Challenges and opportunities for a sustainable e-mobility

Despite technical and engineering challenges, the future outlook for electric vehicles offers many opportunities.

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Meet the Presenter
This article is based on a webinar titled Challenges and Opportunities for a Sustainable E-Mobility: Recent Progress and Future Prospects. Hosted by the American Society of Mechanical Engineers' (ASME) Tribology Division and presented by STLE Past President Dr. Ali Erdemir on Oct. 18, 2023, the session explored the future of e-mobility, its significant challenges and the opportunities that arise from the shift toward more sustainable transportation systems. Courtesy of STLE, this article captures the core insights from this ASME-organized event. For more technical content from the ASME Tribology Division Webinar Series, visit the ASME Tribology Division's website at **www.asme.org/get-involved/groups-sections-and-technical-divisions/technical-divisions/technical-divisions-community-pages/tribology-division**.

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KEY CONCEPTS

The future of electric vehicles is dependent on scaling renewable sources of energy to meet the increased demand for electricity.

Although lubricants have been developed for electric vehicles, they need to be optimized to provide maximum protection.

The ultimate goal is a fill-for-life lubricant with superior electrical and mechanical protection that contributes to reduced energy consumption and extends the lifespan of EV components.

The move toward electric mobility, or e-mobility, has been driven by a combination of environmental, economic and societal factors. With electric vehicle (EV) development at a crossroads, it's time for a new discussion about the future of e-mobility, its significant challenges and the opportunities that arise from the shift toward more sustainable transportation systems.

EVs are not a new concept. In fact, they have been around since the 1800s, when there were actually many EVs on the road. However, with the advent of inexpensive petroleum and issues with driving range, EVs became less attractive, and internal combustion engines (ICEs) took over. It wasn't until the early 2000s when mainstream auto manufacturers began developing and producing hybrid and plug-in hybrid vehicles that the EV market revived. By 2040 more than 60 million cars will be powered by electricity, which could lead to significant environmental benefits.

This article is based on a webinar presented by STLE Past President Dr. Ali

Erdemir, professor and Halliburton Chair in engineering in the J. Mike Walker '66 Department of Mechanical Engineering at Texas A&M University, College Station, Texas, and the Tribology Division of the American Society of Mechanical Engineers (ASME) titled Challenges and Opportunities for a Sustainable E-Mobility: Recent Progress and Future Prospects. See Meet the Presenter for more information.

Transportation efficiency/environmental concerns

ICE vehicles are major contributors to global greenhouse gas (GHG) emissions, and EVs offer a cleaner alternative. It's a fact that the energy efficiency of EVs is significantly greater than that of ICE vehicles. For example, battery electric vehicles (BEVs) consume about 65 megajoules (MJ) of energy per 100 kilometers/62 miles driven, compared to the 230 MJ used by ICE vehicles for the same distance. This substantial energy efficiency advantage, combined with the growing availability of renewable energy, places BEVs as one of the more important drivers of sustainable transportation.

The adoption of BEVs is a step forward, but the environmental impact of these vehicles is significantly affected by the source of the electricity that powers them. When powered by renewable energy sources such as photovoltaics (PV) or concentrated solar power (CSP), the carbon emissions of BEVs can be reduced dramatically—by as much as 500%—compared to ICE vehicles.

One of the major drivers for the transition to EVs is the environmental impact of harmful emissions. Transportation accounts for a significant portion of GHG emissions—28% in the U.S. and about 22% worldwide. For ICE vehicles, each gallon of fuel produces over 20 pounds of CO_2, depending on the size of the vehicle. In addition, the average vehicle only manages 25 miles per gallon, emitting a little less than one pound of CO_2 per mile traveled.

Over time, CO_2 levels have surged dramatically, contributing to global warming and resulting in severe weather events like hurricanes, typhoons and floods, as well as the melting of polar icecaps. Switching to EVs could help mitigate these environmental impacts, especially if the electricity used to power these vehicles comes from green energy sources. However, most of the electricity produced today is still derived from nonrenewable energy sources.

So, while the short-term benefits of reduced emissions may be limited, there is optimism that increasing the share of green energy will significantly reduce GHG emissions attributed to the transportation sector. In addition, EVs are much more efficient than ICEs, for which only about 20% of the fuel energy is used to move the car.

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Key challenges and opportunities

While the benefits of e-mobility are clear, the transition to EVs is challenging; there are still major issues. Following are four key technical and engineering hurdles that need to be addressed prior to widespread adoption.

1. **Materials compatibility.** Issues related to copper corrosion in windings, the degradation of plastics and elastomer seals and the wear of various materials need to be addressed. EVs use a substantial amount of copper—around 180 kilograms per vehicle—which is vulnerable to corrosion. The rapid oxidation and thermal degradation of polymeric materials, for example, can lead to copper corrosion and depletion. This may result in shorting or arcing in electrical components. Better materials and new technologies will be needed to overcome these challenges, as stray electricity and corrosion can cause significant issues in vehicle components.
2. **Electrical conductivity.** Another major hurdle for EV technology is electrical conductivity. Stray electrical currents can flow through the system and cause damage to bearings and other components. These currents can discharge through contact interfaces, leading to wear and pitting. The environment in which EVs operate is highly corrosive, with cooling fluids and other substances contributing to the corrosion of copper components, and this leads to short circuits and other problems. Current leakage in EV drivetrains is a common issue, leading to accelerated degradation of lubricants, increased wear and friction corrosion. In high-voltage or high-current vehicles, small cracks in rotor insulation can cause short circuits or creeping currents, which compromise the performance and durability of the vehicle. As a result, future e-fluids and lubricants must be designed to offer not only friction and wear reduction but also superior electrical properties, high dielectric constants and resistance to electrochemical corrosion.
3. **Thermal management.** Thermal management also is a challenge, as the batteries and converters in EVs generate a significant amount of heat, which needs to be dissipated efficiently to prevent damage. High thermal conductivity materials and fluids are needed to manage this heat effectively. In addition, advanced e-fluids need to have superior heat transfer capabilities, high thermal conductivity and the stability to cool these components without compromising other essential properties, such as lubricity and corrosion resistance.
4. **Tribological challenges.** The internal electrified environments of EV drivetrains expose lubricants and moving parts to accelerated degradation, friction and corrosion. EV lubricants must be able to withstand these harsh conditions while providing superior friction reduction and wear protection. Also, EV drivetrains are complex systems that include a range of mechanical and electrical components, all of which must be optimized to reduce energy consumption, improve durability and minimize maintenance requirements. Unlike ICEs, EVs operate under very high torque and load conditions, which puts severe stress on moving parts. Lubricants, if not properly formulated, can fail under these conditions.

Severe contact conditions

While EVs have fewer moving parts compared to ICEs, the components in EVs undergo much more severe contact conditions, including high load, high torque and high pressure. This puts driveline components like gears and bearings under extreme stress, leading to accelerated wear, increased friction and potential corrosion—particularly when electricity passes through the interfaces. High torque situations, especially at low speeds, can result in micro-pitting and wear. To address these challenges, better lubricants and additive packages are required to ensure the proper functioning of moving parts, even under severe conditions.

As mentioned, stray electricity and current leakages are common in EVs and can cause arcing, which leads to bearing damage and pitting. Research has shown that under electrified conditions, both dry and lubricated interfaces suffer from much higher levels of wear. Additionally, the presence of stray electricity can lead to the formation of carbon-based deposits, which are highly destructive to the surfaces of moving parts. Also, the breakdown of lubricants under electrical stress leads to the formation of aggressive wear debris, which contributes to the accelerated wear of components.

The role of lubricants in overcoming challenges

E-fluids are required to not only provide lubrication but also to dissipate heat. These fluids must have high breakdown voltages to withstand electrical conductivity challenges. They also must have high thermal conductivity and oxidation stability. The fluids also need to have excellent friction and wear characteristics, since the moving parts in EV driveline components face severe operating conditions. The selection of the right fluid is critical to ensuring optimal performance in terms of thermal conductivity and lubrication.

While advanced lubricants will play in a critical role in overcoming EV challenges, they must be formulated to meet an array of demanding criteria such as:

- **Ultra-low viscosity.** To reduce pumping and churning losses and improve energy efficiency.
- **A high dielectric constant.** To ensure adequate electrical properties and prevent electrical breakdown.
- **High thermal conductivity.** To enhance the cooling of critical components such as motors and batteries.
- **Oxidative and thermal stability.** To maintain performance across a broad temperature range, even in extreme conditions.

While the benefits of e-mobility are clear, the transition to EVs is challenging; there are still major issues.

There is the potential for a unified fluid with "fill-for-life" capabilities, eliminating the need for frequent lubricant changes, which would reduce vehicle maintenance costs. For lubricant formulators, this represents a prime opportunity.

Extensive research has been conducted on the properties of automatic transmission fluids (ATFs) used in EVs, specifically in terms of electrical conductivity, thermal conductivity and viscosity. While there were no significant differences in friction coefficients, it was observed that the presence of electricity dramatically increased wear. In some cases, wear levels increased by 70%-90% when electricity was present. This is due to the breakdown of hydrocarbon molecules in the lubricants, resulting in the formation of soot-like wear debris that is highly aggressive.

Another interesting research finding was the softening of sliding contact surfaces under high levels of electric current. The heat generated by the current, in combination with frictional heating, causes the hardness of the steel surfaces to decrease, which in turn increases the rate of wear. This softening effect can have a significant impact on the wear resistance of these surfaces, making it a critical factor to consider when designing lubricants for EV applications.[1]

Ultimately, in order to ensure the safe and efficient operation of EVs, new lubricants need to be developed with low viscosity in order to reduce churning and pumping losses while still providing adequate protection against wear, micro-pitting and scuffing under high torque conditions. New materials with high resistance to corrosion, including alternatives to copper, will be necessary. Lubricants must also have high thermal conductivity to manage the heat generated by the batteries and driveline components.

Future outlook

The development of a single fluid that can both cool the system and provide lubrication would be a significant advancement. This fluid would need to balance electrical and thermal conductivity, lubrication properties and corrosion resistance.

The development of new fluids and additives is crucial for the future of EVs. While the technology is still emerging, with the resources available, these challenges can be addressed over time, leading to a more sustainable and efficient future for transportation.

The future of e-mobility includes both challenges and opportunities in a number of fields. As the transportation industry continues to transition to EVs, there is increasing demand for innovation in tribology, electrical engineering and materials science. The development of advanced lubricants and e-fluids will be critical to overcoming the current challenges facing EVs.

Finally, there needs to be a paradigm shift in the approach toward lubricant design and a future where a single unified fluid can provide fill-for-life capabilities, offering superior electrical and mechanical protection while reducing energy consumption and extending the lifespan of EV components.

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1. Deshpande, P., Yelkarasi, C., Lee, S., Farfan-Cabrera, L.I. and Erdemir, A. (2024), "Electrotribochemical formation of abrasive nano-carbon particles under electrified conditions on lubricated sliding contacts," *Carbon,* 228, p. 119425.