Pinus pinaster*) wood with scCO₂. The maritime pine wood extracts had strong antibacterial effects. Ethanol was used as a co-solvent, and the products extracted accounted for 4.1 wt% of the dried wood. Braga et al. [129] used scCO₂ to extract maritime pine bark, and achieved a maximum extraction of 84%, which was rich in catechin and epicatechin. The extract content was improved after the addition of ethanol solvent during extraction.

An aromatic essential oil can be extracted from *Eucalyptus robusta*. This oil is secreted by eucalyptus leaves and can kill insects, repel mosquitoes, reduce inflammation, and is used for sterilization [130,131]. Zhou et al. [132] analyzed the extraction conditions for volatile oils from *Eucalyptus grandis* × *Eucalyptus urophylla* by scCO₂. The extraction temperature was 80 °C, the extraction pressure was 40 MPa, and the extraction time was 8 h, reaching a maximum extraction rate of 7.86%. Chemical components were analyzed by gas chromatography-mass spectrometry. The content of eucalyptol and α -pinene were 45.57% and 24.78%, respectively. Santos et al. [133] used supercritical CO₂ to extract eucalyptus globulus bark, with added ethanol, and showed an optimal extraction rate and high selectivity for flavonoids. Patinha et al. [134] treated *Eucalyptus grandis* × *Eucalyptus globulus* bark with dichloromethane for 7 h, and then used scCO₂ to extract lipophilic extractives from eucalyptus bark after drying. They detected lipophilic extractives by gas chromatography-mass spectrometry, with beta-sitosterol in the bark interior and triterpene in the bark exterior.

In the latest studies, some scholars have used scCO₂ to extract cedarwood oil from eastern red cedar (*Juniperus virginiana* L.) to protect the wood from termites and fungi. ScCO₂ has also been used to extract an ingredient from *Pinus pinaster* that is used to resist pests, and a volatile oil from *Aquilaria sinensis* with a high economic value [135–137].

Table 5. Wood liquefaction yield by using different liquefaction media.

References	Wood	Effective Constituent
[121]	Candeia (<i>Eremanthus erythropappus</i>)	α -bisabolol
[122]	Candeia (<i>Eremanthus erythropappus</i>)	(-)- α -bisabolol
[123]	Candeia (<i>Eremanthus erythropappus</i>)	α -bisabolol
[125]	<i>Pinus brutia</i>	(-)-catechin, (-)-epicatechin, (-)-catechin gallate
[126]	Maritime pine (<i>Pinus pinaster</i>)	phenolic compounds
[127]	Maritime pine (<i>Pinus pinaster</i>)	Catechin, epicatechin
[130]	<i>Eucalyptus globulus</i>	phenolics
[131]	<i>Eucalyptus grandis</i> \times <i>Eucalyptus urophylla</i>	Eucalyptol, α -pinene
[132]	<i>Eucalyptus grandis</i> \times <i>Eucalyptus globulus</i>	Lipophilic extractives
[133]	<i>Aquilaria sinensis</i>	Volatile oil
[134]	<i>Pinus pinaster</i>	α -pinene, β -pinene, β -myrcene, β -caryophyllene
[137]	Eastern red cedar (<i>Juniperus virginiana</i> L.)	Oil

6.2. CCA Wood Detoxification

The service life of wood can be prolonged by preservation; however, widely used preservatives commonly contain CCA (Cu, Cr, and As). After being treated with CCA, wood is toxic, especially when it is burned or buried. This has terrible effects on the environment, and wood treated with CCA must be disposed of properly [138]. ScCO₂ is a green solvent and can be used to efficiently extract toxic substances from CCA wood. El-Fatah et al. [139] used scCO₂ to extract CCA wood, and the best extraction effect was achieved when the temperature was 59.85 °C and the pressure was 24 MPa. The extraction rates of Cu, Cr, and As were 63.5%, 28.6%, and 31.3%, respectively. Wang and Chiu [140] used scCO₂ to treat CCA wood and showed that this extraction method could significantly reduce the production of acidic and organic solvent wastes, as well as effectively reduce the cost of solvent extraction.

7. Conclusions

This paper presents a summary of the applications in wood processing with scCO₂. In wood impregnation and extraction, scCO₂ is a solvent with strong solubility in low-polar compounds (such as preservative, flame retardant, and the natural composition of wood) and the polarity can be changed by adding a polar solvent. The uses of a non-toxic solvent, scCO₂, instead of organic solvents reduce VOCs emissions. The great pressure difference destroys the pits membrane and increases the permeability of wood, making it easier to impregnate wood with modifiers and the composition in the wood (natural composition and CCA) is also easier to extract. In wood drying, this method reduced CO₂ emissions compared with conventional wood drying. The drying rate is increased due to CO₂ bubbles carrying water out from the wood during depressurization when the scCO₂ transformed into the gas phase. Additionally, collapse in wood is reduced, which is a severe drying defect occurring easily in conventional drying, but because the scCO₂ is a kind of fluid with little interfacial tension between gas and liquid it reduced the negative cell wall pressure caused by water escaping from the wood. In wood thermochemical conversion, scCO₂ is more of a liquefaction medium than gasification, due to the critical conditions of scCO₂ being more suited for the temperature and pressure of liquefaction. For gasification, supercritical water and CO₂ gas are better low-cost green mediums. The efficiency of wood liquefaction with scCO₂ is similar to the organic medium, and it can be improved by adding a catalyst. However, the scCO₂ has an environmental advantage over organic solvents.

ScCO₂ wood processing is a potential technique that has the aforementioned advantages, but it will take a long time to be commercially viable because of the high cost of high-pressure apparatuses and high-power consumption. This obstacle still needs active

research and development to minimize the cost and energy consumption. Moreover, the specific recycling utilization needs to be further studied to show the result of scCO₂ wood processing in business.

Author Contributions: Conceptualization, H.L. and L.Y.; investigation, J.Z.; resources, J.Z.; writing—original draft preparation, J.Z.; writing—review and editing, J.Z., H.L. and L.Y.; visualization, J.Z.; supervision, H.L. and L.Y.; project administration, H.L. and L.Y.; funding acquisition, H.L. and L.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Natural Science Foundation of China, grant number 31870545 and Key Laboratory of Bio-based Material Science & Technology (Northeast Forestry University), Ministry of Education, grant number SWZ-MS201903. The APC was funded by SWZ-MS201903.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflict of interest.

References

- Liu, X.Y.; Lv, M.Q.; Liu, M.; Lv, J.F. Repeated humidity cycling's effect on physical properties of three kinds of wood based panels. *Bioresources* **2019**, *14*, 9444–9453. [[CrossRef](#)]
- Liu, X.Y.; Tu, X.W.; Liu, M. Effects of light thermal treatments on the color, hygroscopicity and dimensional stability of wood. *Wood Res.* **2021**, *66*, 95–104. [[CrossRef](#)]
- Zhou, L.; Fu, Y. Flame-retardant wood composites based on immobilizing with chitosan/sodium phytate/nano-TiO₂-ZnO coatings via layer-by-layer self-assembly. *Coatings* **2020**, *10*, 296. [[CrossRef](#)]
- Santos, A.; Carvalho, A.; Barbosa-Póvoa, A.P.; Marques, A.; Amorim, P. Assessment and optimization of sustainable forest wood supply chains—A systematic literature review. *For. Policy Econ.* **2019**, *105*, 112–135. [[CrossRef](#)]
- Zhao, Z.; Sakai, S.; Wu, D.; Chen, Z.; Zhu, N.; Huang, C.; Sun, S.; Zhang, M.; Umemura, K.; Yong, Q. Further exploration of sucrose–citric acid adhesive: Investigation of optimal hot-pressing conditions for plywood and curing behavior. *Polymers* **2019**, *11*, 1996. [[CrossRef](#)] [[PubMed](#)]
- Xiong, X.Q.; Ma, Q.R.; Yuan, Y.Y.; Wu, Z.H.; Zhang, M. Current situation and key manufacturing considerations of green furniture in China: A review. *J. Clean. Prod.* **2020**, *267*, 121957. [[CrossRef](#)]
- Lu, X.R.; Teng, Q.C.; Li, Z.R.; Zhang, X.L.; Wang, X.M.; Komatsu, K.H.; Que, Z.L. Study on shear property of spruce glulam and steel plate connected with inclined screw. *J. For. Eng.* **2020**, *5*, 48–53. [[CrossRef](#)]
- Huang, C.X.; He, J.; Liang, C.; Tang, S.; Yong, Q. Progress in applications of high value-added lignin materials. *J. For. Eng.* **2019**, *4*, 17–26. [[CrossRef](#)]
- Tchinda, J.B.S.; Ndikontar, M.K.; Belinga, A.D.F.; Mounguengui, S.; Njankouo, J.M.; Durmaçay, S.; Gerardin, P. Inhibition of fungi with wood extractives and natural durability of five Cameroonian wood species. *Ind. Crops Prod.* **2018**, *123*, 183–191. [[CrossRef](#)]
- Susilawati, D.; Kanowski, P. Cleaner production in the Indonesian pulp and paper sector: Improving sustainability and legality compliance in the value chain. *J. Clean. Prod.* **2020**, *248*, 119259. [[CrossRef](#)]
- Jebrane, M.; Sèbe, G. A novel simple route to wood acetylation by transesterification with vinyl acetate. *Holzforschung* **2007**, *61*, 143–147. [[CrossRef](#)]
- Bijaisoradat, O.; Yue, L.; Manas-Zloczower, I.; Manuapiya, H. Wood flour-high density polyethylene composites: Influence of silanization and esterification on mechanical properties. *J. Appl. Polym. Sci.* **2021**, *138*, e50197. [[CrossRef](#)]
- Nypelö, T.; Laine, C.; Aoki, M.; Tammelinn, T.; Henniges, U. Etherification of wood-Based hemicelluloses for interfacial activity. *Biomacromolecules* **2016**, *17*, 1894–1901. [[CrossRef](#)]
- Sun, B.; Wang, X.; Liu, J. Changes in dimensional stability and mechanical properties of Eucalyptus pellita by melamine–urea–formaldehyde resin impregnation and heat treatment. *Eur. J. Wood Prod.* **2013**, *71*, 557–562. [[CrossRef](#)]
- Deka, M.; Saikia, C.N. Chemical modification of wood with thermosetting resin: Effect on dimensional stability and strength property. *Bioresour. Technol.* **2000**, *73*, 179–181. [[CrossRef](#)]
- Dong, Y.; Zhang, W.; Hughes, M.; Wu, M.; Zhang, S.; Li, J. Various polymeric monomers derived from renewable rosin for the modification of fast-growing poplar wood. *Compos. Part B* **2019**, *174*, 106902. [[CrossRef](#)]
- Fawaz, M.; Lautenberger, C.; Bond, T.C. Prediction of organic aerosol precursor emission from the pyrolysis of thermally thick wood. *Fuel* **2020**, *269*, 117333. [[CrossRef](#)]

18. Chu, D.; Zhang, X.; Mu, J.; Avramidis, S.; Xue, L.; Li, Y. A greener approach to byproducts from the production of heat-treated poplar wood: Analysis of volatile organic compound emissions and antimicrobial activities of its condensate. *J. Clean. Prod.* **2019**, *213*, 521–527. [[CrossRef](#)]
19. Moreira, R.; Mendes, C.V.T.; Banaco, M.B.F.; Carvalho, M.G.V.S.; Portugal, A. New insights in the fractionation of *Pinus pinaster* wood: Sequential autohydrolysis, soda ethanol organosolv and acidic precipitation. *Ind. Crops Prod.* **2020**, *152*, 112499. [[CrossRef](#)]
20. Machmudah, S.; Wicaksono, D.T.; Happy, M.; Winardi, S.; Wahyudiono, K.H.; Goto, M. Water removal from wood biomass by liquefied dimethyl ether for enhancing heating value. *Energy Rep.* **2020**, *6*, 824–831. [[CrossRef](#)]
21. Borges, J.C.M.; Haddi, K.; Oliveira, E.E.; Andrade, B.S.; Nascimento, V.L.; Melo, T.S.; Didonet, J.; Carvalho, J.C.T.; Cangussu, A.S.; Soares, I.M.; et al. Mosquitocidal and repellent potential of formulations containing wood residue extracts of a Neotropical plant, *Tabebuia heptaphylla*. *Ind. Crops Prod.* **2019**, *129*, 424–433. [[CrossRef](#)]
22. Haq, M.; Chun, B.S. Characterization of phospholipids extracted from Atlantic salmon by-product using supercritical CO₂ with ethanol as co-solvent. *J. Clean. Prod.* **2018**, *178*, 186–195. [[CrossRef](#)]
23. Dawson, B.S.W.; Pearson, H. Effect of supercritical CO₂ dewatering followed by oven-drying of softwood and hardwood timbers. *Wood Sci. Technol.* **2017**, *51*, 771–784. [[CrossRef](#)]
24. Náthia-Neves, G.; Vardanega, R.; Urango, A.C.M.; Meireles, M.A.A. Supercritical CO₂ extraction of α -bisabolol from different parts of candeia wood (*Eremanthus erythropappus*). *J. Supercrit. Fluids* **2020**, *166*, 105026. [[CrossRef](#)]
25. Jaxel, J.; Amer, H.; Bacher, M.; Roller, A.; Guggenberger, M.; Zwirchmayr, N.S.; Hansmann, C.; Liebner, F. Facile synthesis of 1-butylamino- and 1,4-bis(butylamino)-2-alkyl-9,10-anthraquinone dyes for improved supercritical carbon dioxide dyeing. *Dye. Pigment.* **2020**, *173*, 107991. [[CrossRef](#)]
26. Todd, R.; Baroutian, S. A techno-economic comparison of subcritical water, supercritical CO₂ and organic solvent extraction of bioactives from grape marc. *J. Clean. Prod.* **2017**, *158*, 349–358. [[CrossRef](#)]
27. Ferrentino, G.; Morozova, K.; Mosibo, O.K.; Ramezani, M.; Scampicchio, M. Biorecovery of antioxidants from apple pomace by supercritical fluid extraction. *J. Clean. Prod.* **2018**, *186*, 253–261. [[CrossRef](#)]
28. Freire, A.L.; Moura-Nickel, C.D.; Scaratti, G.; De Rossi, A.; Araújo, M.H.; De Noni Júnior, A.; Rodrigues, A.E.; Castellón, E.R.; de Fátima Peralta Muniz Moreira, R. Geopolymers produced with fly ash and rice husk ash applied to CO₂ capture. *J. Clean. Prod.* **2020**, *273*, 122917. [[CrossRef](#)]
29. Belbute, J.M.; Pereira, A.M. Reference forecasts for CO₂ emissions from fossil-fuel combustion and cement production in Portugal. *Energy Policy* **2020**, *144*, 111642. [[CrossRef](#)] [[PubMed](#)]
30. Zhang, Q.; Li, Y.; Xu, J.; Jia, G. Carbon element flow analysis and CO₂ emission reduction in iron and steel works. *J. Clean. Prod.* **2018**, *172*, 709–723. [[CrossRef](#)]
31. Ehsan, M.M.; Guan, Z.; Klimenko, A.Y. A comprehensive review on heat transfer and pressure drop characteristics and correlations with supercritical CO₂ under heating and cooling applications. *Renew. Sustain. Energy Rev.* **2018**, *92*, 658–675. [[CrossRef](#)]
32. Cabeza, L.F.; de Gracia, A.; Fernández, A.I.; Farid, M.M. Supercritical CO₂ as heat transfer fluid: A review. *Appl. Therm. Eng.* **2017**, *125*, 799–810. [[CrossRef](#)]
33. Taberner, A.; Martín Del Valle, E.M.; Galán, M.A. Supercritical fluids for pharmaceutical particle engineering: Methods, basic fundamentals and modelling. *Chem. Eng. Process. Process Intensif.* **2012**, *60*, 9–25. [[CrossRef](#)]
34. Zhang, X.; Heinonen, S.; Levänen, E. Applications of supercritical carbon dioxide in materials processing and synthesis. *RSC Adv.* **2014**, *4*, 61137–61152. [[CrossRef](#)]
35. Taberner, A.; Cardea, S. Supercritical carbon dioxide techniques for processing microbial exopolysaccharides used in biomedical applications. *Mater. Sci. Eng. C* **2020**, *112*, 110940. [[CrossRef](#)]
36. Luo, X.; Ren, X.; Wang, S. Supercritical CO₂-water-shale Interactions under Supercritical CO₂ Stimulation Conditions. *Energy Procedia* **2018**, *144*, 182–185. [[CrossRef](#)]
37. Alexandre, A.M.R.C.; Serra, A.T.; Matias, A.A.; Duarte, C.M.M.; Bronze, M.R. Supercritical fluid extraction of *Arbutus unedo* distillate residues—Impact of process conditions on antiproliferative response of extracts. *J. CO₂ Util.* **2020**, *37*, 29–38. [[CrossRef](#)]
38. Pishnamazi, M.; Zabihi, S.; Jamshidian, S.; Hezaveh, H.Z.; Hezave, A.Z.; Shirazian, S. Measuring solubility of a chemotherapy-anti cancer drug (busulfan) in supercritical carbon dioxide. *J. Mol. Liq.* **2020**, *317*, 113954. [[CrossRef](#)]
39. Kanimozhi, B.; Mahalingam, S.; Pranesh, V.; Kesavakumar, R.; Senthil, S.; Ravikumar, S.; Pradeep, S.; Senthil, S.; Murugan, R. Colloidal release in high temperature porous media with oversaturated fines during supercritical CO₂ transport. *J. Pet. Sci. Eng.* **2020**, *192*, 107345. [[CrossRef](#)]
40. Sahena, F.; Zaidul, I.S.M.; Jinap, S.; Karim, A.A.; Abbas, K.A.; Norulaini, N.A.N.; Omar, A.K.M. Application of supercritical CO₂ in lipid extraction—A review. *J. Food Eng.* **2009**, *95*, 240–253. [[CrossRef](#)]
41. Smith, R.M. Supercritical fluids in separation science—The dreams, the reality and the future. *J. Chromatogr. A.* **1999**, *856*, 83–115. [[CrossRef](#)]
42. Machado, B.A.S.; Pereira, C.G.; Nunes, S.B.; Padilha, F.F.; Umsza-Guez, M.A. Supercritical fluid extraction using CO₂: Main applications and future perspectives. *Sep. Sci. Technol.* **2013**, *48*, 2741–2760. [[CrossRef](#)]
43. Saltanov, E.; Pioro, I.; Mann, D.; Gupta, S.; Mokry, S.; Harvel, G. Study on Specifics of Forced-Convective Heat Transfer in Supercritical Carbon Dioxide. *J. Nucl. Eng. Radiat. Sci.* **2015**, *1*, 11008. [[CrossRef](#)]
44. Cao, Y.; Zhang, X.R. Flow and heat transfer characteristics of supercritical CO₂ in a natural circulation loop. *Int. J. Therm. Sci.* **2012**, *58*, 52–60. [[CrossRef](#)]

45. Zhao, D.; Yin, J. Overview of supercritical fluid extraction and its application (In Chinese). *J. Anhui Agric. Sci.* **2014**, *42*, 4772–4780. [[CrossRef](#)]
46. Pinto, D.; de la Luz Cádiz-Gurrea, M.; Sut, S.; Ferreira, A.S.; Leyva-Jimenez, F.J.; Dall'Acqua, S.; Segura-Carretero, A.; Delerue-Matos, C.; Rodrigues, F. Valorisation of underexploited *Castanea sativa* shells bioactive compounds recovered by supercritical fluid extraction with CO₂: A response surface methodology approach. *J. CO₂ Util.* **2020**, *40*, 101194. [[CrossRef](#)]
47. Bermejo, D.V.; Ibáñez, E.; Reglero, G.; Fornari, T. Effect of cosolvents (ethyl lactate, ethyl acetate and ethanol) on the supercritical CO₂ extraction of caffeine from green tea. *J. Supercrit. Fluids* **2016**, *107*, 507–512. [[CrossRef](#)]
48. García-Pérez, J.S.; Cuéllar-Bermúdez, S.P.; de la Cruz-Quiroz, R.; Arévalo-Gallegos, A.; Esquivel-Hernandez, D.A.; Rodríguez-Rodríguez, J.; García-García, R.; Iqbal, H.M.N.; Parra-Saldivar, R. Supercritical CO₂-based tailor made valorization of *Origanum vulgare* L extracts: A green approach to extract high-value compounds with applied perspectives. *J. Environ. Manag.* **2019**, *232*, 796–802. [[CrossRef](#)] [[PubMed](#)]
49. Tao, X.; Wu, Y.; Xu, W.; Zhan, X.X.; Zhang, J.L. Preparation and characterization of heating floor impregnated by graphene/phenol-formaldehyde resin. *J. For. Eng.* **2019**, *4*, 167–173. [[CrossRef](#)]
50. Cao, J.Z. A review on wood protectant dispersion systems and their liquid penetration. *J. For. Eng.* **2019**, *4*, 1–9. [[CrossRef](#)]
51. Fernandes, J.; Kjellow, A.W.; Henriksen, O. Modeling and optimization of the supercritical wood impregnation process-Focus on pressure and temperature. *J. Supercrit. Fluids* **2012**, *66*, 307–314. [[CrossRef](#)]
52. Comin, L.M.; Temelli, F.; Saldaña, M.D.A. Barley β-glucan aerogels as a carrier for flax oil via supercritical CO₂. *J. Food Eng.* **2012**, *111*, 625–631. [[CrossRef](#)]
53. Goñi, M.L.; Gañán, N.A.; Strumia, M.C.; Martini, R.E. Eugenol-loaded LLDPE films with antioxidant activity by supercritical carbon dioxide impregnation. *J. Supercrit. Fluids* **2016**, *111*, 28–35. [[CrossRef](#)]
54. Siau, J.F. Permeability. In *Transport Processes in Wood*; Springer Series in Wood Science; Springer: Berlin/Heidelberg, Germany, 1984.
55. Demessie, E.S.; Hassan, A.; Levien, K.L.; Kumar, S.; Morrell, J.J. Supercritical CO₂ treatment: Effect on permeability of douglas-fir heartwood. *Wood Fiber Sci.* **1995**, *27*, 296–300.
56. Matsunaga, M.; Matsunaga, H.; Kataoka, Y.; Matsui, H. Improved water permeability of sugi heartwood by pretreatment with supercritical carbon dioxide. *J. Wood Sci.* **2005**, *51*, 195–197. [[CrossRef](#)]
57. Cookson, L.J.; Qader, A.; Creffield, J.W.; Scown, D.K. Treatment of timber with permethrin in supercritical carbon dioxide to control termites. *J. Supercrit. Fluids* **2009**, *49*, 203–208. [[CrossRef](#)]
58. Muin, M.; Tsunoda, K. Preservative treatment of wood-based composites with 3-iodo-2-propynyl butylcarbamate using supercritical carbon dioxide impregnation. *J. Wood Sci.* **2003**, *49*, 430–436. [[CrossRef](#)]
59. Kang, S.M.; Cho, M.W.; Kim, K.M.; Kang, D.; Koo, W.M.; Kim, K.H.; Park, J.Y.; Lee, S.S. Cyproconazole impregnation into wood using sub- and supercritical carbon dioxide. *Wood Sci. Technol.* **2012**, *46*, 643–656. [[CrossRef](#)]
60. Eastman, S.A.; Lesser, A.J.; McCarthy, T.J. Supercritical CO₂-assisted, silicone-modified wood for enhanced fire resistance. *J. Mater. Sci.* **2009**, *44*, 1275–1282. [[CrossRef](#)]
61. Jaxel, J.; Fontaine, L.; Krenke, T.; Hansmann, C.; Liebner, F. Bio-inspired conformational lipophilization of wood for scCO₂-assisted colouring with disperse dyes. *J. Supercrit. Fluids* **2019**, *147*, 116–125. [[CrossRef](#)]
62. Matsunaga, M.; Kataoka, Y.; Matsunaga, H.; Matsui, H. A novel method of acetylation of wood using supercritical carbon dioxide. *J. Wood Sci.* **2010**, *56*, 293–298. [[CrossRef](#)]
63. Duke, S.O.; Powles, S.B. Glyphosate: A once-in-a-century herbicide. *Pest. Manag. Sci.* **2008**, *63*, 1100–1106. [[CrossRef](#)]
64. Brocco, V.F.; Paes, J.B.; Da Costa, L.G.; Brazolin, S.; Arantes, M.D.C. Potential of teak heartwood extracts as a natural wood preservative. *J. Cleaner Prod.* **2017**, *142*, 2093–2099. [[CrossRef](#)]
65. Reinprecht, L. Chemical Protection of Wood. In *Wood Deterioration, Protection and Maintenance*, 1st ed.; Wiley & Sons, Ltd.: Chichester, UK, 2016; pp. 145–217. [[CrossRef](#)]
66. Pant, H.; Tripathi, S. Fungal decay resistance of wood fumigated with chlorpyrifos. *Int. Biodeterior. Biodegrad.* **2010**, *64*, 665–669. [[CrossRef](#)]
67. Lucas, S.; González, E.; Calvo, M.P.; Palencia, C.; Alonso, E.; Cocero, M.J. Supercritical CO₂ impregnation of Radiata pine with organic fungicides: Effect of operating conditions and two-parameters modeling. *J. Supercrit. Fluids* **2007**, *40*, 462–469. [[CrossRef](#)]
68. Muin, M.; Adachi, A.; Inoue, M.; Yoshimura, T.; Tsunoda, K. Feasibility of supercritical carbon dioxide as a carrier solvent for preservative treatment of wood-based composites. *J. Wood Sci.* **2003**, *49*, 65–72. [[CrossRef](#)]
69. Acda, M.N.; Morrell, J.J.; Levien, K.L. Supercritical fluid impregnation of selected wood species with tebuconazole. *Wood Sci. Technol.* **2001**, *35*, 127–136. [[CrossRef](#)]
70. Kang, S.M.; Ra, J.B.; Levien, K.L.; Morrell, J.J. Developing diffusion coefficients for SCF impregnation of Douglas Fir heartwood with cyproconazole. *J. Wood Chem. Technol.* **2006**, *26*, 111–124. [[CrossRef](#)]
71. Acda, M.N. Supercritical Fluid Impregnation of Wood-Based Composites. Ph.D. Thesis, Oregon State University, Corvallis, OR, USA, 1995.
72. Sun, S.; Zhao, Z.; Umemura, K. Further exploration of sucrose-citric acid adhesive: Synthesis and application on plywood. *Polymers* **2019**, *11*, 1875. [[CrossRef](#)]
73. Lu, J.; Jiang, P.; Chen, Z.; Li, L.; Huang, Y. Flame retardancy, thermal stability, and hygroscopicity of wood materials modified with melamine and amino trimethylene phosphonic acid. *Constr. Build. Mater.* **2021**, *267*, 121042. [[CrossRef](#)]

74. Wang, S.Y.; Yang, T.H.; Lin, L.T.; Lin, C.J.; Tsai, M.J. Fire-retardant-treated low-formaldehyde-emission particleboard made from recycled wood-waste. *Bioresour. Technol.* **2008**, *99*, 2072–2077. [CrossRef] [PubMed]
75. Tsiptsias, C.; Panayiotou, C. Thermal stability and hydrophobicity enhancement of wood through impregnation with aqueous solutions and supercritical carbon dioxide. *J. Mater. Sci.* **2011**, *46*, 5406–5411. [CrossRef]
76. Liu, Y.; Hu, J. Investigation of polystyrene-based microspheres from different copolymers and their structural color coatings on wood surface. *Coatings* **2021**, *11*, 14. [CrossRef]
77. Liu, Y. Self-assembly of poly (styrene-methyl methacrylate-acrylic acid) (P(St-MMA-AA)) colloidal microspheres on wood surface by thermal-assisted gravity deposition. *Wood Sci. Technol.* **2021**, *55*, 403–417. [CrossRef]
78. Jebrane, M.; Pichavant, F.; Sèbe, G. A comparative study on the acetylation of wood by reaction with vinyl acetate and acetic anhydride. *Carbohydr. Polym.* **2011**, *83*, 339–345. [CrossRef]
79. Matsunaga, M.; Hewage, D.C.; Kataoka, Y.; Ishikawa, A.; Kobayashi, M.; Kiguchi, M. Acetylation of wood using supercritical carbon dioxide. *J. Trop. For Sci.* **2016**, *28*, 132–138. Available online: <https://www.jstor.org/stable/43799216> (accessed on 25 April 2021).
80. Khouya, A. Performance assessment of a heat pump and a concentrated photovoltaic thermal system during the wood drying process. *Appl. Therm. Eng.* **2020**, *180*, 115923. [CrossRef]
81. Franich, R.A.; Gallagher, S.; Kroese, H. Dewatering green sapwood using carbon dioxide cycled between supercritical fluid and gas phase. *J. Supercrit. Fluids* **2014**, *89*, 113–118. [CrossRef]
82. Yang, L.; Liu, H. A review of Eucalyptus wood collapse and its control during drying. *BioResources* **2018**, *13*, 2171–2181. [CrossRef]
83. Dawson, B.S.W.; Pearson, H.; Kroese, H.W.; Sargent, R. Effect of specimen dimension and pre-heating temperature on supercritical CO₂ dewatering of radiata pine sapwood. *Holzforschung* **2015**, *69*, 421–430. [CrossRef]
84. Gabitov, R.F.; Khairutdinov, V.F.; Gumerov, F.M.; Gabitov, F.R.; Zaripov, Z.I.; Gaifullina, R.; Farakhov, M.I. Drying and impregnation of wood with propiconazole using supercritical carbon dioxide. *Russ. J. Phys. Chem. B* **2017**, *11*, 1223–1230. [CrossRef]
85. Dawson, B.S.W.; Pearson, H.; Kimberley, M.O.; Davy, B.; Dickson, A.R. Effect of supercritical CO₂ treatment and kiln drying on collapse in *Eucalyptus nitens* wood. *Eur. J. Wood Wood Prod.* **2020**, *78*, 209–217. [CrossRef]
86. Behr, V.C.; Hill, S.J.; Meder, R.; Sandquist, D.; Hindmarsh, J.P.; Franich, R.A.; Newman, R.H. Carbon-13 NMR chemical-shift imaging study of dewatering of green sapwood by cycling carbon dioxide between the supercritical fluid and gas phases. *J. Supercrit. Fluids* **2014**, *95*, 535–540. [CrossRef]
87. Meder, R.; Franich, R.A.; Callaghan, P.T.; Behr, V.C. A comparative study of dewatering of *Pinus radiata* sapwood using supercritical CO₂ and conventional forced air-drying via in situ magnetic resonance microimaging (MRI). *Holzforschung* **2015**, *69*, 1137–1142. [CrossRef]
88. Newman, R.H.; Franich, R.A.; Meder, R.; Hill, S.J.; Kroese, H.; Sandquist, D.; Hindmarsh, J.P.; Schmid, M.W.; Fuchs, J.; Behr, V.C. Proton magnetic resonance imaging used to investigate dewatering of green sapwood by cycling carbon dioxide between supercritical fluid and gas phase. *J. Supercrit. Fluids* **2016**, *111*, 36–42. [CrossRef]
89. Franich, R.A.; Meder, R.; Falge, M.; Fuchs, J.; Behr, V.C. Uncovering supercritical CO₂ wood dewatering via interleaved ¹H-imaging and ¹³C-spectroscopy with real-time reconstruction. *J. Supercrit. Fluids* **2019**, *144*, 56–62. [CrossRef]
90. Gollakota, A.R.K.; Kishore, N.; Gu, S. A review on hydrothermal liquefaction of biomass. *Renew. Sustain. Energy Rev.* **2018**, *81*, 1378–1392. [CrossRef]
91. Parvez, A.M.; Afzal, M.T.; Hebb, T.G.V.; Schmid, M. Utilization of CO₂ in thermochemical conversion of biomass for enhanced product properties: A review. *J. CO₂ Util.* **2020**, *40*, 101217. [CrossRef]
92. Kumar, A.; Jones, D.D.; Hanna, M.A. Thermochemical biomass gasification: A review of the current status of the technology. *Energies* **2009**, *2*, 556–581. [CrossRef]
93. Billaud, J.; Valin, S.; Peyrot, M.; Salvador, S. Influence of H₂O, CO₂ and O₂ addition on biomass gasification in entrained flow reactor conditions: Experiments and modelling. *Fuel* **2016**, *166*, 166–178. [CrossRef]
94. Dhyani, V.; Bhaskar, T. A comprehensive review on the pyrolysis of lignocellulosic biomass. *Renew. Energy* **2018**, *129*, 695–716. [CrossRef]
95. Cui, X.X.; He, L.H.; An, Z.; Zhang, M.H.; Han, W. The research of rheological properties of salix polyol liquefied products. *J. For. Eng.* **2020**, *5*, 90–96. [CrossRef]
96. Guizani, C.; Louisnard, O.; Sanz, F.J.E.; Salvador, S. Gasification of woody biomass under high heating rate conditions in pure CO₂: Experiments and modelling. *Biomass Bioenergy* **2015**, *83*, 169–182. [CrossRef]
97. Butterman, H.C.; Castaldi, M.J. CO₂ as a carbon neutral fuel source via enhanced biomass gasification. *Environ. Sci. Technol.* **2009**, *43*, 9030–9037. [CrossRef]
98. Pohořelý, M.; Jeremiáš, M.; Svoboda, K.; Kameníková, P.; Skoblia, S.; Beňo, Z. CO₂ as moderator for biomass gasification. *Fuel* **2014**, *117*, 198–205. [CrossRef]
99. Chaiwatanodom, P.; Vivanpatarakij, S.; Assabumrungrat, S. Thermodynamic analysis of biomass gasification with CO₂ recycle for synthesis gas production. *Appl. Energy* **2014**, *114*, 10–17. [CrossRef]
100. Wang, Q.; Li, K.; Guo, Z.; Fang, M.; Luo, Z.; Cen, K. Effects of CO₂ atmosphere on slow pyrolysis of high-ash lignite. *Carbon Resour. Convers.* **2018**, *1*, 94–103. [CrossRef]
101. Ding, N.; Azargohar, R.; Dalai, A.K.; Kozinski, J.A. Catalytic gasification of cellulose and pinewood to H₂ in supercritical water. *Fuel* **2014**, *118*, 416–425. [CrossRef]

102. Cengiz, N.Ü.; Eren, S.; Sağlam, M.; Yüksel, M.; Ballice, L. Influence of temperature and pressure on hydrogen and methane production in the hydrothermal gasification of wood residues. *J. Supercrit. Fluids* **2016**, *107*, 243–249. [[CrossRef](#)]
103. Knez, Ž.; Hrnčič, M.K.; Čolnik, M.; Škerget, M. Chemicals and value added compounds from biomass using sub- and supercritical water. *J. Supercrit. Fluids* **2017**, *133*, 591–602. [[CrossRef](#)]
104. Gökkaya, D.S.; Çokkuvvetli, T.; Sağlam, M.; Yüksel, M.; Ballice, L. Hydrothermal gasification of poplar wood chips with alkali, mineral, and metal impregnated activated carbon catalysts. *J. Supercrit. Fluids* **2019**, *152*, 104542. [[CrossRef](#)]
105. Chan, Y.H.; Quitain, A.T.; Yusup, S.; Uemura, Y.; Sasaki, M.; Kida, T. Optimization of hydrothermal liquefaction of palm kernel shell and consideration of supercritical carbon dioxide mediation effect. *J. Supercrit. Fluids* **2018**, *133*, 640–646. [[CrossRef](#)]
106. García-Serna, J.; García-Merino, E.; Cocero, M.J. Gasification of charcoal using supercritical CO₂ at high pressures. *J. Supercrit. Fluids* **2007**, *43*, 228–235. [[CrossRef](#)]
107. Baloch, H.A.; Nizamuddin, S.; Siddiqui, M.T.H.; Riaz, S.; Jatoi, A.S.; Dumbre, D.K.; Mubarak, N.M.; Srinivasan, M.P.; Griffin, G.J. Recent advances in production and upgrading of bio-oil from biomass: A critical overview. *J. Environ. Chem. Eng.* **2018**, *6*, 5101–5118. [[CrossRef](#)]
108. Peterson, A.A.; Vogel, F.; Lachance, R.P.; Fröling, M.; Jr Antal, M.J.; Tester, J.W. Thermochemical biofuel production in hydrothermal media: A review of sub- and supercritical water technologies. *Energy Environ. Sci.* **2008**, *1*, 32–65. [[CrossRef](#)]
109. Morais, A.R.C.; da Costa Lopes, A.M.; Bogel-Lukasik, R. Carbon dioxide in biomass processing: Contributions to the green biorefinery concept. *Chem. Rev.* **2015**, *115*, 3–27. [[CrossRef](#)]
110. Wang, Y.; Wang, H.; Lin, H.; Zheng, Y.; Zhao, J.; Pelletier, A.; Li, K. Effects of solvents and catalysts in liquefaction of pinewood sawdust for the production of bio-oils. *Biomass Bioenergy* **2013**, *59*, 158–167. [[CrossRef](#)]
111. De Caprariis, B.; Bavasso, I.; Bracciale, M.P.; Damizia, M.; De Filippis, P.; Scarsella, M. Enhanced bio-crude yield and quality by reductive hydrothermal liquefaction of oak wood biomass: Effect of iron addition. *J. Anal. Appl. Pyrolysis* **2019**, *139*, 123–130. [[CrossRef](#)]
112. Yu, J.; Biller, P.; Mamahkel, A.; Klemmer, M.; Becker, J.; Glasius, M.; Iversen, B.B. Catalytic hydrotreatment of bio-crude produced from the hydrothermal liquefaction of aspen wood: A catalyst screening and parameter optimization study. *Sustain. Energy Fuels* **2017**, *1*, 832–841. [[CrossRef](#)]
113. Jogi, R.; Mäki-Arvela, P.; Virtanen, P.; Kumar, N.; Hemming, J.; Russo, V.; Samikannu, A.; Lestander, T.A.; Mikkola, J.P. Understanding the formation of phenolic monomers during fractionation of birch wood under supercritical ethanol over iron based catalysts. *J. Energy Inst.* **2020**, *93*, 2055–2062. [[CrossRef](#)]
114. Huber, G.W.; Iborra, S.; Corma, A. Synthesis of Transportation Fuels from Biomass: Chemistry, Catalysts, and Engineering. *Chem. Rev.* **2006**, *106*, 4044–4098. [[CrossRef](#)]
115. Elliott, D.C. Historical Developments in Hydroprocessing Bio-oils. *Energy Fuels* **2007**, *21*, 1792–1815. [[CrossRef](#)]
116. Feng, Y.; Meier, D. Extraction of value-added chemicals from pyrolysis liquids with supercritical carbon dioxide. *J. Anal. Appl. Pyrolysis* **2015**, *113*, 174–185. [[CrossRef](#)]
117. Zhang, L.; Liu, R.; Yin, R.; Mei, Y. Upgrading of bio-oil from biomass fast pyrolysis in China: A review. *Renewable Sustainable Energy Rev.* **2013**, *24*, 66–72. [[CrossRef](#)]
118. Naik, S.; Goud, V.V.; Rout, P.R.; Dalai, A.K. Supercritical CO₂ fractionation of bio-oil produced from wheat-hemlock biomass. *Bioresour. Technol.* **2010**, *101*, 7605–7613. [[CrossRef](#)] [[PubMed](#)]
119. Feng, Y.; Meier, D. Supercritical carbon dioxide extraction of fast pyrolysis oil from softwood. *J. Supercrit. Fluids* **2017**, *128*, 6–17. [[CrossRef](#)]
120. Rout, P.K.; Naik, M.K.; Naik, S.N.; Goud, V.V.; Das, L.M.; Dalai, A.K. Supercritical CO₂ fractionation of bio-oil produced from mixed biomass of wheat and wood sawdust. *Energy Fuels* **2009**, *23*, 6181–6188. [[CrossRef](#)]
121. Danh, L.T.; Mammucari, R.; Truong, P.; Foster, N. Response surface method applied to supercritical carbon dioxide extraction of *Vetiveria zizanioides* essential oil. *Chem. Eng. J.* **2009**, *155*, 617–626. [[CrossRef](#)]
122. Dos Santos, N.O.; Mariane, B.; Lago, J.H.G.; Sartorelli, P.; Rosa, W.; Soares, M.G.; Da Silva, A.M.; Lorenzi, H.; Vallim, M.A.; Pascon, R.C. Assessing the chemical composition and antimicrobial activity of essential oils from Brazilian plants-*Eremanthus erythropappus* (Asteraceae), *Plectrantuns barbatus*, and *P. amboinicus* (Lamiaceae). *Molecules* **2015**, *20*, 8440–8452. [[CrossRef](#)]
123. Santos, K.A.; Klein, E.J.; Gazim, Z.C.; Gonçalves, J.E.; Cardozo-Filho, L.; Corazza, M.L.; da Silva, E.A. Wood and industrial residue of candeia (*Eremanthus erythropappus*): Supercritical CO₂ oil extraction, composition, antioxidant activity and mathematical modeling. *J. Supercrit. Fluids* **2016**, *114*, 1–8. [[CrossRef](#)]
124. Queiroz, A.; Cajaib, J. A sustainable process for (–)- α -bisabolol extraction from *Eremanthus erythropappus* using supercritical CO₂ and ethanol as co-solvent. *J. Supercrit. Fluids* **2016**, *110*, 39–46. [[CrossRef](#)]
125. De Souza, A.T.; Benazzi, T.L.; Grings, M.B.; Cabral, V.; Antônio da Silva, E.; Cardozo-Filho, L.; Ceva Antunes, O.A. Supercritical extraction process and phase equilibrium of Candeia (*Eremanthus erythropappus*) oil using supercritical carbon dioxide. *J. Supercrit. Fluids* **2008**, *47*, 182–187. [[CrossRef](#)]
126. Yesil-Celiktas, O.; Otto, F.; Gruener, S.; Parlar, H. Determination of extractability of pine bark using supercritical CO₂ extraction and different solvents: Optimization and prediction. *J. Agric. Food Chem.* **2009**, *57*, 341–347. [[CrossRef](#)] [[PubMed](#)]
127. Sarikaki, V.; Rallis, M.; Tanojo, H.; Panteri, I.; Dotsikas, Y.; Loukas, Y.L.; Papaioannou, G.; Demetzos, C.; Weber, S.; Moini, H.; et al. In Vitro Percutaneous Absorption of pine bark extract (Pycnogenol) in human skin. *J. Toxicol. Cutan Ocul. Toxicol.* **2005**, *23*, 149–158. [[CrossRef](#)]

128. Conde, E.; Hemming, J.; Smeds, A.; Reinoso, B.D.; Moure, A.; Willför, S.; Domínguez, H.; Parajó, J.C. Extraction of low-molar-mass phenolics and lipophilic compounds from *Pinus pinaster* wood with compressed CO₂. *J. Supercrit. Fluids* **2013**, *81*, 193–199. [[CrossRef](#)]
129. Braga, M.E.M.; Santos, R.M.S.; Seabra, I.J.; Facanali, R.; Marques, M.O.M.; De Sousa, H.C. Fractioned SFE of antioxidants from maritime pine bark. *J. Supercrit. Fluids* **2008**, *47*, 37–48. [[CrossRef](#)]
130. Ramezani, H.; Singh, H.P.; Batish, D.R.; Kohli, R.K. Antifungal activity of the volatile oil of *Eucalyptus citriodora*. *Fitoterapia* **2002**, *73*, 261–262. [[CrossRef](#)]
131. Zhao, S.; Zhang, D. Supercritical CO₂ extraction of *Eucalyptus* leaves oil and comparison with Soxhlet extraction and hydro-distillation methods. *Sep. Purif. Technol.* **2014**, *133*, 443–451. [[CrossRef](#)]
132. Zhou, L.J.; Huang, L.J.; Yang, Z.R.; Bai, L.H. Optimization of supercritical CO₂ extraction conditions for essential oil from *Eucalyptus grandis* × *Eucalyptus urophylla* using box-behnken design-response surface methodology (In Chinese). *J. Sichuan Univ. (Nat. Sci. Ed.)* **2014**, *51*, 1319–1324. [[CrossRef](#)]
133. Santos, S.A.O.; Villaverde, J.J.; Silva, C.M.; Neto, C.P.; Silvestre, A.J.D. Supercritical fluid extraction of phenolic compounds from *Eucalyptus globulus* Labill bark. *J. Supercrit. Fluids* **2012**, *71*, 71–79. [[CrossRef](#)]
134. Patinha, D.J.S.; Domingues, R.M.A.; Villaverde, J.J.; Silva, A.M.S.; Silva, C.M.; Freire, C.S.R.; Neto, C.P.; Silvestre, A.J.D. Lipophilic extractives from the bark of *Eucalyptus grandis* × *globulus*, a rich source of methyl morolate: Selective extraction with supercritical CO₂. *Ind. Crops Prod.* **2013**, *43*, 340–348. [[CrossRef](#)]
135. Eller, F.J.; Kirker, G.T.; Mankowski, M.E.; Hay, W.T.; Palmquist, D.E. Effect of burgundy solid extracted from Eastern Red Cedar heartwood on subterranean termites and Wood-decay fungi. *Ind. Crops Prod.* **2020**, *144*, 112023. [[CrossRef](#)]
136. Gaspar, M.C.; De Sousa, H.C.; Seabra, I.J.; Braga, M.E.M. Environmentally-safe scCO₂ *P. pinaster* branches extracts: Composition and properties. *J. CO2 Util.* **2020**, *37*, 74–84. [[CrossRef](#)]
137. Gwee, Y.L.; Yusup, S.; Tan, R.R.; Yiin, C.L. Techno-economic and life-cycle assessment of volatile oil extracted from *Aquilaria sinensis* using supercritical carbon dioxide. *J. CO2 Util.* **2020**, *38*, 158–167. [[CrossRef](#)]
138. Ramsey, E.; Sun, Q.; Zhang, Z.; Zhang, C.; Gou, W. Mini-Review: Green sustainable processes using supercritical fluid carbon dioxide. *J. Environ. Sci.* **2009**, *21*, 720–726. [[CrossRef](#)]
139. El-Fatah, S.A.; Goto, M.; Kodama, A.; Hirose, T. Supercritical fluid extraction of hazardous metals from CCA wood. *J. Supercrit. Fluids* **2004**, *28*, 21–27. [[CrossRef](#)]
140. Wang, J.S.; Chiu, K. Extraction of chromated copper arsenate from wood wastes using green solvent supercritical carbon dioxide. *J. Hazard. Mater.* **2008**, *158*, 384–391. [[CrossRef](#)] [[PubMed](#)]