World Journal of Biology Pharmacy and Health Sciences

eISSN: 2582-5542

Cross Ref DOI: 10.30574/wjbphs

Journal homepage: https://wjbphs.com/

(Review Article)

Check for updates

Potentials and challenges of biofuels as a replacement for naphtha in steam cracking units

Moyinoluwa Solomon Adekeye [1,*], Ugochukwu Daniel Okwor [2], Samuel Maduekwe [3], Ikechukwu Bismarck Owunna [4], Vivian Chinenye Akunne [5], Israel Oluwaseun Jimson [6] and Isreal Oluwatimileyin Olajide [7]

[1] *Department of Mechanical Engineering, Federal University of Agriculture Abeokuta, Ogun State, Nigeria.*
[2] *Department of Metallurgical and Materials Engineering, University of Nigeria Nsukka.*
[3] *Department of Mechanical Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria.*
[4] *Department of Mechanical Engineering, University of Benin, Nigeria.*
[5] *Department of Industrial Chemistry, Federal University of Technology Owerri, Imo State, Nigeria.*
[6] *Department of Chemical Engineering, Lagos State University of Science and Technology, Ikorodu North, Lagos State, Nigeria.*
[7] *Department of Pure and Applied Chemistry, Ladoke Akintola University of Technology, Ogbomoso Oyo state, Nigeria.*

World Journal of Biology Pharmacy and Health Sciences, 2025, 21(01), 315-322

Publication history: Received on 30 November 2024; revised on 11 January 2025; accepted on 13 January 2025

Article DOI: https://doi.org/10.30574/wjbphs.2025.21.1.0029

Abstract

Bio-naphtha is gaining importance as a renewable feedstock for fossil naphtha in steam cracking which is one of the most critical steps in the manufacture of ethylene and other olefins within the petrochemical industry. Manufactured from biomass, waste oils, and algae; bio-naphtha is associated with considerable environmental benefits from the lower carbon footprint while also meeting global sustainability goals. This review describes the production routes of bio-naphtha, its chemical and physical properties, and its compatibility with steam cracking technologies as they currently stand. While bio-naphtha exhibits comparable ethylene yields to fossil naphtha and lower impurities, challenges persist due to feedstock variability, pretreatment requirements, and generally high production costs. Of the developing technologies, this review identifies hydrothermal liquefaction and Fischer-Tropsch synthesis as key to the scaling and cost-effectiveness of bio-naphtha. These could be facilitated by the adoption of policy interventions, such as subsidies and blending mandates. Conclusively, coordinated research effort, industry collaboration, and regulatory support will enable biomonomers like bio-naphtha to become key enablers for the decarbonization of the petrochemical value chain and the circular economy.

Keywords: Bio-Naphtha; Steam Cracking; Ethylene Production; Sustainable Feedstocks; Renewable Alternatives

1. Introduction

The petrochemical industry relies heavily on naphtha, a key feedstock derived from crude oil, for the production of ethylene and other olefins via steam cracking [1]. This process underpins a vast range of downstream products, including polyethylene, polypropylene, and synthetic rubbers, which are essential in modern economies [2]. However, the dependence on fossil-derived naphtha poses significant challenges, particularly concerning environmental sustainability. The extraction, refining, and utilization of crude oil contribute substantially to greenhouse gas (GHG) emissions and exacerbate resource depletion. Ethylene, the main product of naphtha cracking, is critical for the global production of plastics. In 2023, global ethylene demand exceeded 200 million metric tons, driven by the rapid growth of the packaging, automotive, and construction industries [3]. As this demand continues to rise, the need for more sustainable feedstock solutions becomes imperative. The growing emphasis on reducing carbon footprints and adhering

* Corresponding author: Moyinoluwa Solomon Adekeye

to international climate agreements, such as the Paris Accord, has spurred interest in renewable alternatives to traditional feedstocks. Bio-naphtha, derived from renewable resources such as biomass, waste oils, and agricultural residues, offers a sustainable option. Its utilization aligns with the broader objective of achieving carbon neutrality in industrial processes while addressing the environmental shortcomings of fossil-based naphtha [4]. Bio-naphtha's potential lies not only in its renewable origin but also in its compatibility with existing steam cracking technologies. Unlike other renewable feedstocks, bio-naphtha can serve as a "drop-in" replacement, minimizing the need for extensive infrastructure modifications [5]. However, understanding its viability requires a thorough examination of its production processes, chemical properties, and integration challenges. This paper aims to provide a comprehensive review of bio-naphtha's potential as a replacement for traditional naphtha in steam cracking units. Specific objectives include: Evaluating bio-naphtha production processes and their environmental implications. Assessing the compatibility of bio-naphtha with existing steam cracking technologies, including product yields and byproduct composition. Identifying technical, economic, and logistical challenges associated with its adoption. Offering recommendations for future research and policy development to support bio-naphtha integration in the petrochemical industry.

2. Overview of Steam Cracking and Feedstock Requirements

2.1. Steam Cracking Process

Steam cracking is a high-temperature process that breaks down hydrocarbons into smaller molecules using steam as a diluent to prevent coke formation. Hydrocarbons are heated to temperatures ranging from 800 to 900°C in a tubular reactor, causing molecular bonds to break and form a mixture of products. Ethylene is the primary output, accounting for up to 30–40% of the yield, followed by propylene, butadiene, and other valuable byproducts. The process operates under highly controlled conditions to optimize yields and minimize undesired products. Cracked gas is then quenched, compressed, and separated into its constituent fractions. The efficiency of steam cracking is heavily influenced by the composition of the feedstock, as well as the reactor design and operating conditions [6].

2.2. Feedstock Properties

[7] The choice of feedstock directly impacts the efficiency and economics of steam cracking. Ideal feedstocks possess:

- High Hydrogen-to-Carbon Ratios: Result in higher olefin yields. For instance, paraffinic naphtha generally outperforms aromatic naphtha in ethylene production.
- Thermal Stability: Minimizes coke deposition on reactor walls, extending operational cycles.
- Low Impurities: Reduces equipment fouling and the formation of undesired byproducts, such as sulfur compounds.

Fossil-derived naphtha has historically met these requirements, but bio-naphtha, with its variable composition, requires detailed analysis to ensure compatibility and comparable performance.

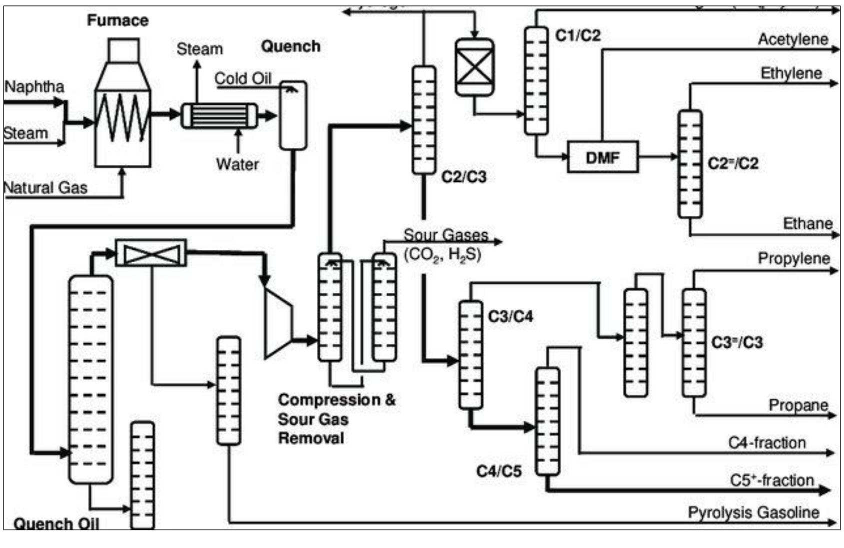

Figure 1 Simplified flow scheme of a naphtha cracker [8]

3. Production of Bio-Naphtha

3.1. Bio-Naphtha Sources [9]

Bio-naphtha can be produced from diverse renewable feedstocks, classified as:

- First-Generation Feedstocks: Derived from food crops such as sugarcane and corn through fermentation. While effective, they raise concerns about food security and land use.
- Second-Generation Feedstocks: Include lignocellulosic biomass, agricultural residues, and waste materials. These are non-food-based and offer higher sustainability.
- Third-Generation Feedstocks: Focus on algae, which can produce high lipid yields and do not compete with arable land. Algae-based bio-naphtha is emerging as a promising alternative due to its scalability and high energy content.

Waste Oils and Fats: Utilized cooking oils and animal fats are converted into bio-naphtha via hydrotreating, offering a circular economy approach.

Table 1 Comparatie analysis for the renewable sources of bio-naptha

Source	Description	Feedstock Availability	Environmental Impact	Economic Feasibility	Challenges
Plant-based oils [10]	Derived from oils like soybean, rapeseed, and palm oil.	High in tropical regions, seasonal.	Can lead to deforestation and biodiversity loss if not sustainably sourced.	Moderate to high, depends on crop yield and oil extraction efficiency.	Competition with food supply, requires large land areas for cultivation.
Waste oils and fats [11]	Includes used cooking oil and animal fats.	Readily available in urban areas.	Low environmental footprint; promotes waste recycling.	High; reduces disposal costs and taps into existing waste streams.	Collection, sorting, and processing infrastructure needed.
Lignocellulosic Biomass [12]	Obtained from agricultural residues, forestry waste, and dedicated energy crops like switchgrass.	Abundant and underutilized globally.	Minimizes competition with food crops and improves soil quality.	Moderate; processing costs are still high due to pretreatment requirements.	High capital cost for biorefineries and complex conversion processes.
Algae [13]	Microalgae and macroalgae cultivated for their high oil yield.	High potential but currently niche.	Low land usage and can utilize wastewater; potential carbon sequestration.	Low to moderate; production costs are still high for commercial scale.	Scaling cultivation and maintaining efficiency under diverse conditions.
Sugar and Starch Crops [14]	Includes sugarcane, corn, and wheat used for fermentation to produce bio-naphtha precursors.	High but seasonal in many regions.	Potential land-use change and fertilizer impact on waterways.	High for regions with established agricultural supply chains.	Competes with food production and raises ethical concerns.
Municipal Solid Waste [15]	Organic fractions of household and industrial waste processed to extract hydrocarbons.	High in urbanized areas.	Reduces landfill usage and greenhouse gas emissions.	Moderate; relies on waste management infrastructure.	Sorting complexity and need for advanced waste-to-energy technology.

3.2. Production Processes [16]

- Hydrothermal Liquefaction (HTL): Converts wet biomass into bio-crude under high pressure and moderate temperatures. Bio-crude is then refined into bio-naphtha.
- Fischer-Tropsch Synthesis: Biomass is gasified into syngas, which is catalytically converted into hydrocarbons, including bio-naphtha [].
- Pyrolysis: Biomass is thermally decomposed into bio-oil, char, and gas. Bio-oil undergoes further upgrading to produce bio-naphtha [].
- Hydrotreating: Converts waste oils into bio-naphtha by removing oxygen, sulfur, and nitrogen impurities through hydrogenation processes.

Each production method has unique advantages and challenges, with scalability and feedstock availability being critical determinants of feasibility.

3.3. Environmental Impact

Bio-naphtha significantly reduces the environmental impact compared to fossil-derived naphtha:

Lifecycle assessments (LCAs) indicate a 80% reduction in GHG emissions when bio-naphtha is derived from second- or third-generation feedstocks [17]. It promotes waste valorization, reducing landfill dependency. The use of renewable resources minimizes resource depletion and supports sustainable development goals (SDGs). However, the environmental benefits depend on the feedstock and production method. For example, first-generation feedstocks can lead to indirect land-use changes, offsetting carbon savings [18].

4. Compatibility of Bio-Naphtha in Steam Cracking Units

4.1. Chemical and Physical Properties

[19] Bio-naphtha's chemical composition varies significantly depending on the feedstock and production method. However, its general composition includes hydrocarbons in the C5–C12 range, similar to fossil naphtha, making it a viable alternative. Key attributes include:

- Hydrocarbon Composition: Bio-naphtha primarily consists of paraffins, olefins, and aromatics. However, it may contain oxygenated compounds, depending on the production pathway. These oxygenates can cause undesired side reactions during steam cracking, requiring pre-treatment.
- Lower Sulfur and Nitrogen Content: Compared to fossil naphtha, bio-naphtha has lower impurity levels, which reduces fouling and extends the lifespan of cracking furnaces.
- Variable Density and Boiling Range: Depending on the source, bio-naphtha may have a slightly broader boiling range, influencing its cracking performance.

These properties highlight the need for quality control to ensure that bio-naphtha meets the specifications required for optimal steam cracking performance.

4.2. Process Efficiency and Product Yields

[20] The efficiency of steam cracking and the yield of key products, such as ethylene, are directly influenced by the feedstock's composition. Studies evaluating bio-naphtha in steam crackers have demonstrated:

- Comparable Ethylene Yields: Bio-naphtha derived from high-purity sources (e.g., Fischer-Tropsch processes) can match ethylene yields of fossil naphtha, typically around 30–40%.
- Reduced Coke Formation: Due to its lower aromatic and sulfur content, bio-naphtha tends to produce less coke, minimizing reactor downtime and maintenance costs.
- Impact of Oxygenates: The presence of oxygenated compounds in some types of bio-naphtha can result in byproducts that require adjustments to downstream separation processes.

Overall, bio-naphtha shows promise as a near drop-in replacement, but achieving optimal yields may require adjustments to cracking conditions, such as temperature and residence time.

4.3. Byproduct Composition

[21] Steam cracking generates a range of byproducts, including hydrogen, methane, propylene, and butadiene. When using bio-naphtha, notable differences in byproduct composition include:

- Lower Aromatic Byproducts: The reduced aromatic content in bio-naphtha results in fewer aromatic byproducts, which could affect downstream operations that rely on these compounds.
- Hydrogen Production: The lower sulfur content in bio-naphtha may influence hydrogen recovery processes, particularly in crackers equipped with hydrogen separation units.
- Coke Deposition: Reduced coke formation due to lower impurity levels is a significant advantage, as it extends operational cycles and reduces energy consumption during decoking operations.

These differences necessitate careful assessment of downstream processing units to accommodate potential shifts in product and byproduct distributions.

4.4. Industrial Insights

[22] Preliminary industrial trials of bio-naphtha in steam cracking units have revealed encouraging results:

Scalability: Bio-naphtha blends with fossil naphtha have been successfully tested without significant changes to cracker performance.

- Infrastructure Compatibility: Bio-naphtha can leverage existing pipelines, storage tanks, and cracking units, reducing the capital expenditures required for adoption.
- Operational Adjustments: Minor adjustments in cracking parameters, such as pre-treatment of feedstock and temperature optimization, have proven sufficient to handle bio-naphtha's variability.

Despite these advantages, widespread adoption is hindered by the inconsistent quality of bio-naphtha and the need for further research into long-term operational impacts.

Table 2 Potential and Callenges of replacing Naphtha with Bio-fuels

Aspect	**Potential**	**Challenges**
Environmental	- Reduced carbon footprint and greenhouse gas emissions - Lower toxic emissions (SOx, NOx) - Renewable resource utilization	- Indirect carbon emissions from land-use changes - Resource-intensive cultivation and processing - Byproduct and waste management complexities
Economic	- Reduced reliance on volatile naphtha markets - Opportunities for local production - Access to subsidies/carbon credits	- Higher production costs than naphtha - Initial capital for retrofitting units - Policy dependence
Technical	- Compatibility with existing infrastructure for some biofuels - Production of green olefins - Improved feedstock quality	- Variability in biofuel quality - Potential catalyst incompatibility - Material corrosion risks
Scalability and Logistics	- Diverse feedstock options from agricultural and organic waste	- Insufficient production scale for industrial needs - Specialized handling and storage requirements
Sustainabiliy and Policy	- Supports global sustainability goals - Compliance with stricter environmental regulations - Enhances corporate social responsibility	- Inconsistent global quality standards -Regulatory and carbon accounting complexities - Policy uncertainty
Social Acceptance	- Aligns with demand for eco-friendly products - Promotes sustainability awareness	- Food vs. fuel debate -Public skepticism about biofuel sustainability

Table 3 Comparative Summary between Naptha and Bio-Naptha

Aspect	Fossil Naptha	Bio-Naptha
Carbon Footprint	High	Low (50% - 80% reduction).
Feedstock Source	Non-renewable (crudeoil)	Renewable (biomass, waste oils, algae)
Production Cost	Low (well-established process)	High (emerging technologies)
Production Yield	High (30–40% ethylene yield)	Comparable but variable
Operational Issues	Minimal (mature optimization)	Requires pre-treatment (oxygenate removal)
Environmetal Impact	Significant (GHG emissions, resource depletion)	Lower but dependent on feedstock and process
Policy Suport	Limited carbon regulations	Requires subsidies, mandates, and incentives

5. Future Perspectives on Bio-Naphtha Adoption

5.1. Emerging Technologies in Bio-Naphtha Production

Advancements in production technologies are critical for making bio-naphtha a viable and scalable alternative to fossil naphtha. Promising developments include:

- Fischer-Tropsch Synthesis Optimization: Improvements in catalysts and reactor designs are enabling higher conversion efficiencies and better hydrocarbon selectivity for bio-naphtha production.
- Hydrothermal Liquefaction (HTL): This technology offers the potential to convert wet biomass, such as algae, into bio-crude that can be refined into bio-naphtha. HTL is particularly attractive for its ability to process non-food feedstocks with high moisture content.
- Second- and Third-Generation Feedstocks: Research on algae and lignocellulosic biomass is reducing dependence on food crops, ensuring more sustainable feedstock sources. Algal bio-naphtha is especially promising due to its high lipid content and rapid growth rate.

Continued research into scalable, cost-effective production methods will be essential for overcoming the current economic barriers.

5.2. Integration with the Oil and Gas Industry

Adopting bio-naphtha within the oil and gas industry requires strategic planning and incremental integration:

- Co-Processing with Fossil Naphtha: Initially blending bio-naphtha with fossil naphtha allows companies to test performance while minimizing disruptions to existing operations. This phased approach also helps offset costs while leveraging renewable content.
- Adaptation of Refining Processes: Refineries can implement pre-treatment units specifically for bio-naphtha to address challenges such as oxygenate removal and feedstock variability.
- Pipeline and Storage Compatibility: Bio-naphtha’s physical and chemical properties are similar enough to fossil naphtha to use existing pipelines and storage facilities with minor adjustments.

As companies embrace sustainability goals and decarbonization mandates, bio-naphtha integration offers a practical step towards reducing the carbon footprint of petrochemical operations.

5.3. Policy and Regulatory Support

To accelerate the adoption of bio-naphtha, robust policy frameworks and incentives are necessary. Key recommendations include:

- Blending Mandates: Governments could introduce requirements for a specific percentage of bio-naphtha in steam cracker feedstocks, similar to biodiesel blending mandates.
- Subsidies for Producers: Financial support for bio-naphtha producers can help offset the high costs associated with feedstock collection, processing, and technology development.

- Carbon Pricing: Introducing or strengthening carbon taxes or cap-and-trade systems would make bio-naphtha more competitive by internalizing the environmental costs of fossil naphtha.
- Research Funding: Increased funding for R&D in bio-naphtha production technologies, feedstock optimization, and lifecycle assessments will drive innovation and cost reductions.

Regions like the European Union are already paving the way with renewable energy directives, but broader global adoption is essential for meaningful impact.

5.4. Industry and Consumer Collaboration

Collaborative efforts between stakeholders can further accelerate bio-naphtha adoption:

- Industry Partnerships: Partnerships between bio-naphtha producers and petrochemical companies can facilitate pilot projects, improve supply chain integration, and address technical challenges.
- Consumer Demand: Educating consumers about the environmental benefits of bio-naphtha-derived products can generate market demand, incentivizing companies to adopt greener practices.

Public-Private Initiatives: Joint ventures between governments and private companies can establish shared infrastructure for bio-naphtha production and distribution.

5.5. Long-Term Vision for Bio-Naphtha Adoption

Looking ahead, bio-naphtha could play a transformative role in the petrochemical sector:

- Decarbonizing Petrochemical Value Chains: By replacing fossil naphtha, bio-naphtha can significantly reduce the carbon footprint of key petrochemical products, including ethylene, propylene, and aromatics.
- Circular Economy Integration: Using waste feedstocks and valorizing byproducts aligns bio-naphtha production with circular economy principles, minimizing waste and maximizing resource efficiency.
- Global Energy Transition: As industries and governments pursue net-zero targets, bio-naphtha represents a crucial step in reducing reliance on fossil fuels while supporting renewable energy goals.

However, realizing this vision will require sustained investment in technology, policy, and collaborative efforts among industry stakeholders

6. Conclusion

Bio-naphtha can herald a critical divergence in the use of renewable feedstocks other than fossil naphtha and offer the petrochemical industry a chance to begin the path of global decarbonization through steam cracking. Produced from biomass and waste oils, these renewable feedstocks offer product performance identical to fossil naphtha in ethylene manufacturing while greatly reducing the associated greenhouse gas emissions and consumption of non-renewable resources. However, feedstock variability, complications in pre-treatment, and higher production cost compared to fossil naphtha are some of the problems that need resolution. Emerging technologies including hydrothermal liquefaction and catalytic upgrading processes offer better potential to improve scalability and economic viability of bio-naphtha. Supportive policy measures like carbon pricing, subsidies, and blending mandates become highly relevant for accelerating its deployment. This will be further streamlined in its integration within the existing infrastructure through investment in research and industry-wide collaboration. In the line of making the petrochemical industry carbon neutral, bionaphtha represents an extremely important step because it is a step whereby the sector can leap operationally with efficiency toward sustainability. Most interestingly, the fact that there is increased carbon neutrality from most industries and governments in the world; bio-naphtha truly epitomizes the much-needed innovation that will bridge the chasm between environmental sustainability and industrial scalability. Where persistence prevails, bio-naphtha can rewrite the role of renewable energy in petrochemical operations for a resilient future in sustainability.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Young, B., Hawkins, T. R., Chiquelin, C., Sun, P., Gracida-Alvarez, U. R., & Elgowainy, A. (2022). Environmental life cycle assessment of olefins and by-product hydrogen from steam cracking of natural gas liquids, naphtha, and gas oil. Journal of Cleaner Production, 359, 131884.

[2] Barrowclough, D., & Deere Birkbeck, C. (2020). Transforming the global plastics economy: the political economy and governance of plastics production and pollution (No. 142). GEG Working Paper.

[3] Mangold, H., & von Vacano, B. (2022). The frontier of plastics recycling: rethinking waste as a resource for high-value applications. Macromolecular Chemistry and Physics, 223(13), 2100488.

[4] Velidandi, A., Gandam, P. K., Chinta, M. L., Konakanchi, S., reddy Bhavanam, A., Baadhe, R. R., ... & Gupta, V. K. (2023). State-of-the-art and future directions of machine learning for biomass characterization and for sustainable biorefinery. Journal of Energy Chemistry, 81, 42-63.

[5] Ram, V., & Salkuti, S. R. (2023). An overview of major synthetic fuels. Energies, 16(6), 2834.

[6] Gholami, Z., Gholami, F., Tišler, Z., & Vakili, M. (2021). A review on the production of light olefins using steam cracking of hydrocarbons. Energies, 14(23), 8190.

[7] Gholami, Z., Gholami, F., Tišler, Z., & Vakili, M. (2021). A review on the production of light olefins using steam cracking of hydrocarbons. Energies, 14(23), 8190.

[8] Meindersma, G. W. (2005). Extraction of aromatics from naphtha with ionic liquids.

[9] Tiwari, R., Mishra, R., Choubey, A., Kumar, S., Atabani, A. E., Badruddin, I. A., & Khan, T. Y. (2023). Environmental and economic issues for renewable production of bio-jet fuel: a global prospective. Fuel, 332, 125978.

[10] Jha, S., Nanda, S., Acharya, B., & Dalai, A. K. (2022). A review of thermochemical conversion of waste biomass to biofuels. Energies, 15(17), 6352.

[11] Ram, V., & Salkuti, S. R. (2023). An overview of major synthetic fuels. Energies, 16(6), 2834.

[12] Raj, T., Chandrasekhar, K., Kumar, A. N., & Kim, S. H. (2022). Lignocellulosic biomass as renewable feedstock for biodegradable and recyclable plastics production: A sustainable approach. Renewable and Sustainable Energy Reviews, 158, 112130.

[13] Chia, S. R., Nomanbhay, S. B. H. M., Chew, K. W., Munawaroh, H. S. H., & Show, P. L. (2022). Algae as potential feedstock for various bioenergy production. Chemosphere, 287, 131944.

[14] Tiwari, R., Mishra, R., Choubey, A., Kumar, S., Atabani, A. E., Badruddin, I. A., & Khan, T. Y. (2023). Environmental and economic issues for renewable production of bio-jet fuel: a global prospective. Fuel, 332, 125978.

[15] Yaashikaa, P. R., Kumar, P. S., Saravanan, A., Varjani, S., & Ramamurthy, R. (2020). Bioconversion of municipal solid waste into bio-based products: A review on valorisation and sustainable approach for circular bioeconomy. Science of the total environment, 748, 141312.

[16] de Klerk, A. (2020). Transport fuel: biomass-, coal-, gas-and waste-to-liquids processes. In Future energy (pp. 199-226). Elsevier.

[17] Collett, K. A., Fry, E., Griggs, S., Hepburn, C., Rosetto, G., Schroeder, N., ... & Williams, C. Cleaning up cleaning: policy and stakeholder interventions to put household formulations on a pathway to net zero.

[18] Koytsoumpa, E. I., Magiri–Skouloudi, D., Karellas, S., & Kakaras, E. (2021). Bioenergy with carbon capture and utilization: A review on the potential deployment towards a European circular bioeconomy. Renewable and Sustainable Energy Reviews, 152, 111641.

[19] Ramezani, T., Sadrameli, S. M., Bayat, A., & Dehaghani, A. S. (2022). Bio-gasoline and bio-naphtha production from catalytic cracking of linseed oil methyl ester over iron-and zinc-modified HZSM-5 and γ-Al2O3 catalysts in a fixed double-beds reactor. Fuel Processing Technology, 238, 107514.

[20] Kusenberg, M., Roosen, M., Zayoud, A., Djokic, M. R., Thi, H. D., De Meester, S., ... & Van Geem, K. M. (2022). Assessing the feasibility of chemical recycling via steam cracking of untreated plastic waste pyrolysis oils: Feedstock impurities, product yields and coke formation. Waste management, 141, 104-114.

[21] Ramezani, T., Sadrameli, S. M., Bayat, A., & Dehaghani, A. S. (2022). Bio-gasoline and bio-naphtha production from catalytic cracking of linseed oil methyl ester over iron-and zinc-modified HZSM-5 and γ-Al2O3 catalysts in a fixed double-beds reactor. Fuel Processing Technology, 238, 107514.

[22] Heracleous, E., Iliopoulou, E. F., Drakaki, K., Papapetrou, M. C., Iatridis, D. K., & Lappas, A. A. (2021). Upgrading of biomass-derived liquids in a biorefinery context: Hydroisomerization and fluid catalytic cracking of heavy naphtha on bench and pilot scale. Catalysis Today, 379, 141-148.