



Resource Efficiency
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Industry Coalition



Transitioning the Chemical Industry: Used Cooking Oil as a Renewable Feedstock for Enabling India's Material Transition



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MESSAGE

India's chemicals and materials industry stands at a critical inflection point. Having developed strong capabilities in scale, efficiency, and increasingly in specialty and performance chemistry, the sector is now navigating a global shift shaped by sustainability expectations, evolving policy frameworks, and changing market dynamics.

This report positions Used Cooking Oil as a practical and underutilised opportunity within this transition. While availability is significant, fragmented aggregation systems present a clear opportunity for industry-led action to unlock both environmental and commercial value. The pathways outlined demonstrate that such alternative feedstocks can be integrated using existing capabilities, offering a pragmatic route forward.

Importantly, the report takes a balanced view of economic readiness-highlighting where opportunities are immediately viable and where enabling mechanisms can accelerate adoption. This supports informed, strategic engagement rather than prescriptive action.

I commend the RECEIC Working Group for this timely and thoughtful report, which provides a valuable basis for forward-looking decision-making.

Manish Sharma

Chair RECEIC



PREFACE

Transitioning from fossil-based carbon to renewable carbon is essential for India's chemical industry to achieve its Net Zero ambitions while strengthening national self-reliance. Recent geopolitical events have exposed vulnerabilities in fossil-based supply chains, highlighting the need for greater material resilience.

Recognizing this imperative, the Material Transition Working Group under RECEIC was established with the belief that reducing dependence on fossil carbon in chemicals requires the same urgency and rigour as the energy transition.

This paper seeks to move the discussion from ambition to action by demonstrating how Used Cooking Oil (UCO) can serve as a viable near-term circular feedstock for India's chemical sector, provided the right policy and ecosystem enablers are in place.

Scaling UCO utilisation can deliver multiple benefits: reducing import dependence, strengthening supply chain resilience, lowering greenhouse gas emissions, improving public health by preventing diversion into informal food systems, and creating inclusive value chains that integrate informal waste collectors.

While UCO offers significant potential as a circular feedstock, the study indicates that India's primary challenge is not theoretical UCO availability, but the effectiveness of collection, aggregation, quality segregation, traceability, and allocation mechanisms needed to mobilise it at scale. As demand for UCO emerges simultaneously from biodiesel, SAF, and chemical value chains, these capabilities will become increasingly important to support both energy-transition and material-transition objectives.

Realising its full value for chemicals will require advances in technology, robust collection and traceability systems, reliable supply chains, and greater consumer awareness. Achieving this at scale will depend on coordinated action across industry, policymakers, academia, and knowledge partners.

We hope this report contributes meaningfully to informed decision-making and catalyses collaboration across the ecosystem, helping build a resilient, competitive, and sustainable chemical industry for India.

Mr. Rajat Arora

Chair, Materials Transition Working Group
Vice President and Head R&D, Home Care, India
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FOREWORD

India's transition toward Net Zero emissions has, over the past decade, been shaped principally by advances in renewable energy, electrification, low-carbon fuels, and sustainable mobility. This research paper broadens that important discourse by directing attention to an equally consequential dimension: the fossil carbon embedded in the materials society produces and consumes. Among the resources with the potential to support this material transition, used cooking oil (UCO) merits particular attention. Generated daily across households, food establishments, institutions, and urban centres, UCO constitutes a domestically available waste stream whose economic, environmental, and public health value can be realized through purposeful collection, sound governance, and efficient industrial utilization.

As a renewable, waste-derived, and chemically versatile feedstock, UCO presents a strategically significant near-term to medium-term opportunity. It can be converted into oleochemical intermediates, employed as a substitute for fossil-derived hydrophobes in surfactants, and processed through refinery-integrated pathways for wider material applications. In comparison with virgin vegetable oils, its productive use can avoid additional pressures on land, water, and food systems. These characteristics position UCO as a credible bridge feedstock within a resource-conscious and circular industrial transition.

The paper also contributes to a more comprehensive understanding of decarbonization. Although renewable power, electric mobility, and green hydrogen remain indispensable, the carbon embodied in everyday products—including detergents, dishwashing liquids, and industrial cleaning agents—requires a complementary transition in material feedstocks. By examining UCO as a circular-carbon resource, the authors place feedstock substitution alongside energy transformation as an essential component of a coherent net-zero strategy.

The significance of this inquiry extends beyond climate mitigation. Appropriate management of degraded cooking oil can strengthen food safety by directing it away from reuse in the food chain and toward traceable, productive applications. The Food Safety and Standards Authority of India's (FSSAI's) Repurpose Used Cooking Oil (RUCO) initiative has established an important institutional foundation for this transition. Building on that foundation, robust industrial demand, supported by credible collection and traceability systems, can reinforce compliance while creating durable markets for responsible recovery and reuse.

International experience further demonstrates that effective UCO recovery is most likely where policy architecture aligns collection obligations, transparent chain-of-custody arrangements, quality

standards, and differentiated end-use incentives. The comparative evidence considered in this paper—from the US, the European Union, Germany, Japan, China, and the UK—offers relevant insights for India as it develops a system suited to its own institutional, market, and urban realities. The opportunity, therefore, lies in translating established lessons into an integrated national framework that encourages innovation, investment, and accountable implementation.

This agenda also carries strategic economic importance. At a time of volatility in global energy and commodity markets, the development of domestic, waste-derived carbon supply chains can advance resource security, industrial competitiveness, and the objectives of Atmanirbhar Bharat. Climate action, public health protection, circular-economy development, and national resilience can thus be pursued as mutually reinforcing priorities rather than as separate policy domains.

The paper provides a rigorous and timely foundation for this evolving field. Its analysis of supply potential, quality grading, economic feasibility, regulatory architecture, and international practice offers policymakers, researchers, industry leaders, and investors a shared evidence base for further inquiry and coordinated action. Importantly, it frames UCO not merely as a waste-management concern, but as a resource situated at the intersection of public health, climate mitigation, energy transition, and industrial development.

We trust that the paper will deepen scholarly and policy engagement with UCO and encourage the development of practical pathways through which India can capture its full environmental, economic, and social value. Treating UCO as a strategic circular-carbon resource is a consequential and achievable step toward a more sustainable material economy, and this publication makes a valuable contribution to that endeavour.

Amit Kumar

Partner, EY



EXECUTIVE SUMMARY



EXECUTIVE SUMMARY

Context

Transitioning to a Net Zero world demands a holistic approach that integrates both energy transition and materials transition as twin pillars of sustainable development. While the global shift toward renewable energy is essential for emissions reduction from the energy sector, this is viewed insufficient to deliver the required deep decarbonization. A sustainable materials transition focuses on improving materials efficiency, substituting high-emission materials with advanced low-carbon alternatives and expanding circular economy practices. This further reduces waste and resource extraction and is of emerging significance for widening decarbonisation pathways. India's own decarbonization commitments, 500 GW non-fossil capacity target by 2030 and Net Zero goal by 2070¹, as reflected in its COP26 pledges, underscore the importance of aligning energy transition along with material transitions for a cleaner, more resilient economy. Advanced materials, recycling systems, digital design tools and resource-efficient manufacturing lie at the core of material transition principles. In essence, sustainable development and decarbonization can both be achieved through coordinated transformation of both energy and materials systems to build a truly Net Zero future.

Rationale of the Study

It is viewed that renewable recycled (waste-derived) feedstocks assume strategic importance for material transition. Such feedstocks retain the benefits of embedded biogenic carbon while avoiding the structural limitations associated with virgin biomass. UCO, also referred to as waste cooking oil (WCO), represents one of the most mature and scalable decarbonisation pathways available.

Study Approach and Methodology

This paper, 'Transitioning the Chemical Industry: Used Cooking Oil as a Renewable Feedstock for Enabling India's Material Transition', has tried to build a comprehensive understanding of the UCO ecosystem in India and establish a strategic roadmap for mobilising UCO for chemical and material applications, beyond its current dominant use in biodiesel. Accordingly, UCO is positioned as a strategically important, near-term opportunity to accelerate material transition alongside energy

¹ Press Information Bureau, Ministry of Power, PRID=2223720, 5th Feb, 2026

transition; subject to policy design evolving from enabling frameworks to outcome-oriented systemic interventions.

In this background, the study undertakes a baseline assessment of UCO supply and demand across energy and chemical applications, evaluating its suitability as a chemical feedstock alongside competing uses. The analysis examines chemical end points of UCO in relation to required chemical thresholds of chemical industries, economic viability of UCO substitution for fossil-based feedstocks, and GHG emission reduction benefits in the event of UCO substitution. Required data for this study is obtained from secondary sources.

Key Findings

- i. FSSAI, through its RUCO initiative estimates consumption of cooking oil in India is 24.67 M MT, of which 9.87 M MT (40%) is the commercial consumption and 14.80 M MT (60%) is the household consumption. UCO availability potential from commercial consumption is 1.48 M MT (15%) and from household consumption is 0.74 M MT (5%). Together, UCO availability is 2.22 M MT, i.e., 9 % of the consumption of cooking oil.
- ii. As of March 2026, India has 72 registered biodiesel production units, of which approximately 40% report no formal linkage with any UCO aggregator, highlighting significant gaps in organised feedstock mobilisation. Among the remaining plants, 26.4% are linked to a single aggregator, 13.9% to two aggregators, and only 19.5% to three or more aggregators. This results in an average of ~1.4 aggregators per biodiesel plant, indicating a narrowly distributed and weakly buffered aggregation network. Beyond biodiesel, formal aggregator linkages to chemical end uses remain limited. Of the 133 aggregators identified nationally, 109 are linked to biodiesel units, while only 24 aggregators (~18%) are linked to soap manufacturers. These soap-linked aggregators are geographically concentrated, with notable presence in a few states including Karnataka, Kerala, Tamil Nadu, West Bengal, Punjab, and Telangana.
- iii. About 60 % of the generated UCO further re-enters the food system (illicitly, amidst serious health risks), which could otherwise be mobilised for effective reuse for energy and material transition, and safeguarding public health.
- iv. UCO based SAF production in India is yet to take a formal shape. In India, the first commercial SAF production is being initiated by Indian Oil Corporation Limited (IOCL) at its Panipat refinery, with a capacity of approximately 35,000 tonnes per year, with UCO envisaged as a key feedstock.
- v. Based on compatibility analysis of chemical end points of UCO and appropriate chemical pathway analysis of selected surfactants, AE, AES/SLES, LAS are validated for material transition opportunities, by substituting UCO as feedstock for fossil-based feedstocks. By considering 100% UCO substitution for fossil feedstocks, it is estimated that surfactant classes alone would require approximately 2.0 million tonnes of UCO per year, tied to 2023–24 volumes.
- vi. Further estimates point out that available UCO volumes are sufficient to support existing biodiesel use, early-stage SAF deployment produced via HEFA, and targeted surfactant material-transition pathways. However, this does not imply surplus or unconstrained feedstock. India's primary

near-term constraint is not theoretical UCO availability potential, but the effectiveness of mobilisation, aggregation, quality segregation, and allocation.

- vii. The study finds that UCO could serve as a versatile renewable feedstock, with its cross-sector usability across surfactants, biodiesel and SAF, as the demand for sustainable alternatives grow, and requirements for increasingly stringent chemical thresholds. Effective segregation, grading, and pretreatment of UCO are therefore critical determinants of its technical and economic viability across different industrial value chains.
- viii. The economic analysis indicates competitiveness of the UCO based production for both surfactants and fuels, with success largely depending on cost efficiency, market positioning, and policy or sustainability-driven demand support.
- ix. The study estimates GHG reduction potential through adopting UCO as a feedstock. It is found that UCO substitution delivers net fossil-carbon avoidance and life cycle GHG reduction across all end-uses considered, although the magnitude and relative ranking are indicative rather than definitive, and are sensitive to process severity, hydrogen demand, and residual fossil inputs.

Way Forward

i. **Strengthen understanding of UCO generation potential**

Despite growing interest in UCO as a renewable feedstock, robust estimates of generation potential and recoverable volumes remain limited. A comprehensive assessment across household and commercial sectors, covering both urban and rural geographies, could provide a stronger evidence base for collection planning, infrastructure investments, and end-use allocation.

ii. **Expand UCO collection coverage and infrastructure**

Current collection systems are largely focused on commercial kitchens consuming more than 50 litres of vegetable oil per day and are concentrated in major urban centres. There may be an opportunity to broaden the scope of eligible UCO source points, supported by expansion of collection infrastructure through Urban Local Bodies (ULBs), licensed aggregators, and dedicated collection mechanisms.

iii. **Strengthen policy and regulatory frameworks**

As UCO utilisation grows, policy mechanisms could be evaluated to support traceable collection, aggregation, and utilisation. An appropriate framework may represent one potential approach, supported by detailed standard operating procedures, monitoring systems, and appropriate legal enforcement provisions. Formalisation of currently unlicensed collection channels could further strengthen the ecosystem.

iv. **Consider allocational planning across end-use sectors**

Growing demand from biodiesel, SAF and chemical value chains may increase competition for finite UCO resources. Improved visibility of UCO flows and consideration of allocation mechanisms could support informed decision-making across competing end uses.

v. **Support deployment of advanced conversion technologies**

Continued development, scale-up, and commercialisation of technologies capable of converting UCO into fuels and chemicals may help expand utilisation pathways and improve the value derived from renewable carbon feedstocks.

vi. **Evaluate targeted incentive mechanisms**

The Government of India may consider facilitating appropriate incentive mechanisms to strengthen UCO collection, aggregation, and utilisation. Such measures could support supply-chain development, improve competitiveness of UCO-derived products, and encourage investment across the value chain.

vii. **Explore sectoral allocation mechanisms for licensed aggregators**

As demand for UCO increases across multiple sectors, consideration may be given to transparent, evidence-led allocation planning that improves visibility of UCO flows across biodiesel, SAF, and chemical value chains. Any sectoral routing mechanism should be phased, market-responsive, and linked to demonstrated cost competitiveness, feedstock availability, quality suitability, and policy objectives.

Closing Perspective:

UCO should be treated as a strategic circular-carbon resource whose allocation materially shapes India's decarbonization pathway. The barriers India faces for effective use of UCO, are not fundamental constraints but systemic challenges. With policy alignment, UCO can simultaneously support energy transition, unlock material transition, and deliver lasting public-health benefits, demonstrating that climate action, industrial growth, and societal welfare, which are mutually reinforcing and not with competing objectives. Thus, policy evolution toward outcome-oriented allocation guided by lifecycle carbon efficiency, public-health impact, and system resilience metrics would enable more deliberate optimisation across competing UCO end uses.



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SECTION 1

INTRODUCTION



1. INTRODUCTION

1.1. Background

Within India's industrial ecosystem, chemicals are foundational, supplying critical inputs across almost all sectors of the economy. Among them, surfactants and polymers stand out due to their scale, functional indispensability, and pervasive presence across consumer and industrial value chains.

Surfactants are integral to hygiene, health, and essential industrial processes, underpinning home and personal care products, industrial and institutional cleaning, textiles, food processing, pharmaceuticals, agrochemicals, and formulation chemistry. Their ability to enable emulsification, dispersion, wetting, and solubilisation makes them indispensable to both basic and advanced manufacturing. Polymers similarly form the material backbone of India's growth and industrialisation, supporting packaging, infrastructure, automotive, electronics, healthcare, textiles, and consumer goods through affordability, durability, lightweighting, and design flexibility.

Together, surfactants and polymers account for a significant share of the chemical industry's economic contribution and downstream value creation, with demand closely tied to population growth, urbanisation, and industrial development. Economically, they represent a substantial and growing portion of the sector: the Indian surfactants market is estimated at USD 2–3 billion, growing at around 6–7% CAGR, while the Indian polymers and plastics market exceed USD 40 billion and is projected to grow at approximately 5–6% annually. Their scale and growth trajectories mean that continued reliance on fossil-derived feedstocks has system-level implications for India's material emissions profile, while their transition offers disproportionately high decarbonisation leverage.

Both classes remain structurally dependent on fossil-derived feedstocks, reflecting the chemical industry's historical co-development with the oil and gas sector. As a result, even where production

processes are decarbonised, the fossil origin of feedstock carbon continues to embed emissions across product life cycles, posing a structural challenge to India's Net Zero ambitions. Their high volumes, broad end-use spread, and embedded fossil carbon make them priority leverage points for material transition.

1.2. Material Transition for Chemicals and Fuels

Material transition refers to the systematic replacement of fossil-derived carbon in materials with renewable, biogenic, circular, or non-fossil alternatives. Over the last decade, substantial progress has been made in decarbonising key energy end-use sectors, and investment flows have increasingly focused on renewable means and efficiency improvement. While these efforts are essential, they address only one dimension of the broader decarbonisation challenge. India's pathway to Net Zero emissions cannot be realised through energy transition alone. Materials—particularly chemicals—remain overwhelmingly dependent on fossil-derived carbon, and this dependency represents a structurally significant source of emission that energy transition alone cannot eliminate.

On the other hand, considerable growth in India's Aviation sector with CAGR of above 10% demands for alternate bio derived aviation fuel like SAF, with regulatory, technical, and environmental compliance, to mitigate GHG reduction and support in achieving India's Net Zero target by 2070. SAF production through HEFA (Hydroprocessed Esters and Fatty Acids) coprocessing pathway in the existing refinery infrastructure is also the most viable and techno-commercially beneficial option. The aviation industry is the least environmentally regulated and decarbonising this industry will have a huge impact in achieving Net Zero goals on the account of its market volume.

In the chemical sector, greenhouse gas emissions arise from two distinct but interconnected sources. The first is energy use during production, which includes process, utilities, and upstream inputs. These emissions can be progressively reduced through decarbonization strategies such as renewable energy integration as highlighted earlier. The second, and often less visible, source is embedded fossil carbon in chemical feedstocks. This carbon is chemically bound into products and materials that circulate through the economy and are ultimately released to the atmosphere at end-of-life through degradation, incineration, or disposal. As long as chemicals continue to be derived from fossil feedstocks, and irrespective of how clean the energy used in the production becomes, a significant portion of emissions remains locked into the material system² and released at the end of life. As a result, merely decarbonisation of energy inputs, although necessary, is insufficient to achieve deep and durable emissions reductions in the chemical sector, unless it is accompanied by a material transition.

Additionally, energy transition drives rising demand for chemically intensive materials such as polymers, resins, surfactants, coatings, and specialty chemicals that find their applications, for instance in solar panels and wind turbines. This positions the chemical industry uniquely: it is both a critical

² Collett, K. A. et al., 2023. Cleaning up Cleaning: policy and stakeholder interventions to put household formulations on a pathway to net zero., s.l.: Oxford, Smith School Working Paper 23-07.

enabler of the energy transition and a significant source of material-related emissions; thereby underscoring the need for rethinking feedstock choices, supply chains, and value-creation pathways. Without such a transition, the chemical industry risks becoming a residual source of emissions even in an otherwise largely decarbonised energy system.

Recognizing the deep interlinkages, the Material Transition Working Group under RECEIC also articulates that energy and material transitions must be pursued together. As highlighted in the Working Group's earlier analysis on transitioning the chemical industry to a Net Zero pathway³, a deliberate material transition—addressing fossil-carbon dependence at the feedstock level—is essential to avoid emissions shifting within the system and to deliver meaningful, long-term decarbonisation.

1.3. Supply Chain Disruptions

Recent geopolitical tensions in the Middle East have further underscored India's vulnerability to disruptions in crude oil supply and price volatility, highlighting the extent of its reliance on imported fossil feedstocks. For the chemical sector, this exposure extends beyond energy to material inputs, particularly for high-volume products such as surfactants and polymers. In this context, increasing the use of domestic, biogenic feedstocks offers a pathway to strengthen supply-chain resilience while reducing dependence on imported crude-derived carbon. Advancing such alternatives can simultaneously support India's Net Zero objectives and reinforce the Atmanirbhar Bharat agenda by anchoring critical material value chains more firmly within the domestic economy.

At the same time, this scale creates opportunity. Transitioning even a fraction of these high-volume product streams towards non-fossil or renewable feedstocks can deliver significant climate benefits, complementing energy transition. Importantly, this is also a strategic industrial consideration: as global markets increasingly factor carbon intensity, circularity, and sustainability into competitiveness, the ability to supply low-carbon or renewable-based materials will influence long-term market access and value creation. In this context, material transition for high-volume chemicals emerges as a critical pillar of India's Net Zero pathway—one that could enable climate progress while supporting continued industrial development and economic growth.

1.4. Case for Renewable Recycled Feedstocks

For both, surfactants and polymers, biobased feedstock pathways are not new; nor are they technically unproven. Oleochemical value chains based on vegetable oils have long supplied fatty acids and fatty alcohols to the surfactant industry, forming the backbone of several established formulations. For biofuels production, the biobased feedstock is more technically proven at commercial scale for Biodiesel (through transesterification) or SAF (through HEFA) production. Similarly, biopolymers and bio-based polymer intermediates are widely recognised as potential substitutes for fossil-derived polymers across a range of applications. Despite this technical maturity, these pathways have not been

³ Transitioning the Chemical Industry to a Net Zero Pathway: The Critical Need for a Material Transition, <https://receic.com/wp-content/uploads/2025/04/Material-Transition-in-Chemical.pdf>

adopted at scale. One of the principal constraints include reliance on virgin biobased feedstocks with trade-offs related to land use, water consumption, and, in some cases, competition with the food ecosystem. As demand scales, these pressures become increasingly material, limiting the sustainability and social acceptability of large-scale deployment.

In this context, renewable recycled (waste-derived) feedstocks assume further strategic importance for material transition. Such feedstocks retain the benefits of embedded biogenic carbon while avoiding the structural limitations associated with virgin biomass. UCO represents one of the most mature and scalable examples of this category in the Indian context. Generated as a by-product of widespread food consumption, UCO is already regulated to prevent unsafe reuse and diversion back into the food chain, positioning it as a potentially future-ready, controlled and traceable waste stream.

1.5. Potential of UCO as Feedstock for Material Transition

UCO has emerged globally as a strategically important feedstock at the intersection of carbon reduction, waste valorisation, and material transition. Its significance arises not from a single attribute, but from a unique combination of advantages that collectively make UCO a high-value enabler for de-fossilising materials and chemicals.

As a recycled renewable feedstock, UCO delivers life-cycle greenhouse gas reduction potential, especially when displacing fossil-derived chemical feedstocks (a reduction of 2.1 to 2.5 tCO₂e/t; refer section 4.4). At the same time, it avoids incremental land-use demand and mitigates pressure on agricultural systems. Chemically, UCO is highly versatile. It can be converted into oleochemicals such as fatty acids, fatty alcohols, and glycerine, directly supporting surfactant value chains. Through established thermochemical and refinery-integrated pathways, it can also yield hydrocarbon streams suitable for polymer and material applications.



“Used Cooking Oil is one of the most promising low-GHG recycled carbon sources for material transition. The real challenge is not recognising its value but deliberately designing the system—from collection and aggregation to allocation—so that this carbon is directed to its highest long-term material and societal value.”

Mr. Rajat Arora – VP, R&D, Home Care, Head of South Asia & Asia, Unilever; Chair of Working Group on Material Transition, RECEIC.



(i) Dual biogenic and recycled carbon enabling GHG reduction

UCO is derived entirely from renewable, biogenic carbon and classified as a waste-derived, recycled carbon stream. This dual characteristic enables some of the highest life-cycle GHG reductions when substituting fossil carbon in fuels, chemicals, and materials. By displacing fossil-derived hydrocarbons with recycled biogenic carbon, UCO directly supports material transition while valorising an otherwise under-utilised waste stream and reducing reliance on fossil resources.

(ii) Chemical compatibility with existing hydrocarbon value chains

UCO exhibits molecular structures closely aligned with fossil-derived intermediates used in fuels and chemicals. Its triglyceride and fatty acid components can be processed through established routes such as transesterification, hydrotreatment, and cracking, enabling integration into existing

infrastructure with limited technological risk. This compatibility lowers barriers for substituting fossil feedstocks across multiple value chains.

Thus, UCO holds tremendous potential for a practical pathway to advance renewable feedstocks for chemicals without the sustainability constraints associated with virgin oils or dedicated biomass. As such, it represents a near- to medium-term bridge feedstock capable of accelerating material transition in surfactants and polymers, while simultaneously addressing waste management, public health, and resource-efficiency.

1.6. Public Health Risks from Improper Reuse and Disposal of UCO

In India, public health risks^{4,5}, from improper reuse and disposal of UCO particularly its diversion into informal and unsafe food channels⁶, have led to regulatory intervention⁷. In response, the Food Safety and Standards Authority of India (FSSAI), India's food safety regulator, introduced the Repurpose Used Cooking Oil (RUCO) initiative to formalise UCO collection and channel it towards approved non-food end uses. This initiative has laid the foundation for an emerging UCO ecosystem in India. However, despite this progress, formal collection remains partial and uneven, with aggregation largely concentrated in organised HoReCa (Hotel, Restaurant, and Café/ Catering) and institutional segments.

Repeated use of cooking oil beyond recommended limits can result in the formation of degraded compounds that pose potential public-health risks. Recognising these concerns, FSSAI links elevated Total Polar Compounds (TPC) in used cooking oil with adverse health impacts and, through the RUCO initiative, seeks to prevent diversion of degraded oil back into the food chain. Detailed discussion of oil degradation and compositional changes is presented in Section 3.1. In India, continued informal reuse of UCO remains a challenge, creating risks for consumers and food-service workers alike. Strengthening formal collection and utilisation pathways therefore supports not only resource efficiency and decarbonisation objectives, but also important public-health outcomes.

1.7. End-Use Landscape and Competing Demand Pathways

Globally, the dominant utilisation of UCO today is in biofuel production, including conventional biodiesel via transesterification and hydroprocessed fuels such as renewable diesel. These pathways are primarily driven by transport-sector decarbonisation mandates and supported by relatively mature collection and aggregation systems, typically involving multiple intermediaries due to the distributed nature of UCO generation.

More recently, UCO has emerged as an important feedstock for SAF, reflecting increased focus on aviation decarbonisation under frameworks such as International Civil Aviation Organization's (ICAO) Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). SAF produced from UCO offers a low-carbon, drop-in alternative to conventional aviation turbine fuel without requiring modifications to aircraft or fuel infrastructure.

⁴ ICMR's Warning on Reused Oil: Best Practices for Safe Cooking and Sustainability

⁵ NHRC notice to Health Ministry, FSSAI on 'widespread reuse of cooking oil' - The Economic Times, NHRC takes notice of widespread reuse of cooking oil across India

⁶ Diversion of Used Cooking Oil into the Food Stream: A Study of Four Indian Cities

⁷ FSSAI: About RUCO, FSSAI: guidance note UCO

Beyond energy applications, UCO can also serve as a renewable feedstock for oleochemicals, including soaps, fatty acids, glycerine, surfactants, lubricants, and polymer intermediates, enabling substitution of petrochemical feedstocks. Additional uses include incorporation into animal feed as an energy-dense fat, subject to stringent quality and safety controls. Taken together, biodiesel, SAF, oleochemicals, and other applications form an integrated and competing demand ecosystem for UCO. The availability of UCO for chemical and material applications must therefore be assessed within this broader landscape of existing and emerging end uses.

1.8. Implications for Chemical and Material Supply-Chain Design

While existing UCO supply chains have evolved largely around fuel applications, their structure and optimisation are not aligned with the requirements of chemical and material value chains. Chemicals differ fundamentally from fuels in terms of quality, consistency, traceability, supply reliability, and risk tolerance, while remaining heavily dependent on fossil-derived feedstocks as their primary source of carbon.

Developing a UCO-based supply chain for chemicals therefore represents a strategic opportunity to de-fossilise material value chains alongside energy transition pathways, enabling deeper, system-level emissions reduction. Unlike fuel-centric models, such supply chains must prioritise feedstock quality, process compatibility, and long-term reliability over volume alone.

UCO is generated in substantial quantities across households, restaurants, food manufacturers, institutions, and commercial establishments. However, current collection systems capture only a fraction of this potential, resulting in the loss of a valuable biogenic carbon resource. Unlocking the circular potential of UCO for chemical applications requires deliberate investment in aggregation, traceability, and supply-chain design to convert dispersed waste generation into an industrially reliable feedstock stream.

1.9. Purpose and Layout of this paper

This paper, 'Transitioning the Chemical Industry: Used Cooking Oil as a Renewable Feedstock for Enabling India's Material Transition', has been commissioned by RECEIC to develop a comprehensive understanding of the UCO ecosystem in India and to establish a strategic roadmap for mobilising UCO for chemical and material applications beyond its current dominant use in biodiesel.

The paper assesses the opportunity to accelerate material transition in the Indian chemical industry using UCO as a renewable, recycled feedstock for surfactants and polymers, substituting conventional petrochemical feedstocks. It further examines key barriers to this transition and outlines the infrastructure, financing, and policy enablers required to realise this opportunity at scale.

Accordingly, the study undertakes a baseline assessment of UCO supply and demand across energy and chemical applications, evaluating its suitability as a chemical feedstock alongside competing uses. The analysis examines chemical characteristics, economic viability, and regulatory considerations, comparing petrochemical-based and UCO-based value chains for chemicals.

SECTION 2



UCO SUPPLY, DEMAND AND COMPETING USES



2. UCO SUPPLY, DEMAND AND COMPETING USES

A system-level understanding of demand and supply across UCO end-uses is essential for evaluating the feasibility of establishing a resilient UCO supply chain for chemical applications. Accordingly, this chapter analyses UCO supply and demand across India, examining volumes, sources, aggregation structures, and competing end-uses to identify gaps and constraints relevant to the development of UCO-based chemical value chains. While biodiesel and SAF are included in the analysis, their primary role within this study is to provide context on competing demand pathways for UCO and the policy environment in which material-transition applications must operate.

2.1 UCO Supply Landscape

2.1.1 Estimating UCO Availability in India

It is worth noting that different studies assessed the potential availability of UCO and figures vary based on their methodology and data reference⁸. As per RUCO estimate (Table 1), consumption of cooking oil in India is 24.67 M MT, of which 40% (9.87 M MT) is the commercial consumption and 60% (14.8 M MT) is the household consumption. UCO availability potential from commercial consumption is 15% (1.48 M MT) and from household (HH) is 5% (0.74 M MT). Together, UCO availability is 9%, i.e., 2.22 M MT. The Biodiesel Association of India (BDAI) reflects consumption of cooking oil in India is 22.5 M

⁸ International Council on Clean Transportation (ICCT) estimates the collection potential assuming 100% collection from urban restaurants, 50% from urban households, and 100% from food processing nationwide, based on the idea that collection from businesses like restaurants and food processing plants is easier than from households, especially in large amounts. As per the estimation, India is having an estimated potential collection of 1,697 kilotonnes (1.7 M MT) and estimated current collection is 224–326 kilotonnes (0.22–0.33 M MT). Current collection share of potential is ranging between 13%–19%. Study of ICCT also observed that any UCO surpluses in India might not exist because the UCO could be used in the gutter oil market. Gutter oil is a problem in the country in spite of governments initiative to address it through biofuel program to increase legal UCO collection. Further as per BDAI, UCO availability potential from household consumption is almost negligible or not available whereas 30.0% UCO availability potential is there from commercial consumption (40% of total) which stands at 2.7 M MT (12% of total consumption). Overall, potential availability of UCO ranges between 2.03 M MT to about 2.5 M MT as per the suggested RUCO norms.

MT. Applying the above distribution, the UCO availability potential remains at 2.03 M MT. This study estimated the consumption of cooking oil considering, production, import and export to establish a net availability of 27.82 M MT, and a corresponding UCO availability potential is 2.50 M MT.

We use the RUCO based estimate of 2.22 M MT in this study for the purpose of supply demand reconciliation.

Table 1: UCO Availability Potential (RUCO Norms)

Parameters	%	M MT
Consumption of Cooking Oil in India		24.67
Commercial Consumption	40%	9.87
UCO Availability Potential-Commercial	15%	1.48
Household (HH) Consumption	60%	14.8
UCO Availability Potential-HH	5%	0.74
UCO Availability Potential-Total	9%	2.22

2.1.2 Existing Collection Pathways & End Uses

At present, the only fully formalised supply-chain mechanism for UCO utilisation is the UCO-to-biodiesel pathway. This is primarily driven by the government policy support under the dedicated Biodiesel Policy, along with facilitation through the Repurpose Used Cooking Oil (RUCO) framework. Some basic filtering or pre-processing comprising degumming and demetallation, are undertaken to remove impurities such as water and food residues, before the UCO is supplied to biodiesel manufacturers.

More recently, the potential for use of UCO for SAF production has gained significance. India, and other countries including the United States and European Union member states have committed to SAF blending targets, and UCO (with intensive upgradation) as one of the possible feedstocks is relevant.

2.1.3 UCO Aggregation Landscape

UCO aggregation is typically characterised by many relatively small, localised and decentralised collection infrastructure, involving feedstock collectors, aggregators, and agents. In some cases, UCO is sent directly for end use, mostly biodiesel production. UCO aggregators are a critical intermediary connecting dispersed sources of UCO to formal end-use industries. Under the RUCO framework, aggregators are empanelled to mobilise UCO from households, HoReCa establishments, and institutional kitchens and channel it towards approved end uses, typically biodiesel.

Structure of the aggregation network: As of March 2026, India has 72 registered biodiesel production units, of which approximately 40% report no formal linkage with any UCO aggregator, highlighting significant gaps in organised feedstock mobilisation. Among the remaining plants, 26.4% are linked to a single aggregator, 13.9% to two aggregators, and only 19.5% to three or more aggregators. This results in an average of ~1.4 aggregators per biodiesel plant, indicating a narrowly distributed and weakly buffered aggregation network⁹ (Table-I, Annexure-III).

From a systems perspective, this distribution points to redundancy and low resilience in UCO mobilisation. A mature aggregation ecosystem typically requires multiple aggregators operating within a catchment area to manage variability in volumes, seasonal fluctuations, quality inconsistencies, and geographic dispersion of sources. The observed concentration of plants with zero or minimal aggregator linkages therefore reflects an under-developed aggregation layer, rather than saturation or efficiency.

Aggregation Alignment across End Uses: Beyond biodiesel, formal aggregator linkages to chemical end uses remain limited. Of the 133 aggregators identified nationally, 109 are linked to biodiesel units, while only 24 aggregators (~18%) are linked to soap manufacturers. These soap-linked aggregators are geographically concentrated, with notable presence in a small number of states, including Karnataka, Kerala, Tamil Nadu, West Bengal, Punjab, and Telangana. Several high UCO-generating states show minimal or no linkage to surfactant or soap manufacturing despite having significant downstream chemical capacity.

This imbalance underscores that biodiesel has emerged as the dominant and default outlet for organised UCO aggregation, not necessarily because of superior system design, but due to early regulatory prioritisation and clearer demand signalling. In contrast, chemical applications—particularly soaps and surfactants—remain structurally under-served within the current aggregation framework (Table-II, Annexure-III).

Ecosystem Resilience and Chemical

Applications: The present aggregation landscape reveals that UCO mobilisation in

India is constrained less by generation potential and more by aggregation capacity. Expanding aggregation depth—both in terms of the number of aggregators per catchment area and the diversity of end-use linkages—is essential to improve recovery rates, enhance supply reliability, and enable quality differentiation.

“India's UCO challenge is not one of theoretical availability but of a structurally weak supply chain. Dispersed generation, weak incentives, and unreliable aggregation mean most UCO never enters formal systems. Until availability is stabilised through better collection and aggregation models, debates on optimal end use—fuels versus chemicals—remain largely academic.”

Dr Anjan Ray – Investor Partner, Navam Capital

⁹ Analysis made from the data retrieved from Enrolled Biodiesel Manufacturers - RUCO: Repurpose Used Cooking Oil and Research Paper on Used Cooking Oil based Biodiesel of www.pahalindia.org

For chemical and material applications, this has two direct implications. First, a biodiesel-centric aggregation network is not optimised for the quality consistency, traceability, and specification alignment required by chemicals. Second, without deliberate linkage of aggregators to chemical value chains, UCO is being structurally absorbed into fuel pathways by default.

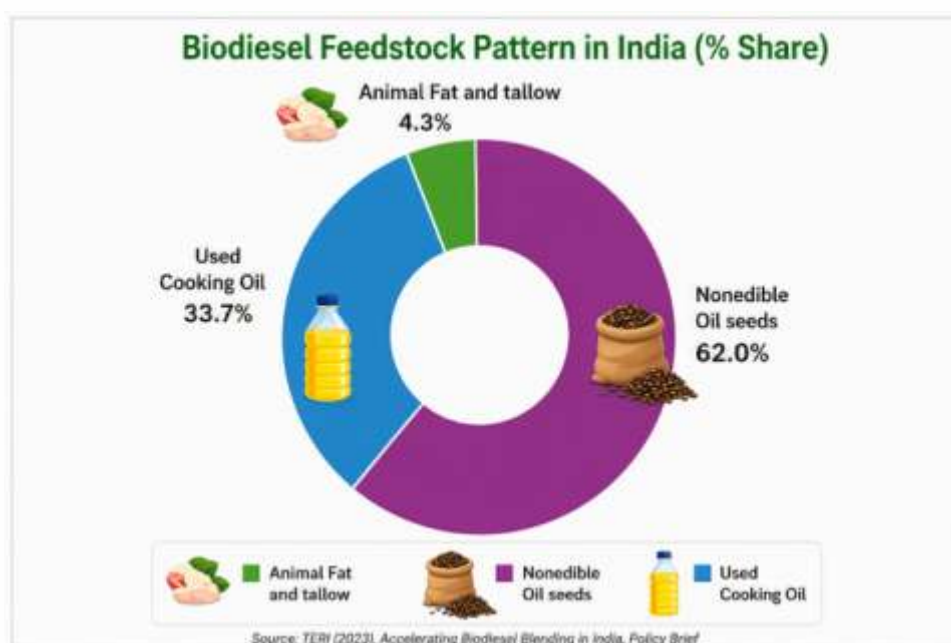
Strengthening and diversifying the aggregation layer, while remaining aligned with existing energy-transition pathways, is therefore a precondition for building a resilient UCO supply chain for chemicals and fuels. An ecosystem-level approach to aggregation can enable differentiated routing of UCO, based on quality and end-use suitability. It will support both energy transition and material transition objectives without undermining either.

2.2 UCO Demand Landscape

2.2.1 Demand for UCO in Biodiesel

India's biodiesel sector represents a clear and established demand for UCO. Based on recent production trends (Table-III, Annexure-III), average annual biodiesel output is ~ 160,000 MT, of which ~ 55,000 MT per year is produced using UCO, accounting for roughly one-third of total biodiesel production (Figure-1). Biodiesel production from UCO occurs via transesterification, which yields biodiesel at an approximately one-to-one mass ratio, with glycerine generated as a co-product. Accordingly, biodiesel output of 55,000 MT implies a corresponding demand of approximately 55,000 MT of UCO.¹⁰

Figure 1: Biodiesel feedstock pattern in India



¹⁰ Accelerating biodiesel blending in India, TERI 2023

Notably, the absolute quantity of UCO absorbed by biodiesel production has remained relatively stable over time, even as total biodiesel output has fluctuated with changes in non-edible oilseed supply. This suggests that UCO availability and aggregation, rather than conversion capacity, constrain further uptake. From a systems perspective, biodiesel therefore constitutes a structurally significant and persistent demand sink for formally aggregated UCO, and this baseline understanding is critical when assessing the availability of UCO for competing chemical and material applications.

2.2.2 Demand for Sustainable Aviation Fuel

SAF is a low-carbon alternative to conventional jet fuel driven by the decarbonisation imperative of the aviation sector. This is produced from renewable feedstocks and can be used in existing aircraft without technical modification. Currently blended (~ 0.3%¹¹) with conventional Aviation Turbine Fuel (ATF), it is constrained by availability, cost, regulatory, and certification-driven considerations rather than a technical limitation. In India, the first commercial SAF production is being initiated by Indian Oil Corporation Limited at its Panipat refinery, with a capacity of approximately 35,000 MT per year, with UCO envisaged as a key feedstock.

“India's UCO system suffers from fragmentation and weak enforcement. Small, dispersed volumes combined with poor traceability make quality control and compliance difficult. Without digital tracking, mandated reporting, and enforcement similar to other regulated waste streams, UCO cannot reliably move into higher-value chemical and material applications.”

Mr Kalyan Deshpande – DGM, Sustainability, Techknowgreen

Therefore, SAF emerges as a significant end use for UCO. Driven by rapid growth in India's aviation sector and forthcoming blending mandates, India's annual jet fuel demand has increased to approximately 9.0 M MT in 2024–25 from around 2.8 M MT in 2004–05, notwithstanding the temporary COVID-19-related contraction (Table-IV, Annexure-III).

Under India's indicative SAF blending targets—1% by 2027, rising to 5% by 2030—even low blend levels translate into material SAF volumes. A 1% blend implies SAF demand of roughly 0.09 M MTs per year, increasing to approximately 0.46 M MT at a 5% blend, based on projected jet fuel consumption.

Commercial SAF production from UCO is predominantly based on the HEFA-SPK pathway, which is relatively feedstock-intensive. Typical commercial yields indicate that 1.33–1.43 MT of UCO are required per MT of SAF produced. Accordingly, meeting a 1% SAF blending requirement would require approximately 0.12 M MT of UCO annually, with demand rising proportionally at higher blend levels.

This mass-balance relationship highlights SAF as a highly UCO-intensive demand sink, capable of absorbing a substantial share of any formally aggregated UCO even at modest blending levels. While SAF plays a critical role in India's energy transition and compliance with international aviation

¹¹ IATA - Disappointingly Slow Growth in SAF Production

frameworks such as CORSIA, its emerging scale reinforces the need to explicitly account for aviation-driven UCO uptake when assessing availability for competing applications¹².

2.2.3 Demand for Surfactants

Sections 2.2.1 and 2.2.2 focussed on UCO as a feedstock for fuels. This section shifts focus from energy uses to material-transition pathways, examining the role of UCO in surfactants and polymers, where the primary objective is fossil-carbon substitution rather than fuel replacement.

This UCO demand analysis for surfactants is intentionally restricted to surfactant value chains where substitution of fossil carbon delivers material greenhouse-gas reduction, rather than incremental circularity benefits. For the same reason, soap and fatty-acid-based surfactants are excluded, as they only provide marginal circularity benefits, as they already come from biogenic feedstocks. Therefore, Alcohol Ethoxylates (AE), Alcohol Ether Sulphates (AES, including SLES) produced from synthetic alcohols and Linear Alkylbenzene Sulphonate (LAS, via LAB), produced from fossil kerosene (benzene retained as fossil) have been selected.

In these applications, fossil-derived hydrophobes can be substituted (via mass balance attribution) with UCO-derived hydrophobes through established industrial pathways, offering high fossil-carbon displacement potential, albeit with required upgrading hydrogen demand, and efficiency requirements as molecular equivalence to petrochemical feedstocks is pursued.

Table 2 shows the Indicative UCO demand for these surfactants (from Table-V, Annexure-III), derived from UCO required per tonne of surfactant, and current surfactant volumes.

Table 2: UCO demand linked to UCO intensity and production volume by types of surfactants

Surfactant	Fossil carbon replaced (via mass balance)	Indicative UCO required / Surfactant (w/w)	Production volumes of Surfactant (M MT/year)	Estimated UCO demand* (M MT/year)
Alcohol Ethoxylates (AE)	Synthetic fatty alcohols (C12–C14)	1.5–1.7	0.25	0.40
Alcohol Ether Sulphates (AES/SLES)	Synthetic fatty alcohols	1.6–1.8	0.32	0.54
Linear Alkylbenzene Sulphonate LAS (via LAB)	Linear paraffins / olefins (C10–C13)	1.6–1.8	0.64	1.09
Total	-	-	-	≈ 2.0

** This represents the theoretical UCO requirement to de-fossilise selected surfactant value chains at current production volumes; it does not imply immediate adoption, access, or priority allocation.*

¹² SAF Association calls for using used cooking oil to produce Sustainable Aviation Fuel

The analysis in Table 2 indicates that de-fossilising these three fossil-dependent surfactant classes alone would require approximately 2.0 M MT of UCO per year, tied to 2024 (or 2023–24) volumes. This scale is material when compared with UCO demand from biodiesel and emerging SAF pathways and highlights the importance of explicitly accounting for material-transition demand when assessing UCO availability, allocation priorities, and supply-chain resilience.

2.2.4 Demand for Polymer Sector

Although polymers such as polyethylene (PE) and polypropylene (PP) are major users of fossil carbon, their relevance within a UCO-based material-transition framework is limited. Polyolefins are durable, long-lived materials in which embedded carbon remains sequestered over extended periods. As a result, substituting fossil feedstocks with UCO in polymer production avoids fossil carbon only at the point of material inception, however, does not deliver meaningful greenhouse-gas abatement, and were hence deprioritised from material transition perspective. The UCO demand assessment therefore does not consider the polymer demand.

2.3 UCO Supply – Demand Gap

The reconciliation of UCO supply and demand in this study is undertaken on a consistent and transparent basis, using UCO availability potential (and not actual UCO collected) as the supply envelope and considering only those end uses retained within the scope of analysis.

For 2024–25, UCO availability potential is estimated at approximately 2.22 M MT, based on recoverable used cooking oil generated primarily from commercial food establishments under realistic use and loss assumptions. The estimated UCO availability is further subject to significant uncertainty in behavioural, collection, and enforcement factors. This represents the upper-bound resource envelope used for supply–demand reconciliation in this study. The reconciliation is therefore conducted at the level of system-wide potential availability, with collection and aggregation constraints treated separately and not accounted in the supply figure.



“For UCO to enter surfactants, sustainability alone is not sufficient. Materials must deliver performance, affordability, and scale. Variability in composition— particularly chain-length mismatch— remains a barrier. Industry will invest in the required R&D only if there is confidence in long-term supply, clear specifications, and credible end-market signals.”

*Dr Jonathan Hague – VP, Bright Future S&T,
Home Care, Unilever*



On the demand side, the analysis aggregates UCO requirements across biodiesel, early-stage SAF, and priority surfactant value chains, which together define the effective demand envelope for UCO in the near term.

The balance between UCO availability potential and aggregated demand from these sectors defines the supply–demand gap explored in Table 3, providing a basis for assessing allocation pressures, constraints, and the feasibility of scaling UCO-based pathways without assuming the existence of surplus or uncommitted feedstock.

Table 3: Indicative UCO Supply–Demand Balance (2024–25)

Demand and Supply	Potential UCO Supply (M MT)	UCO Demand (M MT) #
Total UCO availability (2024–25)	~2.2	-
Surfactants (AE, AES/SLES, LAS) with 100% substitution of the existing level of production	-	~2.0
Biodiesel (current utilisation)	-	~0.06
SAF (early mandate, ~1% blend equivalent)	-	0.12–0.20
Total effective UCO Supply/ Demand	~2.2 Actual collection is ~ 0.06 - 0.30	~2.2–2.3

Biodiesel demand is actual current demand of UCO and for others, the figure are approximated potential demand as estimated in the study

This reconciliation represents an upper-bound, theoretical estimate of India's UCO availability. The current UCO collection as reflected in the above table is limited to formal biodiesel channel as per FSSAI RUCO traceability system. PIB, Government of India notes that 0.06 M MT (about 750 lakh litres) of UCO were collected for biodiesel production in the year 2024-25.

The panel discussion¹³ organized by RECEIC in April 2026 (detailed insights captured in Annexure I) examined UCO as a strategically important renewable carbon resource for India's material transition, rather than viewing it purely through an energy or waste-management lens. While India is often cited as having substantial UCO potential, the panel interrogated why only a small fraction is reliably collected, how current allocation patterns have emerged, and whether higher-value material pathways—particularly chemicals and surfactants—can be enabled through better system design. Together, this composition ensured coverage of both technical feasibility and system-level constraints, clarifying where the UCO value chain breaks down and what enabling conditions are required to unlock higher-value material pathways.

¹³ Panelists: Dr. Venkataraghavan R (Moderator) – Platform Leader, Bright Future S&T, Home Care, Unilever, Dr. Jonathan Hague – VP, Bright Future S&T, Home Care, Unilever, Mr. Sarvesh Kumar – Executive Director, Refining Technology, Indian Oil (IOCL), Mr. Prasanna Desai – General Manager, Desmet India, Mr. Kalyan Deshpande – DGM, Sustainability, Techknowgreen, Dr. Anjan Ray – Investor Partner, Navam Capital; former Director, CSIR-IIP

SECTION 3



UCO QUALITY, GRADING AND END-USE SUITABILITY



3. UCO QUALITY, GRADING AND END-USE SUITABILITY

Collected UCO exhibits significant heterogeneity, arising both from its original vegetable-oil composition and from degradation during repeated cooking cycles and exposure to varying heat and process conditions. As a result, not all UCO streams are equally suitable for all downstream applications. With UCO utilised across multiple fuel and chemical end points, its suitability for any specific application is governed not only by availability but by quality and compositional fitness-for-use. Different end uses impose distinct requirements on chemical composition, contaminants, and variability, which in turn influence how UCO is allocated across competing pathways.

This section therefore evaluates the chemical composition, contaminant profiles, and acceptability thresholds of UCO in relation to intended chemical end-points. Through an analysis of key chemical parameters, the chapter assesses the compatibility of currently aggregated UCO with quality requirements for chemical and material applications, while recognising that these thresholds also shape competition with fuel pathways.

3.1 Chemical Composition of Vegetable Oil & UCO

Given that the key feedstock for UCO is predominantly vegetable oil, it is important to dwell on the composition of vegetable oil, and its transformation during the cooking process.

Fresh cooking oils are largely non-polar and composed almost entirely of intact triglycerides. During deep frying at 150–190 °C, repeated exposure to air, moisture, and high heat progressively degrades the oil through hydrolysis, oxidation, and polymerisation. This breakdown converts triglycerides into non-triglyceride by-products such as free fatty acids, partial glycerides, aldehydes, trans fatty acids, polymers, and other secondary oxidation products, leading to the accumulation of total polar compounds and a progressive loss of oil quality with associated health risk^{14, 15}.

¹⁴ Chemistry of Deep Fat Frying Oils; Vol. 72, Nr. 5, 2007-Journal of Food Science

¹⁵ International Journal of Food Science & Technology, 2022, 57(10), 6763–6772

There are different methods used to measure oil quality ranging from subjective visual inspection to more objective, scientific measurements, such as TPC and free fatty acid values (FFA). In simple terms, they indicate the extent of fat breakdown. The flow chart levelling stages from fresh to used cooking oil in the process of repeated cooking is as shown in Figure 2.

Figure 2. Stages from fresh cooking oil to Used Cooking Oil

STAGE 1: OIL BREAK-IN	STAGE 2: FRESH OIL	STAGE 3: OPTIMUM OIL	STAGE 4: DEGRADING OIL	STAGE 5: SPENT OIL
Clear color with no order and very little oil is soaked up by food	Slight browning at edges and crisping of food with more oil soaked up	Golden brown color, good crisping, and optimal oil soaked into food	Hardening, uneven frying, darker browning and too much oil in food	Very uneven frying, hardening of food, bad order, and too much oil soak

The chemical composition of UCO¹⁶ is shown in Table 4, in comparison to the virgin cooking oil. Vegetable oils, due to exposure to high temperatures during cooking, undergo chemical changes. UCO contains only 43.09 wt.% triglycerides compared to 98.61 wt.% in virgin rapeseed oil. A significant amount of di- and mono-glycerides (27.64 wt.%), along with free fatty acids (12.43 wt.%) and fatty-acid esters (12.49 wt.%), are generated. Other chemical compounds observed in UCO include fatty acid esters, glyceryls and other hydrocarbons at low levels. Chemical classes are reported here as grouped fractions based on GC-MS analysis; and minor species have been combined into functional categories.

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¹⁶ Harris, Jonnathan & Phan, Anh N (2023), Green Approach for "Chemical Production from West Cooking Oils", Sustainable Chemistry for Climate Action, Vol 2 Green approach for chemical production from waste cooking oils

Table 4: Chemical Composition of UCO and Virgin Rapeseed Oil (Weight %)

S. No.	Chemical Compounds	UCO	Vegetable oil (virgin rapeseed oil)
1	Water	0.12	0.12
2	Acetol	0.23	
3	FA	12.43	1.27
4	Glycerol	1.8	
5	Fatty acid esters	12.49	
6	C ₁₄₋₁₈ Hydrocarbons	1.47	
7	C ₁₄₋₁₈ Aldehydes	0.73	
8	Monoglycerides	6.4	
9	Diglycerides	21.24	
10	Triglycerides	43.09	98.61
	Total	100.0	100.0

3.2 Matching Quality with End-Use Severity and Process Requirements

UCO's industrial suitability is governed by its degraded chemical composition resulting from cooking, and by the severity of upgrading required to meet end-use specifications. Together, these factors determine which industrial pathways can technically accommodate UCO and at what economic and operational cost. Across major fuel and chemical applications, this gives rise to a clear hierarchy of end-use severity, defined by increasing sensitivity to feedstock impurities and compositional variability.

Suitability for Surfactant: At the most tolerant end of the spectrum, are surfactants, derived from fatty alcohols routes. i.e., Alcohol Ethoxylates (AE), Alcohol Ether Sulphates (AES/SLES). Linear Alkylbenzene Sulphonate; LAS (via LAB) requires mass balanced substitution of fossil paraffin at refinery and hence requires relatively higher levels of pre-treatment. These processes are inherently designed to handle lipid-based feedstocks with variable composition. High free fatty acid (FFA) levels—often problematic for fuels—are compatible or even desirable for fatty-acid splitting, soap manufacture, and certain surfactant intermediates. Moisture, partial glycerides, phosphorus, and trace metals can be effectively managed through established unit operations such as degumming, drying, hydrolysis, distillation and hydrogenation. As a result, oleochemical feedstock procurement prioritises availability and cost efficiency, provided key contaminants remain within operationally manageable limits. Oleochemical pathways exhibit the widest tolerance to UCO quality variation, although lower-grade UCO typically incurs higher pretreatment costs, yield penalties, and downstream quality management.

Suitability for Bio-Diesel: Biodiesel (FAME) production imposes a higher degree of constraint, as feedstock quality directly affects finished fuel stability, engine compatibility, and regulatory

compliance. Elevated FFA, moisture, metals, and oxidation products promote corrosion, injector fouling, and oxidative instability. While pretreatment can mitigate part of this variability, biodiesel systems have more limited capacity to absorb severely degraded UCO compared to oleochemical routes, shifting greater emphasis to feedstock consistency and quality control.

Suitability for SAF: SAF production represents a further step change in severity. Hydrotreating-based SAF pathways are highly sensitive to oxygenates, sulphur, phosphorus, metals, and advanced oxidation products, all of which shorten catalyst life, increase hydrogen consumption, and reduce overall yields. In addition, aviation fuel performance requirements demand exceptional thermal and oxidative stability. Consequently, only UCO streams with low and stable contaminant levels can be economically routed to SAF without disproportionate pretreatment intensity and cost.

The key chemical parameters for feedstocks used for oleochemical, surfactants, biodiesel and SAF is discussed in Table-VI, Annexure-III, alongside the comparative chemical quality requirements (Table-VII, Annexure-III) for oleochemical, biodiesel and SAF (HEFA) manufacturing.

Overall, the comparison demonstrates a strong and systematic correlation between increasing process severity and decreasing tolerance for UCO degradation and contaminants. Surfactants derived from fatty alcohols retain the greatest flexibility, followed by LAS. Fuels impose progressively tighter constraints, with SAF at the high sensitivity. This hierarchy provides the technical basis for rational UCO allocation and directly underpins the industry-aligned grading and routing framework.

3.3 Industry-Aligned Classification for Chemical Use

Based on the analysis in preceding section, and what the industry informally trades, UCO is classified here in three quality grades, Grade A, Grade B and Grade C, defined by FFA, water/contaminants, phosphorus/metals, and degradation levels (Figure 3). Further, a practical, industry-aligned, mapping of UCO grades to eligible end-use markets discussed, viz., surfactants, biodiesel (FAME) and SAF, considering chemical quality thresholds, processing tolerance, and regulatory practice, can also be made.

Figure 3: UCO grade classification based on chemical specifications



Table 5 below represents the alignment of UCO Grades with the end-use chemical requirement by sectors and explains acceptance and rejection of UCO by different type of manufacturing facilities.

Table 5: UCO Grades & Usage across surfactants and fuels

UCO Grade	Surfactants derived from fatty alcohols, i.e., AE, AES/SLES	Biodiesel (FAME)	SAF (HEFA)/ Petrochemical Surfactants, e.g., LAB
Grade A	✓ Directly Accepted	✓ Preferred Feedstock	✓ Preferred Feedstock
Grade B	✓ Directly Accepted	✓ Accepted with Pretreatment	✓ Accepted with Pretreatment
Grade C	✓ Accepted (with limits)	✗ Generally Rejected	✗ Not Suitable / Generally Rejected

This demonstrates that UCO could serve as a versatile renewable feedstock, with its cross-sector usability governed by increasingly stringent chemical thresholds as one moves through surfactants, biodiesel and SAF. Effective segregation, grading, and pretreatment of UCO are therefore critical determinants of its technical and economic viability across different industrial value chains.

SECTION 4



ECONOMIC ASSESSMENT OF UCO BASED VALUE CHAINS



4. ECONOMIC ASSESSMENT OF UCO BASED VALUE CHAINS

As established earlier, UCO represents a credible renewable feedstock for selected surfactant applications, particularly those requiring hydrocarbon or fatty-alcohol derived hydrophobes. UCO is potentially available at sufficient scale to support industrial processing, and its lipid-derived chemistry is well aligned with the production of key surfactant intermediates. Importantly, substituting fossil-derived hydrophobes with UCO-based alternatives offers a clear cradle-to-grave greenhouse-gas reduction, with the carbon treated as biogenic under prevailing lifecycle accounting conventions. On this basis, UCO provides a relevant and scalable pathway for reducing the emissions intensity of surfactants. The economic assessment presented in this section is conducted at a screening level and designed to compare relative operating cost structures and sensitivities across alternative UCO end uses. Fuel pathways are evaluated as reference cases and competing demand sinks against which material-transition opportunities for chemicals can be assessed. The assessment relies on publicly available market data, and transparent assumptions, without attempting process optimisation or investment-grade costing.

With this background, the cost of production by using UCO as feedstock in the already identified sectors is undertaken. After calculating the cost of production, an industry level median margin is added to the total cost to arrive at the expected market price to remain commercially viable at least in the long run. The calculated expected market price through UCO route is further compared with the benchmarked fossil-based and non fossil-based feedstocks separately. This implies that use of UCO as feedstock in selected surfactants, biodiesel and SAF production simultaneously create three comparable groups, i.e., UCO feedstock based product, fossil feedstock based product and non-fossil feedstock based product, albeit use wise these products meet same expectations, and the feedstock type is the only differentiator. This paper views that UCO as a feedstock can be technically substituted for other comparable feedstocks including fossil-based feedstocks and non fossil-based feedstocks.

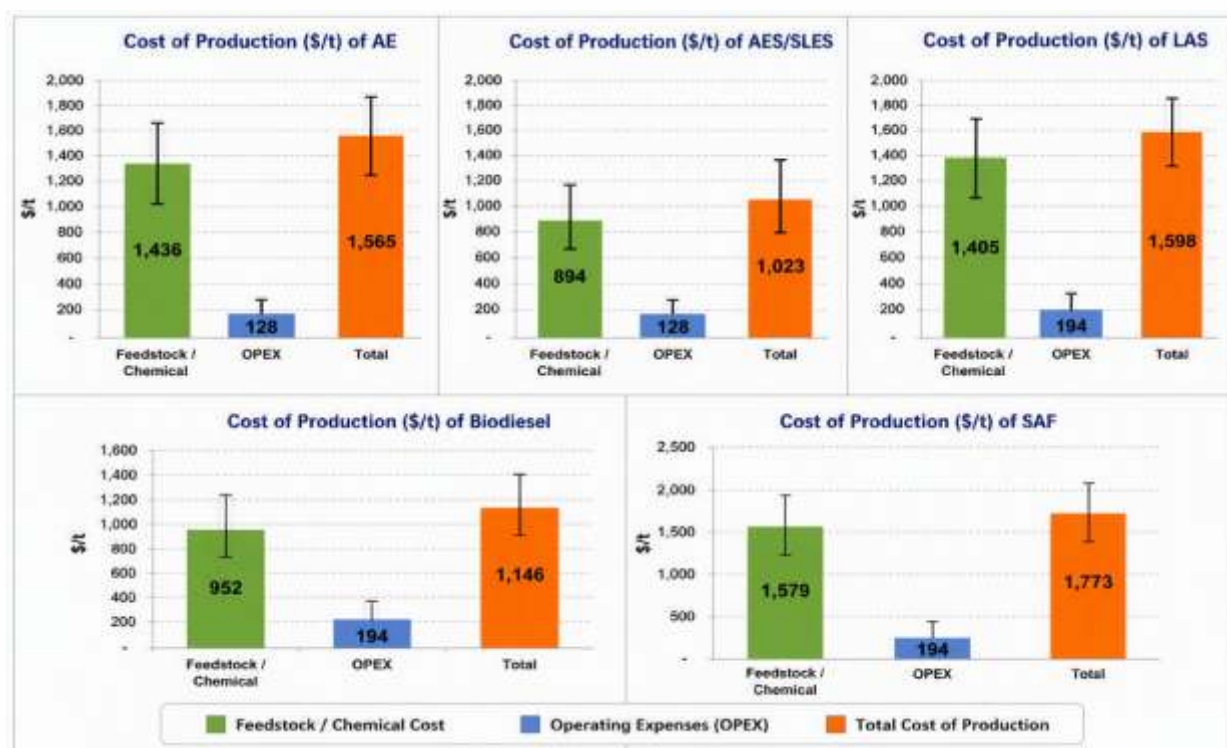
4.1 Cost of Production

The economic analysis presented in Figure 4 below summarises the total cost (\$/t) for the UCO derived surfactant and fuels, i.e., Alcohol Ethoxylates (AE), Alcohol Ether Sulphates (AES/SLES), Linear Alkylbenzene Sulphonate (LAS), biodiesel, and SAF. The cost of production for these UCO derived products is calculated considering feedstock cost, cost of chemicals and utilities / operating cost (OPEX). No co-product credit is applied in this analysis, which would reduce the estimated cost, if applied. CAPEX is also not considered as products are co-produced with other items, so there is implicitly no capital cost, i.e., there does not exist any provision for CAPEX per unit of production. To account for variability in feedstock, chemical, and operating costs, the cost estimates should be interpreted within a $\pm 10\%$ range, reflecting potential fluctuations in market conditions and input prices.

The cost of production per ton in both surfactants and fuel pathways differs due to cost of feedstock and other chemicals. In case of AE, price of EO and UCO are the two dominant cost drivers. EO price is especially critical because EO forms roughly half of the final AE mass in a 6–7 EO grade product. In case of AES/SLES, SO_3 is the major cost driver along with the cost of UCO and EO. Similarly, in case of LAS, UCO is the largest cost contributor, followed by benzene, hydrogen and SO_3 . Producing LAS from UCO is relatively more capital and hydrogen intensive. LAS economics also depend heavily on whether SO_3 is purchased or generated onsite from sulphur, and whether hydrogen is purchased or internally integrated/recycled (green / grey hydrogen).

UCO-based SAF via HEFA is technically proven and commercially relevant, with economics driven mainly by UCO price, hydrogen cost & SAF yield. A similar context applied to biodiesel.

Figure 4: Estimated production costs of selected UCO-based value chains.
Error bars indicate $\pm 10\%$ variation in feedstock/chemical costs and OPEX.
CAPEX and co-product credits are excluded.



For an economically viable production, the cost of production per unit should be at-least, in the short run, equal its market price (a no profit, no loss situation, also referred to as breakeven point); else supported by promotional or supporting pricing in terms of state support for further continuance of the production. In the case of biodiesel and SAF, Govt. of India has been providing such support for making their production viable, as an incentive to support its energy transition commitments. A similar support for sustainable surfactants (as produced from UCO) has not been envisioned, although material transition is equally required to meet its Net Zero commitments.

To understand the market efficiency of the UCO derived products, a price-to-price comparison is made in Table-6 (see also Table-VIII, Annexure-III). For this analysis, to arrive at an expected price for AE, AES/SLES, LAB/LAS, a 15% margin is added to the cost of production, to cover the absence of a support price incentive by Government of India. This 15% margin is not added for biodiesel and SAF, in view of government supported incentives. Expected prices reflect both cost structures and targeted margins. In addition to the UCO derived products, fossil derived and non-fossil derived products are also included in the comparison. High-Speed Diesel (HSD) and Aviation Turbine Fuel (ATF) are taken as fossil comparators to Biodiesel and SAF respectively. For AE, AES/SLES, that produced from synthetic (fossil-derived) fatty alcohols and plant based natural fatty alcohols are taken as fossil comparators and non-fossil derived comparators, respectively. For LAS, the currently produced commercial LAS remains the fossil comparator, while for non-fossil observed bio-feedstock premiums are applied. The price-to-price comparison is made for an understanding of UCO based product competitiveness compared to non-UCO based similar products.

Table 6: Comparative Analysis (UCO and Non-UCO)

Cost Components (\$/t)	AE	AES/SLES	LAS	Biodiesel	SAF
UCO Based Cost of Production (\$/t)	1565	1022	1599	1146	1773
UCO Based Expected Price (+15% for surfactants) (U)	1800	1175	1839	1146	1773
Benchmark Market Price (fossil feedstock) (F)	2000	1190	1350	1075	1200
Price Difference (U-F)	-200	-15	489	71	573
Benchmark Market Price (non-fossil feedstock) (N)	1975	925	1850	1100	2500
Price Difference (U-N)	-175	250	-11	46	-727

Notes:

HSD and ATF market prices used as reference prices, respectively.

Fossil benchmarks based on comparable products derived from conventional fossil feedstocks.

Non-fossil benchmarks based on 2025–26 Asian market prices.

Comparable non-fossil benchmarks: palm/PKO-derived AE (C12–14, 7–9 EO), palm-based AES/SLES, renewable-attributed LAB/LAS, palm-based FAME biodiesel (export parity), and HEFA-SPK SAF derived from UCO, tallow, or vegetable oils.

Table 6 indicates that the economic attractiveness of UCO varies significantly across end uses. UCO-based AE is cost competitive against both fossil- and palm-based alternatives, suggesting a clear substitution opportunity. AES/SLES is broadly at parity with the fossil route but remains at a premium relative to palm-based alternatives. LAB/LAS carries a significant cost disadvantage versus fossil-based production, although it is broadly comparable with renewable-attributed and other non-fossil alternatives, indicating that adoption would likely depend on demand for sustainable products rather than cost leadership.

Among fuel applications, biodiesel exhibits limited economic headroom, with UCO-based pricing marginally above the fossil benchmark, leaving it more exposed to market fluctuations and reliant on supportive policy mechanisms. Despite the provided incentives, SAF remains at a cost disadvantage over fossil benchmark (ATF), and non-fossil SAF (vegetable oils). Overall, UCO-based production appears most competitive for AE and biodiesel, conditionally viable for AES/SLES, and less attractive for LAB/LAS and SAF, with commercial success likely to depend on a combination of cost efficiency, market positioning, and policy or sustainability-driven demand support.

4.2 Market Implications for Substitution of UCO as Feedstock

The potential for UCO to substitute incumbent feedstocks varies across value chains and depends on its relative production cost compared with fossil- and non-fossil-based alternatives. UCO can be considered a commercially viable substitute where UCO-derived products can be produced at or below the prevailing market price of equivalent products from alternative feedstocks.

Based on the cost and pricing analysis presented in Table 6, UCO demonstrates the strongest substitution potential in AE, where UCO-based production is cost competitive against both fossil- and palm-based alternatives. For AES/SLES, UCO remains competitive against the fossil route but is at a premium relative to palm-based feedstocks, suggesting conditional substitution potential depending on feedstock pricing and sustainability preferences. In contrast, UCO-based LAB/LAS is not competitive against fossil-derived alternatives, although it is broadly comparable with renewable-attributed and other non-fossil options, indicating substitution potential primarily in markets seeking lower-carbon or renewable products.

Overall, the analysis suggests that UCO substitution opportunities are product-specific rather than universal. Substitution potential is strongest for AE, conditional for AES/SLES, and more dependent on sustainability-driven demand, policy support, or market differentiation for LAB/LAS. These findings indicate that UCO may offer attractive substitution opportunities where sustainability attributes are valued by downstream customers and consumers. In such markets, UCO-based products may command differentiated positioning, allowing manufacturers to operate as price setters rather than price takers and partially offset any cost premiums associated with renewable feedstocks.

4.3 Market Adjustment Mechanism in the Short and Long Run

In the short run, adopting a higher industry gross margin for UCO-based products can be rationalised by considering a transition phase where a higher margin realization may not be feasible. Given the observed price premiums through UCO route over both fossil-based and non-fossil benchmarks, producers could initially compress margins or leverage policy incentives (such as subsidies, carbon credits, or tax benefits) to bridge the gap and approach a break-even point just by following a pricing strategy which could help to meet expenses.

The relatively lower differentials in segments like AE suggest that selective market entry in higher-value or sustainability-sensitive applications can improve cost recovery. Additionally, operational efficiencies in feedstock aggregation, logistics, and process optimization can reduce cost and partially offset higher input costs. Therefore, even if a higher margin is not fully realized, a calibrated pricing approach combined with external support mechanisms can enable UCO-based pathways to achieve short-term financial viability.

In the long run, enhanced profitability can become more achievable with economies of scale, technological advancements, and supply chain stabilization. Expansion of UCO collection networks and improvements in traceability can enhance feedstock availability and price stability, lowering raw material costs. Simultaneously, rising carbon pricing and stricter environmental regulations are likely to increase the relative cost of fossil-based alternatives, narrowing the pricing gap. As markets increasingly value low-carbon products, willingness to pay green premiums—especially in sectors like aviation fuel and specific chemicals—will strengthen revenue potential. Over time, these structural shifts can align UCO-based pricing with or even below competing alternatives, allowing firms to have a better margin while maintaining competitiveness and supporting long-term profitability.

4.4 Comparative Carbon Avoidance (Screening-Level GHG Perspective, Chemicals)

Replacing conventional fossil-derived feedstocks in surfactant value chains with UCO has the potential to deliver GHG reductions by avoiding the release of fossil carbon that would otherwise occur over the life cycle of the product, and any additional processing required for it. To provide a directional indication of this effect, a screening-level approach is applied. This method is commonly used in comparative policy analysis where pathway-specific LCAs are not available on a harmonised functional unit and boundary basis.

Fossil baseline emission intensities are derived from IPCC default oxidation factors for oil-derived fuels and petrochemical feedstocks, combined with published cradle-to-grave emission factors from GREET and detergent-surfactant LCA databases. These baselines include upstream extraction, refining, processing energy, distribution, and full end-of-life oxidation of embedded fossil carbon, resulting in indicative intensities of approximately 3.2–3.8 tCO₂e per tonne, depending on product type. For UCO-based pathways, waste-residue allocation conventions used in regulatory LCAs are applied, under which UCO carries no upstream agricultural or land-use emissions. Only emissions associated with collection, transport, pretreatment, conversion, distribution, and use-phase processing are counted, with end-of-life CO₂ emissions treated as biogenic and climate-neutral in line with IPCC.

Using peer-reviewed secondary sources, UCO pathway intensities are estimated in the range of 1.1–1.3 tCO₂e per tonne on a cradle-to-grave basis. The difference between the fossil baseline and the corresponding UCO pathway provides a screening-level estimate of carbon avoidance. The calculated carbon avoidance results due to UCO substituted for fossil carbon feedstocks as shown in Table-7 indicate that UCO substitution delivers net fossil-carbon avoidance across all end-uses considered. However, the magnitude and relative ranking are indicative rather than definitive, and are sensitive to process severity, hydrogen demand, and residual fossil inputs. Accordingly, the values presented in Table-7 should be interpreted as directional signals of relative mitigation potential, not as decision-grade abatement estimates. A harmonised screening LCA with consistent system boundaries would be required for robust estimation of quantify route-wise benefits and precise comparisons.

Table 7: End of Life Carbon Avoidance Matrix (per 1 tonne feedstock)

End Use	AE (7–9 EO)	AES/SLES	LAS
Fossil Baseline – Cradle-to-Grave (tCO ₂ e/t) (F)	3.2	3.3	3.8
UCO Route – Cradle-to-Grave (tCO ₂ e/t) (U)	1.1	1.2	1.3
UCO Collection	0.1	0.1	0.15
UCO Pretreatment	0.3	0.45	0.55
End Use Production	0.45	0.3	0.35
Distribution	0.05	0.05	0.05
Use Phase & end of life	0.2	0.3	0.2
GHG Reduction (tCO ₂ e/t) (U-F)	-2.1	-2.1	-2.5
Carbon Benefit (in \$/t @ \$10 per tCO ₂ e)	21.0	21.0	25.0

Source: IPCC emission factors (for fuels) and secondary LCA databases such as *Plastics Europe Eco-profiles* and *Ecoinvent* (for chemicals). Carbon price as per *carboncredits.com*

The above Table 7 suggests that all UCO-based pathways deliver substantial cradle-to-grave GHG reductions compared to fossil baselines, ranging from ~2.1 to 2.5 tCO₂e per tonne of feedstock. The climate benefits for the chemical pathways (AE, AES/SLES, LAB/LAS) reflecting the high fossil intensity and the avoided upstream emissions from crude oil extraction and refining, and the advantage of biogenic carbon and waste feedstock substitution lower overall life-cycle impacts. In essence, diverting UCO from disposal and valorising it into chemicals and material applications convert a waste liability into a low-carbon resource, supporting both material transition and broader circular-economy objectives.

4.5 Monetisation of Carbon Benefits

Most importantly, when carbon benefits are monetised at USD 10/tCO₂e, the economic picture improves further, where carbon value significantly offsets production cost gaps. For chemicals, carbon pricing narrows the competitiveness gap versus fossil routes. Beyond direct economics, UCO utilisation is viewed in terms of delivering multiple ecosystem services including reduced improper oil disposal, lowers water and soil contamination, avoids sewer blockages, and decreases pressure on virgin vegetable oil production, indirectly supporting land, water, and biodiversity conservation. Thus, the combined climate–economic–ecosystem tends to strengthen the case for UCO based feedstock pathways as mitigation and sustainability levers. As it is found from Table 7, the monetary benefits of carbon avoidance per one tonne production through UCO ranges between USD 21 - USD 25. The monetised carbon benefit can be adjusted with optimising margin pressure for UCO route products considered in the study.

4.6 Broader System Implications of UCO-Based Material Pathways

When UCO is used for surfactant manufacturing, several positive impacts accumulate across the economy and environment which lead to better ecosystem realisation. Historically, kerosene from crude oil has served both the chemical industry as a feedstock. Aviation fuel is primarily composed of kerosene. Kumar et al.¹⁷ (2025) confirms that UCO use for chemical conversion routes including soap and surfactants offer high-value, efficient, and greenhouse-gas-mitigating outputs.

The benefits of UCO treatment extend beyond fuel production; it mitigates environmental hazards associated with improper disposal, reducing pollution and promoting a circular economy. As industries worldwide embrace the principles of sustainability, UCO treatment emerges as a key player in reducing carbon footprints and promoting a more responsible approach to waste management¹⁸. Biosurfactants (Bio-based surfactants) are less toxic, more biodegradable and more stable under adverse environmental conditions compared to chemical surfactants. Properties such as detergency, emulsification, dispersion and solubilization confer considerable versatility to these

biomolecules, making them a promising commercial alternative¹⁹. Thus, due to UCO as feedstock, there happens to be industrial and societal gains complementing one another: surfactant producers earn cost and margin leverage through cheaper inputs, while society benefits through waste reduction, safer food chains, and decarbonisation of chemical manufacturing.

In light of the findings from Table 7, different UCO utilisation pathways deliver different economic, carbon, and societal outcomes. Surfactants and oleochemical applications retain carbon within products and value chains, whereas biodiesel and SAF utilise the carbon as energy carriers. These differences influence how value is created and retained across alternative UCO applications and highlight the importance of understanding allocation trade-offs when demand for UCO increases.

With increased competing demands for UCO the fast-growing Indian surfactants market alone could theoretically consume up to 2 million tonnes of UCO at 100 % UCO substitution for fossil-based feedstocks. This might lead to a trade-off situation between economics and ecosystem optimisation.

“Used Cooking Oil is increasingly contested across biodiesel, SAF, and chemicals. In that context, surfactants stand out as a sector where UCO converts efficiently into functional products rather than being consumed in a single combustion cycle. From an industry perspective, prioritising materials allows India to extract higher and more durable value from a constrained circular carbon resource.”

Mr. Nitin Sharma, CEO & GM at Clariant IGL Specialty Chemicals Pvt. Ltd

¹⁷ Kumar, A., Bhayana, S., Kumari Singh, P., Dutt Tripathi, A., Paul, V., Balodi, V., & Agarwal, A. (2025). Valorisation of used cooking oil: challenges, current developments, life cycle assessment and future prospects. Discover Sustainability, 6, Article 119.

¹⁸ Revitalizing Waste: The Transformative Journey of UCO Treatment - Technology

¹⁹ Elayaperumal, S.; Sivamani, Y.; Bhattacharya, D.; Lahiri, D.; Nag, M (2025). Eco-friendly biosurfactant solutions for petroleum hydrocarbon cleanup in aquatic ecosystems. Sustain. Chemical Environment, Vol-9, PP 2949-8392.

UCO exhibits strong technical compatibility with several surfactant and oleochemical pathways due to its C16–C18 fatty acid composition and established conversion routes. These applications are relevant because they represent large downstream markets and enable substitution of fossil-derived feedstocks. At the same time, fuel pathways offer important decarbonisation benefits and established policy support. Consequently, future UCO utilisation is likely to be influenced by economic competitiveness, feedstock availability, policy incentives, quality requirements, and broader sustainability objectives.

Overall, the analysis indicates that UCO can contribute to multiple value chains including surfactants, oleochemicals, biodiesel and SAF. Each pathway delivers differing combinations of economic value, greenhouse-gas reduction, resource efficiency, and public-health benefits. As demand grows across these sectors, understanding these trade-offs becomes increasingly important for future supply-chain design and policy development.



SECTION 5

REGULATORY CONTEXT & POLICY IMPLICATIONS



5. REGULATORY CONTEXT & POLICY IMPLICATIONS

This section examines India's UCO policy architecture and its implications for energy and material transition pathways. It reviews current governance arrangements, explains the dominance of fuel applications, draws lessons from international experience, and identifies policy gaps affecting collection, traceability, and allocation of UCO across competing end uses. As demand for UCO grows, policy design will increasingly influence how this resource is mobilised and utilised.

5.1 Current Governance & Regulatory Structure

India's UCO governance framework has evolved primarily through food-safety and energy-transition objectives rather than an explicit material-transition lens. Collectively, existing instruments define how UCO is diverted from the food chain and which end uses are practically enabled.

At the upstream end, the RUCO initiative administered by FSSAI treats UCO as a controlled waste stream. RUCO mandates diversion of degraded oil from food use, authorises collectors and aggregators, and establishes minimum traceability and disposal requirements. This framework plays a critical public-health role by suppressing unsafe reuse and legitimising formal UCO recovery.

Downstream, UCO is explicitly enabled within India's energy-transition policy architecture. The National Policy on Biofuels (2018) and its 2022 amendment recognise UCO as a preferred waste-derived feedstock for biodiesel, supported by indicative blending targets, procurement frameworks, and sale guidelines. Emerging SAF mandates, alignment with ICAO-CORSIA, and refinery-level co-processing policies further reinforce demand for UCO within fuel pathways.

5.2 Fuel Dominance in Policy Interventions

The dominance of fuel pathways in UCO utilisation is not accidental, but a direct outcome of structural features embedded in the policy framework. First, fuel pathways benefit from explicit demand

creation. Biodiesel and SAF enjoy blending mandates, assured offtake, and refinery integration. In contrast, chemical applications such as surfactants lack comparable market-enabling mechanisms, including green procurement preferences, product carbon-intensity disclosure, certification systems, or targeted incentives that could support adoption where technically and economically viable.

Second, collection and aggregation systems prioritise volume over quality differentiation. Practices designed for biodiesel favour throughput and basic contamination control, while chemical value chains require graded quality, consistency, and tighter specification alignment. Third, compliance regimes focus on safe disposal rather than optimisation. Once UCO exits the food chain, policy frameworks remain largely sceptical to how it should be routed across competing end uses.

In this context, UCO at present flows into the most policy-supported and logistically mature biodiesel pathways. As a result, fuel applications act as the default sink for UCO, not because they always maximise system-level climate value, but because they are supported by a complete policy, market, and offtake architecture.

In India, the limited uptake of used cooking oil as a feedstock for surfactant production can be traced to a policy and market structure that strongly privileges fuel decarbonisation over material circularity, creating an uneven playing field for chemical applications. The RUCO initiative and biodiesel blending mandates have successfully formalised UCO collection, but they also implicitly channel most organised UCO volumes toward biodiesel, where offtake certainty, blending targets, and policy visibility are higher. In contrast, surfactants lack comparable regulatory pull mechanisms such as bio-based content, green procurement norms, or carbon intensity benchmarks. This imbalance is exacerbated by feedstock constraints: UCO availability remains fragmented, quality is inconsistent, and increased competition from biodiesel producers inflates prices, undermining the economics of downstream oleochemical investments. Moreover, surfactants do not enjoy “drop-in” substitution logic like fuels; they compete in highly price-sensitive FMCG markets where sustainability premiums must be justified through brand value rather than compliance. As a result, UCO use in surfactants is perceived as higher risk, policy-unsupported, and less scalable. Overcoming this requires reframing UCO not merely as a fuel decarbonisation input but as a strategic circular feedstock for chemicals, supported by targeted incentives, demand-side standards, and differentiated allocation mechanisms that recognise higher value material uses alongside energy recovery.

5.3 Lessons from International Experience

International experience shows that effective mobilisation and allocation of UCO depend far more on policy design and enforcement than on feedstock availability. Countries that have achieved high formal recovery and stable industrial use of UCO have done so through a small set of deliberate system choices.

In the United States, large-scale UCO recovery is enabled through mandatory grease disposal requirements for commercial food-service establishments, enforced at municipal and state levels. This has resulted in consistently high collection from organised sources. However, because downstream incentives strongly favour fuels through the Renewable Fuel Standard, UCO is routed overwhelmingly into biodiesel and renewable diesel, with little participation from chemical applications. The lesson is clear: mandatory collection enables scale, but allocation follows demand signals.

The United Kingdom and European Union demonstrate the importance of traceability and differentiated incentives. Under the Renewable Transport Fuel Obligation (RTFO) and the Renewable Energy Directive (RED), UCO is explicitly recognised as a waste-derived feedstock eligible for enhanced crediting, supported by digital tracking and audit requirements. These measures have reduced food-chain leakage and fraud while rapidly increasing formal recovery. At the same time, SAF mandates under ReFuelEU Aviation have reinforced fuel demand, again showing that explicit policy incentives determine end use, not technical suitability.

Germany combines strict waste-management enforcement with strong aggregation networks, particularly in urban centres. Licensed collectors, quality requirements linked to biodiesel eligibility, and stable enforcement have created reliable, industrial-scale UCO supply. While most UCO still flows into fuels, Germany illustrates that collection depth and aggregation density are prerequisites for any higher-value optimisation.

In China, strong enforcement driven by public-health concerns has sharply reduced illegal reuse of WCO in major cities. Centralised collection systems have enabled rapid recovery gains. However, limited domestic allocation logic has led to fragmented outcomes, including large-scale conversion to biodiesel and export of UCO, demonstrating that enforcement alone is insufficient without coordinated allocation governance.

Japan highlights the limits of voluntary UCO collection models. Recovery rates from commercial establishments are high due to clear compliance expectations and municipal support, but household-level collection remains weak where participation is voluntary. This reinforces the importance of clear thresholds and enforcement scope in determining realised supply.

Taken together, these examples show that successful UCO systems share three common features: (i) mandatory and enforceable collection, (ii) credible traceability, and (iii) explicit differentiation across end uses. Where any one of these elements is missing, UCO flows default to the most strongly supported application—typically fuels—regardless of broader climate or material-transition value.

Notably, even in jurisdictions with mature UCO ecosystems, material-transition applications remain largely incidental rather than policy-driven. No major economy has yet established explicit demand signals, prioritisation frameworks, or optimisation logic for UCO use in chemicals, despite clear technical feasibility and climate benefits. In parts of the EU and Germany, UCO is increasingly accepted into oleochemical value chains where supply and specifications permit; in Japan, oleochemical and detergent producers routinely utilise waste-derived feedstocks without formal policy preference; and in China, UCO is already being used at scale in oleochemicals, soaps, lubricants, and industrial fatty acids, driven primarily by cost, availability, and industrial demand rather than coordinated material-transition policy. These examples indicate that material applications are technically viable and commercially relevant but remain uncoordinated and secondary to fuel-driven demand in the absence of explicit policy recognition.

The detailed international evidence supporting these conclusions, with country insights is summarised and presented in Annexure II.

5.4 UCO Collection/ Aggregation: Experience of Stakeholders

To complement the above assessment, and bring focus to the landscape in India, targeted consultations were conducted with selected UCO aggregators and biodiesel producers, namely AR

Energy, BioD Energy Private Ltd., and Bluestone Energy Pvt. Ltd. The consultations provided practical insights into the current functioning of the UCO ecosystem, including feedstock collection, quality management, pricing dynamics, regulatory compliance, and end-use utilisation.

The key issues, stakeholder perspectives, and current industry practices emerging from these discussions are summarised in Table 8.

Table 8: Stakeholder opinion regarding functioning of the UCO ecosystem

Issues/ Concerns	Current Status
Biodiesel Production	i. Biodiesel production totally stopped due to lower pricing of biodiesel. ii. Lower pricing of biodiesel and higher price of UCO leads to biodiesel production is margin negative. iii. BioD says that out of its total production capacity only less than 2 % of biodiesel is produced with UCO feedstock.
Collection system	i. UCO collection by own employees and agent-based collection. ii. Collection from identified FBO (food and beverage operators) if aggregated UCO volume reaches to about 12 tonnes. iii. Information about volume availability is shared by local agents. iv. Bio D says that only Kabadiwalas (informal waste collectors) collect UCO and sell at the company collection point. v. Piloted UCO collection at some societies of Gurugram but it was found unsuccessful to collect UCO from household kitchens. vi. Bluestone targets all high value Hotels and food supply chains like Taj, Marriott, Bikaner etc vii. As per Blue stone collection strategy, Clients are onboarded. There is company level assessment of monthly volume generation. Storage Units are provided (200 litre barrel container), once 80 % full, it is collected. Following collection, transaction details are captured in the aggregator's web-based system based on the sale invoice and collection records, and a certificate is subsequently issued to the client.
UCO Quality: UCO is most often adulterated with engine/ lubricant oil	i. Moisture content (using a toolkit) checked ii. Smell, to check if the UCO is adulterated with engine oil. iii. If that is the case the oil is not procured and discarded. iv. BioD notes that TPC checking is hardly done. Only presence of water and solid particles are checked and if solid particles are found, they instruct the commercial kitchens to filter it. v. As per Bluestone, material should be free flowing and free from food, water and other impurities like sludge.
Illegal diversion of UCO to cooking oil making companies	i. Significant portion of UCO around 60% goes to illegal refiners and diverted back to the (food) supply chain.
Regulatory compliance	i. Refiners most often use illegal manufacturing identity and there is no compliance mechanism to whom the refined oil is ultimately sold. ii. Lack of policy enforcement hampers mandatory discarding of UCO. iii. Bluestone notes that as per provision companies discards 30% of every single batch of oil in UK and USA, but that does not happen in India.

Issues/ Concerns	Current Status
Pricing system	i. Weight-based payment system according to agreed price level. ii. Higher UCO supply means higher price as per BioD pricing strategy. iii. Cooking Oil Refiners pay higher price for UCO compared to biodiesel manufacturers' price and with around Rs.3-Rs.4 collection expenses, they sell the refined oil at market prices about Rs.150/ litre. iv. Bluestone energy notes that biodiesel price is Rs.85/ litre as against UCO market price is now above Rs.100/ litre. So, there is no incentive to produce biodiesel from UCO sources.

The stakeholder consultations revealed several recurring system-level issues affecting collection, traceability, compliance, and utilisation of UCO, from which several key insights emerge, as highlighted below.

Enforcement and Food-Chain Leakage: Stakeholders consistently highlighted continued diversion of UCO into informal channels, including re-entry into the food chain. Despite an established regulatory framework, enforcement remains uneven and significant volumes of UCO continue to bypass formal collection systems. The challenge appears to lie more in enforcement than in the absence of regulation.

Weak Traceability and Accountability: Limited visibility of UCO flows beyond collection remains a key concern. Stakeholders emphasised the need for stronger traceability through mandatory reporting, digital records, licensing, and periodic audits to improve accountability and reduce diversion risks.

Economic Viability and Pricing Distortions: Growing competition for UCO, together with higher prices offered by informal channels and edible-oil refiners, can undermine the viability of authorised utilisation pathways. Collection and utilisation outcomes are therefore influenced by market incentives as much as by regulation.

Collection and Aggregation Gaps: Collection remains concentrated around large commercial generators, while households and smaller food outlets are largely outside formal collection networks. Continued reliance on local agents and informal collectors indicates that collection and aggregation infrastructure remains a key bottleneck.

Lack of an Allocation and Utilisation Framework: Current policies have been effective in diverting UCO from the food chain and supporting biodiesel production but provide limited guidance on allocation across competing end uses. As demand emerges from biodiesel, SAF, and chemical value chains, the absence of differentiated routing or allocation mechanisms may constrain optimal utilisation of this limited renewable carbon resource.

Stakeholders also identified several operational measures that could strengthen implementation of the existing framework, including enhanced enforcement against illegal diversion, licensing and reporting requirements, digital traceability systems, periodic audits, stronger compliance monitoring, and measures to improve domestic availability of UCO.

5.5 Policy Gaps and Implications for India

Despite credible foundational regulation, India's UCO ecosystem has not translated into meaningful uptake for material transition applications owing to multiple policy gaps including absence of chemical-specific demand signals, fuel-centric optimisation of aggregation systems, lack of quality-based routing mechanisms, fragmented governance across food safety, energy, and materials, and reliance on enabling rather than outcome-oriented policy design.

Future competitiveness considerations are also becoming increasingly relevant. Global markets are progressively incorporating carbon intensity, sustainability disclosures, product traceability, and supply-chain transparency into procurement and investment decisions. Emerging expectations related to product carbon footprints, sustainability reporting, and low-carbon sourcing may increase the strategic value of renewable and waste-derived feedstocks. In this context, enabling UCO-based material transition is not only a decarbonisation opportunity, but also a means of strengthening the long-term competitiveness and resilience of India's chemical industry. Developing robust traceability, lifecycle accounting, and feedstock-certification systems could position Indian manufacturers more favourably as sustainability requirements continue to evolve across domestic and international markets.

Addressing these gaps does not require dismantling existing energy-transition policies. Rather, it requires selective augmentation—introducing differentiated routing, recognising material-transition value, strengthening aggregation as core infrastructure, improving traceability and lifecycle accounting, and integrating food safety, public health, energy, materials, and competitiveness considerations within a coherent policy framework. These implications should be taken forward in devising a roadmap for UCO collection and mobilisation into the surfactant sector alongside biodiesel and SAF applications.

A person wearing a white lab coat and black gloves is holding two glass vials containing a yellow liquid. The vials are held up, and the liquid inside is clearly visible. The background is a blurred laboratory setting with various pieces of equipment and other vials. The text "SECTION 6" is overlaid in the top right corner.

SECTION 6

CONCLUSION AND WAY FORWARD



6. CONCLUSION AND WAY FORWARD

6.1 Key Conclusions

This study positions UCO not merely as a waste-derived fuel feedstock, but as a strategic circular-carbon resource at the intersection of climate mitigation, industrial competitiveness, and public health. The barriers identified are design challenges and can be addressed through appropriate policy measures. By integrating global learnings with domestic priorities, India can establish a resilient, multi end use UCO ecosystem across diverse industries including the chemical Industry. Such initiative will result in decarbonisation, economic growth, and public health protection.

The inclusion and assessment of fuel pathways is intended to understand how competing demand influences the availability and allocation of UCO for chemical and material applications. It also highlights opportunities to move beyond competition for feedstock and towards a more integrated approach that supports both energy-transition and material-transition objectives.

- **Untapped Potential:** The supply-demand analysis shows that there is sufficient potential of UCO availability within the system which is not getting aggregated for meaningful feedstock uses. Till date, biodiesel sector stands out as the only pathway for formally mobilising UCO from urban commercial and most particularly HoReCa segment. The study indicated that only about 2% of the total availability of UCO is annually collected by biodiesel and other formal sectors like soaps & chemicals, animal feedstock etc. Rest 98% of UCO annually generated within the system are yet to be collected and aggregated.
- **Alternate Pathways:** Based on chemical endpoints of UCO and the required chemical thresholds for feedstock, the study finds that UCO can be substituted as feedstocks in surfactants, biodiesel and SAF. Apart from these major sectors, there is also vast scope of using UCO as feedstock in other chemical sectors.
- **UCO adoption, Lessons from International Initiatives:** Insights from international initiatives to drive UCO adoption show different degree of success to address similar structural and policy

challenges through system design, including mandatory collection regimes, differentiated incentives, digital traceability, and prioritisation of high-value end uses. Where these measures have been implemented, UCO has successfully shifted from an informal waste stream to a regulated, bankable industrial feedstock.

- **Prioritisation of Material Pathways:** All material applications of UCO may not be equally viable. For instance, while polymers were evaluated due to their scale, they were consciously deprioritised. Polymer pathways primarily offer fossil avoidance at material inception, but embed biogenic carbon into long-lived, non-degrading products, deliver limited circularity and deferred climate benefits. International practice similarly treats polymer decarbonisation through recycling-led strategies rather than competition for limited biogenic feedstocks. In contrast, surfactants emerge as highly credible material-transition endpoints. Alcohol Ethoxylates (AE), Alcohol Ether Sulphates (AES/SLES) and Linear Alkylbenzene Sulphonate (LAS), that rely heavily on fossil-derived hydrophobic chains, can be meaningfully substituted with UCO.
- **Policy Coherence for allocation of UCO in Chemical Industry:** International insights show successful UCO ecosystems share common design features: mandatory and enforced collection, differentiation of UCO grades by end-use capability, digital traceability, and targeted incentives to steer allocation toward priority applications. Exclusive reliance on voluntary programmes may result in low enforcement and consistent underperformance. This implies that policy coherence across energy, materials, food safety, and trade is essential at the national context.
- **Competitiveness, Sustainability Disclosure and Futureproofing:** Though carbon pricing in India is at nascent stage, international export markets are rapidly integrating carbon intensity into procurement, border adjustment mechanisms, and sustainability disclosures. Enabling material transition pathway can position Indian chemical manufacturers to remain competitive under future carbon-cost regimes, either through domestic pricing instruments or embedded international compliance requirements.
- **Economic Competitiveness:** UCO is no longer a low-value waste stream, rather it is a globally traded, contested feedstock. Secondly, pathway economics are dominated not by UCO price alone, but by structural drivers, including feedstock intensity, pretreatment severity, and especially hydrogen demand in upgrading steps. Importantly, it is understood that selected SAF pathway or selective surfactant pathways can achieve cost parity or manageable green premiums, while delivering high climate leverage by replacing fossil-based feedstock with UCO.
- **UCO Valorisation for Public Health:** Continued diversion of degraded cooking oil into informal food systems creates chronic exposure risks linked to cardiovascular disease, cancer, and occupational health hazards. International experience shows that creating strong, value-creating industrial sinks for UCO is one of the most effective enforcement mechanisms to prevent leakage back into food use. In this sense, valorisation of UCO into fuels and materials therefore delivers a dual public benefit, simultaneously supporting climate mitigation and protection of public health.

6.2 Policy and System Recommendations

- **Regulatory Policy Provision:** Towards mainstreaming of UCO collection and utilisation as a sustainability-promoting feedstock, an EPR framework may be introduced with appropriate

regulatory enforcement. In line with EPR for used oil, the Ministry of Environment, Forest and Climate Change may consider an EPR framework for UCO to strengthen collection, traceability, and utilisation.

- **Registration, Reporting and Traceability:** A dedicated drive may be undertaken to register collectors, aggregators, traders, and authorised end users across the value chain. This may be supported through mandatory reporting, digital traceability systems, and periodic audits to improve visibility of UCO flows, strengthen accountability, and minimise diversion into informal channels.
- **Awareness Drive:** Large-scale awareness programmes may be undertaken to promote proper UCO generation, handling, and disposal through designated aggregators in line with RUCO guidelines. Awareness efforts may also address health risks associated with the use of oil exceeding 25% TPC.
- **Widening Collection Horizon:** UCO collection and aggregation are currently concentrated in major urban centres. Targeted expansion of collection systems to all Urban Local Bodies (ULBs) may be considered to improve recovery rates.
- **Involving Municipalities / ULBs in Collection and Aggregation:** ULBs already play a central role in waste collection. Additional policy support may enable municipalities to facilitate UCO collection, including installation of dedicated collection points at strategic locations, particularly during the early stages of ecosystem development.
- **Revising the Vegetable Oil Consumption Threshold:** The current focus on commercial kitchens consuming more than 50 litres of vegetable oil per day may be reviewed to broaden the collection base through suitable registration and certification mechanisms, thereby increasing recovery potential.
- **Incentive Mechanism:** Appropriate incentive mechanisms may be considered to support adoption of UCO-based feedstocks within the chemical industry, including technologies that enable substitution of fossil-derived feedstocks.
- **Pricing Policy for UCO Use in Chemicals and Surfactants:** Any future pricing framework for UCO should consider competing demand from biodiesel, SAF, and chemical sectors to ensure balanced and economically efficient utilisation of the resource.
- **Allocation Planning:** As collection and aggregation improve, evidence-led allocation planning may be considered to improve visibility of UCO flows across biodiesel, SAF, and chemical value chains. Such approaches could support sectoral planning and help balance energy-transition and material-transition objectives. However, this should not be interpreted as a recommendation for mandatory end-use quotas. Any future allocation or routing mechanism should be phased, market-responsive, and linked to demonstrated cost competitiveness, reliable feedstock supply, quality suitability, and clear sustainability benefits.

Note: Collection and traceability requirements should be distinguished from end-use mandates. This report supports stronger mobilisation, governance, and quality management of UCO, while recommending that utilisation across energy and chemical applications be enabled through cost-effective, market-based, and incentive-led approaches.

6.3 Concluding Remarks

This study positions UCO not merely as a waste-derived fuel feedstock, but as a strategic circular-carbon resource at the intersection of climate mitigation, industrial competitiveness, and public health. By integrating global learnings with domestic priorities, India can establish a resilient, multi-end-use UCO ecosystem across diverse industries including the chemical Industry. Such initiative will result in decarbonisation, economic growth, and public health protection. UCO-enabled material transition might be seen not only as a sustainability initiative, but also as a strategic instrument supporting India's core economic, industrial, and social priorities; demonstrating that climate action, self-reliance, competitiveness, and public welfare can be advanced simultaneously through deliberate system design. India's Net Zero pathway and its ambition of 'Viksit Bharat' by 2047 can be realised through energy transition along with material transition, to achieve effective GHG mitigation. It is viewed that like centralised management of fossil feedstocks, UCO generation and collection for chemical sector should also be within a centralised support system, expanding formal UCO collection, aggregation, pretreatment, and logistics to become supportive for better energy and material transition. It is further viewed that supportive UCO ecosystem will create employment opportunities in food-service ecosystems, develop waste-management networks, and promote small and medium enterprises. This makes UCO-based material transition uniquely synergistic with inclusive growth and local job creation requirements.

List of Abbreviations

AE	Alcohol Ethoxylates
AES/SLES	Alcohol Ether Sulphates/ Sodium Lauryl Ether Sulphate
ATF	Aviation Turbine Fuel
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
FAME	Fatty Acid Methyl Ester
FFA	Free Fatty Acid
FSSAI	Food Safety and Standards Authority of India
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (Argonne National Laboratory model)
HEFA-SPK	Hydroprocessed Esters and Fatty Acids – Synthetic Paraffinic Kerosene
HoReCa	Hotels, Restaurants and Café/ Catering
ICAO	International Civil Aviation Organisation
ICCT	International Council on Clean Transportation
LAB/LAS	Linear Alkylbenzene / Linear Alkylbenzene Sulphonate
LCA	Life Cycle Assessment
RECEIC	Resource Efficiency & Circular Economy Industry Coalition
RUCO	Repurpose Used Cooking Oil
SAF	Sustainable Aviation Fuel
tCO ₂ e	Tonne Carbon Dioxide Equivalent
TPC	Total Polar Compounds
UCO	Used Cooking Oil
WCO	Waste Cooking Oil



ANNEXURES

Annexure-I

Synthesis of Panel Discussion, RECEIC Global Symposium

Used Cooking Oil as a Strategic Carbon Resource: Choices that Shape Material Transition²⁰

Context and Purpose

The panel discussion examined Used Cooking Oil (UCO) as a strategically important renewable carbon resource for India's material transition, rather than viewing it purely through an energy or waste-management lens. While India is often cited as having substantial UCO potential, the panel interrogated why only a small fraction is reliably collected, how current allocation patterns have emerged, and whether higher-value material pathways—particularly chemicals and surfactants—can be enabled through better system design.

Panellists

- **Dr. Venkataraghavan R (Moderator)** – Platform Leader, Bright Future S&T, Unilever (downstream demand and material-transition perspective; surfactant and chemical end-use requirements)
- **Dr. Jonathan Hague** – VP, Bright Future S&T, Home Care, Unilever (global S&T leadership; surfactant specifications, R&D priorities, end-market requirements)
- **Mr. Sarvesh Kumar** – Executive Director, Refining Technology, Indian Oil (fuel–chemical integration, large-scale processing, policy and infrastructure interfaces)
- **Mr. Prasanna Desai** – General Manager, Desmet India (pretreatment, segregation, and modular upgrading technologies for oils and lipids)
- **Mr. Kalyan Deshpande** – DGM, Sustainability, Techknowgreen (UCO collection systems, traceability, compliance, and sustainability governance)
- **Dr. Anjan Ray** – Investor Partner, Navam Capital; former Director, CSIR-IIP (policy design, allocation economics, and alternative feedstock pools including FOG)

Together, this composition ensured coverage of both technical feasibility and system-level constraints, clarifying where the UCO value chain breaks down and what enabling conditions are required to unlock higher-value material pathways.

²⁰ This annexure summarises key insights from a panel discussion held during the RECEIC Global Symposium on Resource Efficiency & Circular Economy (20 April 2026, New Delhi) on the topic “Used Cooking Oil as a Strategic Carbon Resource: Choices That Shape Material Transition”. It reflects a synthesis of the panel discussion.

Insights

Insight 1: Where the UCO supply chain breaks down

A consistent theme across the panel was that India's UCO collection shortfall is not due to lack of theoretical potential, but due to persistent failures in aggregation, incentives, and governance. While formal initiatives such as RUCO created an initial framework, much of the UCO generated never enters formal collection systems.

Several structural leakages were highlighted:

- **Secondary circulation and informal reuse**, where UCO flows from organized food service into smaller eateries and street vendors.
- **Drain disposal**, exacerbated by broken or poorly maintained grease traps and irregular aggregator collection cycles.
- **Household consumption**, which represents a large share of edible oil use but remains almost entirely outside any collection mechanism.

Panellists emphasized that dispersed micro-volumes, lack of storage space, and unreliable pickup schedules make compliance economically irrational for food service operators. In the absence of consistent enforcement or incentives, UCO predictably exits the system through the lowest-resistance pathway.

An insight beyond current UCO supply chain was on considering fats, oils, and grease (FOG), if recovered from sewage systems.

Insight 2: Allocation today is accidental, not designed

The panel drew a clear distinction between availability and allocation. Current UCO routing, to biodiesel, export markets, or limited SAF production, has not emerged through deliberate national design. Instead, allocation is driven by route simplicity, scale, and short-term price signals.

Fuel pathways dominate because they tolerate higher feedstock variability, absorb large volumes, and in some cases benefit from export-linked price premia. Chemical pathways, by contrast, demand tighter specifications, stable supply, and predictable quality—conditions the current system does not deliver.

Without explicit incentives or governance, UCO continues to flow to the highest-volume sink rather than the highest-value or highest-impact use. Unless chemical and material routes can offer a comparable economic and policy signal, allocation outcomes are unlikely to change.

Insight 3: UCO's chemical potential underutilized

A major contribution of the panel was reframing UCO not as “contaminated fuel” but as a chemically diverse lipid resource. Several panellists argued that current practice discards significant inherent value by defaulting to lowest-denominator conversion routes.

Two levers were repeatedly emphasized:

1. **Severity-based segregation** – categorizing UCO by degradation level to enable differentiated

routing, with higher-quality fractions directed to oleochemicals or surfactants and heavily degraded material to fuels.

- 2. Oil-type differentiation** – recognizing regional variation in cooking oils (soy, sunflower, palm, coconut, etc.) to enable more targeted chemical upgrading pathways.

From a technology perspective, panellists noted that modular processing platforms already exist that can pretreat, fractionate, and divert UCO streams toward oleochemicals, surfactants, glycerine, or fuels. The limiting factor is therefore not technological readiness, but policy-enabled feedstock discipline.

Insight 4: Weak pull from chemicals sector

From the downstream perspective, the panel stressed that chemical and surfactant pathways must meet a three-fold criterion: performance, affordability, and sustainability. Sustainability alone cannot carry the business case, particularly in price-sensitive markets.

A critical technical constraint highlighted was carbon-chain alignment. Most high-volume surfactant systems rely on C12–C14 chains, whereas typical UCO streams skew toward longer chains. Bridging this gap may require selective sourcing, chemical upgrading or cracking, and targeted R&D.

The panel repeatedly returned to the point that end-market certainty is a prerequisite for innovation investment, not its consequence.

Insight 5: Missing middle: aggregation, processing, and risk ownership

Across perspectives, the most critical gap identified was the absence of a functional “middle layer” covering aggregation, segregation, quality control, pretreatment, and traceability. No single actor currently has both the incentive and mandate to invest in this layer.

Enablers discussed included, mandatory registration and reporting across the value chain, and explicit risk-sharing between the state, aggregators, refiners, and downstream material users. Without this foundation, debates about optimal end use—fuel versus chemicals—remain theoretical.

Summary & Reflections

UCO Can Support Material Transition—but Only with Aligned Policy, Industry, and Finance

In its closing reflections, the panel converged on a shared conclusion: failure to valorise UCO would represent a lost opportunity to establish a circular, low-GHG domestic carbon pool for Indian materials manufacturing. Beyond emissions, this would mean forfeiting domestic value creation, technological leadership, and resilience in renewable feedstocks.

The discussion positioned UCO as a system-level test case for how India designs material-transition pathways—linking public health, waste governance, industrial policy, and climate objectives into a coherent whole.

Annexure-II

International Lessons for UCO Governance, Policy and System Design

This Annexure provides select international evidence to support the policy and system-design analysis. It does not aim to describe complete national UCO markets. Instead, it highlights how governance choices, enforcement mechanisms, and incentive structures shape UCO collection, aggregation, and allocation outcomes across different jurisdictions.

International Evidence for UCO Policy and System Design

Across countries with mature or rapidly scaling UCO utilisation, outcomes are driven less by feedstock availability and more by how UCO is governed as a system—including mandatory collection, traceability, incentive design, and prioritisation of end use. The cases below illustrate these design levers and their relevance for India's evolving UCO ecosystem.

1. United States / North America: Mandatory Collection with Fuel-Centric Allocation

In the United States, Used Cooking Oil—commonly referred to as “yellow grease”—is mobilised primarily through mandatory grease disposal requirements applied to commercial food-service establishments at state and municipal levels. These requirements ensure high recovery from restaurants, industrial kitchens, and institutional food providers, supported by licensed private collectors.

Once collected, UCO allocation is shaped downstream by energy-transition incentives rather than waste regulation. UCO-derived biodiesel and renewable diesel benefit from the Renewable Fuel Standard (RFS), where Renewable Identification Numbers (RINs) create clear monetisation pathways. Sustainable Aviation Fuel (SAF) can also earn incentives under the same framework. There are no equivalent policy instruments that recognise or prioritise chemical or material applications of UCO.

Outcome: High formal recovery and strong traceability, coupled with default routing of UCO into fuel pathways.

Design lesson for India: Mandatory collection is necessary for scale, but without differentiated end-use signals, UCO predictably flows to policy-supported fuel applications.

2. United Kingdom / European Union: Differentiated Incentives and Strong Traceability

The UK and EU illustrate how explicit incentive differentiation influences UCO outcomes. Under the Renewable Transport Fuel Obligation (RTFO) and the EU Renewable Energy Directive, UCO qualifies as a waste-derived feedstock eligible for enhanced crediting (commonly referred to as “double counting”). This feature explicitly favours UCO over virgin vegetable oils and has driven high formal recovery from the HoReCa sector.

Digital documentation, licensed collection networks, and audit-based traceability systems are integral to compliance, significantly reducing fraud and food-chain leakage. At the same time, recent SAF mandates under ReFuelEU Aviation and national SAF obligations reinforce demand from aviation, further strengthening fuel-centric pull.

Outcome: Highly structured collection, strong traceability, and explicit policy steering—yet continued dominance of fuel and SAF end uses due to incentive alignment.

Design lesson for India: Differentiated incentives and traceability work, but without explicit material-transition recognition, fuels remain the dominant sink.

3. Germany: Enforcement-Led Recovery with Aggregation Depth

Germany combines stringent waste-management enforcement with strong renewable energy mandates under the EU framework. UCO collection is dominated by commercial food-service establishments, supported by licensed collectors and enforcement at local levels. Quality standards tied to biodiesel eligibility incentivise basic segregation and contamination control.

Aggregation networks are dense in urban centres, enabling reliable mobilisation. While biodiesel remains the dominant outlet, refinery integration and policy certainty have ensured that UCO is treated as a regulated industrial feedstock rather than informal waste.

Outcome: High recovery efficiency, quality-consistent aggregation, and stable industrial utilisation—predominantly fuel-oriented.

Design lesson for India: Enforcement and aggregation depth are prerequisites for stability, even before allocation optimisation is attempted.

4. China: Strong Enforcement, Fragmented Allocation, and Export Orientation

China generates large volumes of WCO due to dietary patterns and urban scale. The government has implemented strict enforcement against illegal reuse, motivated by severe public-health risks. Centralised collection systems, municipal involvement, and licensing have significantly reduced food-chain leakage in major cities.

However, downstream allocation remains fragmented. A large share of legally recovered WCO is converted into biodiesel, with significant volumes exported. Only recently have oleochemical and chemical applications begun to emerge domestically, enabled by improved purification technologies and tightening environmental controls.

Outcome: Rapid recovery gains driven by enforcement but limited domestic optimisation of UCO allocation.

Design lesson for India: Enforcement can quickly improve collection, but without integrated allocation logic, system value may be lost or exported.

5. Japan: High Commercial Recovery, Weak Household Capture

Japan demonstrates the limits of voluntary and municipal-dependent collection models. Recovery of UCO from commercial food establishments is very high, supported by subsidies, public-sector procurement (e.g., municipal fleets), and strong compliance culture. In contrast, household-level UCO collection remains uneven, with participation varying widely across municipalities.

Advanced logistics and traceability systems are increasingly used for commercial streams, but fragmented household capture constrains total recovery.

Outcome: Reliable commercial UCO supply, but constrained overall mobilisation due to weak household inclusion.

Design lesson for India: Commercial UCO is easier to formalise than household UCO; policy thresholds strongly shape realised supply volumes.

6. Middle East (UAE): Import-Dependent UCO Utilisation

In the UAE, UCO utilisation is emerging through isolated initiatives, such as municipal partnerships and private biodiesel producers. However, domestic collection remains limited, and UCO supply is often import-dependent. As a result, buyers are exposed to global feedstock tightness, sustainability certification premiums, and external price volatility.

Outcome: Limited domestic mobilisation and high dependence on international markets.

Design lesson for India: Without domestic collection depth, UCO-based strategies inherit global scarcity and lose strategic resilience.

7. Other Developing Regions: Public-Health Driven Imperatives

In several developing regions, including parts of Africa, UCO is still widely recycled informally, particularly for reuse in food preparation. Weak collection infrastructure and enforcement lead to severe public-health risks, highlighting the social importance of creating regulated, value-creating industrial sinks.

Design lesson for India: Formal UCO valorisation is not only a climate intervention, but a critical public-health measure.

Cross-Cutting Insight

Across all jurisdictions reviewed, one conclusion is consistent: UCO outcomes are determined by policy and system design, not by technical feasibility or feedstock availability. Mandatory collection, enforcement, traceability, and incentive alignment are prerequisites for scale. Allocation across fuels, chemicals, and materials follows design signals, not market neutrality. These international observations directly reinforce the analysis and demonstrate that India's challenges are design-related and solvable rather than structural or resource-driven.

Annexure-III

Supporting Data, Assumptions and Analytical Evidence

Table I: No. of aggregators linked with Biodiesel Production Units

S. No.	No. of Aggregators	No. of reporting biodiesel plants	Percent (%)
1	1	19	26.4
2	2	10	13.9
3	3	7	9.7
4	4	2	2.8
5	5	1	1.4
6	6	2	2.8
7	7	1	1.4
8	11	1	1.4
9	Data Not available	29	40.3
	Total	72	100.0
Biodiesel plants also acting as aggregators		17	23.6
Mean Number of aggregators per biodiesel plant			1.4
Median Number of aggregators per biodiesel plant			3.5

Source: Analysis compiled from the data retrieved from multiple sources including data retrieved from Enrolled Biodiesel Manufacturers - RUCO : Repurpose Used Cooking Oil and Research Paper on Used Cooking Oil based Biodiesel of www.pahalindia.org

Table II: State wise coverage of Aggregators and End Users

S. No.	States	Number of aggregators			
		Biodiesel	Soap	Total	% Share
1	Andhra Pradesh	6		6	4.5
2	Bihar	1		1	0.8
3	Gujarat	3		3	2.3
4	Haryana	8	1	9	6.8
5	Himachal Pradesh	1		1	0.8
6	Karnataka	2	7	9	6.8
7	Kerala	7	4	11	8.3
8	Madhya Pradesh	4		4	3.0
9	Maharashtra	9	1	10	7.5
10	Punjab	1	2	3	2.3
11	Rajasthan	12	1	13	9.8
12	Tamil Nadu	21	3	24	18.0
13	Telangana	6	2	8	6.0
14	Uttar Pradesh	22		22	16.5
15	Uttarakhand	1		1	0.8
16	West Bengal	5	3	8	6.0
	All states	109	24	133	100.0

Source: Analysis compiled from the data retrieved from Enrolled Biodiesel Manufacturers - RUCO: Repurpose Used Cooking Oil

Table III: Biodiesel Production in India

S. No.	Year	Quantity of Biodiesel produced by feedstock category (x1000 MT)	% of Biodiesel produced by feedstock category						
			Animal Fat and Tallow	Non-edible Oil Seeds	Used Cooking Oil	Total	Animal Fat and Tallow	Non-edible Oil Seeds	Used Cooking Oil
1	2013	7		70	49	126	5.6	55.6	38.9
2	2014	6		75	50	131	4.6	57.3	38.2
3	2015	5		85	55	145	3.4	58.6	37.9
4	2016	6		90	55	151	4.0	59.6	36.4
5	2017	6		100	55	161	3.7	62.1	34.2
6	2018	8		110	60	178	4.5	61.8	33.7
7	2019	10		140	65	215	4.7	65.1	30.2
8	2020	9		145	50	204	4.4	71.1	24.5
9	2021	9		90	55	154	5.8	58.4	35.7
	Yearly average	7		101	55	163	4.3	62.0	33.7

Source: TERI (2023), *Accelerating Biodiesel Blending in India*, Policy Brief ²¹

²¹ Jamal F (2023). *Accelerating Biodiesel Blending in India*, The Energy and Resources Institute, New Delhi.

Table IV: Trend of Jet Fuel (ATF) Demand in India and Potential Demand for SAF (during the period 2004-05 to 2024-25, in M MT)

Year	ATF Demand in India	Potential Demand for SAF at 1% blending target	Potential Demand for SAF at 2% blending target	Potential Demand for SAF at 5% blending target
1998-99	2.12	0.02	0.04	0.11
1999-00	2.20	0.02	0.04	0.11
2000-01	2.25	0.02	0.05	0.11
2001-02	2.27	0.02	0.05	0.11
2002-03	2.27	0.02	0.05	0.11
2003-04	2.49	0.02	0.05	0.12
2004-05	2.82	0.03	0.06	0.14
2005-06	3.30	0.03	0.07	0.17
2006-07	3.99	0.04	0.08	0.20
2007-08	4.55	0.05	0.09	0.23
2008-09	4.43	0.04	0.09	0.22
2009-10	4.63	0.05	0.09	0.23
2010-11	5.08	0.05	0.10	0.25
2011-12	5.54	0.06	0.11	0.28
2012-13	5.27	0.05	0.11	0.26
2013-14	5.51	0.06	0.11	0.28
2014-15	5.72	0.06	0.11	0.29
2015-16	6.26	0.06	0.13	0.31
2016-17	7.00	0.07	0.14	0.35
2017-18	7.63	0.08	0.15	0.38
2018-19	8.30	0.08	0.17	0.42
2019-20	8.00	0.08	0.16	0.40
2020-21	3.70	0.04	0.07	0.18
2021-22	5.01	0.05	0.10	0.25
2022-23	7.38	0.07	0.15	0.37
2023-24	8.25	0.08	0.16	0.41
2024-25	8.98	0.09	0.18	0.45
2025-26 (P)	9.16	0.09	0.18	0.46

Source: Petroleum Planning & Analysis Cell (PPAC), Government of India

Table V: Annual Surfactant Production in India during the Period 2004-05 to 2024-25
(Quantity in in Kilo Tonne/ Annum)

S. No.	Year	Linear Alkylbenzene (LAB)	Sodium Lauryl Ether Sulphate (SLES)	Alcohol Ethoxylates (AE)	Alcohol Ether Sulphates (AES – excluding SLES grades)
1	2005	360	85	120	60
2	2006	375	90	125	62
3	2007	390	95	130	65
4	2008	405	100	135	67
5	2009	415	105	140	70
6	2010	430	110	145	72
7	2011	445	115	150	75
8	2012	460	120	155	77
9	2013	475	125	160	80
10	2014	490	130	165	82
11	2015	505	135	170	85
12	2016	520	140	175	87
13	2017	535	145	180	90
14	2018	550	150	185	92
15	2019	565	155	190	95
16	2020	555	150	185	97
17	2021	580	165	200	100
18	2022	600	180	215	105
19	2023	620	195	230	108
20	2024	640	210	250	110

Table VI: Key chemical parameters for feedstocks used for oleochemical, surfactants, biodiesel and SAF

S. No.	Parameter	Oleochemical Feedstock (Typical)	Surfactants (Chemical-grade)	Biodiesel – ASTM D6751 (B100)	Biodiesel – EN 14214	SAF
1	Free Fatty Acid / Acid Value	0.1–15 % FFA allowed (process-dependent)	Acid value $\leq$ 1.0–2.0 mg KOH/g (low corrosion, formulation stability)	Acid value $\leq$ 0.50 mg KOH/g	Acid value $\leq$ 0.50 mg KOH/g	$\leq$ 1.0–2.0 (preferred $\leq$ 1.0) [% as oleic acid]
2	Moisture / Water	0.1–1.0 %	$\leq$ 0.1 % (avoids hydrolysis, microbial growth)	$\leq$ 0.05 % vol (500 ppm approx.)	$\leq$ 500 mg/kg	$\leq$ 0.05 [wt% ($\leq$ 500 ppm)]
3	Insoluble impurities	0.1–1.0 %	$\leq$ 0.05 % (clarity, spray/dissolution performance)	$\leq$ 0.05 % vol (water + sediment)	$\leq$ 24 mg/kg	$\leq$ 0.01 [wt% ($\leq$ 100 ppm)]
4	Phosphorus	$\leq$ 10–100 ppm	$\leq$ 5–10 ppm (discoloration, catalyst poisoning)	$\leq$ 10 ppm (0.001 %)	$\leq$ 4 ppm	$\leq$ 5–10 [ppm]
5	Sulphur	$\leq$ 30–50 ppm	$\leq$ 20–50 ppm (odour & colour control)	$\leq$ 15 ppm (S15 grade)	$\leq$ 10 ppm	$\leq$ 10 [ppm]
6	Alkali metals (Na +K)	Often $\leq$ 50–100 ppm	$\leq$ 10–20 ppm (formulation stability)	$\leq$ 5 ppm	$\leq$ 5 ppm	$\leq$ 5 [ppm]
7	Ca +Mg	Process-specific	$\leq$ 20 ppm (prevents soap scum / precipitation)	$\leq$ 5 ppm	$\leq$ 5 ppm	$\leq$ 5 [ppm]
8	Peroxide value	$\leq$ 2–5 meq/kg	$\leq$ 5–10 meq/kg (foaming + shelf life)	Not permitted (must be stable fuel)	Controlled via oxidation stability	$\leq$ 5 [meq O ₂ /kg]
9	Unsaponifiables / polymers	$\leq$ 1–1.5 %	Controlled (can affect cloud point & clarity)	Not permitted	Not permitted	$\leq$ 1.5 [wt%]
10	Oxidation stability	Not a buying criterion	Important (antioxidant-dependent shelf life)	$\geq$ 3 h	$\geq$ 8 h	$\geq$ 6 [hours]
11	Glycerides / glycerol	Not specified	Not applicable	Strictly limited	Strictly limited	Triglycerides $>$ 95% [wt%]
12	Color (APHA / Hazen)	Yellow–brown acceptable	$\leq$ 50–200 APHA (appearance important)	Not critical		Controlled
13	Carbonyls / Aldehydes	Trace	$\leq$ 0.1 % (odour & stability)	Limited		Limited
14	Nitrogen compounds	Trace	Trace acceptable	Limited		Limited

S. No.	Parameter	Oleochemical Feedstock (Typical)	Surfactants (Chemical-grade)	Biodiesel – ASTM D6751 (B100)	Biodiesel – EN 14214	SAF
15	Dienes / Acetylene	Not relevant	Not relevant	Not relevant		Not relevant
16	Purity / Main component	Mixed fatty chains	Active matter defined by formulation	FAME $\geq$ 96.5 %		Paraffinic
17	Oxygenates	High	Allowed (EO-based)	High		Must be removed
18	Chloride content	$\leq$ 1 – 5 ppm	$\leq$ 1 – 10 ppm	$\leq$ 5 – 20 ppm (feedstock)	Typically $\leq$ 5 ppm (inorganic Cl)	$\leq$ 1 – 2 ppm

Source: Compiled from multiple tender documents of Oleochemical Companies

Table VII: Comparative chemical quality requirements of feedstocks for oleochemical, biodiesel and SAF (HEFA) manufacturing

S. No.	Parameters	Oleochemical Feedstock	Biodiesel (ASTM D6751 / EN 14214)	SAF – HEFA Route
1	Free Fatty Acid / Acid Value	High FFA is desirable for fatty-acid splitting and soap manufacture, improving yield and reducing neutral oil losses ¹ .	High FFA promotes corrosion, injector fouling, and deposit formation; hence acid value is restricted to ≤ 0.50 mg KOH/g ² .	Low and stable FFA (typically $\leq 1\%$) ensures predictable hydrotreating performance and protects HEFA catalysts ³ .
2	Moisture / Water	Water can be removed by degumming, drying, or distillation and is manageable within oleochemical processing ¹ .	Even trace moisture causes corrosion, microbial growth, and filter plugging; water ≤ 500 mg/kg is specified ^{2 4} .	Highly detrimental as it deactivates hydrotreating catalysts, increases hydrogen consumption, and causes corrosion and instability ³ .
3	Phosphorus and Metals	Moderate phosphorus and metal levels are tolerable and managed through pretreatment and refining ¹ .	Strong poisons for engine after-treatment systems; phosphorus ≤ 10 ppm (ASTM) and ≤ 4 ppm (EN) ^{2 4} .	Very tight limits ($\leq 5\text{--}10$ ppm) are mandatory to protect high-value HEFA catalysts and sustain fuel yield ³ .
4	Oxidation Stability	Oxidation products can be largely removed during fractionation and are not a primary purchasing criterion ¹ .	Biodiesel must resist oxidation during storage; stability ≥ 3 h (ASTM) and ≥ 8 h (EN) ^{2 4} .	High stability is required to prevent gum formation, coke precursors, and feed degradation during storage and processing ³ .
5	Unsaturated / Reactive Impurities	Unsaturation is inherent to lipid feedstocks and acceptable depending on the target oleochemical product ¹ .	Excessive unsaturation reduces oxidation stability and storage life of biodiesel ² .	Controlled to prevent side reactions and coke formation under severe hydrotreating conditions ³ .

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Table VIII: Comparative Cost Analysis

Cost Components	Mid-Price (\$/t)				
	AE	AES/SLES	LAB/LAS	Biodiesel	SAF
UCO Route					
Feedstock and Chemicals	1436.2	894.1	1404.7	952.3	1578.9
Utilities / Operating Expenses (OPEX)	128.4	128.4	193.8	193.8	193.8
Sub-Total	1564.6	1022.5	1598.5	1146.1	1772.8
Margin (15%)	234.7	153.4	239.8	0.0	0.0
Expected Price / Price (UCO Route)	1799.3	1175.9	1838.3	1146.1	1772.8
Non-UCO Route (Existing)					
Fossil-based Feedstock (Mid Value Price)	2000	1190	1350	1075	1200
Non fossil-based Feedstock (Mid Value Price)	1975	925	1850	1100	2500
Price Difference					
Fossil-based	-200.7	-14.1	488.3	71.1	573
Non fossil-based	-175.7	250.9	-11.7	46	-727
Percentage Difference in Price					
Fossil-based	-10.03	-1.18	36.17	6.6	48
Non fossil-based	-8.90	27.13	-0.63	4.2	-29

Note:

Price of feedstock / chemicals used for production of different surfactants / fuel is collected from different sources. List of sources are presented here for reference.

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The G20 New Delhi Leaders' Declaration acknowledges the critical role being played by circular economy, extended producer responsibility and resource efficiency in achieving sustainable development. Notably, the 'Green Development Pact for a Sustainable Future' declaration part of the G20 India Presidency in para 37 has mentioned the launching of Resource Efficiency and Circular Economy Industry Coalition.

RECEIC as envisaged is a G20 centric coalition driven by industry. It is first of its kind high-level initiative on encouraging resource efficiency and circular economy which is industry led, independent and self-sustaining, includes all sectors from across the globe, is inclusive and integrative.

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