DOI: 10.24874/ti.987.10.20.11

Tribology in Industry

www.tribology.rs

RESEARCH

Green Tribology

R. Shah[a,*], A. Martini[b], M. Woydt[c], H. Wong[d]

[a]*Koehler Instruments Company, 85 Corporate Drive, Holtsville, NY, United States,*
[b]*Department of Mechanical Engineering at University of California, Merced, 5200 N. Lake Road, Merced, CA, United States,*
[c]*MATRILUB Materials, Tribology, and Lubrication, 16, D-12203 Berlin-Dahlem, Germany,*
[d]*Department of Materials Science and Chemical Engineering at Stony Brook University, Stony Brook University, Stony Brook, NY, United States.*

Keywords:

Tribology
Sustainability
Tribotronics
Friction
Wear
Lubricants

* Corresponding author:

Raj Shah
Email: rshah@koehlerinstrument.com

Received: 17 October 2020
Revised: 6 November 2020
Accepted: 16 November 2020

A B S T R A C T

Green tribology is a branch of tribology that deals with improving technology with the challenge of minimizing negative environmental and biological impact. Green tribology aims to achieve the objectives of tribology along with other objectives such as emission reductions, resource and energy conservations, and material efficiency. Balancing the technological developments that can be made with their environmental and biological impacts can serve as a challenge, but it is rewarding as the future of the planet and society can depend on applying green tribology to technological designs. This article further examines the relationship between energy use and human development, the areas and principles of green tribology and how they can be applied to solve sustainability issues in technological advancements.

1. INTRODUCTION

Energy is essential for virtually all human activities and is a catalyst for every aspect of social, economic, and environmental advancement. Energy contributes to better living and environmental conditions, and to social development via public health and education. In addition, energy is essential to meeting the most fundamental of human needs such as food and shelter, as well as making the most important technological innovations possible. However, all of this is dependent on the availability of energy sources. Engineers consistently face challenges associated with the overuse of energy and resources, increasing the carbon footprint and greenhouse gas emissions. In addition, poor access to and utilization of energy resources can be detrimental to extant ecosystems. It is the responsibility of engineers to develop new and improved technologies that are sustainable and responsible; this includes technological development in the field of tribology through what is called "green tribology". Application of the principles of green tribology is imperative to developing sustainable technologies and minimizing the consumption of fossil fuels. However, the relationships between energy use and human development are symbiotic, nuanced, and multifaceted. These complex interrelationships are the focus of this article that examines the different areas of green tribology and how they address issues of sustainability in technology development.

2. GREEN TRIBOLOGY

2.1 Areas of Green Tribology

Green tribology is a new and specific branch of tribology that emphasizes a balance between technological developments and their potential environmental or biological impacts [1]. The term "Green Tribology" extends the classic goals of tribology, such as friction reduction, wear protection and optimization of lubrication, with new attributes such as energy and material efficiency, resource conservation, emission reductions, environmentally friendly lubricants. Green tribology overlaps with sustainability. Particularly, a key goal of green tribology is to ensure that friction and wear, or the use of lubricants to mitigate friction and wear, do not negatively affect the environment [2]. Green tribology also includes research focused on minimizing any kind of pollution and saving energy and resources to enhance the quality of life for humanity [2]. The figure below shows the three main areas of green tribology and how they rely on and impact one another.

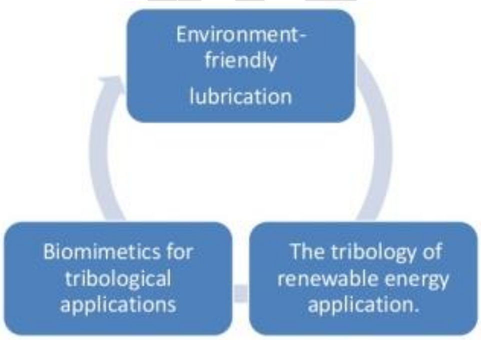

Fig. 1. General Areas of Green Tribology [2].

2.2 Principles of Green Tribology

Building on the basic structure of the three main areas of green tribology, twelve principles have been proposed [2]. These twelve principles include minimization of heat and energy dissipation, minimization of wear, reducing or eliminating lubrication, increasing the use of natural or biodegradable lubrication, following green chemistry and engineering principles, employing biomimetic approaches, using surface texturing, improving the design of surfaces and coatings to minimize wear, considering the environmental impact of surface coating and texturing, developing sustainable energy applications, and monitoring tribological systems to ensure that they are not producing harmful substances [2]. These principles can be applied to the development of new technologies and infrastructures that are sustainable and minimize the consumption of fossil fuels.

2.3 Quality of Life

Applying the principles of green tribology can enable technological innovations that improve the quality of life around the world. Quality of life is a construct that is multilayered and deals with aspects such as sustainability and the safety of social environments [3]. To assess quality of life and the impact of new innovations on it, a sustainability index has been proposed to determine the performance of a company and its products. The sustainability index is also used to quantify a company's values in terms of environmental and social responsibilities [4]. The figure below shows the structure of the sustainability index and the parameters used to assess quality of life.

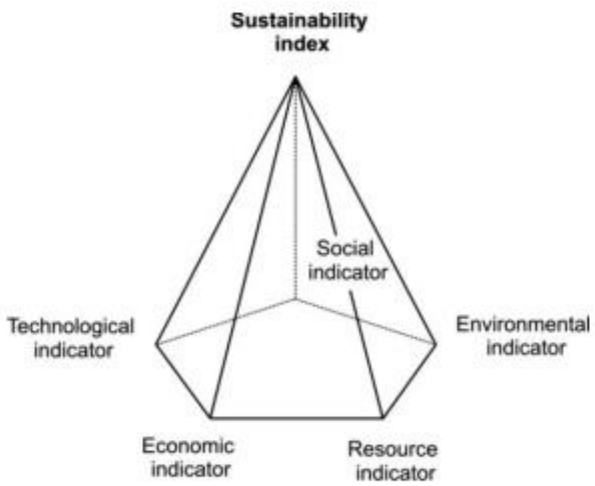

Fig. 2. Sustainability Index Structure [3].

Each company or individual has their own view, perception, and definition of sustainability. However, the general assembly of the United Nation defined 17 sustainability development goals (SDGs) with a total 167 targets approved in October 2015 [7,17]. This globally agreed upon definition may guide societal and industrial development as well as be a common reference point for planning and investment.

There have been many attempts to satisfy the demand for energy needed to operate machinery while minimizing dependence on fossil fuels as an energy source. As mentioned earlier, it is the mission of the designer or engineer to satisfy both of those qualities and find a balance between the two. One approach to achieving this objective is the reduction of wasteful systemic losses through wear and friction. Another approach is to identify and minimize the impact of technologies that have the most pronounced adverse effects on the ecosystem.

2.4 Decreasing Energy & Resource Consumption with Green Tribology

Minimizing friction and wear losses and improving the durability, reparability, and condition monitoring of the primary components of mechanical systems can reduce energy waste and lead to economic savings. In 2017, around 23 % of total global energy consumed was due to tribological contacts where 20 % was attributed to overcoming friction and 3 % to remanufacturing worn out parts [5]. By applying new tribological practices, such as lubrication and material technologies and novel methods, for enhanced protection from wear and increased friction reduction, global energy losses could be cut down by 40 % within the next 15 years and 18 % within the next 8 years [5]. This reduction would correspond to an economic savings of 1.4 % of global GDP annually [5]. Also, 8.7 % of total primary energy consumed globally could be saved within the next few decades [5]. Furthermore, it has been approximated that 11 % of the total annual energy consumption in the U.S. – particularly in "transportation, turbomachinery, power generation, and industrial processes" (Pinkus & Wilcock, 1977) – could be saved via innovations stemming from lubrication and tribology [6].

Another topic relevant to green tribology is consumption of resources for producing consumer goods, housing, or other machinery. In 2017, the material footprint or the global primary material use [7,8] was 92.1 billion metric tons (MT), where 15.0 billion MT were fossil energy sources, 22.9 billion MT were some form of biomass, and the remaining 54.2 MT was other sources of human consumption. The Organization for Economic Co-Operation and Development (OECD) [8] estimates that the global raw material extraction will increase to 167 billion MT in 2060 and the United Nations estimated 190 billion MT would be consumed [7]. These numbers are alarming since any material consumption generates CO_2 and greenhouse gas emissions. The figure below shows the increase of global material footprint with time.

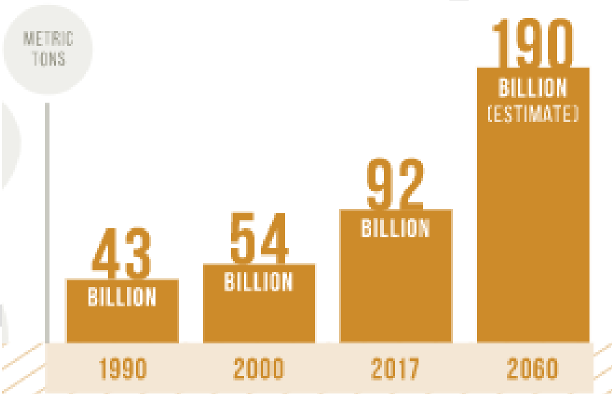

Fig. 3. Global Material Footprint Over Time [7].

Over the last few years, a growing awareness of the adverse effects of chlorofluorocarbons (CFCs) as refrigerants and chlorinated hydrocarbons in metalworking fluids, lead, and sulfur in fuels has resulted in these toxic substances being banned worldwide [9]. Therefore, scientists must identify and implement alternative materials and technologies to provide efficiency, functionality, and reliability of moving mechanical components. This means that new technologies need to both minimize systematic losses and failures while simultaneously developing low-impact options to replace the environmentally harmful lubricant practices currently in use.

Tribological design is also of great importance for major frictional components in automotive internal combustion engines and plays a role in improving energy efficiency, reducing the reliance on oil [10]. In fact, 1.3 billion vehicles were registered for use globally in 2018 with an additional 95 to 100 million cars produced worldwide annually [11]. If mechanical losses could be decreased by effective tribology, even

10 % could reduce fuel usage by 1.5 %, equaling about 340 liters of petrol over a car's lifespan [12]. These relatively small savings ($350 per car), when translated to the huge number of cars operating today, would correspond to significant fiscal savings and environmental benefits [12].

In addition, the dependability and longevity of mechanical parts could be improved by collecting and publishing more extensive and accurate tribological data. It has been posited that laboratory testing of materials in application-relevant conditions and environments is the most accurate means of procuring fundamental tribological data for reliability control purposes [13]. Component life can also be extended through progress in tribotronics, an area of research that merges machine and electronic elements to construct efficient tribological systems [14]. Furthermore, chemical means of analysis must be taken into consideration for research on sustainable tribology and emphasis should be placed on developing, ameliorating, and implementing green lubricants, adhesives, and waxes [15].

2.5 Environmentally Friendly

Another sustainable consideration is plastic recycling. Plastic recycling has several sustainable advantages, such as reduction of the CO_2 footprint and energy consumed, and conservation of oil resources. Most plastics are comprised of crude oil, which represents 4 % of the overall oil consumption [16]. Additionally, the waste that ends up in landfills or must be incinerated can be significantly reduced by recycling suitable materials and turning them into new components for other technology and products. Tribological results show that plastic such as polycarbonate plastic when recycled can be reused to create an alternative product to polyurethane wheels [12]. Plastic recycling promotes better sustainability performance in society and helps reiterate and highlight the significance of green tribology [12].

If the field of tribology is going to realize its full power and potential in the 21st century, natural resources must be used in a realistic and economical manner. Suitable raw materials will have to be developed via ecologically conscious chemistry to produce cutting-edge adhesives, waxes, and lubricants. This is one of the biggest challenges we will face in the next decade as new green reactions have to be discovered and applied properly to create safe products.

Sustainable lubricants differ from so-called "environmentally acceptable lubricants" (EALs) or "biolubes" (see EN16807). EALs focus on human and environmental toxicology. On the other hand, sustainable lubricants are identified based on CO_2 emissions over the entire lifecycle of the product and are made from renewable resources. For example, palm and soja oil are EALs, but their production requires significant use of fossil resources. As a result, the European Union withdrew palm oil from the list of renewable resources in 2019 with the delegation act EU/2019/807. This methodology of differentiating EALs from sustainable lubricants will also apply for fuels.

3. CONCLUSION

Overall, the field of green tribology is vast and there are many different aspects to consider when developing new technologies, infrastructure, and lubricants. As described in this review, there are multiple considerations, all of which use the principles of green tribology to develop technologies that are better for the environment and society. As illustrated by the sustainability index structure, there are different indicators or parameters to assess the quality of life and the performance of a company and its products. Technological, economic, environmental, resource, and social indicators are important factors when trying to balance the environmental impacts of a product and the demand for energy needed to operate that product. It is imperative that engineers develop new and improved tribological designs to improve quality of life while also being sustainable and ecofriendly.

REFERENCES

[1] Understanding Green Tribology, available at: www.azocleantech.com/article.aspx?ArticleID=693

[2] Principles of Green Tribology, available at: www.tribonet.org/principles-of-green-tribology

[3] E. Assenova, V. Majstorović, A. Vencl, M. Kandeva, *Green Tribology And Quality Of Life*,

International Journal of Advanced Quality, vol. 40, no. 2, pp. 1-6, 2012.

[4] Is a Sustainability Index Used for, available at: www.bbva.com/en/what-is-a-sustainability-index-used-for

[5] K. Holmberg, A. Erdemir, *Influence of tribology on global energy consumption, costs and emissions*, Friction, vol. 5, pp. 263–284, 2017, doi: 10.1007/s40544-017-0183-5

[6] O. Pinkus, D.F. Wilcock, *Strategy for Energy Conservation through Tribology*. The American Society of Mechanical Engineers, New York, 1977.

[7] Resource outlook 2019, A Report of the International Resource Panel, available at: www.unstats.un.org/sdgs/report/2019/Overview

[8] OECD, *Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences*, OECD Publishing, p. 212, 2019, doi: 10.1787/9789264307452-en

[9] Chlorofluorocarbons (CFCs): Your Environment, Your Health, available at: www.toxtown.nlm.nih.gov/chemicals-and-contaminants/chlorofluorocarbons-cfcs#:~:text=Because%20they%20damage%20the%20earth's,food%20packaging%2C%20and%20fire%20extinguishers.&text=CFCs%20are%20also%20greenhouse%20gases,by%20contributing%20to%20global%20warming

[10] S.S. Perry, W.T. Tysoe, *Frontiers of Fundamental Tribological Research*, Tribology Letters, vol. 19, pp. 151–161, 2005, doi: 10.1007/s11249-005-6142-8

[11] Will Electric Vehicles Really Create a Cleaner Planet?, available at: www.thomsonreuters.com/en/reports/electric-vehicles.html

[12] I. Tzanakis, M. Hadfield, B. Thomas, S.M. Noya, I. Henshaw, S. Austen. *Future Perspectives on Sustainable Tribology*, Renewable and Sustainable Energy Reviews, vol. 16, iss. 6, pp. 4126–4140, 2012, doi: 10.1016/j.rser.2012.02.064

[13] K. Holmberg, *Tribology in Reliability Engineering*. VTT Manufacturing Technology, 2001.

[14] Tribology Explained, available at: www.machinerylubrication.com/tribology-31340

[15] W. Li, X.H. Kong, M. Ruan, F.M. Ma, Y.F. Jiang, M.Z. Liu, Y. Chen, X.H. Zuo, *Green waxes, adhesives and lubricants*, Philosophical Transactions of the Royal Society A. Mathematical, Physical and Engineering Sciences, vol. 368, iss. 1929, 2010, doi: 10.1098/rsta.2010.0197

[16] Oil Consumption, available at: www.bpf.co.uk/press/oil_consumption.aspx

[17] Transforming our world: the 2030 Agenda for Sustainable Development, available at: www.un.org/en/development/desa/population/migration/generalassembly/docs/globaljostcompact/A_RES_70_1_E.pdf