Perfecting Motion: Tribology and the Quest for Sustainability

Episode 1 – Introduction

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Isaac Newton's first law of motion stated that all bodies in motion tend to stay in motion unless acted upon by an external force. For those of us in the tribology field, the external force that typically stops a body from remaining in motion is friction.

Friction is looked upon as a necessary evil that causes artificial bodies or machinery to perform in a subpar manner. On the other hand, friction is instrumental to prevent us from slipping and sliding on icy surfaces. Frictional effects lead to the evolution of heat which is a type of energy that is usually not reused but tends to dissipate into the environment. This makes friction an inefficient waste of energy that also can contribute to the warming of our environment.

Tribologists study these types of effects armed with an arsenal of materials called lubricants that are used to reduce friction. Ultimately, tribologists are seeking to find the right approach to eliminate friction and achieve the goal of perfecting motion. This goal can arguably be termed the "holy grail" for tribologists as the way to develop the right type of lubricant to optimize the efficiency of a specific machine.

Striving to improve efficiency has become a critical factor in a different sense because of the growing need to reduce the harmful effects of global warming. This action is at the core of the concept of sustainability which points to better efficiency and productivity, lower energy use, lower levels of emissions and minimization of waste generation.

These inefficiencies are placing our environment in a tenuous state where excessive heat generation is driving an increase in temperature that is a threat to our existence. Tribology provides answers to combat this threat through carefully examining the interaction of surfaces in relative motion.

A prime example is the internal combustion engine used to power automobiles and trucks. This enables us to maintain a mobile society but the technology while robust is actually very inefficient. According to findings, from a report entitled, "Tribology Opportunities for Enhancing America's Energy Efficiency," that was published in 2017, a typical passenger car vehicle uses only 21.5% of its fuel energy to move the automobile. The overwhelming amount of the 78.5% of fuel energy left is needed to overcome parasitic losses due to friction in the engine, transmission, tires, and brakes of the vehicle and is released as heat.

In 2018, the US Environmental Protection Agency (EPA) reported that the transportation sector overall contributes the highest level of emissions in the US at 28.2%. One automobile is projected to emit about 4.6 metric tons of carbon dioxide. Currently, the number of automobiles on US roads is estimated to be 276 million which is almost one vehicle for each American. Doing the math based on EPA statistics leads to the conclusion that automobiles contribute 1.27 billion metric tons of carbon dioxide annually. The inefficiency in the internal combustion engine causes a high level of emissions which is not sustainable.

Lubricants are an important component in an internal combustion engine. Without the use of motor oil, no automobile can function. Motor oil is a lubricant that is essential in ensuring that friction and wear are reduced so the automobile, a complex machine, can transport individuals from Point A to Point B.

Tribologists are working on new approaches for further reducing friction and wear that will hopefully improve the efficiency of internal combustion engines leading to a reduction in carbon dioxide emissions and an improvement in sustainability. Current research seeking to achieve this objective will be covered in future podcasts.

What is the goal of this move to sustainability and how can tribology be used in the quest? The answer rests with significantly reducing carbon dioxide emissions to negate the harmful effects of global warming. As some of you may have seen publicized, organizations in academia, government and industry are striving to become 'carbon neutral' which means finding an approach for minimizing carbon dioxide emissions and then balancing remaining emissions by finding ways to reduce carbon dioxide emissions by an equal amount.

Two well known organizations working to be carbon neutral in the near future are the automotive manufacturer, General Motors (GM) and the major oil company, Shell. In January 2021, GM announced that its products and global operations will become carbon neutral by 2040. As part of this commitment, GM also joined the Science based Target Initiative. This organization assists companies with setting emission reduction targets to achieve carbon neutrality. The Target Initiative is led by the Carbon Disclosure Project, the United Nations Global Compact, the World Resources Initiative, and the World Wildlife Fund.

A major reason for GM moving to carbon neutrality is the company's new commitment to manufacturing electric vehicles. At the same time that GM announced its intention to become carbon neutral by 2040, the company also announced that it will only sell zero-emission vehicles by 2035. As part of this strategy, GM plans to spend $ 27 billion from 2021 through 2026 and introduce 30 electric vehicles starting later in 2021.

One of the world's largest lubricant suppliers, Shell Lubricants just announced in February 2021 the largest to date offering of carbon neutral lubricants globally. Shell intends to offer a product line that will offset the annual emissions of more than 200 million liters of advanced synthetic lubricants which has a carbon dioxide equivalent of 700,000 metric tons annually. This is equivalent to taking 340,000 internal combustion powered automobiles off the road annually.

Shell is offering carbon neutral products for automotive and industrial applications that are advanced synthetic lubricants. The company has also taken steps since 2016 to reduce the carbon footprint in its lubricant manufacturing by 30% and now sources more than 50% of its power for its manufacturing plants from renewable sources.

As part of this process, Shell is promising to reduce production of gasoline and diesel fuel by 55% over the next ten years. The company also claims it will close more than 50% of its refineries reducing the number from 14 to 6.

This strategy is consistent with Shell's claim that its oil production peaked in 2019 and is declining at a pace expected to be between 1 – 2%/year now and in the future. The remaining refineries will be reconfigured into integrated energy and chemical manufacturing facilities.

Shell is not alone as at least 4 other refineries are being closed and converted to producing renewable fuels such as biodiesel. Using renewable fuels is a positive step but still does not facilitate the move towards carbon neutrality unless the goal is to recycle or reuse.

This leads to the concept of the 'Circular Economy' where a process starting at a specific point will move on a path back to the original starting point. Instead of the 'cradle to grave' approach that we have been accustomed to, the Circular Economy is moving us to a 'Cradle to Cradle' strategy which will lead to waste minimization and maximum utilization of existing resources.

You might expect that achieving carbon neutrality for the US will be very difficult and very expensive. A study published in 2020 by researchers from the US Department of Energy's Lawrence Berkeley National Laboratory, The University of San Francisco and the consulting firm, Evolved Energy Research paints a realistic picture of how carbon neutrality can be attained by 2050.

These researchers developed eight models after evaluating the energy and industrial sectors. In using a bottom-up approach to analyze energy demand from 64 different subsectors, the researchers were able to optimize the energy supply needed over time from 2020 to 2050.

The lowest cost model showed that carbon neutrality can be achieved by 2050 at a cost of $1 per person per day which represents 0.4% of US Gross Domestic Product. The energy infrastructure in the US does not need to change overnight with the exception that coal power will need to be retired by 2030. The researchers stressed that natural retirement and replacement can proceed over the 30-year period as long as the new technologies are the most efficient and lowest carbon available.

The tribology and lubrication field will be faced with end users such as GM demanding that the raw materials used in their facilities be sustainable and carbon neutral. As a major supplier to the automotive industry, lubricant manufacturers will rely more on renewable resources that can be used to produce high performance, synthetic base stocks and lubricants that can demonstrate outstanding performance over longer operating periods than base stocks derived from petroleum.

Over the past ten years, mineral oil base stocks have been developed from natural raw materials such a sugar cane. Synthetic processing steps are used to convert the sugar cane into mineral oil base stocks.

But most lubricants are currently prepared with some type of mineral base stock which is not renewable nor sustainable if used and then disposed of by incineration, landfill, or some other means. To maximize the use of these base stocks, efforts are underway to more prominently use recycling as a way to reduce waste and improve efficiency. Re-refining is a technique that has been available for some time to convert mineral oil waste streams into useful base stocks for a wide range of automotive and industrial lubricant applications. There is every expectation that re-refined base stocks will continue to grow as the lubricant industry successfully demonstrates the benefits of a 'Circular Economy'.

The EPA just released a report on rerefining that indicates approximately 30% of the used oil generated in the US is recycled. The rest is either burned, dumped illegally or unaccounted for. EPA concludes that there is a good deal of potential for growing the amount of rerefined oil available for use in a sustainable manner.

As we move into the future, sustainability will play an increasingly important role in influencing how lubricants will be used in the transportation, energy, manufacturing, and medical/health sectors. Electric vehicle development and commercialization will accelerate over the next few years as GM and most other major automotive manufacturers are committed to battery technology.

While the prospect for no carbon dioxide emissions is pushing the development of electric vehicles, there is still uncertainty about the type of battery that will exhibit the best cost performance. Lithium-ion batteries have taken the lead but concerns still exist about their performance and safety. In the latter case, the formation of dendrites, which are branch-like structures emanating from the battery electrodes can lead to short circuits and eventually fires.

One of the issues is the flammable organic electrolytes currently in use. Ultimately, solid-state lithium batteries may provide the best compromise between safety and performance. What is clear is two favorable trends are occurring at this time. Battery pricing continues to decline as power density continues to improve.

Battery development though may be hindered because of sustainability concerns. Key components used in the battery are metals that are mined using industry practices that can create high levels of carbon dioxide emissions. The ability to recycle battery components will need to be demonstrated.

The choice of lubricants used in automobiles will change in switching from internal combustion engines to electric vehicles. Motor oil will no longer be in demand when global fleets switch to electric vehicles. But lubricants will continue to be needed in electric vehicles for applications such as transmission fluids, dielectric-heat transfer fluids and greases. Batteries generate high levels of heat during use that can reduce their performance. Heat transfer fluids that exhibit excellent thermal conductivity are needed to quickly remove heat.

The high electrical current present in electric vehicles compared to internal combustion vehicles means that the lubricants in use must carefully balance electrical conductivity and insulation. Better copper corrosion inhibitors will also be needed because electric vehicles contain more of this metal.

Improving and expanding the electric grid will be mandatory if consumers will be able to fully utilize electric vehicles. This leads to the growing development of the two sustainable energy sources solar and wind. The US Energy Information Administration (also known as the EIA) estimates that renewables will double their share of US electricity generation from 21% currently to 42% in 2050. This agency feels that renewables will surpass natural gas as the major source of electric generation in the US by 2030. Growth will be seen more with solar power as compared to wind energy.

As part of its strategy to be carbon neutral, Shell has committed to expand its network of electric vehicle charging stations from 60,000 to 500,000 in 2021 and double electricity sales to retail and business customers. Electricity will be sourced from renewable sources such as wind, solar and biomass.

Even with the growth of renewable energy, conservation through reducing consumption will remain a critical goal in the future. A report issued for the US Department of Energy that has the title, “Tribology Opportunities for Enhancing America’s Energy Efficiency” estimated in 2017 that technologies related through tribology related research will save 11 Quads of energy in the US annually. One quad of energy is equivalent to a quadrillion which can be expressed as a thousand trillion or a million billion. However, it is described, one quad represents an extremely large amount of energy.

Improvements in efficiency and productivity will govern the future of manufacturing. Newer synthetic lubricants and greases made from renewable sources will gain in popularity. But other factors such as robotics and additive manufacturing will affect the use of lubricants. Robots are already used widely particularly in the automotive industry along with a smaller downsized version known as cobots that can handle many different applications. Implementation of artificial intelligence (AI) will enable robots to be even more effective as they will now be able to make independent decisions and interact with each other. The Fourth Industrial Revolution will lead to opportunities for better lubricants particularly needed to ensure that robots can do their functions.

Additive manufacturing or 3D printing represents a new approach in producing parts through a layer-by-layer introduction of materials. This process is more sustainable than currently used metalworking operations which involve the removal or subtraction of waste metal. Lubricants will move from a primary role as metalworking fluids in the subtractive process to a post-processing function needed to ensure a 3D printed part meets stringent specification requirements.

Use of additive manufacturing will grow in the medical/health sector as this technique is very useful in the production of a wide range of products from prosthetics to body tissues. Please note that additive manufacturing has nothing to do with the production of lubricant additives.

Trends in transportation, energy, manufacturing, and medical/health seem clear but the question needs to be asked about what effect the COVID-19 pandemic is having on the movement towards sustainability? Over the past 18 months, the pandemic has caused major interruptions in all of these sectors as much less driving has been done globally, energy use has also declined due to the dramatic reduction in manufacturing particularly through the middle of 2020. The good news is that manufacturing has now bounced back, and transportation is showing signs of rebounding as consumer demand for automobiles and other modes of transportation is increasing as we move through the 3rd quarter of 2021.

Both the private sector and the public sector are accelerating their move towards sustainability despite problems created by the pandemic. More companies that have significant influence in key industrial sectors such as energy and manufacturing are embracing sustainability by pledging to become carbon neutral in the future. This move will act to persuade their suppliers including companies manufacturing lubricants to also move in the same direction. As this pulling effect on the industrial supply chain becomes more significant, regulatory bodies in the developed and developing world are enacting regulations also promoting the push towards sustainability.

A prominent example that is having a significant influence on tribology is the MARPOL regulation enacted by the International Maritime Organization (IMO) and implemented in January 2020. The purpose of this regulation is to reduce the level of sulfur oxide emissions emanating from ocean going vessels by reducing the sulfur content in fuel from 3.5% to 0.5%.

The change to very low sulfur fuel is having a significant impact on the types of lubricants that can be used and is leading to performance difficulties. Ship operators are reporting higher sediment levels in fuel tanks that can lead to sludge formation choking purifiers, filters, and fuel lines. With ocean going vessels primarily operating far-away from maintenance facilities, finding workable solutions is necessary and in progress.

The marine industry is continuing to work together to commercialize zero emission vessels by 2030. This effort from 140 affiliated companies is known as the “Getting to zero Coalition.” The importance of this effort is due to international shipping accounting for 2 – 3% of global greenhouse gas emissions. Without making any changes, emissions may grow by 50% to 250% by 2050.

Related to the MARPOL regulation is the Vessel General Permit (VGP) enacted by the US in 2013 and regulating discharges for vessels operating in US territorial waters. Operators of vessels must use environmentally acceptable lubricants that are biodegradable, minimally toxic, and not bioaccumulative. Once VGP was implemented the lubricant industry responded by developing products from renewable and synthetic sources that can meet these requirements.

Moving forward, our podcast will start to address a series of technology developments that will demonstrate how tribology and lubrication can promote the movement towards sustainability. The first topic we will cover is the role that tribochemistry is having in changing the way lubricants are prepared and how they interact with surfaces.

Lubricants by nature operate to reduce friction and wear as surfaces move towards each other. During these applications, temperature and pressure can increase dramatically making it harder for lubricants to fulfill their functions. Fortunately, lubricant suppliers have developed sophisticated formulations that contain a base stock such as mineral oil with a series of additives each designed to provide a specific function to improve performance. For example, there are additives that can assist with minimizing corrosion, providing additional lubricity, and acting to stop the lubricant from oxidizing.

Tribochemistry explores the reactions that can occur between lubricants and surfaces under boundary lubrication conditions where there is little room between the two. Research is ongoing to determine how specific lubricants can react with surfaces under these severe conditions to produce materials such as diamond-like-carbon (DLC) that have the potential to achieve superlubricity where coefficient of friction values below 0.005. This approach may change the traditional way lubricants are developed by prompting formulators to factor in the composition of the surface of the machinery when determining what lubricant to propose for a specific application. It is anticipated that the lubricants from sustainable sources will be able to achieve this effect leading to the in-situ formation of a new material that can reduce friction and wear to extremely low levels providing more efficient performance over an extended time frame.

A second podcast will be devoted to ongoing research on Additive Manufacturing. The emphasis of this podcast will be on work involving metal alloys which has not progressed as rapidly as polymer resins. The focus will be on challenges faced by researchers in trying to use Additive Manufacturing on specific alloys in particular applications.

In subsequent podcasts, we will examine new developments in lubricant additives, nanolubricants, lubricant testing and taking a look at work involving graphene. In each podcast, we intend to present a brief introduction about the subject matter and then will interview three leading researchers to gain their perspective on how their work is moving the field forward, what challenges they are facing and trying to overcome and what the future for this particular field may look like.

My name is Neil Canter, and I will be your host. During the over 35 years that I have been in the tribology and lubrication field, I have seen evolutionary changes that have slowly moved towards perfecting motion. New market forces are accelerating more rapid changes that will call upon tribology to develop better answers because perfecting motion is now directly linked to carbon neutrality and sustainability. Please join me as we continue the quest to reach this goal.

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CONTRIBUTORS

Dr. Neil Canter is an STLE Fellow and an STLE Certified Metalworking Fluids Specialist (CMFS)™, with more than 35 years of experience in the tribology and lubrication field, working with metalworking fluids. Canter has a strong background in the chemistry of metalworking fluids and in regulations impacting their use. He is a member of the American Chemical Society (ACS), Society of Automotive Engineers (SAE), STLE and a contributing editor to *Tribology & Lubrication Technology* (TLT), STLE's monthly publication.