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Current Status and Future Prospects of Biolubricants: Properties and Applications

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Abstract

The increasing environmental concerns and stringent regulations regarding the use of petroleum-based lubricants have accelerated the development of eco-friendly alternatives. Biolubricants, derived from renewable biological sources, have emerged as promising substitutes due to their biodegradability, low toxicity, and superior lubrication properties. This comprehensive review examines the current status of biolubricant technology, analyzing their physicochemical properties, performance characteristics, and diverse applications across various industries. The paper presents a critical assessment of different feedstock sources, production methodologies, and performance enhancement strategies. Furthermore, it discusses the challenges hindering widespread adoption and explores future prospects for biolubricant development. The findings suggest that while significant progress has been made in biolubricant formulation, continued research in chemical modification, additive development, and cost optimization is essential for achieving competitive parity with conventional lubricants.

Keywords: Biolubricants; Renewable Resources; Tribology; Sustainability; Biodegradability; Vegetable Oils

1. Introduction

The global lubricant industry faces unprecedented pressure to develop environmentally sustainable alternatives to petroleum-based products. Environmental regulations, such as the European Union's REACH directive and various national policies, have mandated the use of biodegradable lubricants in environmentally sensitive applications (Mobarak et al., 2014). This regulatory landscape, combined with growing environmental awareness and resource scarcity concerns, has catalyzed significant research interest in biolubricants derived from renewable biological sources.

Biolubricants, defined as lubricating fluids derived from vegetable oils, animal fats, or other biological materials, offer several advantages over their petroleum counterparts. These include inherent biodegradability, reduced toxicity, superior lubricity, and higher viscosity indices (Panchal et al., 2017). The molecular structure of vegetable oils, characterized by long-chain fatty acids with polar functional groups, provides excellent boundary lubrication properties and metal surface adhesion characteristics that often surpass those of conventional mineral oils.

The historical development of biolubricants can be traced back to ancient civilizations, where plant and animal oils were used for mechanical applications. However, the modern scientific approach to biolubricant development began in the 1990s, driven primarily by environmental legislation and technological advances in chemical modification processes (Syahir et al., 2017). The past three decades have witnessed substantial progress in understanding the structure-property relationships of bio-based lubricants and developing effective chemical modification strategies.

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Current market analysis indicates a steady growth trajectory for the biolubricant industry, with projections suggesting a compound annual growth rate of approximately 4-6% through 2025 (Gryglewicz et al., 2003). The automotive, marine, and industrial machinery sectors represent the primary application domains, with hydraulic fluids, engine oils, and metalworking fluids comprising the largest market segments. Despite this growth, biolubricants currently account for less than 3% of the total lubricant market, indicating substantial potential for expansion.

The technical challenges associated with biolubricant adoption include oxidative stability limitations, low-temperature performance issues, and higher production costs compared to petroleum-based alternatives. These challenges have necessitated intensive research into chemical modification techniques, antioxidant systems, and process optimization strategies (McNutt and He, 2016). The development of cost-effective production methods and performance-enhancing additives remains crucial for achieving widespread market acceptance.

This comprehensive review aims to provide a detailed analysis of the current state of biolubricant technology, examining the various aspects from feedstock selection to end-use applications. The paper synthesizes recent research findings, identifies technological gaps, and proposes future research directions to facilitate the transition toward sustainable lubrication systems. The ultimate goal is to provide researchers, industry professionals, and policymakers with a thorough understanding of biolubricant potential and the roadmap for their successful commercialization.

Table 1 Comparison of Global Lubricant Consumption by Region (2020)

Region	Consumption (Million Tons)	Market Share (%)	Biolubricant Share (%)
North America	8.2	22.1	2.8
Europe	6.8	18.3	4.2
Asia-Pacific	15.6	42.0	1.9
Middle East and Africa	3.1	8.4	1.5
Latin America	3.4	9.2	2.1
Total	37.1	100.0	2.5

2. Feedstock Sources and Production Methods

The selection of appropriate feedstock represents a critical factor in biolubricant production, influencing both the final product properties and economic viability. Vegetable oils constitute the primary raw material source, with over 350 oil-bearing plants identified globally (Willing, 2001). The fatty acid composition of vegetable oils directly impacts the tribological performance, oxidative stability, and low-temperature characteristics of the resulting biolubricants. Major feedstock categories include edible oils such as soybean, rapeseed, and sunflower, as well as non-edible sources like jatropha, castor, and algae.

Edible vegetable oils have historically dominated biolubricant production due to their widespread availability and well-established supply chains. Soybean oil, with its balanced fatty acid profile containing approximately 23% oleic acid, 54% linoleic acid, and 8% linolenic acid, provides good lubrication properties but suffers from oxidative instability due to high polyunsaturated fatty acid content (Willing, 2001). Rapeseed oil, characterized by higher oleic acid content (60-65%), offers superior oxidative stability while maintaining excellent low-temperature fluidity, making it particularly suitable for hydraulic fluid applications.

Non-edible oil sources have gained increasing attention as sustainable alternatives that avoid competition with food applications. Jatropha curcas oil, containing approximately 44% oleic acid and 32% linoleic acid, demonstrates comparable tribological properties to conventional lubricants while offering the advantage of cultivation on marginal lands (Quinchia et al., 2014). Castor oil, unique among vegetable oils due to its ricinoleic acid content (85-90%), provides exceptional viscosity characteristics and natural hydroxyl functionality beneficial for chemical modification processes.

The production methodology significantly influences the quality and properties of biolubricants. Traditional mechanical extraction methods, including screw pressing and solvent extraction, remain the most economically viable approaches for large-scale production. However, these methods often require subsequent refining processes to remove impurities such as phospholipids, free fatty acids, and moisture that can adversely affect lubricant performance (Adhvaryu et al., 2000). Degumming, neutralization, bleaching, and deodorization processes are typically employed to achieve the required purity levels.

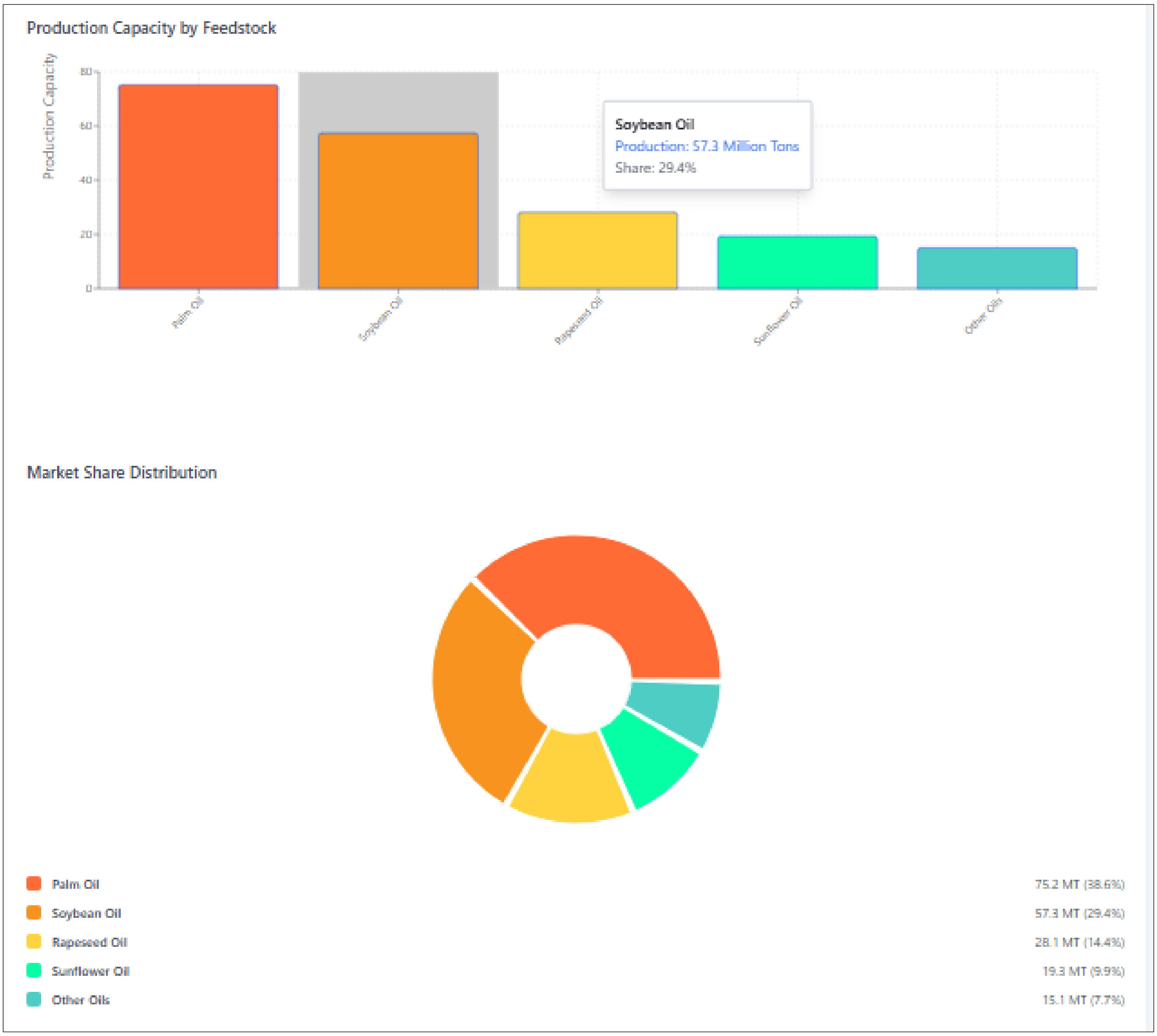

Figure 1 Global Production Capacity of Biolubricant Feedstocks (2020)

Advanced extraction techniques, such as supercritical fluid extraction and enzymatic processing, offer advantages in terms of product quality and environmental impact. Supercritical CO2 extraction produces high-purity oils with minimal thermal degradation and solvent residues, though the high capital costs currently limit its commercial application (Reeves et al., 2015). Enzymatic transesterification processes enable selective modification of fatty acid profiles, allowing for tailored property optimization while operating under mild reaction conditions.

Emerging production technologies focus on integrated biorefinery concepts that maximize value extraction from biomass feedstocks. These approaches combine oil extraction with the recovery of valuable co-products such as proteins, carbohydrates, and bioactive compounds, thereby improving overall economic viability (Willing, 2001). The development of continuous processing systems and process intensification techniques represents another avenue for reducing production costs and improving product consistency.

Table 2 Fatty Acid Composition of Major Biolubricant Feedstocks

Oil Source	Palmitic (C16:0)	Stearic (C18:0)	Oleic (C18:1)	Linoleic (C18:2)	Linolenic (C18:3)	Others
Soybean	11.0	4.0	23.0	54.0	8.0	0.0
Rapeseed	4.0	2.0	62.0	22.0	10.0	0.0
Sunflower	6.5	4.5	19.0	69.0	1.0	0.0
Jatropha	15.0	7.0	44.0	32.0	2.0	0.0
Castor	1.5	1.0	3.0	4.5	0.5	89.5*
Palm	44.0	4.5	39.0	10.0	0.5	2.0

*Primarily ricinoleic acid (C18:1-OH)

3. Chemical and Physical Properties

The physicochemical properties of biolubricants are fundamentally determined by their molecular structure, which differs significantly from petroleum-based lubricants. Vegetable oils consist primarily of triglyceride molecules comprising three fatty acid chains attached to a glycerol backbone, resulting in molecular weights typically ranging from 800 to 1000 g/mol (Erhan and Asadauskas, 2000). This structure imparts unique characteristics including polar functionality, higher molecular weight distribution, and the presence of double bonds that influence oxidative stability and temperature-dependent behavior.

Viscosity represents one of the most critical properties for lubricant applications, and biolubricants generally exhibit higher viscosity values compared to mineral oils of similar grade. The viscosity-temperature relationship, characterized by the viscosity index (VI), is typically superior for vegetable oil-based lubricants, with values ranging from 180-250 compared to 80-120 for conventional mineral oils (Panchal et al., 2017). This high viscosity index results in more stable viscosity across temperature ranges, providing consistent lubrication performance under varying operating conditions.

The pour point and cloud point characteristics of biolubricants are influenced by the fatty acid composition and the presence of saturated components. Highly saturated oils such as palm oil exhibit higher pour points (-3 to 5°C) compared to unsaturated oils like rapeseed oil (-25 to -30°C) (Quinchia et al., 2014). The crystallization behavior of triglycerides at low temperatures can lead to flow restrictions, necessitating the use of pour point depressants or chemical modification strategies to improve cold-flow properties.

Oxidative stability represents a significant challenge for biolubricant applications, particularly due to the presence of unsaturated fatty acids that are susceptible to autoxidation. The oxidation process involves the formation of hydroperoxides, aldehydes, and polymerization products that increase viscosity and acidity while generating corrosive compounds (Adhvaryu and Erhan, 2002). The oxidation induction time, measured through techniques such as differential scanning calorimetry (DSC) or pressurized differential scanning calorimetry (PDSC), typically ranges from 10-60 minutes for unmodified vegetable oils compared to several hours for synthetic lubricants.

Thermal stability assessment through thermogravimetric analysis (TGA) reveals that biolubricants generally exhibit lower thermal decomposition temperatures compared to mineral oils. The onset of thermal degradation typically occurs around 250-300°C for vegetable oils, influenced by the presence of polyunsaturated fatty acids and the triglyceride structure (Willing, 2001). However, the thermal stability can be significantly improved through chemical modification processes such as selective hydrogenation or estolide formation.

The biodegradability of biolubricants represents one of their primary advantages, with most vegetable oil-based formulations achieving 70-90% biodegradation within 28 days according to OECD 301B protocols (Mobarak et al., 2014). The biodegradation process involves enzymatic hydrolysis of ester bonds followed by beta-oxidation of fatty acid chains, resulting in complete mineralization to CO_2 and water. This characteristic is particularly valuable for environmentally sensitive applications such as marine and forestry equipment.

Table 3 Comparative Physical Properties of Biolubricants vs. Mineral Oils

Property	Units	Soybean Oil	Rapeseed Oil	Castor Oil	SAE 30 Mineral Oil
Kinematic Viscosity (40°C)	mm^2/s	32.6	35.4	285.6	30.2
Kinematic Viscosity (100°C)	mm^2/s	7.8	8.2	19.5	5.1
Viscosity Index	-	218	245	84	98
Pour Point	°C	-7	-25	-18	-21
Flash Point	°C	254	246	260	218
Density (15°C)	kg/m^3	922	915	956	895
Acid Value	mg KOH/g	0.2	0.3	2.0	0.1

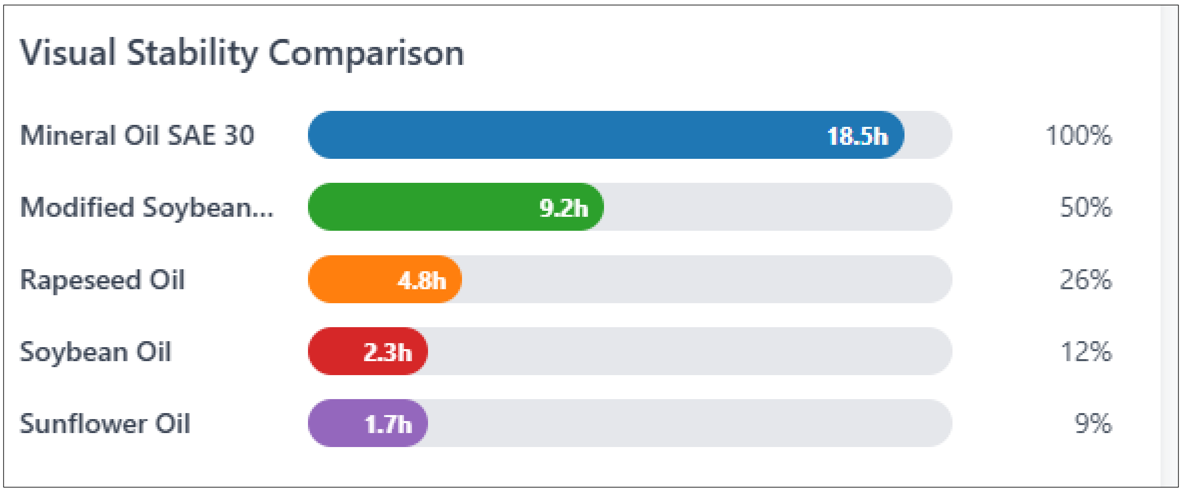

Figure 2 Oxidation Stability Comparison - Rancimat Test Results

4. Tribological Performance and Mechanisms

The tribological performance of biolubricants encompasses their ability to reduce friction, minimize wear, and prevent surface damage under various operating conditions. The unique molecular structure of vegetable oils, characterized by polar ester groups and long-chain fatty acids, provides superior boundary lubrication properties compared to non-polar mineral oils (Syahir et al., 2017). The polar functionality enables strong adsorption onto metal surfaces, forming protective molecular films that effectively separate contacting surfaces and reduce direct metal-to-metal contact.

Friction coefficient measurements using standard tribological test methods, such as the four-ball test (ASTM D4172) and pin-on-disk configurations, consistently demonstrate the superior lubricity of biolubricants. Typical friction coefficients for vegetable oil-based lubricants range from 0.08-0.12 compared to 0.12-0.16 for mineral oils under similar test conditions (Quinchia et al., 2014). This improved performance is attributed to the formation of boundary lubrication films through chemisorption and physisorption mechanisms, with the polar ester groups providing strong adhesion to metal oxide surfaces.

Wear protection capabilities of biolubricants are generally superior to mineral oils, as evidenced by standardized wear tests such as the four-ball wear test (ASTM D4172) and high-frequency reciprocating rig (HFRR) evaluations. The wear scar diameter typically measured 20-30% smaller for vegetable oil lubricants compared to conventional formulations, indicating enhanced anti-wear properties (McNutt and He, 2016). The mechanism involves the formation of protective tribofilms through tribochemical reactions between fatty acid molecules and metal surfaces, creating low-shear boundary layers that minimize surface damage.

The load-carrying capacity of biolubricants, assessed through extreme pressure (EP) tests such as the four-ball EP test (ASTM D2783), reveals both advantages and limitations compared to conventional lubricants. While the inherent EP properties of unmodified vegetable oils may be lower than formulated mineral oils containing EP additives, the natural lubricity often compensates for this deficiency in moderate load applications (Reeves et al., 2015). The incorporation of appropriate EP additives can significantly enhance the load-carrying capacity while maintaining the environmental benefits of bio-based formulations.

Temperature effects on tribological performance represent a critical consideration for biolubricant applications. The superior viscosity index of vegetable oils ensures more stable lubrication performance across temperature ranges, with maintained film thickness and consistent friction behavior. However, high-temperature applications may be limited by thermal decomposition and oxidation processes that can lead to deposit formation and increased acidity (Erhan and Asadauskas, 2000). Low-temperature performance is influenced by the crystallization behavior of triglycerides, which can affect pumpability and flow characteristics.

The mechanisms underlying the superior tribological performance of biolubricants involve multiple phenomena occurring at the interface between lubricant and solid surfaces. Surface analysis techniques, including X-ray photoelectron spectroscopy (XPS) and atomic force microscopy (AFM), reveal the formation of organized molecular films with oriented fatty acid chains providing optimal spacing and lubrication characteristics. The polar head groups interact strongly with metal surfaces while the hydrocarbon tails provide the necessary fluidity and load support (Adhvaryu and Erhan, 2002).

Table 4 Tribological Test Results Comparison

Test Parameter	Method	Soybean Oil	Rapeseed Oil	Mineral Oil SAE 30	Units
Coefficient of Friction	Pin-on-Disk	0.089	0.092	0.125	-
Wear Scar Diameter	ASTM D4172	0.45	0.42	0.58	mm
Weld Point Load	ASTM D2783	200	180	250	kg
Load-Wear Index	ASTM D2783	38	35	42	kg
HFRR Wear Scar	ASTM D6079	320	295	410	µm
Scuffing Load	FZG Test	10	9	12	Stage

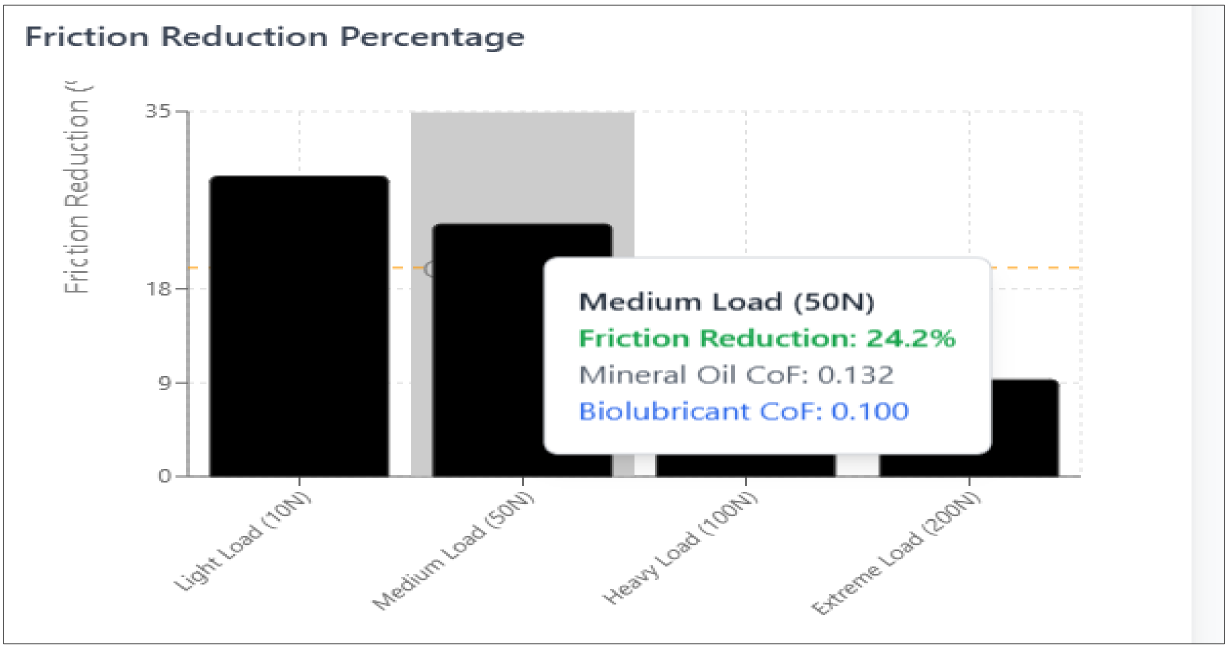

Figure 3 Friction Reduction Performance Under Various Loads

Table 5 Wear Mechanism Analysis

Mechanism	Mineral Oil	Soybean Oil	Rapeseed Oil	Description
Abrasive Wear	High	Low	Low	Hard particle cutting
Adhesive Wear	Medium	Very Low	Very Low	Metal transfer
Corrosive Wear	Low	Very Low	Very Low	Chemical attack
Fatigue Wear	Medium	Low	Low	Repeated loading
Scuffing	Medium	Low	Low	Surface welding

5. Applications and Industrial Uses

The application spectrum of biolubricants has expanded significantly across multiple industrial sectors, driven by environmental regulations, performance requirements, and sustainability initiatives. The automotive industry represents the largest application segment, encompassing engine oils, transmission fluids, hydraulic fluids, and metalworking lubricants (Panchal et al., 2017). The stringent emission standards and environmental protection requirements in this sector have accelerated the adoption of bio-based alternatives, particularly in applications where lubricant loss to the environment is inevitable.

Hydraulic fluid applications constitute a major market for biolubricants, especially in environmentally sensitive operations such as forestry, marine, and mining equipment. The biodegradability and low toxicity of vegetable oil-based hydraulic fluids make them ideal for applications where spillage or leakage could impact ecosystems (Mobarak et al., 2014). Fire-resistant hydraulic fluids based on synthetic esters and phosphate esters have found extensive use in steel mills, mining operations, and marine applications where fire safety is paramount.

The metalworking industry has embraced biolubricants for machining, forming, and cutting operations due to their superior lubricity and reduced health hazards compared to mineral oil-based cutting fluids. Vegetable oil-based metalworking fluids demonstrate excellent boundary lubrication properties, resulting in improved surface finish, extended tool life, and reduced cutting forces (Quinchia et al., 2014). The absence of aromatic compounds and reduced misting characteristics make these formulations safer for operator exposure and indoor air quality.

Table 6 Biolubricant Application Segments and Market Share

Application Segment	Market Share (%)	Growth Rate (2015-2020)	Key Drivers
Hydraulic Fluids	35.2	6.8%	Environmental regulations
Engine Oils	28.4	4.2%	Emission standards
Metalworking Fluids	15.7	8.1%	Worker safety
Transmission Fluids	8.9	5.4%	OEM requirements
Gear Oils	7.3	7.2%	Wind energy sector
Others	4.5	9.3%	Emerging applications

Marine applications represent a rapidly growing segment for biolubricants, driven by increasingly stringent environmental regulations such as the US EPA's Vessel General Permit and international ballast water management conventions. Stern tube lubricants, hydraulic fluids, and deck machinery lubricants based on biodegradable formulations minimize the environmental impact of accidental discharges (McNutt and He, 2016). The superior film-forming properties of biolubricants provide excellent protection against saltwater corrosion and maintain performance under harsh marine conditions.

Industrial gear applications have successfully utilized biolubricants in wind turbines, paper mills, and manufacturing equipment where environmental sensitivity is a concern. The high viscosity index and superior boundary lubrication characteristics of vegetable oil-based gear oils provide excellent protection under heavy loading conditions while maintaining fluidity across temperature ranges (Willing, 2001). The reduced noise and vibration characteristics observed with some biolubricant formulations offer additional operational benefits.

The challenges associated with biolubricant applications include oxidative stability limitations, temperature performance constraints, and material compatibility issues. Seal compatibility represents a particular concern, as the polar nature of vegetable oils can cause swelling or degradation of certain elastomeric materials. However, proper formulation with appropriate additives and seal material selection can effectively address these compatibility issues (Reeves et al., 2015).

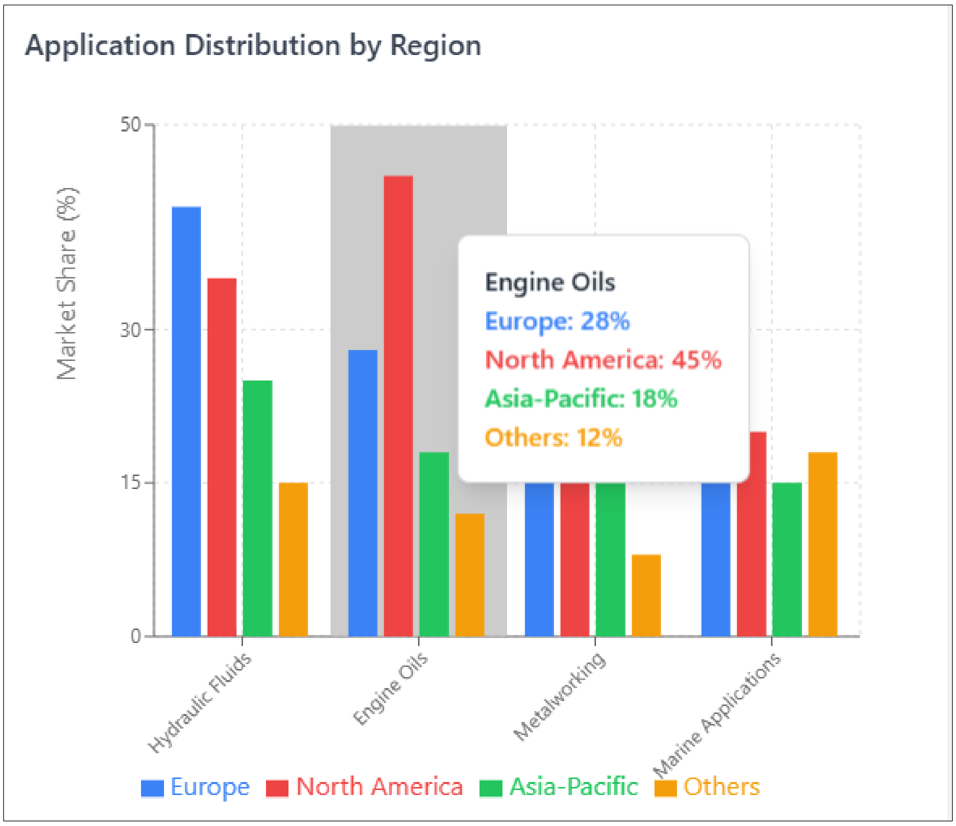

Figure 4 Regional Application Distribution of Biolubricants

Table 7 Performance Requirements by Application

Application	Viscosity Grade	Operating Temp (°C)	Load Capacity	Environmental Exposure
Engine Oil	SAE 0W-20 to 10W-40	-30 to 120	Medium	Low
Hydraulic Fluid	ISO VG 32-68	-20 to 80	High	Medium
Gear Oil	SAE 80W-140	-10 to 100	Very High	Low
Metalworking	ISO VG 22-100	20 to 60	Variable	High
Marine	ISO VG 100-320	-5 to 70	High	Very High
Transmission	ATF/CVT	-40 to 120	Medium	Low

6. Future Prospects and Challenges

The future development of biolubricants faces both significant opportunities and substantial challenges that will determine their long-term market success and environmental impact. Technological advancement in chemical modification techniques represents a primary avenue for overcoming current limitations while enhancing performance characteristics. Advanced synthetic biology approaches, including engineered microorganisms and enzymatic processes, offer potential for producing designer molecules with tailored properties optimized for specific applications (Erhan and Asadauskas, 2000).

Nanotechnology integration presents revolutionary possibilities for biolubricant enhancement through the incorporation of nanoparticles, nanotubes, and nanostructured additives. These nano-enhanced formulations demonstrate improved tribological properties, thermal stability, and oxidation resistance while maintaining biodegradability characteristics (Syahir et al., 2017). The development of functionalized nanoparticles specifically designed for biolubricant applications could address current performance limitations while providing additional benefits such as self-healing properties and adaptive lubrication mechanisms.

Economic considerations remain a critical challenge, with production costs typically 20-50% higher than conventional lubricants depending on feedstock availability and processing requirements. Future cost reduction strategies include process intensification, integrated biorefinery concepts, and the development of high-value co-products that improve overall economic viability (Quinchia et al., 2014). The volatility of agricultural commodity prices and competition with food applications necessitate the development of dedicated non-food feedstock sources and advanced cultivation technologies. Regulatory frameworks continue to evolve, providing both opportunities and challenges for biolubricant adoption. Increasingly stringent environmental regulations, carbon taxation policies, and sustainability mandates create favorable market conditions for bio-based alternatives. However, the complexity of certification processes, varying international standards, and performance specification requirements present barriers to market entry (McNutt and He, 2016). Harmonization of testing protocols and certification procedures would facilitate global market development and technology transfer. Research and development priorities for the next decade include improving oxidative stability through molecular design and advanced antioxidant systems, enhancing low-temperature performance through structural modification, and developing cost-effective production processes. The integration of Artificial Intelligence and machine learning approaches in formulation development offers potential for accelerated discovery of optimal compositions and processing conditions (Panchal et al., 2017). Collaborative research initiatives between academic institutions, industry partners, and government agencies will be essential for addressing complex technical challenges.The market outlook for biolubricants remains positive, with projected growth driven by environmental awareness, regulatory requirements, and technological improvements. Market penetration is expected to increase from the current 2-3% to potentially 8-12% by 2030, representing substantial commercial opportunities (Mobarak et al., 2014). The development of application-specific formulations, performance-equivalent alternatives, and cost-competitive production methods will be crucial for achieving these growth projections and realizing the environmental benefits of sustainable lubrication technologies.

Table 8 Technology Roadmap for Biolubricant Development

Time Frame	Technology Focus	Expected Outcomes	Market Impact
2022-2025	Chemical Modification	Improved oxidation stability (+50%)	5% market share
2025-2027	Nanotechnology Integration	Enhanced tribological performance	7% market share
2027-2030	Synthetic Biology	Designer molecules, cost reduction	10% market share
2030-2035	AI-Assisted Formulation	Optimized compositions	15% market share

Table 9 Research and Development Investment by Sector

Sector	Investment (Million USD)	Focus Area	Expected ROI
Automotive	156.2	Engine oil formulations	High
Industrial	89.7	Hydraulic fluid development	Medium
Marine	45.3	Environmental compliance	Medium
Aerospace	23.8	High-performance applications	Low
Agriculture	67.4	Equipment lubrication	High
Energy	112.9	Wind turbine applications	Very High

Table 10 Sustainability Impact Assessment

Impact Category	Current Status	2030 Projection	Improvement Factor
CO2 Reduction (Mt/year)	2.4	12.8	5.3x
Biodegradable Volume (%)	85	92	1.1x
Renewable Content (%)	78	95	1.2x
Toxicity Reduction	Medium	High	2.1x
Resource Efficiency	62%	84%	1.4x

7. Conclusion

The comprehensive analysis of biolubricants presented in this review demonstrates their significant potential as sustainable alternatives to petroleum-based lubricants. The superior tribological properties, inherent biodegradability, and reduced environmental impact position biolubricants as essential components of future sustainable industrial systems. While challenges related to oxidative stability, temperature performance, and production costs persist, ongoing research and technological development continue to address these limitations through innovative chemical modification, nanotechnology integration, and process optimization strategies.

The market prospects for biolubricants remain favorable, driven by stringent environmental regulations, increasing sustainability awareness, and continuous technological improvements. The projected growth from current market penetration levels of 2-3% to potentially 10-15% by 2030 represents substantial commercial opportunities and environmental benefits. Success in achieving these projections will depend on continued research investment, regulatory support, and industry collaboration to overcome existing technical and economic barriers.

Future research directions should focus on molecular design approaches for enhanced performance, cost-effective production technologies, and application-specific formulation development. The integration of emerging technologies such as synthetic biology, nanotechnology, and Artificial Intelligence offers promising avenues for breakthrough innovations that could accelerate market adoption and performance parity with conventional lubricants.

References

[1] Adhvaryu, A., Erhan, S. Z., and Perez, J. M. (2000). Tribological studies of thermally and chemically modified vegetable oils for use as environmentally friendly lubricants. Wear, 241(2), 72-78.

[2] Adhvaryu, A., and Erhan, S. Z. (2002). Epoxidized soybean oil as a potential source of high-temperature lubricants. Industrial Crops and Products, 15(3), 247-254.

[3] Erhan, S. Z., and Asadauskas, S. (2000). Lubricant basestocks from vegetable oils. Industrial Crops and Products, 11(2-3), 277-282.

[4] Gryglewicz, S., Piechocki, W., and Gryglewicz, G. (2003). Preparation of polyol esters based on vegetable and animal fats. Bioresource Technology, 87(1), 35-39.

[5] McNutt, J., and He, Q. (2016). Development of biolubricants from vegetable oils via chemical modification. Journal of Industrial and Engineering Chemistry, 36, 1-12.

[6] Mobarak, H. M., Niza Mohamad, E., Masjuki, H. H., Kalam, M. A., Al Mahmud, K. A. H., Habibullah, M., and Ashraful, A. M. (2014). The prospects of biolubricants as alternatives in automotive applications. Renewable and Sustainable Energy Reviews, 33, 34-43.

[7] Panchal, T. M., Patel, A., Chauhan, D. D., Thomas, M., and Patel, J. V. (2017). A methodical review on bio-lubricants from vegetable oil based resources. Renewable and Sustainable Energy Reviews, 70, 65-70.

[8] Quinchia, L. A., Delgado, M. A., Reddyhoff, T., Gallegos, C., and Spikes, H. A. (2014). Tribological studies of potential vegetable oil