Review

Not peer-reviewed version

Strategies for the Transformation of Waste Cooking Oils into High Value Products: A Critical Review

Valentina Beghetto *

Posted Date: 14 January 2025

doi: 10.20944/preprints202501.0911.v1

Keywords: waste cooking oil; recycling; polymer synthesis; circular economy

Review

Strategies for the Transformation of Waste Cooking Oils into High Value Products: A Critical Review

Valentina Beghetto [1,2,3]

[1] Department of Molecular Sciences and Nanosystems, University Ca' Foscari of Venice, Via Torino 155, 30172, Mestre, Italy; beghetto@unive.it; Tel.: 00390412348928

[2] Crossing S.r.l., Viale della Repubblica 193/b, 31100, Treviso, Italy, valentina.beghetto@crossing-srl.com

[3] Consorzio Interuniversitario per le Reattività Chimiche e La Catalisi (CIRCC), Via C. Ulpiani 27, 70126, Bari, Italy

Abstract: Waste Cooking Oils (WCOs) ARE produced in large quantities worldwide from hospitality, household and other industrial compartments. Today many Countries have no specific legislation regarding WCOs management, generating a crucial environmental problem. Presently WCOs are mainly employed by industry as feedstock for biodiesel and energy production. Nevertheless, the use of WCOs as a primary feedstock for second generation biodiesel production depends on its availability, and often import of biodiesel or WCOs from other countries is required. Additionally, the EU is pushing towards the privileged use of biowaste for alternative high value products, other than biodiesel, to reach carbon neutrality by 2050. Thus, the aim of this review is to give an overall comprehensive panorama of the production, impacts, regulations and restrictions affecting WCOs, and their possible uses to produce high value materials such as bio lubricants, bio surfactants, polymers and polymer additives, road and construction additives, bio solvents among others. Interestingly many reviews have been reported in the literature addressing the use of WCOs for the preparation of a specific class of polymer, but a general comprehensive review on the argument is missing.

Keywords: waste cooking oil; recycling; polymer synthesis; circular economy

---

1. Introduction

Demand and consumption of vegetable oils have significantly increased in the last 15 years, moving from 83 Miot in 2000, to over 217 Miot in 2023, of which 167 Miot were employed for biodiesel production, while the remaining part was used primarily by the food, feed, and pharma industry [1,2].

Globally, palm and soybean oils dominate the market with respectively 40.0% and 29.0% of the share, while other vegetable oils are produced in smaller quantities and include sunflower (9.7%), rape (6.3%), peanut (4.1%), corn (2.1%), coconut (1.9%), olives (1.8%) and sesame oil (1.1%) [2] (Figure 1a). Asia satisfies over 54.0% of worldwide vegetable oils demand, and in particular Indonesia is the world's greatest producer, followed by China, Malaysia, USA and Brazil (Figure 1b), [3–9]. Although biodiesel may be considered an attractive alternative for the partial substitution of fossil-based fuels, edible oils are an essential source of nutrition accounting for approximately 10.0% of the global average caloric food supply, second in importance only to cereals [10].

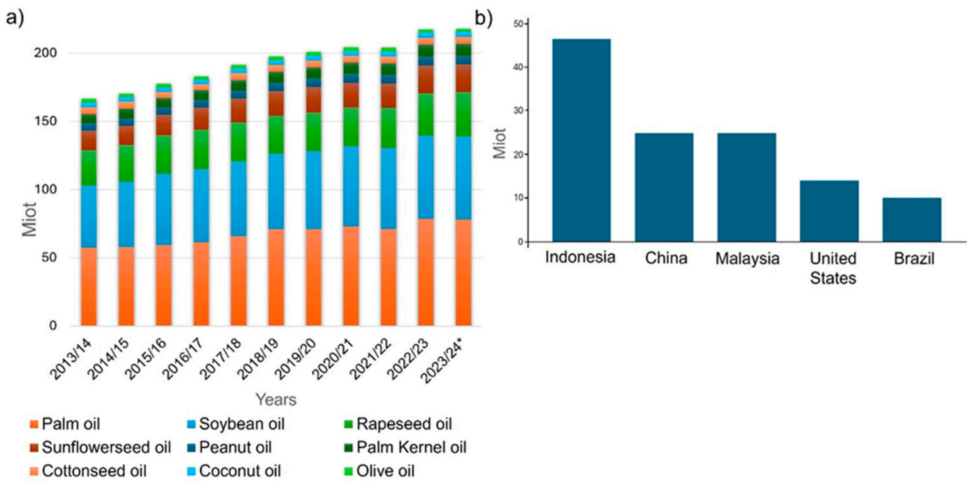


Figure 1. a) source of Vegetable oils and b) main geographical areas of production (Miot/year).

Additionally, it has been demonstrated that a correlation exists between the rise in biodiesel consumption in the USA and that of palm oil plantations in Southeast Asia, consequently increasing deforestation and global warming [11]. Thus, high production costs, threat for the food and feed value chain, together with socio-environmental impacts have made the use of edible oils as feedstock for biodiesel less appealing over time [12–14].

Alternative valuable feedstocks for biodiesel production are known as waste cooking oils (WCOs), fats, and grease together with more recent technologies starting from algae [1,15,16].

The term WCOs refers to exhausted cooking oils coming from hospitality and industrial sectors, no longer suitable for human consumption [13]. If disposed of in drains or sewers, WCOs form products that linger in the environment for many years, generating odors and problems in wastewater treatment plants, polluting soil and water courses, causing highly negative environmental impacts [17–19]. Additionally, WCOs may contain intermediate products formed by oxidation or microbial degradation which are toxic for microorganisms, algae, plankton, mussels, and amphipods [20,21], but also for humans causing serious illnesses such as dyspepsia, stomach-ache, diarrhea or gastric cancer [22]. The reuse and recycling of WCOs therefore opens new frontiers, reducing disposal costs and environmental impacts derived [23].

Presently WCOs are mainly employed at industrial level to produce biofuels and energy [24–35], yet in consideration of the EU requirements to reach carbon neutrality by 2050, the use of WCOs and in general of by-products and waste as fuels should be disfavored compared to their valorization for the production of high value chemicals [15,36,37]. In fact, the need to recover and recycle by-products or end of life products, reducing primary resource consumption and CO_2 emissions is becoming increasingly urgent, leading to a change from a linear economy based on a "take-make-discard" model, to a circular economy based on green chemistry and eco-design [38–41].

Alternative applications of WCOs include the production of bio lubricants [31,42–44], bio solvents [45], animal feed [46–49], asphalt additives [50,51], composite materials [52,53], polymers [54,55], fine chemicals production [56–58], non-aqueous gas sorbent devices [59,60], among others.

Within this panorama, the present review intends to give a general overview on the reuse of WCOs to produce high value products (polymeric materials), other than fuel and energy, published in the last ten years. Data available in the literature will be subdivided according to different application areas. Interestingly many reviews have been reported in the literature addressing specific topics on the use of WCOs for the preparation of a specific class of polymer, but a general comprehensive review of the argument is missing.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 January 2025 doi:10.20944/preprints202501.0911.v1

2. Methods

Systematic research of the existing literature was carried out thoroughly analyzing the current status of WCOs production, recycling techniques and valorization, EU directives and legislation on WCOs recovery and reuse, together with impacts derived. A combination of different keywords such as "waste cooking oil", "used cooking oil", "bio lubricant", "bio surfactant", "bio solvent", "polyurethane", "bio polymer", "non isocyanate polymer", "acrylic polymer", "alkyd ester", "epoxy resin", "asphalt/construction additive, rejuvenating, anti-aging", "circular economy", "EU directives". Specifically, one or a combination of two keywords were chosen for the selection of the papers and only those published in English language on peer reviewed journals were reported.

Research papers included in the review were collected through Web of Science Scopus, Google Scholar, ScienceDirect, ResearchGate, and were published between 2014 and 2024. In order to find the most updated data and regulations, we also searched websites of relevant organizations, such as European commission portal [61], and European Law portal [62], the European Commission press corner [63], the European Environment Agency (EEA) [64], the European Chemicals Agency (ECHA) [65], Statista [66] and Eurostat [67]. Once relevant sources were identified, references were reviewed for additional relevant information. This review focuses on WCOs reuse for the production of polymeric materials.

3. WCOs Production and Market

Although a large number of information are known on the production of vegetable oil worldwide (see Figure 1a, 1b), it is rather difficult to find accurate data quantifying the amounts of WCOs produced and available for valorization. Teixeira and co-workers reported that about 320 Kg of WCOs are produced for every ton of oil employed for cooking, with a valorization rate between 75% to 23%, according to the geographical area [18]. A rather worrying fact that emerges from the analysis by Teixeira is that out of 23 states evaluated, over 85% had no specific legislation regarding WCOs management. This data was also confirmed by a more recent paper by Zhao and coworkers indicating a general static trend over the last years in the adoption of more sustainable management strategies of WCOs, where the main alternative remains inadequate disposal in the environment [68].

In the USA, according to the Environmental Protection Agency, nearly 11.4 Miot of WCOs are collected from restaurants yearly, only small percentages of which are adequately managed [69], while production estimates are of about 15.0 Miot of WCOs [70]. Even the virtuous EU has a long way to go, considering that according to estimations, WCOs pro-capita production in the EU is of 8L/year, which considering a population of around 500 million people corresponds to a WCOs yearly production of 4.0 Miot. This value, which is four times higher than the currently collected amount, clearly evidences the gap between WCOs produced and collected [43]. Another possible estimation of WCOs yearly production in the EU can be done starting from EU yearly consumption of vegetable oils (24.0 Miot) and considering that according to Teixeira 32% is discarded, WCOs yearly production in EU could be even higher (around 7.7 Miot) [18]. This also accounts for the great difference between vegetable oils consumption (220.0 Miot), and WCOs collected worldwide (about 50.0 Miot) [69], distributed geographically as reported in Figure 2.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 January 2025 doi:10.20944/preprints202501.0911.v1

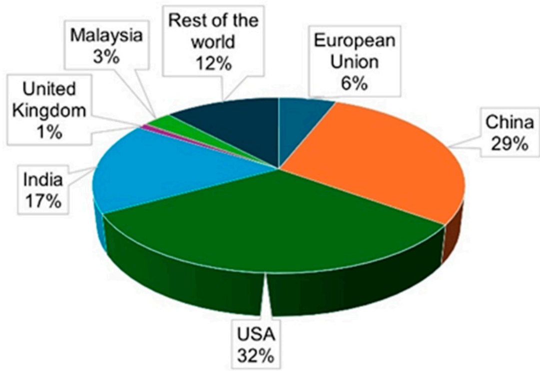


Figure 2. Geographical distribution of WCOs production worldwide.

Presently WCOs are mainly employed by the industry as feedstock for biodiesel and energy production [71–79]. In fact, it is well known that WCOs can be used to produce Fatty Acid Methyl Esters (FAME) through alkali catalyzed transesterification, and used as biodiesel [34,54,80,81]. Other processes for the valorization of WCOs are known such as cracking or hydrocracking, pyrolysis, and gasification processes for the production of biofuels [75]. Additionally, energy production by WCOs combustion has been reported in the literature, in different conditions, and with WCOs having different viscosity and acidity [82,83].

It should nevertheless be considered that although the use of WCOs can reverse the noncompetitive price of biodiesel from virgin biomass and reduce environmental negative impacts [84,85], however, the use of WCOs as a primary feedstock for second generation biodiesel production depends on its large-scale availability, and since local food waste is often insufficient, import of biodiesel or WCOs from other countries is required [86–88]. As evidenced by various LCA studies, import of WCOs is not a sustainable practice to guarantee energy supply, neither it contributes to reduce gas emissions [71,89]. In this concern, the EU renewable energy directive recently approved (Directive (EU) 2023/2413) states that "the share of biofuels and bioliquids, as well as of biomass fuels consumed in transport, where produced from food and feed crops, shall be no more than one percentage point higher than the share of such fuels in the final consumption of energy in the transport sector in 2020 in that Member State, with a maximum of 7 % of final consumption of energy in the transport sector in that Member State" [90]. Within this panorama alternative use of WCOs for high value products should be privileged in alternative to their use as biodiesel. Thus, in this review, no further discussion on the use of WCOs for biodiesel production is reported.

4. EU Regulations and Restrictions Affecting WCOs

As far as the EU is concerned, starting from the 1970s, with the waste oil directive 75/439/EEC, the European Commission committed to collecting used oils, limiting environmental hazards, and promoting recovery and recycling technologies [43,91].

During the last decade many regulatory updates have been implemented at EU level for the classification, storage, recovery or disposal of waste oils from hospitality, household and other industrial compartments. Amending Directive 2008/98/EC and European Commission (EC) Decision 2000/532/EC, EC Decision 2014/955/EU of 18 December 2014 [92] reports a harmonized list of wastes, continuously updated based on new knowledge and research studies. It should nevertheless be stressed that the inclusion of a material in this list does not necessarily imply that the material is a waste in all circumstances. Materials are considered to be waste only when the definition of waste in Article 1(a) of Directive 75/442/EEC is met [93].

Different wastes are defined by a six-digit code (Directive 2014/955/EU) [92] where the first two digits identify the manufacturing compartment generating the waste, the second two, processing operations, and the last ones a specific material. This implies that a waste may be identified by different EWC according to the manufacturing process which generates it, and vice versa specific

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 January 2025 doi:10.20944/preprints202501.0911.v1

production units may need to classify their wastes in several chapters. As regards WCOs, they are classified as 200125 where 20 corresponds to "municipal wastes (household waste and similar commercial, industrial and institutional wastes)", 01 to "separately collected fractions", 25 to "edible oil and fat". Edible oils are also found as mixtures with grease coming from wastewater treatment plants and are identified by EWC 190809, while if coming from agriculture, horticulture, aquaculture, forestry, hunting and fishing, food preparation and processing wastes the EWC is 0203.

Additionally, WCOs classified under EWC 200125 code are not hazardous for human health, but their inadequate disposal makes them potentially harmful for the environment. For this reason, Art. 1 of Directive 2008/98/EC laid down the "measures to protect the environment and human health by preventing or reducing the adverse impacts of waste mismanagement and improving the efficiency for reuse", requiring Member States to adopt waste management plans [94]. As in other occasions the need to promote the development of a unified EU policy program, preserving Member State sovereignty, to adopt different approaches to waste management, recycling and disposal, inevitably creates logistic barriers across borders [36].

Considering that in 2018 still many Member States had not yet developed the necessary waste management infrastructures, EU Directive 2018/851 was issued amending EU Directive 2008/98/EC to "prevent the creation of structural overcapacities for the treatment of residual waste" and "improve the efficiency of resource use and ensuring that waste is valued as a resource, can contribute to reducing the Union's dependence on the import of raw materials and facilitate the transition to more sustainable material management and to a circular economy model"(Directive (EU) 2018/851) [95]. This Directive among many others, sets out the EU legislative framework pushing towards the achievement of the EU Action Plan, the Sustainable development goals of the UN Agenda 2030 and achieving carbon neutrality by 2050. It is of fundamental importance for the development of new sustainable processes based on the circular economy model that a congruent and unified legislative framework should be adopted within the EU to allow development of new processes to transform waste in secondary primary materials, promoting neat-zero waste processes [31,43,45,96].

In this connection, the End of Waste directive EU 2008/98 is a fundamental milestone, determining necessary criteria to transform a waste into a valuable secondary primary material [94,97]. In particular, Directive 2008/98/EC defines "recovery" as "any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy" [97]. Additionally, "recycling" is defined as "any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes not including energy … fuels or for backfilling operations".

Specifically, requirements for "End of waste status" are that a waste shall cease to be waste if: (i) it has been demonstrated that "the substance is commonly used for specific purposes"; (ii) "a market or demand exists for such a substance or object"; (iii) "the substance fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products" and (iv) "the use of the substance will not lead to overall adverse environmental or human health impacts".

5. Environmental Impacts of WCOs

The environmental impacts derived from the inadequate disposal of WCOs are numerous and derive from accidental or deliberate release, causing environmental and biological alterations. WCOs highest environmental impact occurs when discharged into water bodies, or indirectly, if introduced into the sewer system [98–100]. WCOs are immiscible with water and generate a thin film, reducing oxygenation, limiting light filtration, affecting the life of aquatic plants and living beings. It is estimated that 1 kg of used vegetable oil can be evenly distributed to cover an area of 1000 m^2 [18]. Similarly, WCOs tend to form a hydrophobic film around the particles of earth and on the surface of plant roots creating a barrier to water and, consequently, precluding the intake of nutrients. Moreover, if WCOs penetrate the ground, they may reach wells of drinking water, making it

 doi:10.20944/preprints202501.0911.v1

unsuitable for human consumption [99]. For this reason, it is essential to take appropriate precautions to protect groundwater and wells, but also surface waters that may be in contact with the deeper water reservoirs. Moreover, like synthetic oils and fossil-based products, WCOs can cover the surfaces of living organisms (for example birds and aquatic animals) forming an insulating film, decreasing their ability to breath, exchange heat and in some cases move.

The great risks associated with improper disposal of these substances has led to the development of different regulation, establishment of Consortiums devoted to WCOs collection, even if to date they are mandatory only for industrial activities, while management of WCOs produced by citizens, defined as "urban waste", is in charge of municipalities.

6. WCOs Composition and Pre-Treatments

In general, WCOs are mainly composed of 95% triglycerides with aliphatic chains ranging from 16 to 18 carbon atoms [101], deriving from palm, soybean, canola, sunflower, peanut, cottonseed, coconut, olive, and corn oils [3] (Figure 1a).

WCOs are mostly produced from food frying at temperatures between 150 °C and 200 °C and cannot be reused for food processing [54,102,103]. In fact, during use, vegetable oils undergo three mail chemical reactions, i.e. hydrolysis, oxidation, and polymerization which alter their physical chemical characteristics [3,47,101] (Figure 3). Hydrolysis occurs due to the presence of moisture in food, forming glycerol, and Free Fatty Acids (FFA), leading to changes in color and forming smoke. Oxidation reactions occur as a natural reaction between double bonds present in vegetable oil and atmospheric oxygen, forming highly reactive hydroperoxides. Polymerization reactions may occur between unsaturated fatty acyl groups, forming dimeric or oligomeric triacyl glycerides [47,54]. Additionally, thermal cracking of unsaturated fatty acids, followed by oxidation at high temperatures may also promote polymerization reactions, originating a variety of toxic compounds such as heterocyclics [104].

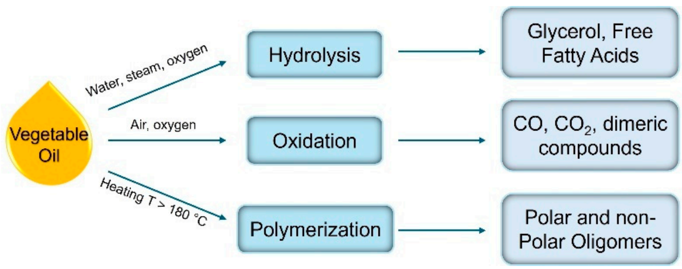


Figure 3. Chemical degradation reactions of vegetable oil.

Because of chemical degradation [25,27] of WCOs differ in color, viscosity, density, pH, flash point, number of unsaturated bonds, chemical composition, toxic components [13,58,105–107]. Data reported in the literature clearly highlight changes in pH (from 5.34 to 7.38), kinematic viscosity (from 28.744 mm2/s to 68.568 mm2/s) and molecular weight of WCOs generated by different vegetable oils or different cooking conditions (Table 1) [107,108] and for this reason many different pre-treatment methodologies have been reported in the literature for WCOs prior to recycling, such as filtration, extraction and distillation to eliminate water and impurities [26,109].

Additionally, WCOs recycling depends on its acidic, iodine value, number of conjugated diene or trienes making their recyclability more complex [54]. For example, it is evident that highly acidic WCOs will need to be neutralized if base-catalyzed transesterification has to be performed [27]. Further pre-treatments may be necessary to meet specific standards such as for example EN 14214 for biodiesel [110], while specific standards related to the volatile components present in WCOs must be met for polymers synthesis [27,54].

A very interesting work has been published by Mannu and co-workers reporting an extensive characterization of different WCOs subjected to several different frying cycles and purified with different methods (pH, Temperature) [45]. This complex study was carried out in order to increase

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 January 2025 doi:10.20944/preprints202501.0911.v1

the standardization of pre-treatment procedures and improve recyclability of different WCOs. In fact, according to the authors, the combination of data acquired allowed to determine the best recycling protocols for a given WCO [44,45].

Table 1. Chemical physical characteristics of vegetable oils and WCOs derived.

Component	Sunflower oil[(a)]	Sunflower oil WCO[(b)]	Rapeseed oil[(a)]	Rapeseed oil WCO[(a)]	Palm Oil[(a)]	Palm oil WCO[(a)]	Sun foil[(a)]	Sun foil WCO[(a)]
Saturated Fatty Acids	71.5	32.0				80.0-93.0	74.4	73-15
Monounsaturated Fatty Acids	-	62.0				20.0-7.0		27-6
Polyunsaturated Fatty Acids	28.5	6.0					25.6	0-79
Acidic value (mg KOH/g oil)	0.30	2.29	0.06	1.06		0.66-1.13		0.72-1.44
pH	7.38	5.34			6.34	5.73-6.19	8.63	6.14-6.61
Density at 20°C (kg/m^3)	919.21	920.40	918.00	929.00	919.48	923.2-913.4	919.6	919.8-923.2
Kinetic Viscosity at 40°C (mm^2/s)	28.744	31.381	63.286	68.568	27.962	44.254-38.407	28.224	43.521-35.236
Molecular weight (g/mol)	670.82	51.94	869.16	871.01	535.08	135.66-586.05	119.71	55.18-395.28

[a] Ref. 13. [b] Ref. 108.

Leaving aside its main use for biodiesel production, WCOs can be chemically modified and used as bio lubricants [47,111], bio surfactants [107,112], bio-based plasticizers [113–115], for the production of polymers and polymer additives [54,56,116,117], binders and additive for road and constructions [50,118–121], bio solvents [31]. All these applications will be further discussed in separate sections.

7. WCOs for Bio Lubricants and Bio Surfactants

7.1. Bio Lubricants

Bio lubricants (BL) are anti-friction agents with improved viscosity, higher thermal tolerance, lower volatility, compared with petroleum-based lubricants. BL world market was of 2 Mio$ in 2022 and is projected to reach a value of 2.8 Mio$ by 2031, registering a CAGR of 3.8% during the forecast period 2023-2031 [122]. WCOs are an efficient and environmentally sustainable feedstock for BL due to their high lubricity, biodegradability, low volatility and cost. Different modification routes have been reported for the conversion of WCOs into BL such as hydrolysis, esterification, transesterification, hydrogenation and epoxidation using both chemical and enzymatic catalyzed reactions [111,123–127] summarized in Figure 4.

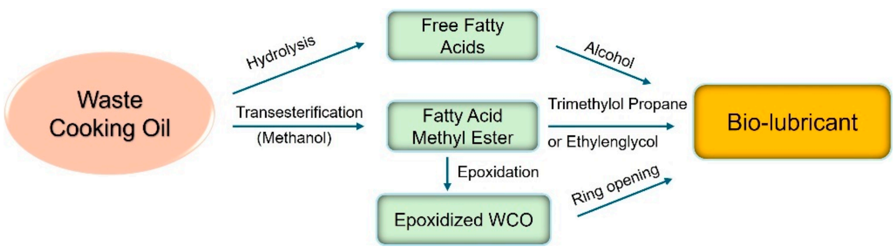


Figure 4. Main chemical reactions for the production of bio lubricants from WCO.

The different routes foresee hydrolysis of WCOs to FFAs followed by esterification with high molecular weight alcohols or polyols [128–130], or transesterification of WCOs to FAME followed by transesterification with high molecular weight alcohols such as trimethylol propane (TMP) [131–136], or other polyols [111,137]. Alternatively, FAME may be epoxidized with hydrogen peroxide and acetic acid [128,138,139], followed by epoxy ring opening by alcoholysis or hydrolysis in the presence of a catalyst [133;135,140,141].

From an industrial point of view transesterification is one of the most feasible routes for the conversion of WCOs into BL and consequently the most investigated [111,135,142–144]. Although in most cases high conversions are reported, nevertheless BL produced by transesterification reaction have low viscosity index and modest performances at low temperatures.

Zhang et al. improved the efficiency of the process [127] employing lipase and [HMIm][PF_6], a recyclable ionic liquid used as catalyst, giving a product with excellent lubricant properties, such as low pour point (-61 °C), high viscosity index (149) and high thermal-oxidation stability (312 °C). Sarno and coworkers adopted a similar transesterification process starting with WCOs and neopentyl glycol for the production of bio-lubricants [145]. A lipase immobilized on nanoparticles of modified magnetite was employed as catalyst showing high activity and recyclability up to ten times.

Alternatively, Jahromi and coworkers also explored the improved thermophysical and rheological properties of BL generated by epoxidation in the presence of cyclic oxygenated compounds (cyclopentanone, cyclopentanol, anisole, and 2-methylfuran) via a four-step pathway: hydrolysis, dehydration/ketonization, Friedel−Crafts acylation/alkylation, and hydrotreatment [140]. The process allowed to achieve BLs with low pour-point (-12 °C), kinematic viscosity of 47.5 cP (at 40 °C), viscosity index 186, and Noack volatility of 17 wt %, comparable to commercially available lubricants.

7.2. Bio Surfactants

Another interesting application of WCOs is for the production of bio-surfactants (BS), employed by the food, cosmetic, textile, health, pharmaceutical, mining and paper industry [100,112,146–152]. The market of BS has grown constantly during the last two decades and is expected to reach 4.8 Mio€ by 2025 [153].

BS are secondary metabolites generated by a variety of microorganisms such as fungi (yeasts) or bacteria (actinomycetes), that can either remain attached to the cell surface or be secreted outside the cell [154,155]. As for BL, also BS have several advantages over their synthetic equivalents since they can be produced from renewable feedstocks by fermentation, are environmentally compatible, and show better foaming properties in a wide range of conditions (pH, salinity, and temperature) [34,156].

BS have been classified either by their molecular weight (high and low molecular weight), ionic charges (anionic, cationic, non-ionic and neutral) and secretion type (intracellular, extracellular and adhered to microbial cells). However, their identification based on chemical structure remains the most widely adopted, divided in glycolipids, lipopeptides, fatty acids, phospholipids, neutral lipids and polymeric surfactants [149]. Glycolipids are low-molecular-weight amphiphiles that consist of a hydrophilic polysaccharide headgroup and one or more hydrophobic fatty acid tails [153,157], which may be produced from WCOs [158–160]. In fact, WCOs are an interesting feedstock for BS which may be converted by various yeast species in sophorolipids, rhamnolipids, mannosylerythritol lipids, and other glycolipids [107,158,159]. Several microbials such as Bacillus, Pseudomonas, Acinetobacter, and Candida have been extensively reported for biosurfactant production with different methodologies (metagenomics, metatranscriptomics, and metaproteomics) [158]. Nevertheless, to date BS are not widely employed, due to unsustainable production costs [100].

Chemical modification of WCOs for BS production could be a more economically sustainable alternative and therefore has been extensively studied. For example, Yusuff and coworkers recently reported the use of WCOs as a low-cost carbon source to produce anionic surfactant fatty acid methyl ester sulfonate via a transesterification-sulfonation process [161]. Furthermore, Permadani developed a bio-detergent from methyl ester sulfonated (MES) WCOs using titanium dioxide nanoparticles as catalyst [162]. In fact, several studies have been reported in the literature on the production of MES from WCOs [100,163] and are among the leading renewable surfactants and detergents at industrial scale, exhibiting superior detergency efficiency compared to fossil-based products, lower toxicity and

 doi:10.20944/preprints202501.0911.v1

better skin compatibility [105,162]. The production of MES from WCOs foresees preliminary purification, followed by transesterification to form the corresponding methyl esters which are then reacted with sodium bisulfite as sulfonating agent [105]. Various papers dealing with the environmental performance of BS using WCOs as feedstock clearly demonstrate that their use significantly reduces environmental impacts compared to the use of other feedstocks [158,159,164].

In the field of branched non-ionic surfactants, Dong and coworker synthesized a new series of bio-based branched non-ionic surfactants (ethoxylated dihydroxy stearic acid methyl ester, DMOE), from renewable oleic acid derived from WCOs [165]. Results show that DMOE, has low foaming, strong defoaming ability, good wetting performance and outstanding emulsifying capabilities enabling the application of these surfactants for industrial cleaning activities.

Another interesting study has been published by Khalaf and coworkers [166] on the preparation and use of cationic gemini surfactants prepared from WCOs, as green inhibitors against acidic corrosion of N80-steel. Gemini surfactants are highly demanded worldwide also for their promising applications in the paper, medical hygiene, and textile industry [167]. Additionally, cost-effective and efficient adsorbent macro-porous organic polymers based on WCOs were synthesized on Kgs scale by Wu and co-workers, allowing to remove oil and heavy metals from wastewater (≥94%), exhibiting excellent hydrophobic and super oleophilic properties [119].

8. WCOs for Polymer Additives

With the introduction of new regulations that are increasingly restrictive in the use of components classified as toxic, research is opening new horizons for the use of new bio based components as additives in the plastics industry [31,113]. The addition of plasticizers in polymers formulation plays a very important role in modifying the chemical and physical properties of plastic manufacts [31,168,169]. Plasticizers have been extensively used to produce flexible polyvinyl chloride (PVC) plastics, which otherwise are hard and brittle [170–172]. Phthalate esters, conventionally employed at industrial level for PVC production are known to exhibit a migration phenomenon from the polymer matrix to the surrounding media and to accumulate in the environment [113,168,172–174] and are subject to REACH restriction.

Due to their negative impact on human health and the environment, they have been banned in several countries for the production of toys and packaging materials [115,175,176]. In this context the syntheses of epoxidized soybean oil (ESO), methyl epoxy soyate, amyl epoxy soyate, acetylated derivatives of castor oil, tall-oil fatty esters, dicapryl sebacate have been described as alternative ecofriendly substitutes of phthalate esters, yet with limited applications due to high costs of starting materials used [173,177,178]. More sustainable alternatives have recently been reported employing WCOs as feedstock [114,115,176,179–182].

As reported by Liu et al. [180], acetylated-fatty acid methyl ester-malic acid ester (AC-FAME-MAE), obtained by modification of WCOs (Figure 5, route I), may be used as additive in PVC formulations giving a product with chemical and physical performances in line with the common industrial additive (phthalate), making it an excellent environmentally safe substitute to phthalate esters. Cai and co-workers also reported the synthesis of bio-plasticizers from WCOs according to the strategy reported in Figure 5, route II and III [179]. Two different highly epoxidized compounds (EGE-WCO and EP-WCO) were obtained and their characteristics as plasticizers for PVC tested. EGE-WCO with an epoxy value of 6.57% showed a high compatibility with PVC and plasticizing efficiency, decreasing Tg of PVC films from 62.8°C to 15.8°C and improving elongation at break. Migration phenomena of EGE-WCO were found to be negligible.

Additionally, Jia and co-workers proposed the synthesis of a covalently bonded plasticizer to the PVC backbone (WCOs methyl esters), avoiding possible migration phenomena which have also been reported with some WCOs based plasticizers [113].

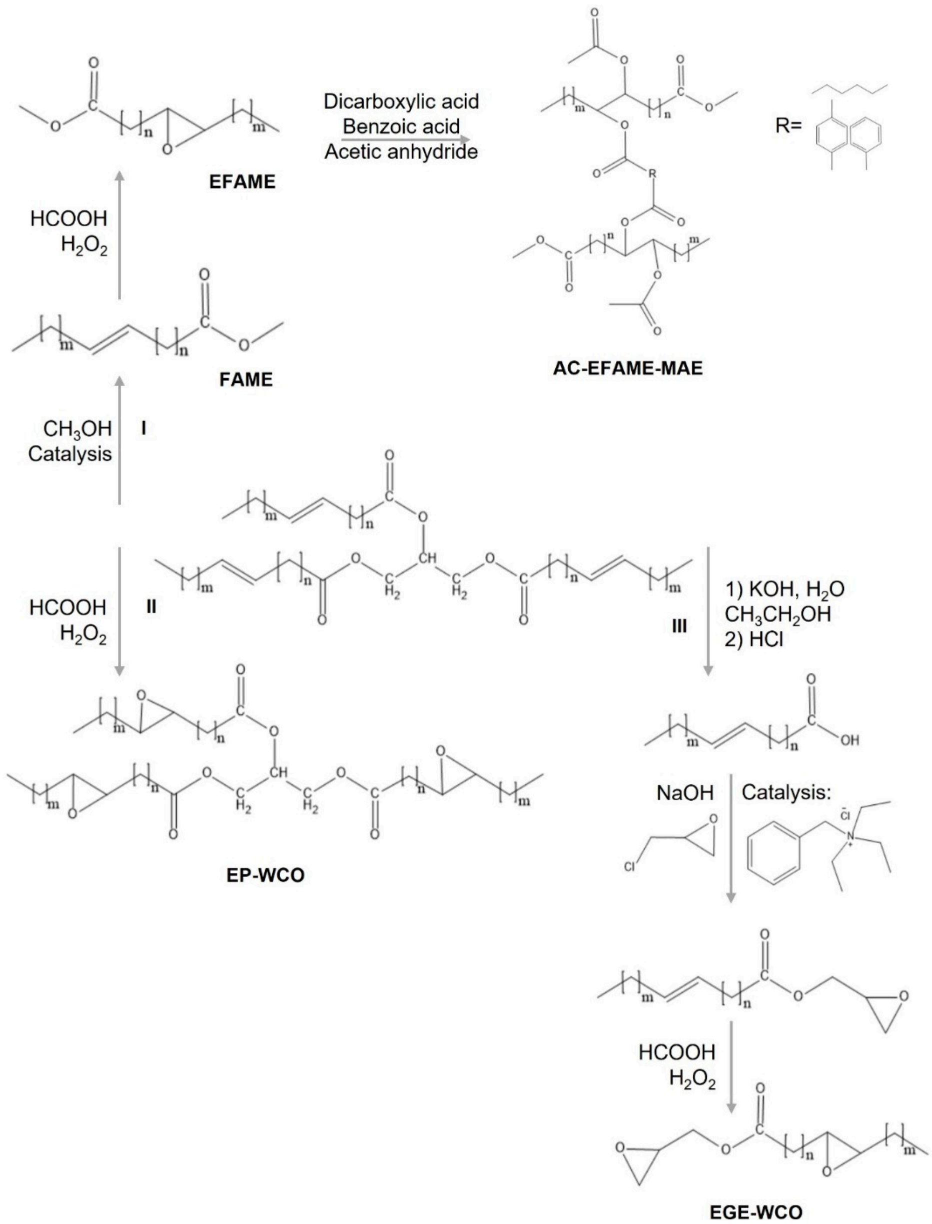


Figure 5. Examples of PVC additives prepared from WCOs.

9. WCOs for Polymer Synthesis

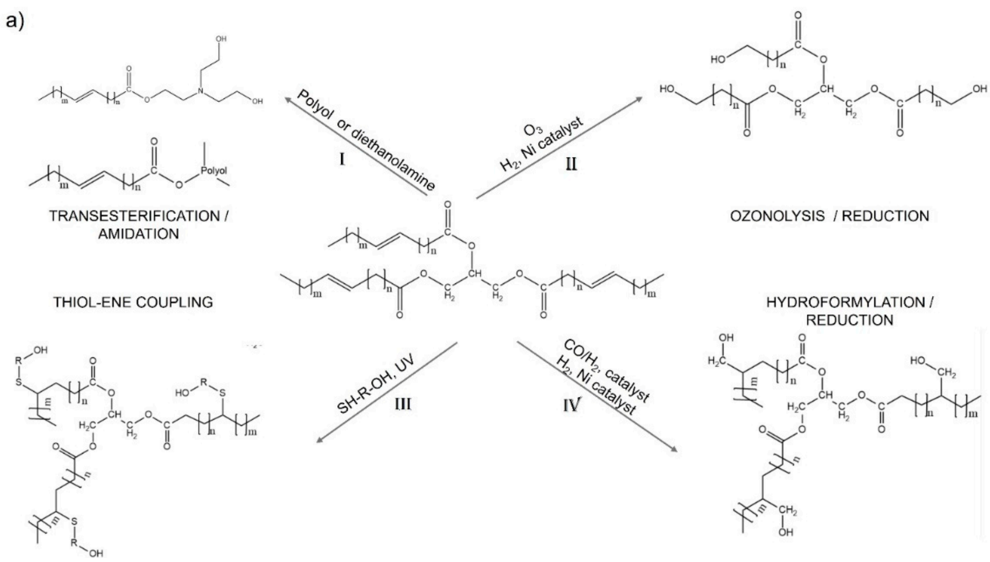
9.1. Polyurethane

Polyurethanes (PUs) are an important class of polymers with a global market of about 26 Miot in 2022, estimated to reach 31 Miot by 2030, positioning PUs as a major player in the polymer market [44,183]. In fact, due to the broad chemical and physical characteristics of these polymers, it is possible to produce flexible and rigid foams, or nonporous materials for different applications ranging from the automotive sector to the construction industry [184,185]. Currently, PUs are prepared from virgin naphtha, however, scientific research is pushing towards replacement with renewable raw materials. In this context, many efforts have been made to prepare bio-based polyols from WCOs and achieve more renewable and sustainable PUs [56,186–189].

Although many strategies have been used for the production of polyols from vegetable oils, as for example transesterification, epoxidation, ozonolysis, thiolene coupling reaction, hydroformylation, and photochemical oxidation (Figure 6) [184,190–193], polyols from WCOs are mainly produced by transesterification or epoxidation (Figure 6a, route I and Figure 6b) [183,188,194,195].

Polyols generated from the transesterification of WCOs are mixtures of triglycerides, monoglycerides and diglycerides together with glycerol (Figure 6a, route I). Since transesterification is an equilibrium reaction, to achieve high ester yields, an excess of alcohol, in most cases methanol, must be used to shift the equilibrium towards the products. A catalyst (alkali, acid or enzyme) is also added to improve the reaction rate, and esters yields [196–198].

Kuranska and coworkers reported the synthesis of polyols from WCOs in the presence of ethylene glycol, propylene glycol, diethylene glycol and triethanolamine (Figure 6a, route I), and their characterization by Gel Permeation Chromatography [195,199]. Taking into consideration the principles of Green Chemistry, the work by Kuranska and coworkers tried to maximize the incorporation of all reagents used in the final product, avoiding solvents and employing renewable reagents, so that bio polyols produced with optimized reaction conditions could be used for PUs synthesis without purification [199]. A different approach was reported by various researchers, who reported the modification of WCOs by epoxidation and ring-opening reactions, allowing to obtain rigid polyurethane foam with chemical and physical properties alike common polyurethane materials used in building and construction [194,200,201]. Particular attention has been given to the optimization of the catalysts employed for epoxidation and ring opening reactions and data reported demonstrate that Amberlite IR-120, an ion exchange resin, and tetrafluoro boric acid gave highest yields and selectivities [200,201]. Interestingly, it has also been verified that changing the additives used to prepare PUs containing WCOs polyols allowed to modulate physical-mechanical characteristics and biodegradability of PUs [201]. For example, combination of polyethylene glycol (PEG), 4,4’-diphenylmethane diisocyanate (MDI) and WCOs, allowed to achieve biodegradable PU sheets.



Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 January 2025 doi:10.20944/preprints202501.0911.v1

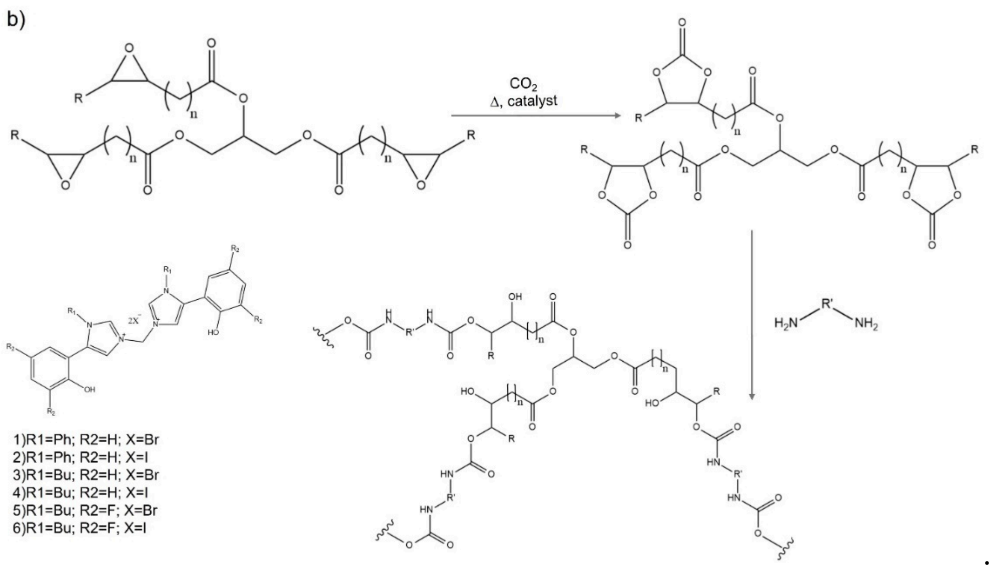


Figure 6. Different strategies for the synthesis of polyols from vegetable oils and WCOs.

PUs prepared with WCOs having adequate properties for solid polymer electrolytes production was reported by Salleh and co-workers [188] by pre-polymerization (epoxidation and hydrolysis), in the presence of lithium iodide as charge carrier and ethylene carbonate. Finally, MDI was added and films casted [188,202,203]. Few other works have been published on the production of composite materials containing PUs prepared from WCOs derived polyols. For instance, Lubis and coworkers [204] tested the preparation of reinforced sugar palm fibers for PU foams preparation from WCOs, polyols and toluene diisocyanate. According to the authors WCOs promote cross-linking and improve the interfacial adhesion between the fiber and the matrix. Additionally, WCOs have been employed as precursors for super-hydrophobic coating applications through a process of amidation of WCOs, followed by functionalization with diisocyanates and fatty acids [205] or with diisocyanates and amino-terminated polydimethylsiloxane [179].

Silva and coworkers recently reported a comparative life cycle analysis on fossil and bio based polyurethane foams evidencing different benefits and criticalities encountered by PU production [206]. A major concern remains on the use of toxic diisocyanates employed also for the production of PUs with bio-based polyols. Alternatively, non-isocyanate polyurethanes (NIPU) have been widely studied, yet their industrial application is still hampered by low physical-chemical properties of PUs obtained, together with unsustainable production costs. Nevertheless, NIPU constitutes the most promising frontier to produce environmentally sustainable PUs and should therefore be implemented.

Within this panorama the efficient synthesis of polyurethanes from WCOs and CO_2, in the presence of different organocatalysts are a promising alternative (Figure 6b) [207,208]. These interesting works not only promote the recovery and reuse of a waste (WCOs), but also imply the consumption of CO_2, thus helping to reduce greenhouse emissions, avoiding the use of fossil-based chemicals and toxic diisocyanates. Werlinger and coworkers reported the synthesis of bis-imidazole salts catalysts (Figure 6b) bearing two -OH groups for the synthesis of cyclic carbonates derived from WCOs, employed as starting materials for the synthesis of different NIPUs by polyaddition reaction of carbonated vegetable oils with a variety of diamines. Catalysts and cyclic carbonates prepared were characterized by NMR, whereas NIPUs were characterized by NMR, IR, GPC, and their thermal properties studied by TGA and DSC analysis.

9.2. Acrylic Polymers

A wide range of applications exist for the use of vegetable oil triglycerides to prepare acrylic polymers, and similar protocols have also been adopted starting from WCOs [54,209].

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 January 2025 doi:10.20944/preprints202501.0911.v1

For example, Wu and coworkers [210,211] reported that they successfully converted WCOs from McDonald restaurants into acrylic polymers via a straightforward one step reaction for additive 3D printing manufacturing. Filtered WCOs were reacted with acrylic acid in the presence of boron trifluoride etherate (BF3xEt2O) at 80 °C for 4 h. The product was characterized, showing that the double bonds of the triglyceride molecule brake as a consequence of the grafting of the acrylic groups. After purification to eliminate residual unreacted acrylic acid, the product could be 3D printed with or without the addition of a photo inhibitor. Interestingly, the polymers were found to be biodegradable, showing 18% weight loss after 14 days incubation in soil [212]. Further papers have also studied 4D Yan Liu, printing of multifunctional photocurable resin based on waste cooking oil [135].

Onn and coworkers recently reported the modification of WCOs through enzymatic acidolysis carried out to increase unsaturation sites and chemical reactivity of WCOs to produce an acrylic pre-polymer which was photo crosslinked in the presence of a photo initiator [209].

9.3. Alkyd Esters

Alkyd ester resins are prepared by condensation reaction between a polyol and polybasic acid and a fatty acid. Alkyd esters are used in paint, varnishes, and casting molds with a yearly world production of around 200,000 tons [213]. Fatty acids employed for alkyd resins formulation may derive from vegetable oils, animal fats or WCOs, improving their sustainability. A common strategy employed to produce alkyd resins from vegetable oils, known as the monoglyceride process, is reported in Figure 7 [54] and foresees a twostep strategy: i) base or acid catalyst alcoholysis of WCOs to generate monoglycerides and diglycerides; ii) polycondensation reaction of the monoglycerides with an anhydride (aromatic or aliphatic). According to the type and concentration of anhydride used, as well as the length of the oil the properties of alkyd ester resins can be changed.

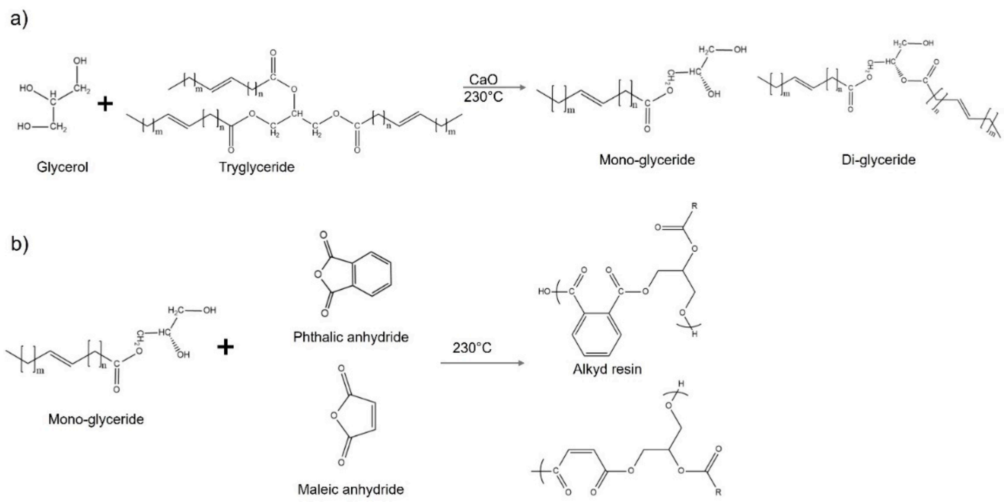


Figure 7. Monoglyceride process for the synthesis of alkyd resins.

Research carried out by Silvianti and coworkers [123] allowed to successfully synthesize alkyd ester resins from Waste Palm Cooking Oil using zeolites as water adsorbents in alternative to distillation and at the same time reducing the concentration of FFA content, contaminants, toxic products, bad odors and color. WCOs have also been employed to produce alkyd-based printing inks for vehicles by Phunphoem and co-workers (Phunphoem et al., 2020).

9.4. Epoxy Resins

Epoxy resins are thermosetting polymers made of monomers that have a three-membered epoxide ring. Epoxy resins are widely used for many applications thanks to their outstanding thermal and mechanical properties and worldwide consumption of epoxy thermo-set resins is expected to

 doi:10.20944/preprints202501.0911.v1

reach 17.0 Mio$ by 2028 [214]. The epoxy resin industry is presently based on diglycidyl ether of bisphenol A (DGEBA), produced by reaction between bisphenol A and epichlorohydrin. All these chemicals are listed as highly toxic for human health and DGEBA is identified as endocrine disruptor, teratogen and has long-term effects on aquatic life, and has therefore been banned from materials used in baby milk bottles [215]. Bio epoxy resins thus appear as a very important biobased, renewable, biodegradable and biocompatible alternative to petroleum-based epoxy resins and triglycerides coming from WCOs have been demonstrated to be applicable for the scope [216,217]. Epoxide resins are produced either by chain-growth ring-opening polymerization or step-growth polymerization [217]. Fernandes and co-workers are claimed to be the first to have used epoxy resins from WCOs in combination with recycled carbon fibres followed by casting to produce composites with interesting tensile strength (53 MPa), Young's Modulus (3.2 GPa) and reducing characteristic brittleness of DGEBA [218].

10. Waste Cooking Oil for Roads and Constructions

Increasing need of renewable resources as alternatives to fossil-based ones has pushed many researchers to study the use of WCOs also in the construction industry. In particular, due to its similar elemental composition to petroleum, WCOs have been widely employed for construction materials mainly for asphalt and concrete production as described below [134,211,219–227].

10.1. WCO for Asphalt Production

Many different works have been published in the last decade on the use of WCOs as additives for asphalt concrete and asphalt cement to improve various characteristics such as softening point, viscosity, complex modulus, creep stiffness, resistance to deformation, voids in mineral aggregate and elastic recovery [69,181,228–230]. On the other hand, in most cases WCOs additives adversely affect penetration, ductility, phase angle, stress relaxation, thermal cracking resistance and reduce overall stability of asphalt concrete [221,231,232].

Wang and coworkers investigated the use of WCOs as modifiers for fossil-based asphalt binders. Based on infrared spectroscopy, frequency sweep rheological analysis, multiple stress creep recovery test, and linear amplitude sweep tests, the authors verified that WCOs modified binders displayed higher carbonyl index, lower binder stiffness and softening effect and reduced rutting resistance at high temperatures [51]. Also fatigue life of bio binders under cyclic fatigue loading was significantly improved at increasing WCOs wt% by wt of bitumen, further confirming their potential applicability as sustainable asphalt binders [51].

Additionally, WCOs have been extensively studied for the recycling of Reclaimed Asphalt Pavement (RAP) and grinded tire rubber (GTR), that would otherwise be discarded [97,227,233].

The recycling of RAP generates economic savings, reducing the exploitation of non-renewable resources, energy consumption and polluting emissions in mining and transportation operations [234,235]. However, as bitumen ages, it loses its original properties causing distresses in pavement that may endanger traffic safety and reduce travel comfort. In fact, when quantities above 20 wt.% of RAP by wt. of bitumen are used, a gradual decrease of pavement's fatigue cracking, and low temperature cracking [236]. WCOs are an economically and environmentally sustainable alternative to fossil based rejuvenating agents allowing to solve these shortcomings [233]. Independently from the geographical origin of RAP and WCOs derivation, data reported in the literature generally agree that WCOs between 1-8% wt.% by weight of bitumen, positively affect penetration value [231,236–241]. This can be attributed to the alteration in the consistency of asphalt, contributing to improve fluidity and workability of the modified asphalt.

Pretreatment of WCOs is normally required to reduce acidity, due to variable quantities of FFAs present which negatively influences performances [50]. Common practices are esterification, transesterification in the presence of methanol or refining processes which promote the overall performance of WCOs modified bitumen [242–244]. An interesting study has recently been published by Bardella and coworkers on the possibility to achieve highly performing rejuvenating agents by chemical modification of WCOs or hydrolysed WCOs by transesterification (other than methanol) or amidation reactions to achieve various WCOs esters and amides. All samples were characterised by nuclear magnetic resonance, melting, and boiling point. Efficiency of WCOs esters was assessed by means of the Asphaltenes Dispersant Test and the Heithaus Parameter showing that bitumen blends containing 25 wt.% of WCOs by weight of bitumen, modified with 2-phenylethyl alcohol, performed better than bitumen alone [50].

Alternatively, in his recent work, Enfrin and coworkers studied the pre-treatment of WCOs by epoxidation reaction, which were used as rejuvenating agents for RAP [245]. This low-cost procedure allowed to produce rejuvenating agents with immediate cracking resistance comparable to commercially available fossil based rejuvenating agents, and higher long-term cracking resistance. The authors suppose that epoxide groups promote dispersion of the asphaltene clusters of bitumen, creating bridges between the molecules and preventing their agglomeration, slowing ageing phenomena.

Another interesting work has been reported on the rejuvenating and self-healing efficiency of WCOs capsules preparation by mixing WCOs and sodium alginate or chitosan powder which was then poured in a CaCl2 solution, and capsules produced with a micro peristaltic pump. In general, WCOs performances were superior to commercially available products and in particular fatigue healing performances of asphalt mixtures were improved by 10~30% [220].

From an environmental point of view, WCOs rejuvenating agents reduce greenhouse gas emissions and energy consumption. For instance, emissions of CO2 are reduced from 20.06 to 18.44 KgCO2e/t, switching from conventional bitumen to bio-bitumen and energy consumption respectively from 48.33 × 109 to 42.81 × 109 J for ton of material produced [127,246].

Elahi and coworkers very recently reported a study on the modification of WCOs with styrene-butadiene-styrene (SBS) from GTR to give a rubbery-solid used as bitumen additive. WCOs promote the swelling and cross-linking process of SBS, improving the adhesion between the modified WCOs and the bitumen [235]. A three-step process was used for the modification of WCOs foreseeing: i) filtration; ii) pre-swelling of SBS with various wt./wt.% of WCOs/SBS (45:55 and 50:50 wt./wt.%) at 160 °C; iii) modified WCOs mixtures were reduced in size and mixed with the bitumen (between 5 wt.% and 25 wt.% by weight of bitumen). Data reported show that increasing the content of SBS modified WCOs improve bitumen stiffening, temperature susceptibility, viscoelastic response and elasticity of the bitumen. Also, ethylene-vinyl acetate (EVA) has been used in combination with WCOs giving highly performing rejuvenating agents [53,246].

10.2. WCOs for Concrete

WCOs have also been studied for the production of sustainable cements. Li and co-workers developed a cement clinker and gypsum mixture containing different WCOs, and verified their physical mechanical characteristics, together with economic and environmental impacts [139]. Results show that, overall, WCOs favourably improved cement grinding and when highly unsaturated WCOs were employed also cement strength was improved. Additionally, WCOs improved microstructure density, hardening the cement paste. The authors concluded that the use of WCOs as grinding promoter in cement processing is economically and environmentally beneficial.

Recently Liu and co-workers studied the use of WCOs emulsions as shrinkage reducing admixture to improve concrete durability. Oil and water emulsions prepared were able to reduce cement shrinkage, enhance its dispersion and stability [247]. The addition of different contents of WCOs and water emulsions reduce the total porosity and refine the pore size by reducing significantly $Ca(OH)_2$ crystals, probably as a consequence of saponification reaction between WCOs and $Ca(OH)_2$.

 doi:10.20944/preprints202501.0911.v1

11. WCOs as Bio Solvents

Another interesting characteristic of WCOs is their ability to capture volatile organic compounds (VOC) [31,59], originated from different manufacturing procedures such as emissions from rice husk pyrolysis, rubber vulcanization [59,248].

Lhuissier and coworkers [59] developed a non-aqueous-phase absorption and degradation bioreactor for Volatile Organic Compounds (VOC). VOC targeted were n-heptane, ethyl acetate, isopropanol, methyl isobutyl ketone, toluene, m-xylene and 1,3,5-trimethylbenzene. Results allowed to conclude that WCOs have an absorption efficiency which is comparable to fossil-based oils.

Tarnpradab and co-workers employed WCOs to reduce emissions produced during rice husk pyrolysis [248], and also in this case WCOs were able to reduce the content of organic hydrocarbons formed. Other different examples exist of the use of WCOs for the adsorption of VOC produced by the leather industry [249] or other industrial contaminants such as mercury [60].

In addition, WCOs have been employed as solvents for the pretreatment of GTR to compensate for the insufficient storage stability of GTR modified asphalt [221,250]. GTR is one of the most common bitumen modifiers used to improve bitumen rheological properties. However, bitumen containing GTR generally has poor storage stability and workability, affecting the performance of the pavement [221,250]. Pretreatment of GTR with WCOs reduces polymer segregation phenomena, improving ageing resistance and reducing environmental impacts [251,252]. In addition, recent research also indicated that a rejuvenator with excellent storage stability and regeneration effects can be obtained when GTR is pyrolyzed in a WCOs rich phase [253].

12. Other Applications

Although different studies have recently reported the use of edible [254,255] and non-edible waste oils [256,257], as organic phase change materials, few literature data are available on the use of WCOs for the scope and applied to food preservation, asphalt or building thermoregulation [258–262].

Different works have been reported on the use of filtered WCOs for thermal energy storage analogously to other virgin or waste oils [257,259]. LCA data were reported showing that WCOs allowed to reduce significantly energy consumption.

Alternatively, phase change capsules (PCC) were prepared by mixing WCOs in the presence of sodium alginate and Tween80, an emulsifying agent, and microcapsules prepared by microfluidic technology [258]. PCC were employed for the preparation of foamed concrete having mechanical properties within standard requirements (strength >4.80 MPa), with interesting thermal insulation properties.

13. Conclusions

According to the literature it evidently emerges that WCOs are a valuable food waste that can be used as feedstock to produce a variety of different bio based polymeric materials. Although WCOs are renewable starting materials for a sustainable biorefinery, nonetheless they struggle to find industrial applications. Complexity and variability of WCOs composition together with an inadequate collecting system are among the main barriers for the introduction of WCOs as feedstock at industrial level. Competing use of WCOs for biofuel market is also a drawback, reducing its availability.

To overcome these problems different legislative strategies should be adopted in order to harmonize throughout EU the collecting system and promoting an awareness campaign among consumers on the importance of WCOs separate collection.

From a technological point of view many different strategies and applications exist for the production of high value polymeric products from WCOs although only few of them have been implemented at industrial level today. This evidently testifies that further efforts need to be done both by the scientific community and the industry to reduce the complexity of processes necessary to transform WCOs in polymeric materials and is strictly connected also to the capacities of WCOs collecting systems and management.

Once WCOs will be collected, managed and used properly, they will surely become a valuable feedstock for the polymer industry satisfying most of the Sustainable development goals of the agenda 2030 and of the Principles of Green Chemistry.

Author Contributions: Valentina Beghetto: Conceptualization, Investigation, Data curation, Formal analysis, Writing – original draft, Writing - review & editing, Fund raising.

Funding: This research was funded by This research was carried out within the "Interconnected Nord-Est Innovation Ecosystem (iNEST)" project and received funding from the European Union Next-Generation EU—National Recovery and Resilience Plan (NRRP)—MISSION 4 COMPONENT 2, INVESTIMENT N. ECS00000043—CUP N. H43C22000540006. This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

Data Availability Statement: Further material is available on request.

Acknowledgments: The author would like to thank PhD. Dr. Gloria Saorin for her support for the graphical editing and reviewing activities.

Conflicts of Interest: The author declares no conflicts of interest.

References

1. Ferrusca, M.C.; Romero, R.; Martínez, S.L.; Ramírez-Serrano, A.; Natividad, R. Biodiesel Production from Waste Cooking Oil: A Perspective on Catalytic Processes. *Processes* **2023**, *11*, 1952. https://doi.org/10.3390/pr11071952
2. Statista, 2024a. Global production of vegetable oils from 2000/01 to 2023/24. https://www.statista.com/statistics/263978/global-vegetable-oil-production-since-2000-200.
3. Azahar, W.N.A.W.; Bujang, M.; Jaya, R.P.; Hainin, M.R.; Mohamed, A.; Ngad, N.; Jayanti, D.S. The potential of waste cooking oil as bio-asphalt for alternative binder - an overview. *J. Teknol.* **2016**, *78*, 3722. https://doi.org/10.11113/jt.v78.8007
4. Iowa Farm Bureau, 2022. What's Cooking with Vegetable Oils. https://www.iowafarmbureau.com/Article/Whats-Cooking-with-Vegetable-Oils.
5. 5. Markets and Markets, 2023. Biofuel market. https://www.marketsandmarkets.com/Market-Reports/biofuels-market-297.html?gad_source=1&gclid=Cj0KCQjwwMqvBhCtARIsAIXsZpYveQ0-50boErhnWFXCgq_Z0oq8tQpxCUuu7vgZ44hackufMVylwJEaAmf-EALw_wcB
6. NationMaster, 2023. Vegetable Oils Production.
7. Oils and fats international, 2021. Global vegetable oil production in 2021/22 crop year set to reach record high. https://www.ofimagazine.com/news/global-vegetable-oil-production-in-2021-22-crop-year-set-to-reach-record-high.
8. Statista, 2024b. Forecast volume of vegetable oil consumed in the European Union (EU 27) from 2018 to 2032. https://www.statista.com/statistics/614522/vegetable-oil-consumption-volume-european-union-28/.
9. Statista, 2024c. Consumption of vegetable oils worldwide from 2013/14 to 2023/2024, by oil type. https://www.statista.com/statistics/263937/vegetable-oils-global-consumption/.
10. Isaksson, B. Demand for edible oils increases as biofuel industry grows. Biofuels International **2023**. https://biofuels-news.com/news/demand-for-edible-oils-increases-as-biofuel-industry-grows/ (accessed 7.10.24).
11. Waters, K., Altiparmak, S.O., Shutters, S.T., Thies, C. The Green Mirage: The EU's Complex Relationship with Palm Oil Biodiesel in the Context of Environmental Narratives and Global Trade Dynamics. *Energies* **2024**, *17*, 343. https://doi.org/10.3390/en17020343
12. Awogbemi, O., Inambao, F., Onuh, E.I., 2018. A review of the performance and emissions of compression ignition engine fuelled with waste cooking oil methyl ester, in: 2018 International Conference on the Domestic Use of Energy (DUE). IEEE, pp. 1–9. https://doi.org/10.23919/DUE.2018.8384399

13. Awogbemi, O.; Onuh, E.I.; Inambao, F.L. Comparative study of properties and fatty acid composition of some neat vegetable oils and waste cooking oils. *International Journal of Low-Carbon Technologies* **2019**, *14*, 417–425. https://doi.org/10.1093/ijlct/ctz038
14. Saba, T., Estephane, J., El Khoury, B., El Khoury, M., Khazma, M., El Zakhem, H., Aouad, S., 2016. Biodiesel production from refined sunflower vegetable oil over KOH/ZSM5 catalysts. *Renew. Energy* **2016**, *90*, 301–306. https://doi.org/10.1016/j.renene.2016.01.009
15. Foo, W.H., Chia, W.Y., Tang, D.Y.Y., Koay, S.S.N., Lim, S.S., Chew, K.W. The conundrum of waste cooking oil: Transforming hazard into energy. *J. Hazard Mater.* **2021**, *417*, 126129. https://doi.org/10.1016/j.jhazmat.2021.126129
16. Lombardi, L., Mendecka, B., Carnevale, E. Comparative life cycle assessment of alternative strategies for energy recovery from used cooking oil. *J. Environ. Manage* **2018**, *216*, 235–245. https://doi.org/10.1016/j.jenvman.2017.05.016
17. Aniołowska, M., Zahran, H., Kita, A. The effect of pan frying on thermooxidative stability of refined rapeseed oil and professional blend. *J. Food Sci. Technol.* **2016**, *53*, 712–720. https://doi.org/10.1007/s13197-015-2020-z
18. Teixeira, M.R., Nogueira, R., Nunes, L.M. Quantitative assessment of the valorisation of used cooking oils in 23 countries. *Waste Management* **2018**, *78*, 611–620. https://doi.org/10.1016/j.wasman.2018.06.039
19. Olu-Arotiowa, O.A., Odesanmi, A.A, Adedotun, B.K., Ajibade, O.A., Olasesan, I.P., Odofin, O.L., Abass, A. O. Review on environmental impact and valourization of waste cooking oil. LAUTECH *Journal of Engineering and Technology* **2022**, *16*, 144–163. https://www.researchgate.net/publication/366618878
20. Fingas, M. Vegetable Oil Spills, in: Handbook of Oil Spill Science and Technology. Wiley, **2014**, pp. 79–91. https://doi.org/10.1002/9781118989982.ch4
21. Zahri, K.N.M., Zulkharnain, A., Sabri, S., Gomez-Fuentes, C., Ahmad, S.A. Research Trends of Biodegradation of Cooking Oil in Antarctica from 2001 to 2021: A Bibliometric Analysis Based on the Scopus Database. *Int. J. Environ. Res. Public Health* **2021**, *18*, 2050. https://doi.org/10.3390/ijerph18042050
22. Foo, W.H., Koay, S.S.N., Chia, S.R., Chia, W.Y., Tang, D.Y.Y., Nomanbhay, S., Chew, K.W. Recent advances in the conversion of waste cooking oil into value-added products: A review. *Fuel* **2022**, 324. https://doi.org/10.1016/j.fuel.2022.124539
23. Cárdenas, J., Orjuela, A., Sánchez, D.L., Narváez, P.C., Katryniok, B., Clark, J. Pre-treatment of used cooking oils for the production of green chemicals: A review. *J. Clean. Prod.* **2021**, *289*, 1215129. https://doi.org/10.1016/j.jclepro.2020.125129
24. Capuano, D., Costa, M., Di Fraia, S., Massarotti, N., Vanoli, L. Direct use of waste vegetable oil in internal combustion engines. *Renewable and Sustainable Energy Reviews* **2017**. https://doi.org/10.1016/j.rser.2016.11.016
25. Carmona-Cabello, M., Garcia, I.L., Leiva-Candia, D., Dorado, M.P. Valorization of food waste based on its composition through the concept of biorefinery. *Curr. Opin. Green Sustain. Chem.* **2018**, *14*, 67–79. https://doi.org/10.1016/j.cogsc.2018.06.011
26. Carmona-Cabello, M., García, I.L., Sáez-Bastante, J., Pinzi, S., Koutinas, A.A., Dorado, M.P. Food waste from restaurant sector – Characterization for biorefinery approach. *Bioresour. Technol.* **2020**, *301*, 122779. https://doi.org/10.1016/j.biortech.2020.122779
27. Carmona-Cabello, M., Leiva-Candia, D., Castro-Cantarero, J.L., Pinzi, S., Dorado, M.P. Valorization of food waste from restaurants by transesterification of the lipid fraction. *Fuel* **2018**, *215*, 492–498. https://doi.org/10.1016/j.fuel.2017.11.096
28. Chrysikou, L.P., Dagonikou, V., Dimitriadis, A., Bezergianni, S. Waste cooking oils exploitation targeting EU 2020 diesel fuel production: Environmental and economic benefits. *J. Clean. Prod.* **2019**, *219*, 566–575. https://doi.org/10.1016/j.jclepro.2019.01.211
29. D'Alessandro, B., Bidini, G., Zampilli, M., Laranci, P., Bartocci, P., Fantozzi, F. Straight and waste vegetable oil in engines: Review and experimental measurement of emissions, fuel consumption and injector fouling on a turbocharged commercial engine. *Fuel* **2016**, *182*, 198–209. https://doi.org/10.1016/j.fuel.2016.05.075

30. Hasan, M.R., Anzar, N., Sharma, P., Malode, S.J., Shetti, N.P., Narang, J., Kakarla, R.R. Converting biowaste into sustainable bioenergy through various processes. *Bioresour. Technol. Rep.* **2023**. https://doi.org/10.1016/j.biteb.2023.101542
31. Mannu, A., Ferro, M., Di Pietro, M.E., Mele, A. Innovative applications of waste cooking oil as raw material. *Sci. Prog.* **2019**, *102*, 153–160. https://doi.org/10.1177/0036850419854252
32. Namoco, C.S., Comaling, V.C., Buna, C.C. Utilization of used cooking oil as an alternative cooking fuel resource. *ARPN J. Eng. Appl. Sci.* **2017**, *12*, 435–442.
33. Ostadkalayeh, Z.H., Babaeipour, V., Pakdehi, S.G., Sazandehchi, P. Optimization of Biodiesel Production Process from Household Waste Oil, Rapeseed, and Microalgae Oils as a Suitable Alternative for Jet Fuel. *Bioenergy Res.* **2023**, *16*, 1733–1745. https://doi.org/10.1007/s12155-022-10510-5
34. Sahar, Sadaf, S., Iqbal, J., Ullah, I., Bhatti, H.N., Nouren, S., Habib-ur-Rehman, Nisar, J., Iqbal, M. Biodiesel production from waste cooking oil: An efficient technique to convert waste into biodiesel. *Sustain. Cities Soc.* **2018**, *41*, 220–226. https://doi.org/10.1016/j.scs.2018.05.037
35. Sudalai, S., Prabakaran, S., Varalakksmi, V., Sai Kireeti, I., Upasana, B., Yuvasri, A., Arumugam, A. A review on oilcake biomass waste into biofuels: Current conversion techniques, sustainable applications, and challenges: Waste to energy approach (WtE). *Energy Convers. Manag.* **2024**, *314*, 118724. https://doi.org/10.1016/j.enconman.2024.118724
36. Beghetto, V., Gatto, V., Samiolo, R., Scolaro, C., Brahimi, S., Facchin, M., Visco, A. Plastics today: Key challenges and EU strategies towards carbon neutrality: A review. *Environ. Pollut.* **2023**, *334*, 122102. https://doi.org/10.1016/j.envpol.2023.122102
37. Visco, A., Scolaro, C., Facchin, M., Brahimi, S., Belhamdi, H., Gatto, V., Beghetto, V. Agri-Food Wastes for Bioplastics: European Prospective on Possible Applications in Their Second Life for a Circular Economy. *Polymers* **2022**, *14*, 2752. https://doi.org/10.3390/polym14132752
38. Facchin, M., Gatto, V., Samiolo, R., Conca, S., Santandrea, D., Beghetto, V. May 1,3,5-Triazine derivatives be the future of leather tanning? A critical review. *Environ. Pollut.* **2024**, *345*, 123472. https://doi.org/10.1016/j.envpol.2024.123472
39. Sole, R., Gatto, V., Conca, S., Bardella, N., Morandini, A., Beghetto, V. Sustainable Triazine-Based Dehydro-Condensation Agents for Amide Synthesis. *Molecules*, **2021**, *26*, 191. https://doi.org/10.3390/molecules26010191
40. Purohit, V.B., Pięta, M., Pietrasik, J., Plummer, C.M. Towards sustainability and a circular Economy: ROMP for the goal of fully degradable and chemically recyclable polymers. *Eur. Polym. J.* **2024**, *208*, 112847. https://doi.org/10.1016/j.eurpolymj.2024.112847
41. Thushari, I., Babel, S. Comparative study of the environmental impacts of used cooking oil valorization options in Thailand. *J. Environ. Manage* **2020**, *310*, 114810. https://doi.org/10.1016/j.jenvman.2022.114810
42. Hamze, H., Akia, M., Yazdani, F. Optimization of biodiesel production from the waste cooking oil using response surface methodology. *Process Safety and Environmental Protection* **2015**, *94*, 1–10. https://doi.org/10.1016/j.psep.2014.12.005
43. Ibanez, J., Martel Martín, S., Baldino, S., Prandi, C., Mannu, A. European Union Legislation Overview about Used Vegetable Oils Recycling: The Spanish and Italian Case Studies. *Processes* **2020**, *8*, 798. https://doi.org/10.3390/pr8070798
44. Mannu, A., Garroni, S., Ibanez Porras, J., Mele, A. Available Technologies and Materials for Waste Cooking Oil Recycling. *Processes* **2020**, *8*, 366. https://doi.org/10.3390/pr8030366
45. Mannu, A., Ferro, M., Dugoni, G.C., Panzeri, W., Petretto, G.L., Urgeghe, P., Mele, A. Improving the recycling technology of waste cooking oils: Chemical fingerprint as tool for non-biodiesel application. *Waste Management* **2019**, *96*, 1–8. https://doi.org/10.1016/j.wasman.2019.07.014
46. Dou, Z., Dierenfeld, E.S., Wang, X., Chen, X., Shurson, G.C. A critical analysis of challenges and opportunities for upcycling food waste to animal feed to reduce climate and resource burdens. *Resour. Conserv. Recycl.* **2024**, *203*, 107418. https://doi.org/10.1016/j.resconrec.2024.107418

47. Panadare, D.C., Rathod, V.K. Applications of Waste Cooking Oil Other Than Biodiesel: A Review, *Iranian J. Chem. Eng.* **2015**, *12*, 55-76. https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://www.ijche.com/article_11253_54b41ee620eb7a8972ee3e37776dad5f.pdf&ved=2ahUKEwiMoK66rouIAxWPg_0HHbj0DNgQFnoECBsQAQ&usg=AOvVaw11QJ42AupQ5PiqrF-UlbHz
48. Salemdeeb, R., zu Ermgassen, E.K.H.J., Kim, M.H., Balmford, A., Al-Tabbaa, A. Environmental and health impacts of using food waste as animal feed: a comparative analysis of food waste management options. *J. Clean. Prod.* **2017**, *140*, 871–880. https://doi.org/10.1016/j.jclepro.2016.05.049
49. Sarker, A., Ahmmed, R., Ahsan, S.M., Rana, J., Ghosh, M.K., Nandi, R. A comprehensive review of food waste valorization for the sustainable management of global food waste. *Sustainable Food Technology* **2024**, *2*, 48–69. https://doi.org/10.1039/D3FB00156C
50. Bardella, N., Facchin, M., Fabris, E., Baldan, M., Beghetto, V. Waste Cooking Oil as Eco-Friendly Rejuvenator for Reclaimed Asphalt Pavement. *Materials* **2024**, *17*, 1477. https://doi.org/10.3390/ma17071477
51. Wang, C., Xue, L., Xie, W., You, Z., Yang, X. Laboratory investigation on chemical and rheological properties of bio-asphalt binders incorporating waste cooking oil. *Constr. Build. Mater.* **2018**, *167*, 348–358. https://doi.org/10.1016/j.conbuildmat.2018.02.038
52. Staroń, A., Chwastowski, J., Kijania-Kontak, M., Wiśniewski, M., Staroń, P. Bio-enriched composite materials derived from waste cooking oil for selective reduction of odour intensity. *Sci. Rep.* **2024**, *14*, 16311. https://doi.org/10.1038/s41598-024-67302-4
53. Zhang, R., Wang, J., Kang, H. Effect of waste cooking oil on the performance of EVA modified asphalt and its mechanism analysis. *Sci. Rep.* **2024**, *14*, 14072. https://doi.org/10.1038/s41598-024-64816-9
54. Onn, M., Jalil, M.J., Mohd Yusoff, N.I.S., Edward, E.B., Wahit, M.U. A comprehensive review on chemical route to convert waste cooking oils to renewable polymeric materials. *Ind. Crops Prod.* **2024**, *211*, 118194. https://doi.org/10.1016/j.indcrop.2024.118194
55. Singh, N., Agarwal, P., Porwal, J., Porwal, S.K. Evaluation of multifunctional green copolymer additives–doped waste cooking oil–extracted natural antioxidant in biolubricant formulation. *Biomass Convers. Biorefin.* **2024**, *14*, 761–770. https://doi.org/10.1007/s13399-022-02348-w
56. Marriam, F., Irshad, A., Umer, I., Asghar, M.A., Atif, M. Vegetable oils as bio-based precursors for epoxies. *Sustain. Chem. Pharm.* **2023**, *31*, 100935. https://doi.org/10.1016/j.scp.2022.100935
57. Singh, N., Agarwal, P., Porwal, S.K. Natural Antioxidant Extracted Waste Cooking Oil as Sustainable Biolubricant Formulation in Tribological and Rheological Applications. *Waste Biomass Valorization* **2022**, *13*, 3127–3137. https://doi.org/10.1007/s12649-022-01745-6
58. Wierzchowska, K., Derewiaka, D., Zieniuk, B., Nowak, D., Fabiszewska, A. Whey and post-frying oil as substrates in the process of microbial lipids obtaining: a value-added product with nutritional benefits. *Eur. Food Res. Technol.* **2023**, *249*, 2675–2688. https://doi.org/10.1007/s00217-023-04322-w
59. Lhuissier, M., Couvert, A., Amrane, A., Kane, A., Audic, J.L. Characterization and selection of waste oils for the absorption and biodegradation of VOC of different hydrophobicities. *Chem. Eng. Res. Des.* **2018**, *138*, 482–489. https://doi.org/10.1016/j.cherd.2018.08.028
60. Worthington, M.J.H., Kucera, R.L., Albuquerque, I.S., Gibson, C.T., Sibley, A., Slattery, A.D., Campbell, J.A., Alboaiji, S.F.K., Muller, K.A., Young, J., Adamson, N., Gascooke, J.R., Jampaiah, D., Sabri, Y.M., Bhargava, S.K., Ippolito, S.J., Lewis, D.A., Quinton, J.S., Ellis, A. V., Johs, A., Bernardes, G.J.L., Chalker, J.M. Laying Waste to Mercury: Inexpensive Sorbents Made from Sulfur and Recycled Cooking Oils. *Chem. Eur. J.* **2017**, 23, 16219–16230. https://doi.org/10.1002/chem.201702871
61. European Commission. Available online: URL https://commission.europa.eu/index_en (accessed on 15 December 2024)
62. European Law portal. Available online: URL https://eur-lex.europa.eu/homepage.html?locale=en (accessed on 18 December 2024)
63. European Commission press corner. Available online: URL https://eur-lex.europa.eu/homepage.html?locale=en (accessed on 15 December 2024)
64. European Environment. Agency Available online: URL https://www.eea.europa.eu/en (accessed on 15 December 2024)

65. European Chemicals Agency. Available online: URL https://echa.europa.eu/it/home (accessed on 15 December 2024)
66. Statista. Available online: URL https://www.statista.com/ (accessed on 15 December 2024)
67. Eurostat portal. Available online: URL https://ec.europa.eu/eurostat (accessed on 15 December 2024)
68. Zhao, Yakun, Zhu, K., Li, J., Zhao, Yu, Li, S., Zhang, C., Xiao, D., Yu, A. High-efficiency production of bisabolene from waste cooking oil by metabolically engineered Yarrowia lipolytica. *Microb. Biotechnol.* **2021**, *14*, 2497–2513. https://doi.org/10.1111/1751-7915.13768
69. Khedaywi, T., Melhem, M. Effect of Waste Vegetable Oil on Properties of Asphalt Cement and Asphalt Concrete Mixtures: An Overview. *Int. J. Pavement Res. Technol.* **2024**, *17*, 280–290. https://doi.org/10.1007/s42947-022-00234-2
70. Math, M.C., Kumar, S.P., Chetty, S. V. Technologies for biodiesel production from used cooking oil - A review. *Sustain. Energy Dev.* **2010**, *14*, 339–345. https://doi.org/10.1016/j.esd.2010.08.001
71. Manikandan, G., Kanna, P.R., Taler, D., Sobota, T. Review of Waste Cooking Oil (WCO) as a Feedstock for Biofuel—Indian Perspective. *Energies* **2023**, *16*, 1739. https://doi.org/10.3390/en16041739
72. Matušinec, J., Hrabec, D., Šomplák, R., Nevrlý, V., Pecha, J., Smejkalová, V., Redutskiy, Y. Cooking oil and fat waste management: A review of the current state. *Chem. Eng. Trans.* **2020**, *81*, 763–768. https://doi.org/10.3303/CET2081128
73. Monika, Banga, S., Pathak, V. V. Biodiesel production from waste cooking oil: A comprehensive review on the application of heterogenous catalysts. *Energy Nexus* **2023**, *10*, 100209. https://doi.org/10.1016/j.nexus.2023.100209
74. Nanda, S., Rana, R., Hunter, H.N., Fang, Z., Dalai, A.K., Kozinski, J.A. Hydrothermal catalytic processing of waste cooking oil for hydrogen-rich syngas production. *Chem. Eng. Sci.* **2019**, *195*, 935–945. https://doi.org/10.1016/j.ces.2018.10.039
75. Nascimento, L., Ribeiro, A., Ferreira, A., Valério, N., Pinheiro, V., Araújo, J., Vilarinho, C., Carvalho, J. Turning waste cooking oils into biofuels—valorization technologies: A review. *Energies* **2022**, *15*, 116. https://doi.org/10.3390/en15010116
76. Ortner, M.E., Müller, W., Schneider, I., Bockreis, A. Environmental assessment of three different utilization paths of waste cooking oil from households. *Resour. Conserv. Recycl.* **2016**, *106*, 59–67. https://doi.org/10.1016/j.resconrec.2015.11.007
77. Rocha-Meneses, L., Hari, A., Inayat, A., Yousef, L.A., Alarab, S., Abdallah, M., Shanableh, A., Ghenai, C., Shanmugam, S., Kikas, T. Recent advances on biodiesel production from waste cooking oil (WCO): A review of reactors, catalysts, and optimization techniques impacting the production. *Fuel* **2023**, *348*, 128514. https://doi.org/10.1016/j.fuel.2023.128514
78. Tamošiūnas, A., Gimžauskaitė, D., Aikas, M., Uscila, R., Praspaliauskas, M., Eimontas, J. Gasification of Waste Cooking Oil to Syngas by Thermal Arc Plasma. *Energies* **2019**, *12*, 2612. https://doi.org/10.3390/en12132612
79. Xu, L., Li, Y., Liao, M., Song, Q., Wang, C., Weng, J., Zhao, M., Gao, N. Catalytic pyrolysis of waste cooking oil for hydrogen-rich syngas production over bimetallic Fe-Ru/ZSM-5 catalyst. *Fuel Processing Technology* **2023**, *247*, 107812. https://doi.org/10.1016/j.fuproc.2023.107812
80. Sabino, J., Liborio, D.O., Arias, S., Gonzalez, J.F., Barbosa, C.M.B.M., Carvalho, F.R., Frety, R., Barros, I.C.L., Pacheco, J.G.A. Hydrogen-Free Deoxygenation of Oleic Acid and Industrial Vegetable Oil Waste on CuNiAl Catalysts for Biofuel Production. *Energies* **2023**, 16. https://doi.org/10.3390/en16176131
81. Suzihaque, M.U.H., Alwi, H., Kalthum Ibrahim, U., Abdullah, S., Haron, N. Biodiesel production from waste cooking oil: A brief review. *Mater. Today Proc.* **2022**, *63*, S490–S495. https://doi.org/10.1016/j.matpr.2022.04.527
82. Aransiola, E.F., Ojumu, T.V., Oyekola, O.O., Madzimbamuto, T.F., Ikhu-Omoregbe, D.I.O. A review of current technology for biodiesel production: State of the art. *Biomass Bioenergy* **2014**, *61*, 276–297. https://doi.org/10.1016/j.biombioe.2013.11.014
83. Tsoutsos, T., Tournaki, S., Gkouskos, Z., Paraíba, O., Giglio, F., García, P.Q., Braga, J., Adrianos, H., Filice, M. Quality Characteristics of Biodiesel Produced from Used Cooking Oil in Southern Europe. *Chem. Eng.* **2019**, *3*, 19. https://doi.org/10.3390/chemengineering3010019

84. Caldeira, C., Freire, F., Olivetti, E.A., Kirchain, R., Dias, L.C. Analysis of cost-environmental trade-offs in biodiesel production incorporating waste feedstocks: A multi-objective programming approach. *J. Clean. Prod.* **2019**, *216*, 64–73. https://doi.org/10.1016/j.jclepro.2019.01.126
85. Cordero-Ravelo, V., Schallenberg-Rodriguez, J. Biodiesel production as a solution to waste cooking oil (WCO) disposal. Will any type of WCO do for a transesterification process? A quality assessment. *J. Environ. Manage* **2018**, *228*, 117–129. https://doi.org/10.1016/j.jenvman.2018.08.106
86. Cadillo-Benalcazar, J.J., Bukkens, S.G.F., Ripa, M., Giampietro, M. Why does the European Union produce biofuels? Examining consistency and plausibility in prevailing narratives with quantitative storytelling. *Energy Res. Soc. Sci.* **2021**, 71, 101810. https://doi.org/10.1016/j.erss.2020.101810
87. Outili, N., Kerras, H., Meniai, A.H. Recent conventional and non-conventional WCO pretreatment methods: Implementation of green chemistry principles and metrics. *Curr. Opin. Green Sustain. Chem.* **2023**, *41*, 100794. https://doi.org/10.1016/j.cogsc.2023.100794
88. Ripa, M., Cadillo-Benalcazar, J.J., Giampietro, M. Cutting through the biofuel confusion: A conceptual framework to check the feasibility, viability and desirability of biofuels. *Energy Strategy Reviews* **2021**, *35*, 100642. https://doi.org/10.1016/j.esr.2021.100642
89. Caldeira, C., Queirós, J., Freire, F. Biodiesel from Waste Cooking Oils in Portugal: Alternative Collection Systems. *Waste Biomass Valorization* **2015**, *6*, 771–779. https://doi.org/10.1007/s12649-015-9386-z
90. Directive (EU) 2023/2413, **2023**. Amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652, European Parliament and of the Council. http://data.europa.eu/eli/dir/2023/2413/oj. (accessed 03.08.2024)
91. Directive 75/439/EEC, **1975**. Disposal of waste oils, The council of the European communities. http://data.europa.eu/eli/dir/1975/439/oj. (accessed 20.09.2024)
92. Directive 2014/955/EU, **2014**. Commission Decision of 18 December 2014 amending Decision 2000/532/EC on the list of waste pursuant to Directive 2008/98/EC of the European Parliament and of the Council Text with EEA relevance, European Parliament and of the Council . http://data.europa.eu/eli/dec/2014/955/oj. (accessed 03.02.2024)
93. Directive 75/442/EEC, **1975**. Council Directive 75/442/EEC of 15 July 1975 on waste, The council of the european communities. http://data.europa.eu/eli/dir/1975/442/oj. (accessed 15.10.2024)
94. Directive 2008/98/EC, **2008**. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance), European Parliament and of the Council . http://data.europa.eu/eli/dir/2008/98/oj. (accessed 25.12.2024)
95. Directive (EU) 2018/851, **2018**. Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste (Text with EEA relevance), European Parliament and of the Council. http://data.europa.eu/eli/dir/2018/851/oj. (accessed 03.12.2024)
96. Borrello, M., Caracciolo, F., Lombardi, A., Pascucci, S., Cembalo, L. Consumers' Perspective on Circular Economy Strategy for Reducing Food Waste. *Sustainability* **2017**, *9*, 141. https://doi.org/10.3390/su9010141
97. Beghetto, V., Bardella, N., Samiolo, R., Gatto, V., Conca, S., Sole, R., Molin, G., Gattolin, A., Ongaro, N. By-products from mechanical recycling of polyolefins improve hot mix asphalt performance. *J. Clean. Prod.* **2021**, *318*, 128627. https://doi.org/10.1016/j.jclepro.2021.128627
98. CONOE Annual Report 2018. https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=http://www.conoe.it/wp-content/uploads/2018/11/ANNUAL-REPORT-2018.pdf&ved=2ahUKEwiB-v_3touIAxVJ8LsIHS8kAKAQFnoECBUQAQ&usg=AOvVaw0pNXsTRFSIaiWl9aUnWgPQ (accessed 23.11.2024)
99. De Feo, G., Di Domenico, A., Ferrara, C., Abate, S., Sesti Osseo, L. Evolution of Waste Cooking Oil Collection in an Area with Long-Standing Waste Management Problems. *Sustainability* **2020**, *12*, 8578. https://doi.org/10.3390/su12208578
100. De Feo, G., Ferrara, C., Giordano, L., Ossèo, L.S. Assessment of Three Recycling Pathways for Waste Cooking Oil as Feedstock in the Production of Biodiesel, Biolubricant, and Biosurfactant: A Multi-Criteria Decision Analysis Approach. Recycling **2023**, *8*, 64. https://doi.org/10.3390/recycling8040064

101. Foo, W.H., Koay, S.S.N., Tang, D.Y.Y., Chia, W.Y., Chew, K.W., Show, P.L. Safety control of waste cooking oil: transforming hazard into multifarious products with available pre-treatment processes. *Food Mater. Res.* **2022**, *2*, 1–11. https://doi.org/10.48130/FMR-2022-0001
102. Bazina, N., He, J. Analysis of fatty acid profiles of free fatty acids generated in deep-frying process. *J. Food Sci. Technol.* **2018**, *55*, 3085–3092. https://doi.org/10.1007/s13197-018-3232-9
103. Park, J.-M., Kim, J.-M. Monitoring of Used Frying Oils and Frying Times for Frying Chicken Nuggets Using Peroxide Value and Acid Value. *Korean J. Food Sci. Anim. Resour.* **2016**, *36*, 612–616. https://doi.org/10.5851/kosfa.2016.36.5.612
104. Kulkarni, M.G., Dalai, A.K. Waste Cooking OilAn Economical Source for Biodiesel: A Review. *Ind. Eng. Chem. Res.* **2006**, *45*, 2901–2913. https://doi.org/10.1021/ie0510526
105. Awogbemi, O., Kallon, D.V. Von, Aigbodion, V.S., Panda, S. Advances in biotechnological applications of waste cooking oil. *CSCEE* **2021**, *4*, 100158. https://doi.org/10.1016/j.cscee.2021.100158
106. Fabiszewska, U.A., Białecka-Florjańczyk, E. Factors influencing synthesis of extracellular lipases by yarrowia lipolytica in medium containing vegetable oils. J. microbiol., biotechnol. food sci. **2014**, *4*, 231–237. https://doi.org/10.15414/jmbfs.2014-15.4.3.231-237
107. Liepins, J., Balina, K., Soloha, R., Berzina, I., Lukasa, L.K., Dace, E. Glycolipid biosurfactant production from waste cooking oils by yeast: Review of substrates, producers and products. *Fermentation* **2021**, *7*, 136. https://doi.org/10.3390/fermentation7030136
108. Wadekar, S., Kale, S., Lali, A., Bhowmick, D., Pratap, A. Sophorolipid Production by Starmerella bombicola (ATCC 22214) from Virgin and Waste Frying Oils, and the Effects of Activated Earth Treatment of the Waste Oils. J. Am. Oil Chem. Soc. **2012**, *89*, 1029–1039. https://doi.org/10.1007/s11746-011-1986-6
109. Carmona-Cabello, M., Sáez-Bastante, J., Pinzi, S., Dorado, M.P. Optimization of solid food waste oil biodiesel by ultrasound-assisted transesterification. *Fuel* **2019**, *255*, 115817. https://doi.org/10.1016/j.fuel.2019.115817
110. EN 14214. International standard that describes the minimum requirements for Biodiesel production from vegetable oils. https://www.chemeurope.com/en/encyclopedia/EN_14214.html. (Accessed 08.23.2024)
111. Hussein, R.Z.K., Attia, N.K., Fouad, M.K., ElSheltawy, S.T. Experimental investigation and process simulation of biolubricant production from waste cooking oil. *Biomass Bioenergy* **2021**, *144*, 105850. https://doi.org/10.1016/j.biombioe.2020.105850
112. Liang, M.-Y., Ma, C., Qin, W.-Q., Mtui, H.I., Wang, W., Liu, J., Yang, S.-Z., Mu, B.-Z. A synergetic binary system of waste cooking oil-derived bio-based surfactants and its interfacial performance for enhanced oil recovery. Colloids and Surfaces C: *Environmental Aspects* **2024**, *2*, 100039. https://doi.org/10.1016/j.colsuc.2024.100039
113. Jia, P., Zhang, M., Hu, L., Song, F., Feng, G., Zhou, Y. A Strategy for Nonmigrating Plasticized PVC Modified with Mannich base of Waste Cooking Oil Methyl Ester. *Sci. Rep.* **2018**, *8*. https://doi.org/10.1038/s41598-018-19958-y
114. Suzuki, A.H., Botelho, B.G., Oliveira, L.S., Franca, A.S. Sustainable synthesis of epoxidized waste cooking oil and its application as a plasticizer for polyvinyl chloride films. *Eur. Polym J.* **2018**, *99*, 142–149. https://doi.org/10.1016/j.eurpolymj.2017.12.014
115. Zheng, T., Wu, Z., Xie, Q., Fang, J., Hu, Y., Lu, M., Xia, F., Nie, Y., Ji, J. Structural modification of waste cooking oil methyl esters as cleaner plasticizer to substitute toxic dioctyl phthalate. J. Clean. Prod. **2018**, *186*, 1021–1030. https://doi.org/10.1016/j.jclepro.2018.03.175
116. Moretti, C., Junginger, M., Shen, L. Environmental life cycle assessment of polypropylene made from used cooking oil. Resour. Conserv. Recycl. **2020**, *157*, 104750. https://doi.org/10.1016/j.resconrec.2020.104750
117. Tremblay-Parrado, K.K., Astrain, C. G., Avérous, L. click chemistry for the synthesis of biobased polymers and networks derived from vegetable oils. Green Chem. **2021**, *23*, 4296–4327. https://doi.org/10.1039/D1GC00445J
118. Huang, J., Huo, Y., Su, Q., Lu, D., Wu, Y., Dong, X., Gao, Y. Sustainable high-strength alkali-activated slag concrete is achieved by recycling emulsified waste cooking oil. *Front Mater.* **2024**, 11. https://doi.org/10.3389/fmats.2024.1388122

119. Ingrassia, L.P., Lu, X., Ferrotti, G., Canestrari, F. Renewable materials in bituminous binders and mixtures: Speculative pretext or reliable opportunity? Resour. Conserv. Recycl. **2019**, *144*, 209–222. https://doi.org/10.1016/j.resconrec.2019.01.034
120. Ozdemir, K.D., Dokandari, A.P., Raufi, H., Topal, A., Sengoz, B. Feasibility and mixture performance assessment of waste oil based rejuvenators in high-RAP asphalt mixtures. Mater. Res. Express **2023**, *10*, 045306. https://doi.org/10.1088/2053-1591/accd3e
121. Sun, D., Lu, T., Xiao, F., Zhu, X., Sun, G. Formulation and aging resistance of modified bio-asphalt containing high percentage of waste cooking oil residues. *J. Clean. Prod.* **2017**, *161*, 1203–1214. https://doi.org/10.1016/j.jclepro.2017.06.155
122. Straits research, **2024**. Bio-Lubricants Market Size, Share & Trends Analysis Report By Base Oil Type (Vegetable Oils, Animal Fats), By Application (Chainsaw Oils, Hydraulic Fluids), By End-User (Industrial, Commercial Transport, Passenger Vehicles) and By Region(North America, Europe, APAC, Middle East and Africa, LATAM) Forecasts, 2023-2031 [WWW Document]. https://straitsresearch.com/report/bio-lubricants-market#:~:text=The%20global%20bio%2Dlubricants%20market,the%20forecast%20period%202023%2D2031 (accessed 8.19.24).
123. Joshi, J.R., Bhanderi, K.K., Patel, J. V. Waste cooking oil as a promising source for bio lubricants- A review. J. Indian Chem. Soc. **2023**, *100*, 100820. https://doi.org/10.1016/j.jics.2022.100820
124. Khodadadi, M.R., Malpartida, I., Tsang, C.-W., Lin, C.S.K., Len, C. Recent advances on the catalytic conversion of waste cooking oil. *Molecular Catal.* **2020**, *494*, 111128. https://doi.org/10.1016/j.mcat.2020.111128
125. Kutluk, B.G., Kutluk, T., Kapucu, N. Enzymatic Synthesis of Trimethylolpropane-Bases Biolubricants from Waste Edible Oil Biodiesel Using Different Types of Biocatalysis. *Iran. J. Chem. Chem. Eng* **2022**, *41*, 3234–3243. DOI 10.30492/ijcce.2023.552815.5308
126. Mukherjee, S., Chandar, T., Pradhan, S., Prasad, L. Lubricant from Waste Cooking Oil, in: Lubricants from Renewable Feedstocks. Wiley, **2024**, pp. 291–335. https://doi.org/10.1002/9781394173037.ch10
127. Zhang, W., Ji, H., Song, Y., Ma, S., Xiong, W., Chen, C., Chen, B., Zhang, X. Green preparation of branched biolubricant by chemically modifying waste cooking oil with lipase and ionic liquid. *J. Clean. Prod.* **2020**, *274*, 122918. https://doi.org/10.1016/j.jclepro.2020.122918
128. Borugadda, V.B., Goud, V. V. Improved thermo-oxidative stability of structurally modified waste cooking oil methyl esters for bio-lubricant application. *J. Clean. Prod.* **2016**, *112*, 4515–4524. https://doi.org/10.1016/j.jclepro.2015.06.046
129. Chowdhury, A., Mitra, D., Biswas, D. Biolubricant synthesis from waste cooking oil via enzymatic hydrolysis followed by chemical esterification. *JCTB* **2023**, *88*, 139–144. https://doi.org/10.1002/jctb.3874
130. Dabai, U.M., Owuna, J.F., Sokoto, A.M., Abubakar, L.A. Assessment of Quality Parameters of Ecofriendly Biolubricant from Waste Cooking Palm Oil. *Asian J. Applied Chemistry Research* **2018**, 1–11. https://doi.org/10.9734/ajacr/2018/v1i49691
131. Bahadi, M., Salimon, J., Derawi, D. Synthesis of di-trimethylolpropane tetraester-based biolubricant from Elaeis guineensis kernel oil via homogeneous acid-catalyzed transesterification. *Renew. Energy* **2021**, *171*, 981–993. https://doi.org/10.1016/j.renene.2021.02.163
132. Carvalho, W.C.A., Luiz, J.H.H., Fernandez-Lafuente, R., Hirata, D.B., Mendes, A.A. Eco-friendly production of trimethylolpropane triesters from refined and used soybean cooking oils using an immobilized low-cost lipase (Eversa>® Transform 2.0) as heterogeneous catalyst. *Biomass Bioenergy* **2021**, *155*, 106302. https://doi.org/10.1016/j.biombioe.2021.106302
133. Ivan-Tan, C.T., Islam, A., Yunus, R., Taufiq-Yap, Y.H. Screening of solid base catalysts on palm oil based biolubricant synthesis. *J. Clean. Prod.* **2017**, *148*, 441–451. https://doi.org/10.1016/j.jclepro.2017.02.027
134. Owuna, F.J., Dabai, M.U., Sokoto, M.A., Dangoggo, S.M., Bagudo, B.U., Birnin-Yauri, U.A., Hassan, L.G., Sada, I., Abubakar, A.L., Jibrin, M.S. Chemical modification of vegetable oils for the production of biolubricants using trimethylolpropane: A review. *Egypt. J. Pet.* **2020**, *29*, 75–82. https://doi.org/10.1016/j.ejpe.2019.11.004

135. Liu, Y., Liu, M.Y., Fan, X.G., Wang, L., Liang, J.Y., Jin, X.Y., Che, R.J., Ying, W.Y., Chen, S.P. 4D printing of multifunctional photocurable resin based on waste cooking oil. *ACS Sustain. Chem. Eng.* **2022**, *10*, 16344-16358
136. Wang, E., Ma, X., Tang, S., Yan, R., Wang, Y., Riley, W.W., Reaney, M.J.T. Synthesis and oxidative stability of trimethylolpropane fatty acid triester as a biolubricant base oil from waste cooking oil. *Biomass Bioenergy* **2014**, *66*, 371–378. https://doi.org/10.1016/j.biombioe
137. Lakkoju, B., Vemulapalli, V. Synthesis and characterization of triol based bio-lubricant from waste cooking oil. AIP Conference proceedings **2020**, *2297*, p. 020002. https://doi.org/10.1063/5.0030013
138. Bashiri, S., Ghobadian, B., Dehghani Soufi, M., Gorjian, S. Chemical modification of sunflower waste cooking oil for biolubricant production through epoxidation reaction. *Mater. Sci. Energy Technol.* **2021**, *4*, 119–127. https://doi.org/10.1016/j.mset.2021.03.001
139. Li, W., Wang, X. Bio-lubricants derived from waste cooking oil with improved oxidation stability and low-temperature properties. *J. Oleo. Sci.* **2015**, *64*, 367–374. https://doi.org/10.5650/jos.ess14235
140. Jahromi, H., Adhikari, S., Roy, P., Shelley, M., Hassani, E., Oh, T.-S. Synthesis of Novel Biolubricants from Waste Cooking Oil and Cyclic Oxygenates through an Integrated Catalytic Process. ACS Sustain. Chem. Eng. **2021**, *9*, 13424–13437. https://doi.org/10.1021/acssuschemeng.1c03523
141. Turco, R., Tesser, R., Vitiello, R., Russo, V., Andini, S., Serio, M. Di. Synthesis of Biolubricant Basestocks from Epoxidized Soybean Oil. *Catalysts* **2017**, *7*, 309. https://doi.org/10.3390/catal7100309
142. Borah, M.J., Das, A., Das, V., Bhuyan, N., Deka, D. Transesterification of waste cooking oil for biodiesel production catalyzed by Zn substituted waste egg shell derived CaO nanocatalyst. *Fuel* **2019**, *242*, 345–354. https://doi.org/10.1016/j.fuel.2019.01.060
143. Ghafar, F., Sapawe, N., Dzazita Jemain, E., Safwan Alikasturi, A., Masripan, N. Study on The Potential of Waste Cockle Shell Derived Calcium Oxide for Biolubricant Production. *Mater. Today Proc.* **2019**, *19*, 1346–1353. https://doi.org/10.1016/j.matpr.2019.11.148
144. Guimarães, J.R., Miranda, L.P., Fernandez-Lafuente, R., Tardioli, P.W. Immobilization of Eversa® Transform via CLEA Technology Converts It in a Suitable Biocatalyst for Biolubricant Production Using Waste Cooking Oil. *Molecules* **2021**, *26*, 193. https://doi.org/10.3390/molecules26010193
145. Sarno, M., Iuliano, M., Cirillo, C. Optimized procedure for the preparation of an enzymatic nanocatalyst to produce a bio-lubricant from waste cooking oil. *Chem. Eng. J.* **2019**, *377*, 120273. https://doi.org/10.1016/j.cej.2018.10.210
146. Su, Y., Lin, H., Zhang, S., Yang, Z., Yuan, T. One-Step Synthesis of Novel Renewable Vegetable Oil-Based Acrylate Prepolymers and Their Application in UV-Curable Coatings. *Polymers* **2020**, *12*, 1165. https://doi.org/10.3390/polym12051165
147. Ahmad, A., Kuching Sarawak, P., Hafizah Naihi, M. Analysis of Produced Bio-Surfactants from Waste Cooking Oil and Pure Coconut. *IJISRT* **2019**, *4*, 682–685. ISSN 2456-2165.
148. De, S., Malik, S., Ghosh, A., Saha, R., Saha, B. A review on natural surfactants. *RSC Adv.* **2015**, *5*, 65757–65767. https://doi.org/10.1039/C5RA11101C
149. Inès, M., Dhouha, G. Glycolipid biosurfactants: Potential related biomedical and biotechnological applications. *Carbohydr. Res.* **2015**, *416*, 59–69. https://doi.org/10.1016/j.carres.2015.07.016
150. Miao, Y., To, M.H., Siddiqui, M.A., Wang, H., Lodens, S., Chopra, S.S., Kaur, G., Roelants, S.L.K.W., Lin, C.S.K. Sustainable biosurfactant production from secondary feedstock—recent advances, process optimization and perspectives. *Front. Chem.* **2024**, *12*, 1–12. https://doi.org/10.3389/fchem.2024.1327113
151. Rawat, N., Alam, P., Bhonsle, A.K., Ngomade, S.B.L., Agarwal, T., Singh, R.K., Atray, N. Valorization of used cooking oil into bio-based surfactant: modeling and optimization using response surface methodology. *Biomass Convers. Biorefin.* **2024**. https://doi.org/10.1007/s13399-024-05753-5
152. Zhang, Q.Q., Cai, B.X., Xu, W.J., Gang, H.Z., Liu, J.F., Yang, S.Z., Mu, B.Z. The rebirth of waste cooking oil to novel bio-based surfactants. *Sci. Rep.* **2015**, 5. https://doi.org/10.1038/srep09971
153. Market Research Engine, **2022**. Biosurfactants Market Research. Available on line URL https://www.marketresearchengine.com/biosurfactants-market?srsltid=AfmBOopWbMrQRk5GEZTHLe-xSaQJk4fBT84YEX_zBlJ5Rqe64EyXE1tJ (accessed 08.12.2024)

154. Jahan, R., Bodratti, A.M., Tsianou, M., Alexandridis, P. Biosurfactants, natural alternatives to synthetic surfactants: Physicochemical properties and applications. *Adv. Colloid Interface Sci.* **2020**, *275*, 102061. https://doi.org/10.1016/j.cis.2019.102061
155. Jiménez-Peñalver, P., Koh, A., Gross, R., Gea, T., Font, X. Biosurfactants from Waste: Structures and Interfacial Properties of Sophorolipids Produced from a Residual Oil Cake. J. Surfactants Deterg. **2020**, *23*, 481–486. https://doi.org/10.1002/jsde.12366
156. Sharma, K., Toor, S.S., Brandão, J., Pedersen, T.H., Rosendahl, L.A. Optimized conversion of waste cooking oil into ecofriendly bio-based polymeric surfactant- A solution for enhanced oil recovery and green fuel compatibility. *J. Clean. Prod.* **2021**, 294. https://doi.org/10.1016/j.jclepro.2021.126214
157. Cameotra, S.S., Makkar, R.S. Biosurfactant-enhanced bioremediation of hydrophobic pollutants. *Pure Appl. Chem.* **2010**, *82*, 97–116. https://doi.org/10.1351/PAC-CON-09-02-10
158. Gaur, V.K., Sharma, P., Sirohi, R., Varjani, S., Taherzadeh, M.J., Chang, J.-S., Yong Ng, H., Wong, J.W.C., Kim, S.-H. Production of biosurfactants from agro-industrial waste and waste cooking oil in a circular bioeconomy: An overview. *Bioresour. Technol.* **2022**, *343*, 126059. https://doi.org/10.1016/j.biortech.2021.126059
159. Gautam, K., Sharma, P., Gaur, V.K., Gupta, P., Pandey, U., Varjani, S., Pandey, A., Wong, J.W.C., Chang, J.S. Oily waste to biosurfactant: A path towards carbon neutrality and environmental sustainability. *Environ. Technol. Innov.* **2023**, 30. https://doi.org/10.1016/j.eti.2023.103095
160. Nurdin, S., Yunus, R.M., Nour, A.H., Gimbun, J., Aisyah Azman, N.N., Sivaguru, M. V. Restoration of waste cooking oil (WCO) using alkaline hydrolysis technique (ALHYT) for future biodetergent 11. *ARPN J. Eng. Appl. Sci.* **2016**, *11*, 6405–6410. ISSN 1819-6608
161. Yusuff, A.S., Porwal, J., Bhonsle, A.K., Rawat, N., Atray, N. Valorization of used cooking oil as a source of anionic surfactant fatty acid methyl ester sulfonate: process optimization and characterization studies. *Biomass Convers. Biorefin.* **2023**, *13*, 8903–8914. https://doi.org/10.1007/s13399-021-01663-y
162. Permadani, R.L., Ibadurrohman, M., Slamet. Utilization of waste cooking oil as raw material for synthesis of Methyl Ester Sulfonates (MES) surfactant, in: IOP Conference Series: Earth and Environmental Science. Institute of Physics Publishing **2018**. https://doi.org/10.1088/1755-1315/105/1/012036
163. Jin, Y., Tian, S., Guo, J., Ren, X., Li, X., Gao, S. Synthesis, Characterization and Exploratory Application of Anionic Surfactant Fatty Acid Methyl Ester Sulfonate from Waste Cooking Oil. *J. Surfactants Deterg.* **2016**, *19*, 467–475. https://doi.org/10.1007/s11743-016-1813-z
164. Lucchetti, M.G., Paolotti, L., Rocchi, L., Boggia, A. The Role of Environmental Evaluation within Circular Economy: An Application of Life Cycle Assessment (LCA) Method in the Detergents Sector. *Environ. Climate Technol.* **2019**, *23*, 238–257. https://doi.org/10.2478/rtuect-2019-0066
165. Dong, Q., Li, X., Dong, J. Synthesis of branched surfactant via ethoxylation of oleic acid derivative and its surface properties. *Chem. Eng. Sci.* **2022**, *258*, 117747. https://doi.org/10.1016/j.ces.2022.117747
166. Khalaf, M.M., Tantawy, A.H., Soliman, K.A., Abd El-Lateef, H.M. Cationic gemini-surfactants based on waste cooking oil as new 'green' inhibitors for N80-steel corrosion in sulphuric acid: A combined empirical and theoretical approaches. *J. Mol. Struct.* **2020**, *1203*, 127442. https://doi.org/10.1016/j.molstruc.2019.127442
167. Guerrero-Hernández, L., Meléndez-Ortiz, H.I., Cortez-Mazatan, G.Y., Vaillant-Sánchez, S., Peralta-Rodríguez, R.D. Gemini and Bicephalous Surfactants: A Review on Their Synthesis, Micelle Formation, and Uses. *Int. J. Mol. Sci.* **2022**, *23*, 1798. https://doi.org/10.3390/ijms23031798
168. Bocqué, M., Voirin, C., Lapinte, V., Caillol, S., Robin, J.J. Petro-based and bio-based plasticizers: Chemical structures to plasticizing properties. *J. Polym. Sci. A Polym. Chem.* **2016**, *54*, 11–33. https://doi.org/10.1002/pola.27917
169. Silviana, Anggoro, D.D., Kumoro, A.C. Waste cooking oil utilisation as bio-plasticiser through epoxidation using inorganic acids as homogeneous catalysts. *Chem. Eng. Trans.* **2017**, *56*, 1861–1866. https://doi.org/10.3303/CET1756311
170. Carlos, K.S., de Jager, L.S., Begley, T.H. Investigation of the primary plasticisers present in polyvinyl chloride (PVC) products currently authorised as food contact materials. *Food Addit.* **2018**, *35*, 1214–1222. https://doi.org/10.1080/19440049.2018.1447695

171. Friday Etuk, I., Ekwere Inyang, U. Applications of Various Plasticizers in the Plastic Industry-Review. *IJEMT* **2024**, *10*, 38–55. https://doi.org/10.56201/ijemt.v10.no1.2024.pg38.54
172. Greco, A., Ferrari, F., Maffezzoli, A. UV and thermal stability of soft PVC plasticized with cardanol derivatives. *J. Clean. Prod.* **2017**, *164*, 757–764. https://doi.org/10.1016/j.jclepro.2017.07.009
173. He, Z., Lu, Y., Lin, C., Jia, H., Wu, H., Cao, F., Ouyang, P. Designing anti-migration furan-based plasticizers and their plasticization properties in poly (vinyl chloride) blends. *Polym. Test* **2020**, *91*, 106793. https://doi.org/10.1016/j.polymertesting.2020.106793
174. Sahnoune Millot, M., Devémy, J., Chennell, P., Pinguet, J., Dequidt, A., Sautou, V., Malfreyt, P. Leaching of plasticizers from PVC medical devices: A molecular interpretation of experimental migration data. *J. Mol. Liq.* **2024**, *396*, 123965. https://doi.org/10.1016/j.molliq.2024.123965
175. Cheng, Y., Miao, D., Kong, L., Jiang, J., Guo, Z. Preparation and Performance Test of the Super-Hydrophobic Polyurethane Coating Based on Waste Cooking Oil. *Coatings* **2019**, *9*, 861. https://doi.org/10.3390/coatings9120861
176. Feng, G., Ma, Y., Zhang, M., Jia, P., Liu, C., Zhou, Y. Synthesis of Bio-base Plasticizer Using Waste Cooking Oil and Its Performance Testing in Soft Poly(vinyl chloride) Films. *J. Bioresour. Bioprod.* **2019**, *4*, 99–110. https://doi.org/10.21967/jbb.v4i2.214
177. Jia, P., Ma, Y., Kong, Q., Xu, L., Hu, Y., Hu, L., Zhou, Y. Graft modification of polyvinyl chloride with epoxidized biomass-based monomers for preparing flexible polyvinyl chloride materials without plasticizer migration. *Mater. Today Chem.* **2019**, *13*, 49–58. https://doi.org/10.1016/j.mtchem.2019.04.010
178. Thirupathiah, G., Satapathy, S., Palanisamy, A. Studies on epoxidised castor oil as co-plasticizer with epoxidised soyabean oil for PVC processing. *J. Renew. Mater.* **2019**, *7*, 775–785. https://doi.org/10.32604/jrm.2019.06399
179. Cai, D.-L., Yue, X., Hao, B., Ma, P.-C. A sustainable poly(vinyl chloride) plasticizer derivated from waste cooking oil. *J. Clean. Prod.* **2020**, *274*, 122781. https://doi.org/10.1016/j.jclepro.2020.122781
180. Liu, D., Jiang, P., Nie, Z., Wang, H., Dai, Z., Deng, J., Cao, Z. Synthesis of an efficient bio-based plasticizer derived from waste cooking oil and its performance testing in PVC. *Polym. Test* **2020**, *90*, 106625. https://doi.org/10.1016/j.polymertesting.2020.106625
181. Ma, D.-X., Yin, G.-Z., Ye, W., Jiang, Y., Wang, N., Wang, D.-Y. Exploiting Waste towards More Sustainable Flame-Retardant Solutions for Polymers: A Review. *Materials* **2024**, *17*, 2266. https://doi.org/10.3390/ma17102266
182. Tan, J., Zhang, S., Lu, T., Li, R., Zhong, T., Zhu, X. Design and synthesis of ethoxylated esters derived from waste frying oil as anti-ultraviolet and efficient primary plasticizers for poly(vinyl chloride). *J. Clean. Prod.* **2019**, *229*, 1274–1282. https://doi.org/10.1016/j.jclepro.2019.04.395
183. Polaczek, K., Kurańska, M., Auguścik-Królikowska, M., Prociak, A., Ryszkowska, J. Open-cell polyurethane foams of very low density modified with various palm oil-based bio-polyols in accordance with cleaner production. *J. Clean. Prod.* **2021**, *290*, 125875. https://doi.org/10.1016/j.jclepro.2021.125875
184. Gadhave, R. V., Mahanwar, P.A., Gadekar, P.T. Bio-Renewable Sources for Synthesis of Eco-Friendly Polyurethane Adhesives—Review. *Open J. Polym. Chem.* **2017**, *7*, 57–75. https://doi.org/10.4236/ojpchem.2017.74005
185. Sarim, M., Alavi Nikje, M.M., Dargahi, M. Preparation and Characterization of Polyurethane Rigid Foam Nanocomposites from Used Cooking Oil and Perlite. *Int. J. Polym. Sci.* **2023**, 1–13. https://doi.org/10.1155/2023/7185367
186. Mangal, M., Rao, C.V., Banerjee, T. Bioplastic: an eco-friendly alternative to non-biodegradable plastic. *Polym Int.* **2023**, *72*, 984–996. https://doi.org/10.1002/pi.6555
187. Orjuela, A., Clark, J. Green chemicals from used cooking oils: Trends, challenges, and opportunities. *Curr. Opin. Green Sustain. Chem.* **2020**, *26*, 100369. https://doi.org/10.1016/j.cogsc.2020.100369
188. Salleh, W.N.F.W., Tahir, S.M., Mohamed, N.S. Synthesis of waste cooking oil-based polyurethane for solid polymer electrolyte. *Polymer Bulletin* **2018**, *75*, 109–120. https://doi.org/10.1007/s00289-017-2019-x
189. Sawpan, M.A. Polyurethanes from vegetable oils and applications: a review. *J. Polym. Res.* **2018**, *25*, 184. https://doi.org/10.1007/s10965-018-1578-3

190. Delavarde, A., Savin, G., Derkenne, P., Boursier, M., Morales-Cerrada, R., Nottelet, B., Pinaud, J., Caillol, S. Sustainable polyurethanes: toward new cutting-edge opportunities. *Prog. Polym. Sci.* **2024**, *151*, 101805. https://doi.org/10.1016/j.progpolymsci.2024.101805
191. Maulana, S., Wibowo, E.S., Mardawati, E., Iswanto, A.H., Papadopoulos, A., Lubis, M.A.R. Eco-Friendly and High-Performance Bio-Polyurethane Adhesives from Vegetable Oils: A Review. *Polymers* **2024**, *16*, 1613. https://doi.org/10.3390/polym16111613
192. Paciorek-Sadowska, J., Borowicz, M., Isbrandt, M., Czupryński, B., Apiecionek, Ł. The Use of Waste from the Production of Rapeseed Oil for Obtaining of New Polyurethane Composites. *Polymers* **2019**, *11*, 1431. https://doi.org/10.3390/polym11091431
193. Pu, M., Fang, C., Zhou, X., Wang, D., Lin, Y., Lei, W., Li, L. Recent Advances in Environment-Friendly Polyurethanes from Polyols Recovered from the Recycling and Renewable Resources: A Review. *Polymers* **2024**, *16*, 1889. https://doi.org/10.3390/polym16131889
194. Asare, M.A., de Souza, F.M., Gupta, R.K. Waste to Resource: Synthesis of Polyurethanes from Waste Cooking Oil. *Ind. Eng. Chem. Res.* **2022**, *61*, 18400–18411. https://doi.org/10.1021/acs.iecr.2c03718
195. Kurańska, M., Banaś, J., Polaczek, K., Banaś, M., Prociak, A., Kuc, J., Uram, K., Lubera, T. Evaluation of application potential of used cooking oils in the synthesis of polyol compounds. *J. Environ. Chem. Eng.* **2019**, *7*, 103506. https://doi.org/10.1016/j.jece.2019.103506
196. Malewska, E., Polaczek, K., Kurańska, M. Impact of Various Catalysts on Transesterification of Used Cooking Oil and Foaming Processes of Polyurethane Systems. *Materials* **2022**, *15*, 7807. https://doi.org/10.3390/ma15217807
197. Raofuddin, D.N.A., Azmi, I.S., Jalil, M.J. Catalytic Epoxidation of Oleic Acid Derived from Waste Cooking Oil by In Situ Peracids. J. Polym. Environ. **2024**, *32*, 803–814. https://doi.org/10.1007/s10924-023-02978-9
198. Sánchez, B.S., Benitez, B., Querini, C.A., Mendow, G. Transesterification of sunflower oil with ethanol using sodium ethoxide as catalyst. Effect of the reaction conditions. *Fuel Processing Technology* **2015**, *131*, 29–35. https://doi.org/10.1016/j.fuproc.2014.10.043
199. Kurańska, M., Malewska, E. Waste cooking oil as starting resource to produce bio-polyol - analysis of transesteryfication process using gel permeation chromatography. *Ind. Crops Prod.* **2021**, *162*, 113294. https://doi.org/10.1016/j.indcrop.2021.113294
200. Kurańska, M., Benes, H., Polaczek, K., Trhlikova, O., Walterova, Z., Prociak, A. Effect of homogeneous catalysts on ring opening reactions of epoxidized cooking oils. *J. Clean. Prod.* **2019**, *230*, 162–169. https://doi.org/10.1016/j.jclepro.2019.05.096
201. Skleničková, K., Abbrent, S., Halecký, M., Kočí, V., Beneš, H. Biodegradability and ecotoxicity of polyurethane foams: A review. *Crit. Rev. Environ. Sci. Technol.* **2022**, 157–202. https://doi.org/10.1080/10643389.2020.1818496
202. Haq, I. ul, Akram, A., Nawaz, A., Zohu, X., Abbas, S.Z., Xu, Y., Rafatullah, M. Comparative analysis of various waste cooking oils for esterification and transesterification processes to produce biodiesel. *Green Chem. Lett. Rev.* **2021**, 462–473. https://doi.org/10.1080/17518253.2021.1941305
203. Moreno, D., Velasco, M., Malagón-Romero, D. Production of polyurethanes from used vegetable oil-based polyols. *Chem. Eng. Trans.* **2020**, *79*, 337–342. https://doi.org/10.3303/CET2079057
204. Lubis, M., Prayogo, M.A., Harahap, M.B., Iriany, Ginting, M.H.S., Lazuardi, I.N., Akbar, R. The effect of fibre loading on characterization and mechanical properties of polyurethane foam composites derived waste cooking oil, polyol and toluene diisocyanate with adding filler sugar palm (Arenga pinnata) fibre. *IOP Conf. Ser. Mater. Sci. Eng.* **2021**, *1122*, 012109. https://doi.org/10.1088/1757-899x/1122/1/012109
205. Paraskar, P.M., Prabhudesai, M.S., Hatkar, V.M., Kulkarni, R.D. Vegetable oil based polyurethane coatings – A sustainable approach: A review. *Prog. Org. Coat.* **2021**, *156*, 106267. https://doi.org/10.1016/j.porgcoat.2021.106267
206. Silva, R., Barros-Timmons, A., Quinteiro, P. Life cycle assessment of fossil- and bio-based polyurethane foams: a review. *J. Clean. Prod.* **2023**, *430*, 139697. https://doi.org/10.1016/j.jclepro.2023.139697

207. Castro-Osma, J.A., Martínez, J., de la Cruz-Martínez, F., Caballero, M.P., Fernández-Baeza, J., Rodríguez-López, J., Otero, A., Lara-Sánchez, A., Tejeda, J. Development of hydroxy-containing imidazole organocatalysts for CO2 fixation into cyclic carbonates. *Catal. Sci. Technol.* **2018**, *8*, 1981–1987. https://doi.org/10.1039/C8CY00381E
208. Werlinger, F., Caballero, M.P., Trofymchuk, O.S., Flores, M.E., Moreno-Villoslada, I., Cruz-Martínez, F. de la, Castro-Osma, J.A., Tejeda, J., Martínez, J., Lara-Sánchez, A. Turning waste into resources. Efficient synthesis of biopolyurethanes from used cooking oils and CO2. *J. CO2 Util.* **2024**, *79*, 102659. https://doi.org/10.1016/j.jcou.2023.102659
209. Onn, M., Mustafa, H., Azman, H.A., Ahmad, Z., Wahit, M.U. Synthesis and Characterization of Photocrosslinkable Acrylic Prepolymers from Waste Palm Frying Oil. *Chem. Eng. Trans.* **2023**, *106*, 379–384. https://doi.org/10.3303/CET23106064
210. Wu, B., Sufi, A., Ghosh Biswas, R., Hisatsune, A., Moxley-Paquette, V., Ning, P., Soong, R., Dicks, A.P., Simpson, A.J. Direct Conversion of McDonald's Waste Cooking Oil into a Biodegradable High-Resolution 3D-Printing Resin. *ACS Sustain. Chem. Eng.* **2020**, *8*, 1171–1177. https://doi.org/10.1021/acssuschemeng.9b06281
211. Wu, W., Deng, X., Tian, S., Wang, S., He, Y., Zheng, B., Xin, K., Zhou, Z., Tang, L. Whole-Waste synthesis of Kilogram-Scale Macropores adsorbent materials for Wide-Range oil and heavy metal removal. *Sep. Purif. Technol.* **2025**, *354*, 128750. https://doi.org/10.1016/j.seppur.2024.128750
212. Voet, V.S.D., Guit, J., Loos, K. Sustainable Photopolymers in 3D Printing: A Review on Biobased, Biodegradable, and Recyclable Alternatives. *Macromol. Rapid Commun.* **2021**, 42. https://doi.org/10.1002/marc.202000475
213. Heriyanto, H., Suhendi, E., Asyuni, N.F., Shahila, I.K. Effect of Bayah natural zeolite for purification of waste cooking oil as feedstock of alkyd resin. Teknika: *Jurnal. Sains dan Teknologi.* **2022**, *18*, 49. https://doi.org/10.36055/tjst.v18i1.15542
214. Silvianti, F., Wijayanti, W., Sudjarwo, W.A.A., Dewi, W.B. Synthesis of Alkyd Resin Modified with Waste Palm Cooking Oil as Precursor Using Pretreatment with Zeolite Adsorbent. *Sci. Technol. Indonesia* **2018**, *3*, 119–122. https://doi.org/10.26554/sti.2018.3.3.119-122
215. Markets and Markets, **2024**. Epoxy resin market by physical form, raw materilas, application, end-use industry and region- global forecast to 2028. https://www.marketsandmarkets.com/Market-Reports/epoxy-resins-market-762.html
216. Jaengmee, T., Pongmuksuwan, P., Kitisatorn, W. Development of bio-based epoxy resin from palm oil. *Mater. Today Proc.* **2022**, *52*, 2357–2360. https://doi.org/10.1016/j.matpr.2021.10.059
217. Chong, K.L., Lai, J.C., Rahman, R.A., Adrus, N., Al-Saffar, Z.H., Hassan, A., Lim, T.H., Wahit, M.U. A review on recent approaches to sustainable bio-based epoxy vitrimer from epoxidized vegetable oils. *Ind. Crops Prod.* **2022**, *189*, 115857. https://doi.org/10.1016/j.indcrop.2022.115857
218. Gonçalves, F.A.M.M., Santos, M., Cernadas, T., Ferreira, P., Alves, P. Advances in the development of biobased epoxy resins: insight into more sustainable materials and future applications. *Int. Mater. Rev.* **2022**, 119–149. https://doi.org/10.1080/09506608.2021.1915936
219. Fernandes, F.C., Kirwan, K., Wilson, P.R., Coles, S.R. Sustainable Alternative Composites Using Waste Vegetable Oil Based Resins. *J. Polym. Environ.* **2019**, *27*, 2464–2477. https://doi.org/10.1007/s10924-019-01534-8
220. Wang, Z., Pei, Q., Li, K., Wang, Zhonghui, Huo, X., Wang, Y., Zhang, X., Kong, S. Molecular Dynamics Simulation of the Rejuvenation Performance of Waste Cooking Oil with High Acid Value on Aged Asphalt. *Molecules* **2024**, *29*, 2830. https://doi.org/10.3390/molecules29122830
221. Xu, N., Wang, Hainian, Wang, Huimin, Kazemi, M., Fini, E. Research progress on resource utilization of waste cooking oil in asphalt materials: A state-of-the-art review. J. Clean. Prod. **2023**, *385*, 135427. https://doi.org/10.1016/j.jclepro.2022.135427
222. Baranowska, W., Rzepna, M., Ostrowski, P., Lewandowska, H. Radiation and Radical Grafting Compatibilization of Polymers for Improved Bituminous Binders—A Review. *Materials* **2024**, *17*, 1642. https://doi.org/10.3390/ma17071642

223. Chamaa, A., Khatib, J., Elkordi, A. A review on the use of vegetable oil and its waste in construction applications. *BAU Journal - Science and Technology* **2020**, 1. https://doi.org/10.54729/2959-331X.1005
224. Chandrasekar, M., Kavitha Kathikeyan, S., Snekha, G., Vinothini, A. Experimental Investigation on Usage of Waste Cooking Oil (WCO) in Concrete Making and Adopting Innovative Curing Method. International Journal of Engineering Research and V5 **2016**. https://doi.org/10.17577/IJERTV5IS040276
225. Jain, S., Chandrappa, A.K. Influence of Blended Waste Cooking Oils on the Sustainable Asphalt Rejuvenation Considering Secondary Aging. International Journal of Pavement Research and Technology **2024**. https://doi.org/10.1007/s42947-023-00408-6
226. Uz, V.E., Gökalp, İ. Sustainable recovery of waste vegetable cooking oil and aged bitumen: Optimized modification for short and long term aging cases. *Waste Management* **2020**, *110*, 1–9. https://doi.org/10.1016/j.wasman.2020.05.012
227. Wang, Y., Su, J., Liu, L., Liu, Z., Sun, G. Waste cooking oil based capsules for sustainable self-healing asphalt pavement: Encapsulation, characterization and fatigue-healing performance. *Constr. Build. Mater.* **2024**, *425*, 136032. https://doi.org/10.1016/j.conbuildmat.2024.136032
228. Ji, H., Li, B., Li, X., Han, J., Liu, D., Dou, H., Fu, M., Yao, T. Waste cooking oil as a sustainable solution for UV-aged asphalt binder: Rheological, chemical and molecular structure. *Constr. Build. Mater.* **2024**, *420*, 135149. https://doi.org/10.1016/j.conbuildmat.2024.135149
229. Mamun, A. Al, Wahhab, H.I.A.-A., Dalhat, M.A. Comparative laboratory evaluation of waste cooking oil rejuvenated asphalt concrete mixtures for high contents of reclaimed asphalt pavement. *Int. J. Pavement Eng.* **2020**, *21*, 1297–1308. https://doi.org/10.1080/10298436.2018.1539486
230. Taherkhani, H., Noorian, F. Laboratory investigation on the properties of asphalt concrete containing reclaimed asphalt pavement and waste cooking oil as recycling agent. *Int. J. Pavement Eng.* **2021**, *22*, 539–549. https://doi.org/10.1080/10298436.2019.1626387
231. Al-Omari, A.A., Khedaywi, T.S., Khasawneh, M.A. Laboratory characterization of asphalt binders modified with waste vegetable oil using SuperPave specifications. *Int. J. Pavement Res. Techn.* **2018**, *11*, 68–76. https://doi.org/10.1016/j.ijprt.2017.09.004
232. Jalkh, R., El-Rassy, H., Chehab, G.R., Abiad, M.G. Assessment of the Physico-Chemical Properties of Waste Cooking Oil and Spent Coffee Grounds Oil for Potential Use as Asphalt Binder Rejuvenators. *Waste Biomass Valorization* **2018**, *9*, 2125–2132. https://doi.org/10.1007/s12649-017-9984-z
233. Ahmed, R.B., Hossain, K. Waste cooking oil as an asphalt rejuvenator: A state-of-the-art review. *Constr. Build. Mater.* **2020**, *230*, 116985. https://doi.org/10.1016/j.conbuildmat.2019.116985
234. Elahi, Z., Mohd Jakarni, F., Muniandy, R., Hassim, S., Ab Razak, M.S., Ansari, A.H., Ben Zair, M.M. Waste Cooking Oil as a Sustainable Bio Modifier for Asphalt Modification: A Review. *Sustainability* **2021**, *13*, 11506. https://doi.org/10.3390/su132011506
235. Elahi, Z., Jakarni, F.M., Muniandy, R., Hassim, S., Ab Razak, M.S., Ansari, A.H. Influence of novel modified waste cooking oil beads on rheological characteristics of bitumen. *Constr. Build. Mater.* **2024**, *414*, 134829. https://doi.org/10.1016/j.conbuildmat.2023.134829
236. Zahoor, M., Nizamuddin, S., Madapusi, S., Giustozzi, F. Sustainable asphalt rejuvenation using waste cooking oil: A comprehensive review. *J. Clean. Prod.* **2021**, *278*, 123304. https://doi.org/10.1016/j.jclepro.2020.123304
237. Alkuime, H., Kassem, E., Alshraiedeh, K.A., Bustanji, M., Aleih, A., Abukhamseh, F. Performance Assessment of Waste Cooking Oil-Modified Asphalt Mixtures. *Applied Sciences* **2024**, *14*, 1228. https://doi.org/10.3390/app14031228
238. Chen, M., Xiao, F., Putman, B., Leng, B., Wu, S. High temperature properties of rejuvenating recovered binder with rejuvenator, waste cooking and cotton seed oils. *Constr. Build. Mater.* **2014**, *59*, 10–16. https://doi.org/10.1016/j.conbuildmat.2014.02.032
239. Huo, Y., Dong, X., Gao, Y., Xu, X., Zeng, L., Wu, Y., Zhao, Y., Yang, Y., Su, Q., Huang, J., Lu, D. Effects of cooking oil on the shrinkage-reducing of high-strength concrete. *Results in Materials* **2024**, *23*, 100602. https://doi.org/10.1016/j.rinma.2024.100602

240. Joni, H.H., Al-Rubaee, R.H.A., Al-zerkani, M.A. Rejuvenation of aged asphalt binder extracted from reclaimed asphalt pavement using waste vegetable and engine oils. Case Studies in Construction *Materials* **2019**, *11*, e00279. https://doi.org/10.1016/j.cscm.2019.e00279
241. Xinxin, C., Xuejuan, C., Boming, T., Yuanyuan, W., Xiaolong, L. Investigation on Possibility of Waste Vegetable Oil Rejuvenating Aged Asphalt. *Applied Sciences* **2018**, *8*, 765. https://doi.org/10.3390/app8050765
242. Azahar, W.N.A.W., Jaya, R.P., Hainin, M.R., Bujang, M., Ngadi, N. Mechanical performance of asphaltic concrete incorporating untreated and treated waste cooking oil. *Constr. Build. Mater.* **2017**, *150*, 653–663. https://doi.org/10.1016/j.conbuildmat.2017.06.048
243. Oldham, D., Rajib, A., Dandamudi, K.P.R., Liu, Y., Deng, S., Fini, E.H. Transesterification of Waste Cooking Oil to Produce A Sustainable Rejuvenator for Aged Asphalt. *Resour. Conserv. Recy.* **2021**, *168*, 105297. https://doi.org/10.1016/j.resconrec.2020.105297
244. Sun, Z., Yi, J., Huang, Y., Feng, D., Guo, C. Properties of asphalt binder modified by bio-oil derived from waste cooking oil. *Constr. Build. Mater.* **2016**, *102*, 496–504. https://doi.org/10.1016/j.conbuildmat.2015.10.173
245. Enfrin, M., Gowda, A., Giustozzi, F. Low-cost chemical modification of refined used cooking oil to produce long-lasting bio-asphalt pavements. *Resour. Conserv. Recycl.* **2024**, *204*, 107493. https://doi.org/10.1016/j.resconrec.2024.107493
246. Yi, X., Dong, R., Shi, C., Yang, J., Leng, Z. The influence of the mass ratio of crumb rubber and waste cooking oil on the properties of rubberised bio-rejuvenator and rejuvenated asphalt. *Road Mater. Pavement Des.* **2023**, *24*, 578–591. https://doi.org/10.1080/14680629.2022.2041070
247. Liu, Y., Yu, Z., Lv, C., Meng, F., Yang, Y. Preparation of waste cooking oil emulsion as shrinkage reducing admixture and its potential use in high performance concrete: Effect on shrinkage and mechanical properties. *J. Build. Eng.* **2020**, *32*, 101488. https://doi.org/10.1016/j.jobe.2020.101488
248. Tarnpradab, T., Unyaphan, S., Takahashi, F., Yoshikawa, K. Tar removal capacity of waste cooking oil absorption and waste char adsorption for rice husk gasification. *Biofuels* **2016**, *7*, 401–412. https://doi.org/10.1080/17597269.2016.1147919
249. Cappello, M., Brunazzi, E., Rossi, D., Seggiani, M. Absorption of n-butyl acetate from tannery air emissions by waste vegetable oil/water emulsions. *J. Environ. Chem. Eng.* **2024**, *12*, 112443. https://doi.org/10.1016/j.jece.2024.112443
250. Dong, R., Zhao, M., Tang, N. Characterization of crumb tire rubber lightly pyrolyzed in waste cooking oil and the properties of its modified bitumen. *Constr. Build. Mater.* **2019**, *195*, 10–18. https://doi.org/10.1016/j.conbuildmat.2018.11.044
251. Aldagari, S., Kabir, S.F., Lamanna, A., Fini, E.H. Functionalized Waste Plastic Granules to Enhance Sustainability of Bituminous Composites. *Resour. Conserv. Recycl.* **2022**, *183*, 106353. https://doi.org/10.1016/j.resconrec.2022.106353
252. Mousavi, M., Fini, E.H. Preventing emissions of hazardous organic compounds from bituminous composites. *J. Clean. Prod.* **2022**, *344*, 131067. https://doi.org/10.1016/j.jclepro.2022.131067
253. Yi, X., Dong, R., Tang, N. Development of a novel binder rejuvenator composed by waste cooking oil and crumb tire rubber. *Constr. Build. Mater.* **2020**, *236*, 117621. https://doi.org/10.1016/j.conbuildmat.2019.117621
254. Gallart-Sirvent, P., Martín, M., Villorbina, G., Balcells, M., Solé, A., Barrenche, C., Cabeza, L.F., Canela-Garayoa, R. Fatty acid eutectic mixtures and derivatives from non-edible animal fat as phase change materials. *RSC Adv.* **2017**, *7*, 24133–24139. https://doi.org/10.1039/C7RA03845C
255. Kahwaji, S., White, M.A. Edible Oils as Practical Phase Change Materials for Thermal Energy Storage. *Applied Sciences* **2019**, *9*, 1627. https://doi.org/10.3390/app9081627
256. Afonso, I.S., Nobrega, G., Lima, R., Gomes, J.R., Ribeiro, J.E. Conventional and Recent Advances of Vegetable Oils as Metalworking Fluids (MWFs): A Review. *Lubricants* **2023**, *11*, 160. https://doi.org/10.3390/lubricants11040160
257. Landi, F.A.F., Fabiani, C., Pisello, A.L. Palm oil for seasonal thermal energy storage applications in buildings: The potential of multiple melting ranges in blends of bio-based fatty acids. *J. Energy Storage* **2020**, *29*, 101431. https://doi.org/10.1016/j.est.2020.101431

 doi:10.20944/preprints202501.0911.v1

258. Chen, D., Chen, M., Zhao, Y., Zhang, Y., Wu, Y., Zhang, J., Yang, X. Waste cooking oil applicable phase change capsules to improve thermoregulation of foamed concrete. *Constr. Build. Mater.* **2024**, *432*, 136538. https://doi.org/10.1016/j.conbuildmat.2024.136538
259. Irsyad, M., Amrizal, Harmen, Amrul, Susila Es, M.D., Diva Putra, A.R. Experimental study of the thermal properties of waste cooking oil applied as thermal energy storage. *Results in Engineering* **2023**, *18*, 101080. https://doi.org/10.1016/j.rineng.2023.101080
260. Okogeri, O., Stathopoulos, V.N. What about greener phase change materials? A review on biobased phase change materials for thermal energy storage applications. *Int. J. Thermofluids* 2021, 10, 100081. https://doi.org/10.1016/j.ijft.2021.100081
261. Gatto, V., Conca, S., Bardella, N., Beghetto, V. Efficient Triazine Derivatives for Collagenous Materials Stabilization. *Materials* **2021**, *14*, 3069. https://doi.org/10.3390/ma14113069
262. Zhao, Y., Chen, M., Wu, S., Xu, H., Wan, P., Zhang, J. Preparation and characterization of phase change capsules containing waste cooking oil for asphalt binder thermoregulation. *Constr. Build. Mater.* **2023**, *395*, 132311. https://doi.org/10.1016/j.conbuildmat.2023.132311