Waste Lipids Conversion to Sustainable Aviation Fuel

Chuhan Fu*, Lu Liu

Training Center, Guangdong Food and Drug Vocational Technical School, Guangzhou 510663, China

Abstract: The decarbonization of the aviation sector requires scalable, drop-in sustainable aviation fuels (SAFs) capable of meeting stringent performance specifications while achieving substantial lifecycle greenhouse gas reductions. Among certified SAF pathways, the upgrading of waste lipids—such as used cooking oil, animal fats, and acid oils—via catalytic hydroprocessing has emerged as the most technologically mature and commercially deployed solution. Owing to their intrinsic molecular similarity to long-chain hydrocarbons, triglycerides and free fatty acids provide a structurally favorable platform for jet fuel production. However, compositional heterogeneity, high free fatty acid content, contaminant-induced catalyst deactivation, and hydrogen-intensive deoxygenation pose significant upgrading challenges. Catalytic conversion toward jet-range hydrocarbons involves an integrated network of hydrogenation, hydrodeoxygenation, decarboxylation/decarbonylation, hydroisomerization, and selective hydrocracking reactions. Balancing hydrogen efficiency, carbon retention, and product selectivity within the C8–C16 range is central to achieving aviation-grade fuel specifications. Advances in multifunctional metal–acid catalysts, hierarchical porous materials, and hydrogen management strategies are improving jet fuel yield and process stability. Although feedstock availability limits long-term scalability, waste lipid valorization provides a critical near-term pathway for aviation decarbonization and serves as a technological foundation for future SAF innovations. Continued progress in catalyst design, renewable hydrogen integration, and process intensification will determine its evolving role within a low-carbon aviation ecosystem.

Keywords: Waste Lipids; Sustainable Aviation Fuel (SAF); Hydroprocessed Esters and Fatty Acids (HEFA); Hydrocracking; Jet-range Hydrocarbons

DOI: 10.57237/j.cse.2026.01.002

1 Introduction

The aviation sector is widely recognized as one of the most challenging domains to decarbonize within the global energy transition [1, 2]. Unlike ground transportation, which can progressively electrify, long-haul aviation remains fundamentally dependent on liquid hydrocarbon fuels due to stringent requirements for high gravimetric energy density, thermal stability, low freezing point, and compatibility with existing turbine engines and fuel infrastructure [3]. Consequently, sustainable aviation fuel (SAF) has emerged as the most realistic near- and mid-term pathway to reduce lifecycle greenhouse gas (GHG) emissions from aviation [4]. Among the various SAF production routes certified under ASTM D7566, the conversion of waste lipids into hydrocarbon jet fuel through the hydroprocessed esters and fatty acids (HEFA) pathway has achieved the highest level of technological maturity and commercial deployment [5].

Waste lipids—including used cooking oil (UCO), waste animal fats, trap grease, soapstock, and acid oils—represent an especially attractive feedstock class [6]. Unlike first-generation vegetable oils derived from soybean, palm, or rapeseed, waste lipids do not directly compete with food

*Corresponding author: Chuhan Fu, 815526370@qq.com

Received: 27 February 2026; Accepted: 19 March 2026; Published Online: 20 March 2026 http://www.chemscieng.com

supply chains or agricultural land use [7]. Their utilization therefore mitigates indirect land-use change concerns and enhances the overall carbon intensity reduction of the fuel [8]. From a molecular standpoint, these feedstocks are composed primarily of triglycerides and free fatty acids (FFAs) [9], which contain long aliphatic carbon chains (typically C16–C18) already within the range required for jet-fuel hydrocarbons [10]. This structural proximity to petroleum-derived paraffins significantly lowers the extent of carbon–carbon bond reconstruction needed during upgrading [11–13], thereby improving theoretical carbon efficiency relative to carbohydrate- or lignocellulose-based pathways [14, 15].

Commercial implementation of waste lipid upgrading has been led by companies such as Neste and World Energy [16, 17], which have demonstrated that lipid hydroprocessing can be integrated into existing refinery infrastructure. The compatibility of HEFA technology with conventional hydrotreating units allows relatively rapid scale-up compared with emerging routes such as alcohol-to-jet (ATJ) [18, 19] or Fischer–Tropsch synthesis from gasified biomass [20, 21]. As a result, waste lipid–derived SAF currently constitutes the dominant share of global SAF production capacity [22, 23].

Despite these advantages, the transformation of heterogeneous waste lipids into specification-compliant aviation fuel is far from trivial [24]. Waste-derived feedstocks often exhibit high variability in free fatty acid content, water concentration, trace metals (Na, K, Ca, Mg), sulfur compounds, and oxidative degradation products [25, 26]. These impurities can poison active metal sites [27, 28], accelerate coke formation [29], and shorten catalyst lifetime. Moreover, triglycerides must undergo sequential hydrogenation [30], C–O bond cleavage [31], propane removal [32], and hydroisomerization to yield branched iso-paraffins with sufficiently low freezing points (typically below –47 ℃ for Jet A-1) [33]. Achieving these transformations with high carbon efficiency while minimizing hydrogen consumption remains a central catalytic challenge [34].

At the reaction-network level, waste lipid conversion involves a complex interplay among hydrodeoxygenation, decarboxylation, decarbonylation, hydrocracking, and skeletal isomerization pathways [35]. Each elementary route carries trade-offs between hydrogen demand, carbon retention, product selectivity, and energy efficiency. For instance, hydrodeoxygenation preserves carbon number but requires substantial hydrogen input [36], whereas decarboxylation reduces hydrogen consumption at the expense of carbon loss as CO_2 [37]. The subsequent isomerization and controlled hydrocracking steps must then tailor the molecular architecture to satisfy aviation fuel specifications without excessive formation of light gases [38].

Therefore, the upgrading of waste lipids into aviation fuel sits at the intersection of catalysis science, reaction engineering, refinery integration, and sustainability assessment. Continued advances in multifunctional catalyst design, hydrogen management, and feedstock pretreatment will be essential to enhance economic viability and carbon performance. As global aviation demand rebounds and decarbonization targets tighten, waste lipid valorization stands as both a practical solution for immediate emission reductions and a platform for future catalytic innovation.

2 Feedstock Characteristics and Upgrading Challenges

Waste lipids constitute a highly heterogeneous class of renewable carbon resources, encompassing used cooking oil (UCO), waste animal fats (tallow, lard, poultry fat), brown grease from wastewater treatment systems, soapstock from vegetable oil refining, and acid oils generated during chemical processing [39]. Unlike refined vegetable oils with relatively uniform composition, these materials originate from diverse collection networks and undergo varying degrees of thermal oxidation, hydrolysis, and contamination during use and storage [40]. As a result, their physicochemical properties—acid value, moisture content, metal concentration, degree of unsaturation, and polymerized residue fraction—can fluctuate substantially from batch to batch. This compositional variability presents one of the most critical barriers to stable catalytic upgrading toward aviation fuel [41].

At the molecular level, waste lipids are primarily composed of triglycerides and free fatty acids (FFAs), with carbon chain lengths typically in the C14–C22 range and a predominance of C16 and C18 species. The fatty acid profile often includes palmitic acid (C16:0) [42], stearic acid (C18:0) [43], oleic acid (C18:1) [44], and linoleic acid (C18:2) [45], though the relative distribution depends strongly on the original feedstock and cooking history. The presence of unsaturated C=C bonds has dual implications. On the one hand, hydrogenation of these double bonds is relatively facile and can enhance fuel stability. On the other hand, polyunsaturated species are more prone to thermal

polymerization and oxidative degradation, forming high-molecular-weight oligomers that contribute to coke precursors during hydrotreating [46]. Consequently, understanding the unsaturation degree is essential for predicting hydrogen demand and catalyst deactivation trends.

One defining characteristic of many waste lipid streams is their elevated free fatty acid content [47]. While refined edible oils typically contain less than 1 wt.% FFA, waste-derived materials may contain 10–80 wt.% FFA, particularly in acid oils and trap grease [48]. High FFA levels significantly influence process design. In ester-based feedstocks, triglycerides must first undergo hydrogenolysis to release fatty acids and propane, whereas FFA-rich streams bypass this step but introduce higher corrosivity and potential acid-catalyzed side reactions [6]. Moreover, FFAs readily form soaps in the presence of alkaline metals, complicating separation and pretreatment [49–51]. From a catalytic standpoint, FFAs can adsorb strongly on active metal sites [22], altering surface coverage and affecting selectivity between hydrodeoxygenation (HDO), decarboxylation (DCO_2), and decarbonylation (DCO) pathways.

Impurities represent an equally critical challenge [52]. Waste lipids frequently contain water (0.1–5 wt.% or higher), suspended solids, phospholipids, and trace metals such as Na, K, Ca, Mg, and Fe. Even ppm-level concentrations of alkali and alkaline earth metals can poison sulfided hydrotreating catalysts by neutralizing acid sites or forming stable surface compounds. Phosphorus-containing species are particularly detrimental, as they irreversibly deactivate active metal phases and reduce catalyst lifetime [53]. In addition, chlorine and sulfur impurities may induce corrosion or alter the sulfidation state of catalysts [54]. Therefore, rigorous pretreatment—degumming, filtration, adsorption, and drying—is often required before catalytic upgrading. However, each additional pretreatment step increases operational cost and energy consumption, thereby influencing overall process economics [55].

Another intrinsic upgrading challenge arises from the mismatch between fatty acid carbon numbers and jet fuel specifications [56]. Most waste lipids are rich in C16–C18 chains, whereas aviation fuels ideally consist of hydrocarbons in the C8–C16 range with controlled branching [29]. Direct hydrodeoxygenation of C18 fatty acids yields predominantly n-C18 paraffins (or n-C17 via decarboxylation), which exhibit high freezing points and poor cold-flow properties. Thus, subsequent hydroisomerization and selective hydrocracking are mandatory to tailor chain length and introduce branching [57]. Achieving this transformation without excessive overcracking to light gases (C1–C4) requires precise tuning of metal–acid balance, pore structure, and reaction severity [58]. Diffusion limitations within microporous catalysts can further exacerbate secondary cracking and coke formation, especially when processing heavy or partially polymerized waste lipid fractions.

Hydrogen consumption constitutes another major upgrading constraint [59]. Hydrodeoxygenation theoretically requires three moles of hydrogen per mole of fatty acid to fully remove oxygen as water, in addition to hydrogen for double-bond saturation and hydrocracking. In large-scale facilities, hydrogen supply often dominates operational expenditure and carbon intensity. While decarboxylation and decarbonylation pathways reduce hydrogen demand, they incur carbon loss as CO_2 or CO and may alter heat management within the reactor [41]. Optimizing hydrogen efficiency while maintaining high carbon retention and jet-range selectivity is therefore a central design objective [60]. The integration of renewable hydrogen [61], membrane reactors [51], or alternative deoxygenation strategies may play a decisive role in future process improvements [62, 63].

Thermal stability and storage behavior of waste lipids also influence upgrading performance. Prolonged storage under ambient conditions promotes oxidation [64], increasing peroxide value and generating aldehydes, ketones, and polymeric species. These compounds not only complicate reaction networks but also accelerate coke deposition on catalyst surfaces. In continuous fixed-bed reactors [65], coke accumulation leads to pressure drop, loss of active surface area, and shortened cycle length. Developing coke-resistant catalysts with enhanced hydrogenation capability or hierarchical porosity is therefore essential for maintaining long-term stability under realistic feedstock conditions.

3 Catalytic Pathways Toward Jet-range Hydrocarbons

The catalytic upgrading of waste lipids into jet-range hydrocarbons involves a cascade of interconnected reactions that collectively remove oxygen, tailor carbon-chain length, and engineer molecular architecture to meet aviation fuel specifications [5]. Unlike conventional petroleum refining—where hydrocarbons are already oxygen-free—the transformation of triglycerides and free fatty acids requires selective C–O bond cleavage while preserving as much carbon backbone as possible [66]. Simultaneously, the final

product must exhibit appropriate volatility, low freezing point, high thermal stability, and compatibility with turbine engines. Therefore, catalytic pathways toward jet fuel are inherently multifunctional, integrating hydrogenation, deoxygenation, cracking, and isomerization within carefully designed reaction environments [5].

The most established pathway is the hydroprocessed esters and fatty acids (HEFA) route [67]. In this process, triglycerides first undergo hydrogenation of unsaturated C=C bonds over supported transition metal catalysts such as sulfided NiMo or CoMo [68]. This step stabilizes the feed and suppresses polymerization reactions. Subsequently, C–O bond cleavage proceeds via three principal routes: hydrodeoxygenation (HDO), decarboxylation (DCO_2), and decarbonylation (DCO) [22]. HDO removes oxygen as water and retains the carbon number of the fatty acid, yielding n-paraffins (e.g., C18 fatty acid to n-C18). In contrast, DCO_2 and DCO release CO_2 or CO, producing n-C17 hydrocarbons from C18 fatty acids [69]. The relative contribution of these pathways depends on catalyst composition, hydrogen partial pressure, temperature, and feed acidity. Sulfided catalysts under high hydrogen pressure generally favor HDO [70], while noble-metal catalysts or lower hydrogen environments promote decarboxylation routes [71].

From a thermodynamic and kinetic perspective, the competition among HDO, DCO, and DCO_2 directly influences hydrogen consumption and carbon efficiency. HDO is hydrogen-intensive but maximizes carbon retention [72], whereas decarboxylation reduces hydrogen demand at the cost of carbon loss [73]. In industrial HEFA plants, process optimization seeks a balance between these pathways to minimize hydrogen cost while maintaining acceptable carbon yield. Reaction temperatures typically range from 300–400 ℃, with hydrogen pressures between 3–10 MPa. Under these conditions, glycerol backbones are hydrogenolyzed to propane [74], which can be recovered as a valuable co-product. The resulting long-chain n-paraffins, however, exhibit poor cold-flow properties and must undergo further upgrading before meeting jet fuel standards [75].

Hydroisomerization constitutes the next critical catalytic step [76]. Aviation fuels require freezing points below –47 ℃ (Jet A-1 specification), which cannot be achieved with linear paraffins due to their high crystallization tendency. Bifunctional catalysts combining metallic hydrogenation sites (e.g., Pt, Pd, or Ni) with acidic supports (e.g., SAPO-11, β-zeolite, or amorphous silica–alumina) enable skeletal isomerization via a classical metal–acid mechanism [38]. On the metal site, paraffins dehydrogenate to form olefins, which migrate to Brønsted acid sites where carbenium ion intermediates undergo hydride shifts and methyl branching [77]. Subsequent hydrogenation on metal sites stabilizes the branched iso-paraffins. Controlling acid strength and pore topology is crucial: excessive acidity induces overcracking [29], while insufficient acidity limits branching. Medium-pore molecular sieves such as SAPO-11 are often preferred because they promote mono-branched isomers with minimal cracking, thereby preserving jet-range carbon distribution.

In addition to isomerization, selective hydrocracking is often necessary to adjust carbon-chain length [41]. Since waste lipids predominantly yield C16–C18 hydrocarbons after deoxygenation, controlled cracking is required to generate C8–C16 fractions characteristic of aviation fuel [78]. Hydrocracking occurs through β-scission of carbenium ions formed on acidic sites. The extent of cracking depends on temperature, acidity, and residence time [38]. A delicate balance must be achieved: insufficient cracking produces heavy diesel-range hydrocarbons, whereas excessive cracking yields gasoline-range or light gaseous products, reducing jet fuel yield [31]. Hierarchical zeolites with mesoporous networks have gained attention because they alleviate diffusion limitations and reduce secondary cracking, thereby improving selectivity toward the desired carbon window [79].

Beyond conventional sulfided catalysts, noble-metal systems (e.g., Pt, Pd, Ru) supported on oxides or zeolites have been explored for sulfur-free processing [80, 81]. These catalysts eliminate the need for sulfiding agents and reduce sulfur contamination in products. However, they are more sensitive to feed impurities and may suffer from sintering or metal leaching under hydrothermal conditions [82]. Recent research has focused on tailoring metal–support interactions to stabilize small metal nanoparticles and enhance resistance to deactivation [83]. For instance, strong metal–support interactions (SMSI) in reducible oxides such as TiO_2 or CeO_2 can modify electronic properties and promote selective decarboxylation pathways [31]. Meanwhile, bimetallic catalysts (e.g., Ni–Mo, Ni–W, Pt-Re) are being investigated to exploit synergistic effects that improve hydrogenation activity and suppress coke formation [84, 85].

An emerging area of interest is the development of multifunctional single-reactor systems that integrate deoxygen-

ation, isomerization, and cracking in one step [86]. Traditionally, HEFA processes employ sequential reactors—first hydrotreating, then hydroisomerization. Integrating these functions could reduce capital expenditure and energy consumption [87]. However, combining metal and acid functionalities in a single catalyst introduces challenges in balancing reaction rates. If deoxygenation proceeds too slowly relative to acid-catalyzed cracking, oxygenates may polymerize and form coke. Conversely, rapid deoxygenation without sufficient isomerization yields linear paraffins unsuitable for jet fuel. Rational catalyst architecture—such as core–shell structures or spatially separated active sites—has been proposed to address these kinetic mismatches.

Alternative catalytic strategies are also under exploration. One approach involves partial deoxygenation followed by aromatization to introduce controlled aromatic content [88]. Aromatics contribute to seal swelling in aircraft fuel systems and improve volumetric energy density. Tandem dehydrocyclization over metal–acid catalysts can convert long-chain paraffins into alkylbenzenes and cycloalkanes. However, excessive aromatization reduces hydrogen content and may compromise thermal stability. Thus, careful modulation of dehydrogenation and cyclization activity is required. Another strategy integrates lipid upgrading with light olefin streams, enabling alkylation reactions that adjust molecular structure and diversify product distribution [89].

Reaction mechanism studies using isotopic labeling and operando spectroscopy have provided insights into intermediate species and rate-determining steps [90]. For example, infrared spectroscopy reveals that fatty acids adsorb on metal surfaces through carboxylate species prior to C–O cleavage. Density functional theory (DFT) calculations indicate that hydrogen-assisted C–O bond scission barriers depend strongly on metal identity and surface coverage [22].

Hydrogen management remains a cross-cutting theme across all catalytic pathways [59]. Since hydrogen production often accounts for a significant fraction of lifecycle emissions, improving hydrogen efficiency directly enhances sustainability performance. Strategies include operating under conditions favoring decarboxylation to reduce hydrogen demand, integrating renewable hydrogen from electrolysis [91, 92], or exploring catalytic transfer hydrogenation using hydrogen-donor solvents [93]. Each approach introduces trade-offs in carbon yield, reactor complexity, and economic feasibility. Consequently, hydrogen integration must be considered holistically within the broader refinery or biorefinery context.

4 Conclusion and Outlook

The catalytic upgrading of waste lipids into jet-range hydrocarbons represents one of the most technologically mature and commercially implemented pathways toward sustainable aviation fuel (SAF). Owing to their intrinsic molecular similarity to petroleum-derived paraffins, triglycerides and free fatty acids provide a structurally advantageous platform for producing drop-in aviation fuels. The HEFA route has demonstrated industrial scalability, refinery compatibility, and substantial lifecycle greenhouse gas reduction potential. Through integrated sequences of hydrogenation, deoxygenation, hydroisomerization, and selective hydrocracking, waste lipids can be transformed into aviation-grade iso-paraffins that meet stringent specifications for freezing point, energy density, and thermal stability.

Nevertheless, the pathway is not without limitations. Feedstock heterogeneity, impurity-induced catalyst deactivation, hydrogen-intensive processing, and finite global availability of waste lipids collectively constrain long-term scalability. Catalytically, the central challenge lies in balancing hydrogen efficiency with carbon retention while maintaining high selectivity toward C8–C16 branched hydrocarbons. Multifunctional catalyst design, precise metal–acid synergy, hierarchical pore architectures, and coke-resistant materials remain critical research priorities. Equally important is the integration of renewable hydrogen sources, which will ultimately determine the true decarbonization impact of lipid-derived SAF.

Looking forward, several strategic directions can be identified. First, the development of sulfur-free, earth-abundant catalytic systems capable of operating under milder conditions could enhance economic and environmental performance. Second, reactor and process intensification—such as single-step multifunctional upgrading or modular distributed units near feedstock sources—may reduce capital and logistical barriers. Third, coupling waste lipid conversion with valorization of co-products (e.g., propane, light gases) and integration within broader biorefinery concepts could improve overall carbon efficiency and profitability.

From a systemic perspective, waste lipids alone cannot satisfy projected global aviation fuel demand. However, they provide an essential bridging solution and a realistic

near-term mitigation pathway. Continued advances in catalysis science, reaction engineering, and lifecycle optimization will determine whether this platform evolves beyond incremental emission reduction toward a fully integrated component of a circular, low-carbon aviation ecosystem. In this context, waste lipid–to–jet fuel technology stands not merely as a transitional option, but as a foundational model for transforming heterogeneous bio-resources into high-performance transportation fuels.

References

[1] Chiaramonti D. Sustainable Aviation Fuels: the challenge of decarbonization. Energy Procedia 2019; 158: 1202–7. https://doi.org/10.1016/J.EGYPRO.2019.01.308

[2] Ivanova B. Structural Analysis of Polylactic Acid in Composite Starch Biopolymers – A Stochastic Dynamics Mass Spectrometric Approach. Innov Discov 2024; 1: 26. https://doi.org/10.53964/ID.2024026

[3] Sanchez DL, Nelson JH, Johnston J, Mileva A, Kammen DM. Biomass enables the transition to a carbon-negative power system across western North America. Nat Clim Chang 2015;5:230–4. https://doi.org/10.1038/nclimate2488

[4] Nematov DD. Titanium Dioxide and Photocatalytic CO_2 Reduction: A Detailed Review of the Current Status and Future Prospects. Innov Discov 2025; 2: 5. https://doi.org/10.53964/ID.2025005

[5] Laveille P, Uratani J, Barron JGG, Brodeur-Campbell M, Chandak NR, George A, et al. Sustainable pilot-scale production of a Salicornia oil, its conversion to certified aviation fuel, and techno-economic analysis of the related biorefinery. Biofuels, Bioprod Biorefining 2022; 16: 27–42. https://doi.org/10.1002/BBB.2260

[6] Yao X, Strathmann TJ, Li Y, Cronmiller LE, Ma H, Zhang J. Catalytic hydrothermal deoxygenation of lipids and fatty acids to diesel-like hydrocarbons: a review. Green Chem 2021; 23: 1114–29. https://doi.org/10.1039/D0GC03707A

[7] Lin CSK, Pfaltzgraff LA, Herrero-Davila L, Mubofu EB, Abderrahim S, Clark JH, et al. Food waste as a valuable resource for the production of chemicals, materials and fuels. Current situation and global perspective. Energy Environ Sci 2013; 6: 426–64. https://doi.org/10.1039/c2ee23440h

[8] Sims REH, Mabee W, Saddler JN, Taylor M. An overview of second generation biofuel technologies. Bioresour Technol 2010; 101: 1570–80. https://doi.org/10.1016/j.biortech.2009.11.046

[9] Shu Q, Gao J, Nawaz Z, Liao Y, Wang D, Wang J. Synthesis of biodiesel from waste vegetable oil with large amounts of free fatty acids using a carbon-based solid acid catalyst. Appl Energy 2010; 87: 2589–96. https://doi.org/10.1016/j.apenergy.2010.03.024

[10] Mazziotta A, Madsen R. Ruthenium-Catalyzed Dehydrogenative Decarbonylation of Primary Alcohols. European J Org Chem 2017; 2017: 5417–20. https://doi.org/10.1002/ejoc.201701173

[11] Li Z, Zhou G, Xie S, Zheng X, Xie C, Huang H, et al. Chemically catalytic upgrading of fermentation-derived biobutanol to long-chain biofuels. Sustain Chem Pharm 2024; 41: 101739. https://doi.org/10.1016/J.SCP.2024.101739

[12] Fu C, Li Z, Song W, Yi C, Xie S. A new process for separating biofuel based on the salt + 1-butanol + water system. Fuel 2020; 278: 118402. https://doi.org/10.1016/j.fuel.2020.118402

[13] Xie S, Li Z, Zhu G, Yi C. One-pot reaction-separation process to produce jet fuel. Energy Convers Manag X 2022; 13: 100155. https://doi.org/10.1016/J.ECMX.2021.100155

[14] Cui X, Zhao X, Liu D. A novel route for the flexible preparation of hydrocarbon jet fuels from biomass-based platform chemicals: a case of using furfural and 2,3-butanediol as feedstocks. Green Chem 2018; 20: 2018–26. https://doi.org/10.1039/C8GC00292D

[15] Shen R, Tao L, Yang B. Techno-economic analysis of jet-fuel production from biorefinery waste lignin. Biofuels, Bioprod Biorefining 2019; 13: 486–501. https://doi.org/10.1002/bbb.1952

[16] Aviation fuel | Neste n.d. https://www.neste.com/en-us/products-and-innovation/fossil-products/aviation-fuel (accessed March 4, 2026).

[17] World Energy | Innovative Energy Solutions for Aviation and Beyond n.d. https://worldenergy.net/ (accessed March 4, 2026).

[18] Sanicola L. Microsoft invests $50 million in alcohol-to-jet fuel biorefinery 2022. https://www.reuters.com/business/aerospace-defense/microsoft-invests-50-million-alcohol-to-jet-fuel-biorefinery-2022-01-13/

[19] Xie S, Li Z, Luo S, Zhang W. Bioethanol to jet fuel: Current status, challenges, and perspectives. Renew Sustain Energy Rev 2024; 192: 114240. https://doi.org/10.1016/j.rser.2023.114240

[20] Jiao F, Li J, Pan X, Xiao J, Li H, Ma H, et al. Selective conversion of syngas to light olefins. Science (80-) 2016; 351: 1065–8. https://doi.org/10.1126/science.aaf1835

[21] Demirbas A. Progress and recent trends in biofuels. Prog Energy Combust Sci 2007; 33: 1–18. https://doi.org/10.1016/J.PECS.2006.06.001

[22] Huang H, Intan NN, Tan J, Liu Z, Zhang D, Cai X, et al. Low-temperature hydrodeoxygenation of fatty acids to biodiesel via Ru–Mo strong metal-support interaction. AIChE J 2025: e70039. https://doi.org/10.1002/AIC.70039;REQUESTEDJOURNAL:JOURNAL:15475905;WEBSITE:WEBSITE:AICHE;WGROUP:STRING:PUBLICATION

[23] Xie S, Chen Z, Zhang W. Techno-economic Analysis of Jet Fuel Production from Vegetable Oil Using Self-produced Solvent and Non-noble Metallic Catalyst. Innov Discov 2025; 2: 16. https://doi.org/10.53964/ID.2025016

[24] Gonzalez-Garay A, Heuberger-Austin C, Fu X, Klokkenburg M, Zhang D, van der Made A, et al. Unravelling the potential of sustainable aviation fuels to decarbonise the aviation sector. Energy Environ Sci 2022; 15: 3291–309. https://doi.org/10.1039/d1ee03437e

[25] Xie S, Li Z. Closing carbon and nitrogen cycles and addressing a critical global challenge: From seafood waste to sustainable chemicals. J Clean Prod 2023; 388: 135931. https://doi.org/10.1016/J.JCLEPRO.2023.135931

[26] Huang H, Zhou G, Luo S, Xie S. Catalytic upgrading of chitin: Advances, mechanistic insights, and prospect. J Ind Eng Chem 2023; 128: 127–42. https://doi.org/10.1016/J.JIEC.2023.08.014

[27] Xie S, Jia C, Wang Z, Ong SSG, Zhu MJ, Lin H. Mechanistic Insight into Selective Deoxygenation of l -Lysine to Produce Biobased Amines. ACS Sustain Chem Eng 2020; 8: 11805–17. https://doi.org/10.1021/acssuschemeng.0c04052

[28] Huang H, Liu S, Guo X, Jiang H, Cai Y, Tan Z, et al. Sustainable ammonia and amines from chitin. Bioresour Technol 2024; 414: 131582. https://doi.org/10.1016/j.biortech.2024.131582

[29] Kim MY, Kim JK, Lee ME, Lee S, Choi M. Maximizing Biojet Fuel Production from Triglyceride: Importance of the Hydrocracking Catalyst and Separate Deoxygenation/Hydrocracking Steps. ACS Catal 2017; 7: 6256–67. https://doi.org/10.1021/ACSCATAL.7B01326/ASSET/IMAGES/LARGE/CS-2017-01326T_0010.JPEG

[30] Xie S, Jia C, Prakash A, Palafox MI, Pfaendtner J, Lin H. Generic Biphasic Catalytic Approach for Producing Renewable Diesel from Fatty Acids and Vegetable Oils. ACS Catal 2019; 9: 3753–63. https://doi.org/10.1021/acscatal.9b00215

[31] Jia C, Zhang C, Xie S, Zhang W, Wang Z, Lin H. One-pot production of jet fuels from fatty acids and vegetable oils in biphasic tandem catalytic process. Fuel 2021; 302: 121060. https://doi.org/10.1016/J.FUEL.2021.121060

[32] Liang G, He L, Cheng H, Li W, Li X, Zhang C, et al. The hydrogenation/dehydrogenation activity of supported Ni catalysts and their effect on hexitols selectivity in hydrolytic hydrogenation of cellulose. J Catal 2014; 309: 468–76. https://doi.org/10.1016/j.jcat.2013.10.022

[33] Hunsiri W, Chaihad N, Ngamcharussrivichai C, Tungasmita DN, Reubroycharoen P, Hinchiranan N. Branched-chain biofuels derived from hydroisomerization of palm olein using Ni/modified beta zeolite catalysts for biojet fuel production. Fuel Process Technol 2023; 248: 107825. https://doi.org/10.1016/J.FUPROC.2023.107825

[34] Alonso DM, Bond JQ, Dumesic JA. Catalytic conversion of biomass to biofuels. Green Chem 2010. https://doi.org/10.1039/c004654j

[35] Galadima A, Muraza O. Catalytic upgrading of vegetable oils into jet fuels range hydrocarbons using heterogeneous catalysts: A review. J Ind Eng Chem 2015; 29: 12–23. https://doi.org/10.1016/J.JIEC.2015.03.030

[36] Tang H, Dai Q, Cao Y, Li J, Wei X, Jibran K, et al. Production of jet fuel range hydrocarbons using a magnetic Ni–Fe/SAPO-11 catalyst for solvent-free hydrodeoxygenation of jatropha oil. Biomass and Bioenergy 2023; 177: 106927. https://doi.org/10.1016/J.BIOMBIOE.2023.106927

[37] Santillan-Jimenez E, Morgan T, Shoup J, Harman-Ware AE, Crocker M. Catalytic deoxygenation of triglycerides and fatty acids to hydrocarbons over Ni-Al layered double hydroxide. Catal Today 2014; 237: 136–44. https://doi.org/10.1016/j.cattod.2013.11.009

[38] Chen YK, Hsieh CH, Wang WC. The production of renewable aviation fuel from waste cooking oil. Part II: Catalytic hydro-cracking/isomerization of hydro-processed alkanes into jet fuel range products. Renew Energy 2020; 157: 731–40. https://doi.org/10.1016/J.RENENE.2020.04.154

[39] Stöcker M. Biofuels and biomass-to-liquid fuels in the biorefinery: Catalytic conversion of lignocellulosic biomass using porous materials. Angew Chemie - Int Ed 2008;47:9200–11. https://doi.org/10.1002/anie.200801476.

[40] D CS, Devarajan Y, T R. Sewage sludge as a sustainable feedstock for biodiesel: Advances in conversion technologies and catalytic applications. Results Eng 2025; 25: 104000. https://doi.org/10.1016/J.RINENG.2025.104000

[41] Vásquez MC, Silva EE, Castillo EF. Hydrotreatment of vegetable oils: A review of the technologies and its developments for jet biofuel production. Biomass and Bioenergy 2017; 105: 197–206. https://doi.org/10.1016/J.BIOMBIOE.2017.07.008

[42] Fu J, Lu X, Savage PE. Catalytic hydrothermal deoxygenation of palmitic acid. Energy Environ Sci 2010; 3: 311–7. https://doi.org/10.1039/b923198f

[43] Berenblyum AS, Podoplelova TA, Shamsiev RS, Katsman EA, Danyushevsky VY. On the mechanism of catalytic conversion of fatty acids into hydrocarbons in the presence of palladium catalysts on alumina. Pet Chem 2011; 51: 336–41. https://doi.org/10.1134/S0965544111050069

[44] Ahmadi M, Macias EE, Jasinski JB, Ratnasamy P, Carreon MA. Decarboxylation and further transformation of oleic acid over bifunctional, Pt/SAPO-11 catalyst and Pt/chloride Al_2O_3 catalysts. J Mol Catal A Chem 2014; 386: 14–9. https://doi.org/10.1016/j.molcata.2014.02.004

[45] Abedi E, Sahari MA. Long-chain polyunsaturated fatty acid sources and evaluation of their nutritional and functional properties. Food Sci Nutr 2014; 2: 443. https://doi.org/10.1002/FSN3.121

[46] Ochoa A, Barbarias I, Artetxe M, Gayubo AG, Olazar M, Bilbao J, et al. Deactivation dynamics of a Ni supported catalyst during the steam reforming of volatiles from waste polyethylene pyrolysis. Appl Catal B Environ 2017; 209: 554–65. https://doi.org/10.1016/j.apcatb.2017.02.015

[47] Zubr J. Dietary fatty acids and amino acids of Camelina sativa seed. J Food Qual 2003; 26: 451–62. https://doi.org/10.1111/j.1745-4557.2003.tb00260.x

[48] Iqbal J, Martin S, Carney Jr. W. Feedstock Quality issue for biodiesel production. https://www.lsuagcenter.com/MCMS/RelatedFiles/%7BF89D987C-121F-49D6-92DC-0F77FB792BF7%7D/Feedstock-Quality.pdf

[49] Xie S, Sun Z, Tan J, Zhang W, Cai X, Fang Y. Emerging Micromolecule-based Aqueous Two-phase Systems and Their Application in Biofuels. Innov Discov 2024; 1: 30. https://doi.org/10.53964/id.2024030

[50] Bhattacharjee J, Roy S. Advanced Techniques Using Ionic Liquids for Efficient Separation of Sugar Alcohols. Innov Discov 2025; 2: 3. https://doi.org/10.53964/ID.2025003

[51] Katibi KK, Shitu IG, Mutalovich AA, Abba MU, Zakar MN. Application of Nanocomposite Membrane Fibre Blended with $CoFe_2O_4$ Nanoparticles for the Sequestration of Bisphenol S from Aqueous Solution: Fouling and Permeability Studies. Innov Discov 2025; 2: 19. https://doi.org/10.53964/id.2025019

[52] Zhang Z, Zhang X, Wang Q. Influence of Impurities and Oxidation on Hydroconversion of Waste Cooking Oil into Bio-jet Fuel. Chem Eng Technol 2020; 43: 273–81. https://doi.org/10.1002/CEAT.201900357;WGROUP:STRING:PUBLICATION

[53] Zhang L, Su X, Zhou L, Li J, Xiao T, Li J, et al. Reversal Effect of Phosphorus on Catalytic Performances of Supported Nickel Catalysts in Reductive Amination of 1,6-Hexanediol. ChemSusChem 2024; 17: e202400211. https://doi.org/10.1002/CSSC.202400211;CTYPE:STRING:JOURNAL

[54] Claus P, Berndt H, Mohr C, Radnik J, Shin EJ, Keane MA. Pd/MgO: Catalyst characterization and phenol hydrogenation activity. J Catal 2000; 192: 88–97. https://doi.org/10.1006/jcat.2000.2834

[55] Bond JQ, Upadhye AA, Olcay H, Tompsett GA, Jae J, Xing R, et al. Production of renewable jet fuel range alkanes and commodity chemicals from integrated catalytic processing of biomass. Energy Environ. Sci., vol. 7, 2014, p. 1500–23. https://doi.org/10.1039/c3ee43846e

[56] Reddy Kannapu HP, Kim M, Jeong C, Suh YW. An efficient $CuCeO_2$ citrate catalyst for higher aliphatic ketone synthesis via alkali-free alkylation of acetone with butanol. Mater Chem Phys 2019; 229: 402–11. https://doi.org/10.1016/j.matchemphys.2019.03.035

[57] Chintakanan P, Vitidsant T, Reubroycharoen P, Kuchonthara P, Kida T, Hinchiranan N. Bio-jet fuel range in biofuels derived from hydroconversion of palm olein over Ni/zeolite catalysts and freezing point of biofuels/Jet A-1 blends. Fuel 2021; 293: 120472. https://doi.org/10.1016/J.FUEL.2021.120472

[58] Wang HY, Bluck D, Van Wie BJ. Conversion of microalgae to jet fuel: Process design and simulation. Bioresour Technol 2014; 167: 349–57. https://doi.org/10.1016/J.BIORTECH.2014.05.092

[59] Tomasek S, Lónyi F, Valyon J, Hancsók J. Fuel purpose hydrocracking of biomass based Fischer-Tropsch paraffin mixtures on bifunctional catalysts. Energy Convers Manag 2020; 213: 112775. https://doi.org/10.1016/J.ENCONMAN.2020.112775

[60] Miao C, Marin-Flores O, Dong T, Gao D, Wang Y, Garcia-Pérez M, et al. Hydrothermal Catalytic Deoxygenation of Fatty Acid and Bio-oil with in Situ H_2. ACS Sustain Chem Eng 2018; 6: 4521–30. https://doi.org/10.1021/ACSSUSCHEMENG.7B02226/ASSET/IMAGES/LARGE/SC-2017-02226B_0008.JPEG

[61] Xie S, Dong H, Peng X, Chu PK. Non-precious Electrocatalysts for the Hydrogen Evolution Reaction. Innov Discov 2024; 1: 11. https://doi.org/10.53964/ID.2024011

[62] Kim JH, Cook M, Peeva L, Yeo J, Bolton LW, Lee YM, et al. Low energy intensity production of fuel-grade bio-butanol enabled by membrane-based extraction. Energy Environ Sci 2020; 13: 4862–71. https://doi.org/10.1039/d0ee02927k

[63] Xie S, Huynh TH, Qin P, Tan T, Lin H. Facile biphasic catalytic process for conversion of monoterpenoids to tricyclic hydrocarbon biofuels. J Energy Chem 2020; 49: 42–50. https://doi.org/10.1016/j.jechem.2020.01.032

[64] Sun YS, Qu W. Dietary Apigenin promotes lipid catabolism, thermogenesis, and browning in adipose tissues of HFD-Fed mice. Food Chem Toxicol 2019; 133: 110780. https://doi.org/10.1016/J.FCT.2019.110780

[65] Hossain MZ, Chowdhury MBI, Jhawar AK, Xu WZ, Charpentier PA. Continuous low pressure decarboxylation of fatty acids to fuel-range hydrocarbons with in situ hydrogen production. Fuel 2018; 212: 470–8. https://doi.org/10.1016/j.fuel.2017.09.092

[66] King AE, Brooks TJ, Tian YH, Batista ER, Sutton AD. Understanding ketone hydrodeoxygenation for the production of fuels and feedstocks from biomass. ACS Catal 2015; 5: 1223–6. https://doi.org/10.1021/CS501965W/SUPPL_FILE/CS501965W_SI_001.PDF

[67] Tanzil AH, Brandt K, Wolcott M, Zhang X, Garcia-Perez M. Strategic assessment of sustainable aviation fuel production technologies: Yield improvement and cost reduction opportunities. Biomass and Bioenergy 2021; 145: 105942. https://doi.org/10.1016/J.BIOMBIOE.2020.105942

[68] Grudanova AI, Gulyaeva LA, Krasilnikova LA, Shmelkova OI, Boldushevskii RE. Jet fuel and arctic diesel fuel production by isodewaxing of waxy middle distillate fractions. Fuel 2017; 193: 485–7. https://doi.org/10.1016/j.fuel.2016.12.032

[69] Sharifvaghefi S, Zheng Y. Deoxygenation of stearic acid with a novel ni (CO)-MoS_2/Fe_3S_4 Catalyst. Can J Chem Eng 2018; 96: 231–40. https://doi.org/10.1002/cjce.23027

[70] Eller Z, Varga Z, Hancsok J. Renewable jet fuel from kerosene/coconut oil mixtures with catalytic hydrogenation. Energy and Fuels 2019; 33: 6444–53. https://doi.org/10.1021/ACS.ENERGYFUELS.9B00996/ASSET/IMAGES/LARGE/EF-2019-009968_0010.JPEG

[71] Sugami Y, Minami E, Saka S. Hydrocarbon production from coconut oil by hydrolysis coupled with hydrogenation and subsequent decarboxylation. Fuel 2017; 197: 272–6. https://doi.org/10.1016/j.fuel.2017.02.038

[72] Liao J, Zhong Q, Gu J, Qiu S, Meng Q, Zhang Q, et al. New approach for bio-jet fuels production by hydrodeoxygenation of higher alcohols derived from C-C coupling of bio-ethanol. Appl Energy 2022; 324: 119843. https://doi.org/10.1016/J.APENERGY.2022.119843

[73] Peng B, Zhao C, Kasakov S, Foraita S, Lercher JA. Manipulating catalytic pathways: Deoxygenation of palmitic acid on multifunctional catalysts. Chem - A Eur J 2013; 19: 4732–41. https://doi.org/10.1002/chem.201203110

[74] Vam A. Kinetics of The Hydro-deoxygenation of Stearic Acid over Palladium on Carbon Catalyst in Fixed-Bed Reactor for the Production of Renewable Diesel. UNIVERSITY OF DAYTON, 2013.

[75] Rabaev M, Landau M V., Vidruk-Nehemya R, Koukouliev V, Zarchin R, Herskowitz M. Conversion of vegetable oils on Pt/Al_2O_3/SAPO-11 to diesel and jet fuels containing aromatics. Fuel 2015; 161: 287–94. https://doi.org/10.1016/J.FUEL.2015.08.063

[76] Hengsawad T, Srimingkwanchai C, Butnark S, Resasco DE, Jongpatiwut S. Effect of Metal-Acid Balance on Hydroprocessed Renewable Jet Fuel Synthesis from Hydrocracking and Hydroisomerization of Biohydrogenated Diesel over Pt-Supported Catalysts. Ind Eng Chem Res 2018; 57: 1429–40. https://doi.org/10.1021/ACS.IECR.7B04711/ASSET/IMAGES/LARGE/IE-2017-047119_0013.JPEG

[77] Bhattacharjee S, Tan CS. Production of Biojet Fuel from Octadecane and Derivatives of Castor Oil Using a Bifunctional Catalyst Ni-Pd@Al-MCF in a Pressurized CO_2-Hexane-Water Solvent. Energy and Fuels 2022; 36: 3119–33. https://doi.org/10.1021/ACS.ENERGYFUELS.1C03881/ASSET/IMAGES/LARGE/EF1C03881_0008.JPEG

[78] Li T, Cheng J, Huang R, Zhou J, Cen K. Conversion of waste cooking oil to jet biofuel with nickel-based mesoporous zeolite Y catalyst. Bioresour Technol 2015; 197: 289–94. https://doi.org/10.1016/J.BIORTECH.2015.08.115

[79] Serrano DP, Aguado J, Escola JM. Developing advanced catalysts for the conversion of polyolefinic waste plastics into fuels and chemicals. ACS Catal 2012; 2: 1924–41. https://doi.org/10.1021/cs3003403

[80] Han Z, Xue Q, Hu X, Guo T, Ma J, Guo Q. A Comprehensive Review of Chemical Looping Ammonia Synthesis. Innov Discov 2024; 1: 9. https://doi.org/10.53964/id.2024009

[81] Yang H, Hu P, Li Z, Hu C. Catalytic Conversion of Complex Reactant Systems Makes the World Greener, More Sustainable and Hopeful: Where and How to Go? Innov Discov 2024; 1: 8. https://doi.org/10.53964/ID.2024008

[82] Demel J, Čejka J, Štěpnička P. Palladium catalysts deposited on silica materials: Comparison of catalysts based on mesoporous and amorphous supports in Heck reaction. J Mol Catal A Chem 2010;329:13–20. https://doi.org/10.1016/j.molcata.2010.06.011

[83] Zhou J, Gao Z, Xiang G, Zhai T, Liu Z, Zhao W, et al. Interfacial compatibility critically controls Ru/TiO_2 metal-support interaction modes in CO_2 hydrogenation. Nat Commun 2022; 13: 1–10. https://doi.org/10.1038/s41467-021-27910-4

[84] Saviola AJ, Syoufian A, Oh WC, Wijaya K. Atmospheric hydrotreatment of used palm cooking oil over nickel-dispersed phosphated zirconia as highly stable nano-catalyst for bio-jet fuel production. Inorg Chem Commun 2025; 173: 113790. https://doi.org/10.1016/J.INOCHE.2024.113790

[85] Zhang Z, Cheng J, Zhu Y, Guo H, Yang W. Jet fuel range hydrocarbons production through competitive pathways of hydrocracking and isomerization over HPW-Ni/MCM-41 catalyst. Fuel 2020; 269: 117465. https://doi.org/10.1016/J.FUEL.2020.117465

[86] Li M, Fu J, Xing S, Yang L, Zhang X, Lv P, et al. A novel catalyst with variable active sites for the direct hydrogenation of waste oils into jet fuel. Appl Catal B Environ 2020; 260: 118114. https://doi.org/10.1016/J.APCATB.2019.118114

[87] Lin CH, Wang WC. Direct conversion of glyceride-based oil into renewable jet fuels. Renew Sustain Energy Rev 2020; 132: 110109. https://doi.org/10.1016/J.RSER.2020.110109

[88] Scaldaferri CA, Pasa VMD. Hydrogen-free process to convert lipids into bio-jet fuel and green diesel over niobium phosphate catalyst in one-step. Chem Eng J 2019; 370: 98–109. https://doi.org/10.1016/J.CEJ.2019.03.063

[89] Pires APP, Han Y, Kramlich J, Garcia-Perez M. Chemical composition and fuel properties of alternative jet fuels. BioResources 2018; 13: 2632–57. https://doi.org/10.15376/BIORES.13.2.2632-2657

[90] Dietrich PJ, Lobo-Lapidus RJ, Wu T, Sumer A, Akatay MC, Fingland BR, et al. Aqueous phase glycerol reforming by PtMo bimetallic nano-particle catalyst: Product selectivity and structural characterization. Top Catal 2012; 55: 53–69. https://doi.org/10.1007/S11244-012-9775-5/FIGURES/17

[91] Liu J, Peng X. Interface-engineering of the Catalysts for Efficient Electrocatalytic Upcycling of Polyethylene Terephthalate Waste. Innov Discov 2024; 1: 1. https://doi.org/10.53964/ID.2024001

[92] Deng J, Ren P, Deng D, Bao X. Enhanced Electron Penetration through an Ultrathin Graphene Layer for Highly Efficient Catalysis of the Hydrogen Evolution Reaction. Angew Chemie Int Ed 2015; 54: 2100–4. https://doi.org/10.1002/ANIE.201409524

[93] Kumar A, Semwal S, Choudhury J. Catalytic Conversion of CO_2 to Formate with Renewable Hydrogen Donors: An Ambient-Pressure and H_2 -Independent Strategy. ACS Catal 2019; 9: 2164–8. https://doi.org/10.1021/acscatal.8b04430