

THE EMERGENCE OF BIOGREASE TECHNOLOGY: AN EXPLORATION OF THE EVOLUTION OF SUSTAINABLE LUBRICANTS

Abstract

The biolubricants industry has grown quickly in recent years, largely because of rising environmental regulations, industrial demands, and a global push toward sustainable practice. This paper looks at some of the most recent innovations in bio grease technologies, focusing on breakthroughs in chemical modifications, nanotechnology integration, biocatalytic processes, next-generation biodegradable additives, and emerging sustainable feedstocks. Additionally, emerging manufacturing technologies like green chemistry and automation have fostered efficiency and sustainability in biogrease production. Moreover, market research indicates a growing demand for bio greases, especially in the automotive and industrial sectors, alongside government policies that encourage implementation. Through continued research and innovation, bio greases will be an increasingly standard alternative to conventional lubricants, aligning with global sustainability objectives without compromising high-performance requirements.

Introduction

The 20th century has seen an increase in regulations regarding the emissions and environmental impact of mechanical systems and engines. Among these, the United States Environmental Protection Agency (EPA) and the EU carbon emission limits have driven a move towards more sustainable systems for personal vehicles [1]. In the marine shipping industry, mandates like Annex VI of MARPOL and port-specific regulations have sparked a shift away from traditional, more environmentally harmful fuels and lubricants [2]. These rising environmental regulations are causing the increasing adopting more environmentally conscious fuels and lubricants. Biogreases have emerged as a greener alternative to petroleum and mineral-based lubricants. Bio greases made from vegetable oils, animal fats, and algae have become more popular because they are biodegradable, less toxic, and better for the environment [3]. However, older bio grease formulas had issues: poor oxidative stability, limited load-bearing strength, thermal breakdown, and poor performance in tough conditions. In recent years, new research and innovations have introduced a new generation of bio greases designed to overcome these problems and meet the demanding needs of industries like automotive, aerospace, and heavy machinery [3]. These innovations have allowed biogreases to become competitive supplementary lubricants, which although have slightly worse performance and price at times, benefit industry through environmental compliance and novel usage [4]. This paper focuses specifically on the latest technological developments, including advanced biocatalytic processes, nanoparticle integrations, biodegradable additives, and sustainable feedstocks from the past five years that helped make bio greases top players in the industrial lubrication world. Particularly, works by Prasanth

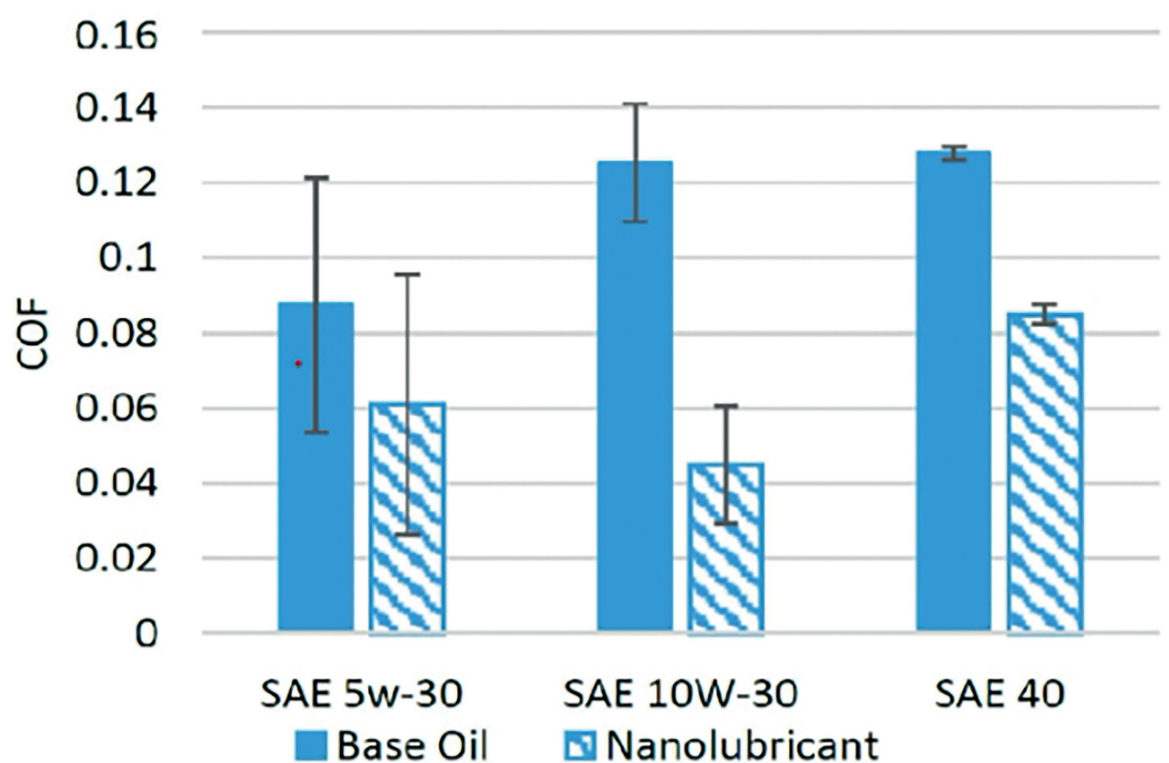


Figure 1: A graph of friction coefficients observed in several bio greases with and without nano additives such as graphene, carbon nanotubes (CNTs), and metal oxides [16].

et al and Hettiarachchi et al are highlighted for their relevance in biogrease compared to traditional formulations. To evaluate the real-world viability and performance of these next-generation bio greases, this paper examines recent testing methodologies used in tribological assessments and explores their broader implications across critical industrial sectors.

Chemical Innovations: Biocatalytic Processes and Advanced Modifications

One major advancement in bio grease technology is the adoption of biocatalytic processes. Unlike traditional chemical modification techniques such as hydroprocessing, which require high temperatures, significant energy input, and expensive metal-based catalysts, biocatalysis uses enzyme-driven reactions to improve the molecular structure of vegetable oils under milder and more energy-efficient conditions [5]. Lipases such as *Candida antarctica* lipase B (CALB) catalyze transesterification of fatty acids (or triglycerides) with alcohols, forming ester-based lubricants at moderate temperatures (40–70 °C), often in solvent-free systems [6], [7]. Afifah et al. (2019) report enzymatic transesterification of palm stearin with methanol (4:1 molar

ratio, 60 °C, 8 h, 6 wt% CALB) achieving ~95% yield. The resulting biolubricant showed a viscosity index above 120 and better friction properties than mineral oil lubricants [8]. This enzymatic process operates at ~60 °C without high-pressure hydrogen or metal catalysts. In contrast, hydrotreating (e.g. Ni–Mo at 350 °C, 4 MPa H₂) converts oils into paraffins but requires much harsher conditions [8], [9].

These enzyme-based changes improve oxidative stability, thermal resistance, and the lifespan of bio greases, all while keeping their biodegradability. For example, Uppar et al showed that enzymatically modified esters show up to 40% better thermal stability compared to traditional formulas, maintaining viscosity and reducing deposits even at high temperatures [3]. Early-generation bio-based greases, typically formulated from unmodified vegetable oils, offered excellent biodegradability but suffered from significant drawbacks such as poor oxidative stability, high volatility, limited cold-flow properties, and weak load-bearing capacity. These limitations hindered their adoption in high-performance or extreme-condition applications. To address these challenges, researchers began exploring hybrid formulations. Recently, hybrid formulas combining chemically modified vegetable oils with synthetic esters or polymer blends emerged, creating products with improved viscosity, reduced

Global Lubricant Market

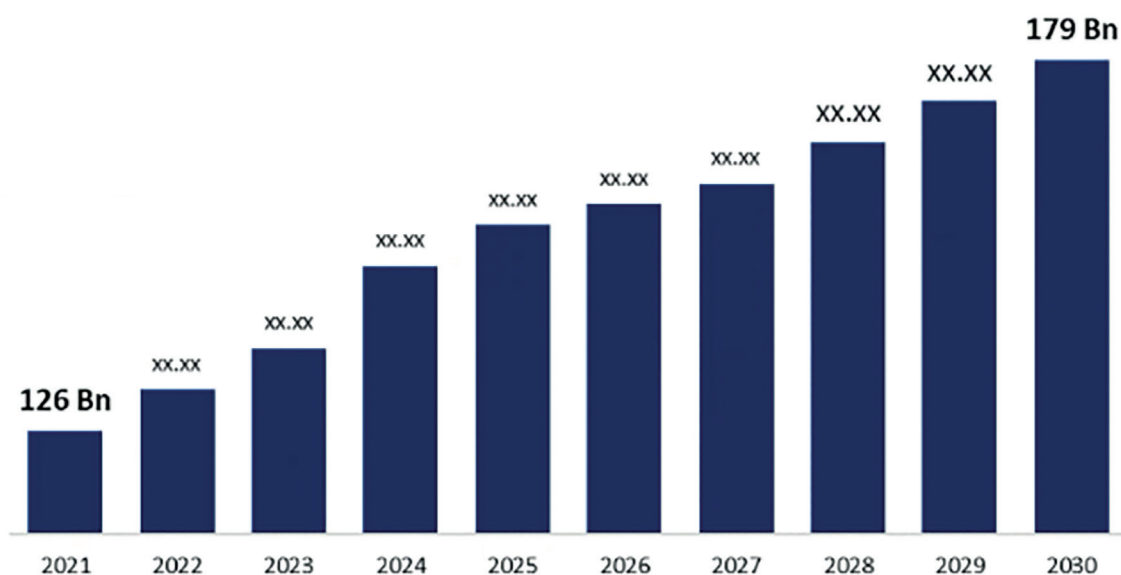


Figure 2: The expected value of the global lubricant/grease market, projected to reach 179 billion USD by 2030 at a CAGR of 4% [29].

volatility, and better shear stability. Data from Prasanth et al. (2024) shows that advanced hybrid bio-greases, formulated from chemically modified blends of rice bran oil and Calophyllum inophyllum oil, offer up to 85 to 90 percent better resistance to oxidation and sludge buildup compared to earlier-generation vegetable oil-based greases [10]. This conclusion was supported by standardized chemical tests measuring acid and peroxide values, along with tribological evaluations using the Four-Ball Wear Test. These improvements enable the modified bio-greases to perform reliably in high-speed bearings, high-load gearboxes, and precision mechanical components, addressing the thermal breakdown and limited durability issues associated with older bio-based lubricants [10]. Data from Dube et al. (2024) confirms and extends the findings of Prasanth et al. by demonstrating that modern bio-greases can achieve significant performance improvements in demanding mechanical applications such as bearings and gearboxes. In this study, a lithium-based grease formulated with jojoba oil and plant-waste-derived activated carbon nanoparticles was tested for tribological and thermal properties. Compared to unmodified bio-grease, the nano-enhanced formulation showed a 38 percent reduction in friction, a 24 percent decrease in wear scar diameter, and a 25 percent drop in power consumption during bearing operation [11]. These results closely align with the oxidation and wear improvements reported by Prasanth et al. using chemically modified rice bran and Calophyllum oils. Both studies confirm that with targeted chemical or nano-based enhancements, bio-greases can overcome previous limitations such as thermal degradation and poor load-bearing capacity. As such, these advanced formulations are increasingly viable for use in high-speed, high-load applications where traditional vegetable oil-based greases previously failed.

Nanotechnology Integration: Graphene, Boron Nitride, and Biodegradable Nanoparticles

Nanotechnology has presented itself as an innovative way to improve bio grease performance. Recent developments include adding ultra-fine materials like graphene, boron nitride, and biodegradable nanoparticles to improve friction reduction, load capacity, and wear resistance in the bearings [12]. Earlier nanoparticle additives like metallic and metal oxide nanoparticles raised concerns about toxicity and environmental disposal, but newer research focuses on eco-friendly nanomaterials designed for sustainability and minimal environmental harm [13]. For instance, biodegradable cellulose-based nanofibers increase load-carrying performance and reduce the coefficient of friction by up to 30%, offering similar results to conventional metal oxide nanoparticles but with a greener footprint [14]. Research by Hettiarachchi et al. shows that adding graphene/base oil to bio greases reduces friction by over 35%, improves heat dissipation by up to 50%, and extends the lifespan of lubricated parts under extreme stress [15]. Figure 1 further exemplifies this point by providing the coefficient of friction comparisons across various formulas when biodegradable nanomaterials are included, highlighting their critical role in next-generation lubrication.

Next-Generation Additives: Lignin-Based Antioxidants and Ionic Liquids

Another exciting trend in bio grease research is the development of next-generation, fully biodegradable additives that match or

surpass the performance of traditional lubricant enhancers. Conventional anti-wear and extreme pressure additives such as Zinc Dialkylthiophosphate (ZDDP) have long been valued for their ability to protect metal surfaces under high pressure and friction. ZDDP is especially effective in forming a protective tribofilm that minimizes wear and reduces scuffing, with numerous tribological studies confirming its effectiveness at concentrations as low as 0.08–0.12 wt% in industrial greases [17], [18]. For instance, standardized Four-Ball Wear Test results often show wear scar diameters below 0.5 mm when ZDDP is used, confirming its reliable performance in demanding applications [19]. However, ZDDP and similar additives are facing growing scrutiny due to their environmental impact. Upon degradation, ZDDP releases zinc and phosphorus compounds, which can accumulate in wastewater and pose risks to aquatic ecosystems [20], [21]. Phosphorus, in particular, contributes to eutrophication, leading to oxygen depletion and harmful algal blooms in water bodies [20]. Regulatory agencies in Europe and North America have already imposed stricter phosphorus content limits in automotive and industrial lubricants, prompting a search for cleaner alternatives [20]. In response, researchers have developed lignin-based antioxidants and bio-derived EP agents that enhance oxidative stability while offering greater biodegradability. These next-generation additives not only meet environmental regulations but also improve grease longevity and wear protection, making them strong contenders to replace legacy chemistries like ZDDP in sustainable lubricant formulations [22]. Additionally, ionic liquids (ILs) are a class of salts that remain liquid at temperatures below 100 °C and have attracted increasing interest as advanced lubricant additives [23]. Their key properties include high thermal stability, non-volatility, and strong polarity, which allow them to form durable boundary films on metal surfaces [23]. This contributes to lower friction, improved wear resistance, and enhanced corrosion protection. Common ILs studied for lubrication include imidazolium-based compounds with tetrafluoroborate ($[\text{BF}_4]^-$) or hexafluorophosphate ($[\text{PF}_6]^-$) anions, as well as newer and more environmentally acceptable ILs such as phosphonium and ammonium salts with alkylsulfate or phosphate anions [23]. In a study by Khemchandani et al. (2021), the ionic liquid 1-butyl-3-methylimidazolium tetrafluoroborate ($[\text{BMIM}][\text{BF}_4]$) was added at 1 to 2 weight percent to a biodegradable ester-based grease [24]. Bench testing using the Four-Ball Wear Test (ASTM D4172) and a ball-on-disk tribometer showed that the IL-enhanced grease reduced the wear scar diameter by 45 to 55 percent and the coefficient of friction by 30 to 40 percent compared to the base grease. These results were obtained under a load of 392 newtons at 75 °C over 60 minutes [24]. Another study by Munavirov et al. (2019) evaluated phosphonium orthoborate ionic liquids in pentaerythritol ester oils. These formulations demonstrated superior tribological behavior, especially in steel-on-steel and steel-on-aluminum contact tests, and maintained performance at elevated temperatures [25]. Corrosion resistance was also improved, as confirmed through salt spray chamber evaluations. These findings support the use of ionic liquids as multifunctional additives that can improve bio-grease performance in harsh industrial environments [25].

Emerging Sustainable Feedstocks: Algae-Derived Lipids and Waste Oils

The raw materials used for bio greases are also advancing. While traditional feedstocks like soybean and canola oils have been the

main sources, concerns about competing with food supplies and land use pushed research toward second-generation feedstocks. Algae-derived lipids, waste cooking oils, and byproducts from food processing are gaining attention as sustainable alternatives [26]. Algae, in particular, offers high lipid yields per hectare, fast growing cycles, and low freshwater needs, making it a promising option for next-generation bio grease base oils [26]. Furthermore, enzymatic processes now make it possible to efficiently convert low-value waste oils into high-performance lubricants, turning potential waste into valuable products. Recent life-cycle assessments show that bio greases made from these advanced feedstocks can achieve up to 60% lower greenhouse gas emissions compared to petroleum-based options, helping align with global decarbonization targets [27]. By shifting to waste-derived or algae-derived oils, manufacturers not only boost their environmental profile but also reduce costs and lessen reliance on fresh agricultural resources.

Latest Testing Methods and Performance Benchmarks

As bio grease technology improves, so do the methods used to test and measure performance. New developments in tribological testing, like nanoscale wear analysis and in-situ friction monitoring, provide detailed insights into how bio greases behave under extreme conditions. Advanced rheological testing now looks at shear-thinning behavior, thermal stability, and viscoelastic properties, ensuring today's bio greases meet the tough demands of industries like wind energy, marine transport, and aviation. These new testing methods highlight that cutting-edge bio greases can outperform conventional mineral oil greases in four-ball wear tests, ball-on-disc tribometer tests, and rolling-sliding contact simulations, proving they are ready for demanding industrial applications.

In a study by Jafari et al. (2023), a trimethylolpropane ester-based bio lubricant enhanced with graphene oxide nanoparticles was evaluated using advanced tribological tools such as ball-on-disk tribometry with in-situ friction monitoring and post-test surface characterization via atomic force microscopy [28]. Compared to conventional mineral greases tested with only standard four-ball wear data and basic rheological properties, this approach allowed researchers to observe nanoscale wear features, boundary film formation, and dynamic friction behavior under realistic contact conditions. The bio lubricant showed a 35 percent reduction in coefficient of friction and significantly reduced wear scar diameter relative to its petroleum-based counterpart [28]. These findings demonstrate that modern test platforms can provide deeper insight into the mechanisms of surface protection and film durability, making them essential tools for developing high-performance, environmentally friendly greases.

Industrial Implications and Regulatory Impact

The combination of these latest innovations raised bio greases to a competitive and often superior level compared to petroleum-based lubricants. Industries that were once hesitant to use bio-based lubricants are now incorporating them into high-stress applications because of their improved thermal, oxidative, and mechanical performance. These advances also match up with strict regulatory standards, including the European Union's REACH regulations, the U.S. Environmental Protection Agency's Vessel General Permit rules, and international requirements under the International Maritime Organization. For example, bio greases made with biodegradable nanoparticles and sustainable feedstocks meet eco-labeling standards like the EU Ecolabel and USDA BioPreferred certifications making them more appealing to manufacturers and users aiming to cut environmental impact. As government policies continue to push for circular economic practices, the newest bio grease innovations will likely play a key role in supporting sustainable industrial operations.

In addition to environmental certifications, several specific regulations guide the formulation and usage of lubricants in sensitive environments. The U.S. Environmental Protection Agency's Vessel General Permit (VGP) mandates the use of Environmentally Acceptable Lubricants (EALs) in all oil-to-sea interface applications for vessels operating in U.S. waters, unless technically infeasible. Similarly, the EU's Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH) regulation requires manufacturers to assess the safety of chemical substances, pushing the industry toward safer, low-toxicity alternatives. The International Maritime Organization (IMO), through conventions like MARPOL Annex VI, emphasizes minimizing marine pollution from ships, encouraging the adoption of biodegradable and low-emission lubricants. Bio greases formulated from natural esters, enhanced with

additives like ashless anti-wear agents and ionic liquids, satisfy these requirements by exhibiting low aquatic toxicity, rapid biodegradability (often exceeding OECD 301B standards), and minimal bioaccumulation potential. Their compliance with such regulations not only ensures legal operation in environmentally sensitive areas but also aligns with the sustainability commitments of major maritime, aerospace, and industrial stakeholders.

Future Directions and Challenges

Even with these major advancements, several challenges remain. Scaling up biocatalytic processes for industrial production needs more optimization, especially when it comes to enzyme stability, reaction speeds, and cost-efficiency. While biodegradable nanoparticles hold great promise, making sure they stay uniformly dispersed and stable over time within grease formulas is still a technical challenge. Additionally, although algae-derived oils look promising, their commercial success depends on improving large-scale cultivation, harvesting, and lipid extraction techniques. Future research will likely focus on developing multifunctional additives that combine anti-wear, antioxidant, and friction-reducing features into one eco-friendly compound. There is also growing interest in creating self-healing greases that can repair tiny damage during use, extending equipment life and reducing downtime. As these innovations progress, bio greases will not just serve as green alternatives; they will become superior technical solutions that reshape performance expectations across industries.

Conclusion

The latest advancements in bio grease technology signal a major shift in lubrication science. By using biocatalytic processes, adding eco-friendly nanotechnology, developing next-generation biodegradable additives, and sourcing materials from sustainable feedstocks, researchers and manufacturers are pushing bio greases to new levels of performance and sustainability. As industries continue to focus on balancing environmental responsibility with technical performance, these innovations are set to shape the future of lubrication, opening the door to a greener and more resilient industrial world.

Works Cited

- [1] K. Kuklinska, L. Wolska, and J. Namiesnik, "Air quality policy in the U.S. and the EU – a review," *Atmospheric Pollut. Res.*, vol. 6, no. 1, pp. 129–137, Jan. 2015, doi: 10.5094/APR.2015.015.
- [2] M. Sheikh Mehbuba, "Critical Analysis of Annex VI of MARPOL: Evaluating the Need for New Restriction Limits to Preserve the Ozone Layer," *Law Soc. Stud. J.*, vol. 3, no. 1, June 2025, doi: 10.5281/zenodo.15646744.
- [3] R. Uppar, P. Dinesha, and S. Kumar, "A critical review on vegetable oil-based bio-lubricants: preparation, characterization, and challenges," *Environ. Dev. Sustain.*, vol. 25, no. 9, pp. 9011–9046, Sept. 2023, doi: 10.1007/s10668-022-02669-w.
- [4] J. S. García-Miranda, L. D. Aguilera-Camacho, M. T. Hernández-Sierra, and K. J. Moreno, "A Comparative Analysis of the Lubricating Performance of an Eco-Friendly Lubricant vs Mineral Oil in a Metallic System," *Coatings*, vol. 13, no. 8, Art. no. 8, Aug. 2023, doi: 10.3390/coatings13081314.
- [5] N.-S. Mussa, K. Toshtay, and M. Capron, "Catalytic Applications in the Production of Hydrotreated Vegetable Oil (HVO) as a Renewable Fuel: A Review," *Catalysts*, vol. 14, no. 7, Art. no. 7, July 2024, doi: 10.3390/catal14070452.
- [6] R. R. C. Monteiro, Á. Berenguer-Murcia, J. Rocha-Martin, R. S. Vieira, and R. Fernandez-Lafuente, "Biocatalytic production of biolubricants: Strategies, problems and future trends," *Biotechnol. Adv.*, vol. 68, p. 108215, Nov. 2023, doi: 10.1016/j.biotechadv.2023.108215.
- [7] M. C. Montiel, M. Gómez, M. D. Murcia, S. Ortega-Requena, F. Máximo, and J. Bastida, "Sustainable Biocatalytic Synthesis of a Second-Generation Biolubricant," *Sustainability*, vol. 16, no. 4, Art. no. 4, Jan. 2024, doi: 10.3390/su16041615.
- [8] A. N. Afifah, S. Syahrullail, N. I. Wan Azlee, N. A. Che Sidik, W. J. Yahya, and E. Abd Rahim, "Biolubricant production from palm stearin through enzymatic transesterification method," *Biochem. Eng. J.*, vol. 148, pp. 178–184, Aug. 2019, doi: 10.1016/j.bej.2019.05.009.
- [9] H. de Paz Carmona, E. Svobodová, Z. Tišler, U. Akhmetzyanova, and K. Strejcová, "Hydrotreating of Atmospheric Gas Oil and Co-Processing with Rapeseed Oil Using Sulfur-Free PMoCx/Al2O3 Catalysts," *ACS Omega*, vol. 6, no. 11, pp. 7680–7692, Mar. 2021, doi: 10.1021/acsomega.0c06336.
- [10] M. A. Prasanth, S. Rani, S. P. Singh, D. E. Raja, and P. Barmavatu, "Formulation and evaluation of bio-grease from the blend of chemically modified rice bran oil and Calophyllum inophyllum oil," *J. Eng. Appl. Sci.*, vol. 71, no. 1, p. 80, Mar. 2024, doi: 10.1186/s44147-024-00414-w.
- [11] N. N. Dube, M. ElKady, H. Noby, and M. G. A. Nassef, "Developing a sustainable grease from jojoba oil with plant waste based nanoadditives for enhancement of rolling bearing performance," *Sci. Rep.*, vol. 14, no. 1, p. 539, Jan. 2024, doi: 10.1038/s41598-023-50003-9.
- [12] G. Aroor, M. A. Khan, A. R. Shetty, R. Rai, H. Ganesha, and M. K. Navada, "From chemistry to performance: How nano additives are transforming bio-lubricants for enhanced tribological applications," *J. Mol. Liq.*, vol. 425, p. 127242, May 2025, doi: 10.1016/j.molliq.2025.127242.
- [13] S. P. Darminesh, N. A. C. Sidik, G. Najafi, R. Mamat, T. L. Ken, and Y. Asako, "Recent development on biodegradable nanolubricant: A review," *Int. Commun. Heat Mass Transf.*, vol. 86, pp. 159–165, Aug. 2017, doi: 10.1016/j.icheatmasstransfer.2017.05.022.
- [14] M. Taha et al., "Utilizing cellulose nanofibers to enhance spent engine oil performance: A sustainable environmental solution," *Results Eng.*, vol. 23, p. 102395, Sept. 2024, doi: 10.1016/j.rineng.2024.102395.
- [15] S. J. Hettiarachchi, J. Bowen, M. Kershaw, I.-A. Baragau, A. Nicolae, and S. Kellici, "Nanostructured Al2O3/graphene additive in bio-based lubricant: A novel approach to improve engine performance," *Tribol. Int.*, vol. 186, p. 108619, Aug. 2023, doi: 10.1016/j.triboint.2023.108619.
- [16] M. Waqas, R. Zahid, M. U. Bhutta, Z. A. Khan, and A. Saeed, "A Review of Friction Performance of Lubricants with Nano Additives," *Materials*, vol. 14, no. 21, Art. no. 21, Jan. 2021, doi: 10.3390/ma14216310.
- [17] A. E. Tsai and K. Komvopoulos, "Wear Mechanisms, Composition and Thickness of Antiwear Tribofilms Formed from Multi-Component Lubricants," *Materials*, vol. 17, no. 10, Art. no. 10, Jan. 2024, doi: 10.3390/ma17102324.
- [18] A. E. Tsai and K. Komvopoulos, "Dynamics of Tribofilm Formation in Boundary Lubrication Investigated Using In Situ Measurements of the Friction Force and Contact Voltage," *Mater. Basel Switz.*, vol. 17, no. 6, p. 1335, Mar. 2024, doi: 10.3390/ma17061335.
- [19] F. J. DeBlase, "Development of Organic Ashless Antiwear-Friction Modifier additives," 2008.
- [20] A. Dorgham et al., "Understanding the effect of water on the transient decomposition of zinc dialkyldithiophosphate (ZDDP)," *Tribol. Int.*, vol. 157, p. 106855, May 2021, doi: 10.1016/j.triboint.2021.106855.
- [21] "Tech Beat." Accessed: July 17, 2025. [Online]. Available: https://www.stle.org/files/TLTArchives/2019/09_September/Tech_Beat.aspx
- [22] M. A. Jedrzejczyk et al., "Lignin-Based Additives for Improved Thermo-Oxidative Stability of Biolubricants," *ACS Sustain. Chem. Eng.*, vol. 9, no. 37, pp. 12548–12559, Sept. 2021, doi: 10.1021/acssuschemeng.1c02799.
- [23] A. E. Somers, P. C. Howlett, D. R. MacFarlane, and M. Forsyth, "A Review of Ionic Liquid Lubricants," *Lubricants*, vol. 1, no. 1, Art. no. 1, Mar. 2013, doi: 10.3390/lubricants1010003.
- [24] B. Khemchandani, A. Somers, P. Howlett, A. K. Jaiswal, E. Sayanna, and M. Forsyth, "A biocompatible ionic liquid as an antiwear additive for biodegradable lubricants," *Tribol. Int.*, vol. 77, pp. 171–177, Sept. 2014, doi: 10.1016/j.triboint.2014.04.016.
- [25] B. Munavirov et al., "The effect of anion architecture on the lubrication chemistry of phosphonium orthoborate ionic liquids," *Sci. Rep.*, vol. 11, no. 1, p. 24021, Dec. 2021, doi: 10.1038/s41598-021-02763-5.
- [26] D. T. Nguyen et al., "Microalgae-derived biolubricants: Challenges and opportunities," *Sci. Total Environ.*, vol. 954, p. 176759, Dec. 2024, doi: 10.1016/j.scitotenv.2024.176759.
- [27] P. Cuevas, "COMPARATIVE LIFE CYCLE ASSESSMENT OF BIOLUBRICANTS AND MINERAL BASED LUBRICANTS".
- [28] A. Jafari, M. Majdoub, D. Sengottuvelu, M. G. Ucak-Astarlioglu, A. Al-Ostaz, and S. Nouranian, "Tribological Properties of Synthetic and Biosourced Lubricants Enhanced by Graphene and Its Derivatives: A Review," *ACS Omega*, vol. 9, no. 52, pp. 50868–50893, Dec. 2024, doi: 10.1021/acsomega.4c06845.
- [29] "Lubricant market Includes Latest Trends, Share, Forecast 2030," *Spherical Insights*. Accessed: July 17, 2025. [Online]. Available: <https://www.sphericalinsights.com/reports/lubricant-market>

About the Authors

Dr. Raj Shah, is a Director at Koehler Instrument Company in New York, where he has worked for the last 25 plus years. He is an elected Fellow by his peers at ASTM, IChemE, ASTM, AOCs, CMI, STLE, AIC, NLGI, INSTMC, Institute of Physics, The Energy Institute and The Royal Society of Chemistry. An ASTM Eagle award recipient, Dr. Shah recently coedited the bestseller, "Fuels and Lubricants handbook", details of which are available at ASTM's Long-awaited Fuels and Lubricants Handbook <https://bit.ly/3u2e6GY>

He earned his doctorate in Chemical Engineering from The Pennsylvania State University and is a Fellow from The Chartered Management Institute, London. Dr. Shah is also a Chartered Scientist with the Science Council, a Chartered Petroleum Engineer with the Energy Institute and a Chartered Engineer with the Engineering council, UK. Dr. Shah was recently granted the honorific of "Eminent engineer" with Tau beta Pi, the largest engineering society in the USA. He is on the Advisory board of directors at Farmingdale university (Mechanical Technology), Auburn Univ (Tribology), SUNY, Farmingdale, (Engineering Management) and State university of NY, Stony Brook (Chemical engineering/ Material Science and engineering). An Adjunct Professor at the State University of New York, Stony Brook, in the Department of Material Science and Chemical Engineering, Raj also has over 700 publications and has been active in the energy industry for over 3 decades. More information on Raj can be found at <https://shorturl.at/JDPZn>

Mathew Roshan is a Chemical and Molecular Engineering Undergraduate Student at Stony Brook University where he is a research assistant at the Advanced Energy Research and Technology Center performing research on carbon capture and hydrogen storage. He also works as an intern under Dr. Raj Shah studying tribology, alternative energy, and fuels at Koehler Instrument Company and is a member of the SBU chapter of the American Institute of Chemical Engineers (AIChE).



Mathew Roshan

Mr. Bishesh Shah is a freshman studying Chemical Engineering at Stony Brook University, set to graduate in May 2028. On campus, he is a freshman representative for his university's Himalayan Student Association (HSA), a member of his university's Bollywood dance team (SBU Junoon), a member of the American Institute of Chemical Engineers (AIChE) Chapter at Stony Brook University, and a member of the Stony Brook Environmental Club. He aspires to pursue a career in the energy and sustainability industries.



Bishesh Shah

Mr. Gavin Thomas is a part of a thriving internship program at Koehler Instrument company in Holtsville, and just graduated with a degree in Chemical and Molecular Engineering from Stony Brook University, Stony Brook, New York, where Dr. Shah is the chair of the external advisory board of directors. He also works as a process engineer at Mill-Max where he optimizes performance with sustainability.



Gavin Thomas

Dr. Raj Shah, Koehler Instrument Company

Holtsville, NY 11742 USA

Email: rshah@koehlerinstrument.com

Web: www.koehlerinstrument.com

