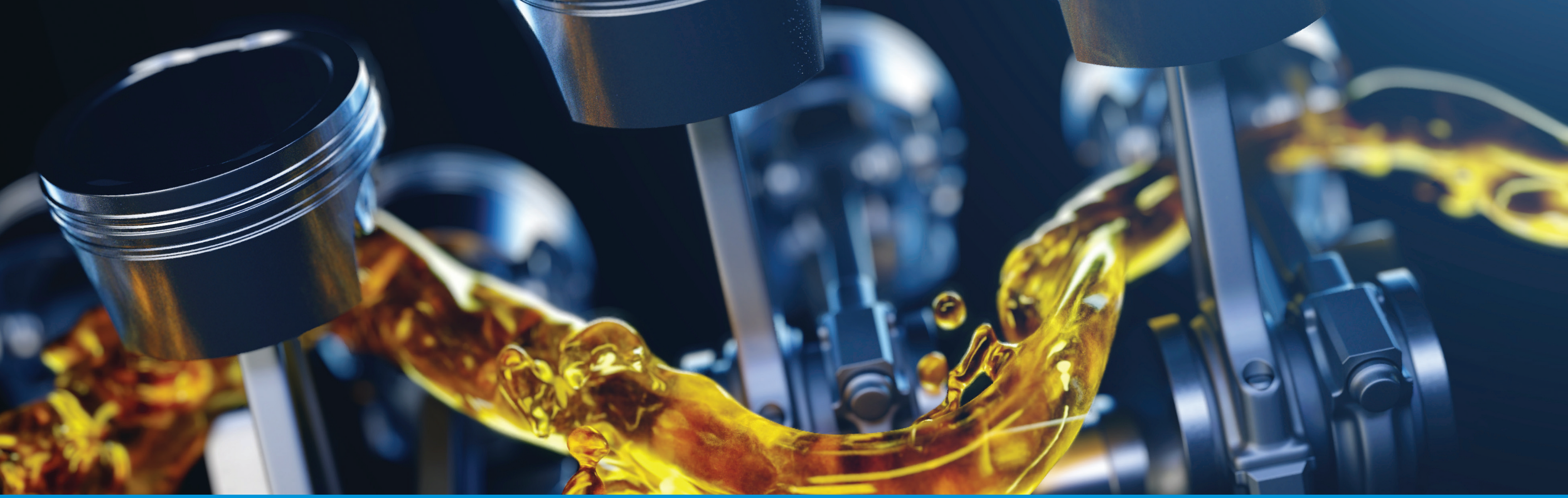


GLOBAL COLLABORATION AND DEVELOPMENT OF THE LATEST ENGINE OIL STANDARDS

Introduction

Throughout the world engine oils have been vital in the lubrication of automobile engines whether they are the more technologically advanced turbocharged direct injection (TGDI) engine or the older naturally aspirated engine. Engine oils not only enhance engine performance by reducing friction of moving parts but also support and protect engines and their components by reducing wear, transferring heat, and sealing components such as bearings and piston rings. These multitasking fluids are mostly base stock, which by itself has limited capability despite advancements in refining and availability of high quality base oils globally.

As such, the addition of complex and advanced additives remains paramount. The latter enhances the benefits or reduces the deficits of lubricating oils. For example, dispersants and detergents suspend contaminants within the oil and assist in cleaning the engine from sludge and varnish. Recently, modern engine oils must also act in additional roles not originally assigned to them. One example is the need of engine oils to operate akin to hydraulic oil and facilitate the operation of variable valve timing systems. However, the most notable role of engine oils worldwide is the role of supporting emissions reduction devices in engines in order to meet strict and evolving emissions reduction regulations.

With a multitude of vital supporting and enhancing roles, engine oils must be developed and characterized with utmost scrutiny; yet engine oils have varying hydrocarbon compositions which combined with an extensive range of additives result in a wide spectrum of performance. One of the most important properties of an engine oil is its viscosity. The ability of an oil to retain a high enough viscosity to form a robust lubricating film between moving components, while maintaining a viscosity low enough to decrease viscous drag during hydrodynamic lubrication is vital to identifying its applications. As such, the Society of Automotive Engineers (SAE) has established the SAEJ300 standard, which categorizes motor oils into grades by their viscometric properties. A combination of an engine oil's kinematic viscosity, high temperature-high shear (HTHS) viscosity, and low temperature performance determines its viscosity grade.

Along with the SAE viscosity grades, organizations around the world have developed engine oil standards to set minimum performance benchmarks and meet original equipment manufacturer (OEM) requirements. The most prominent standards are set by the American Petroleum Institute (API), International Lubricant Standardization and Approval Committee (ILSAC), and European Automobile Manufacturers Association (ACEA). Currently, these standards were developed based on the markets in their respective areas of North America and Europe; while other countries like China and India have adopted and modified these standards to fit their own markets.

Creation of a Global Lubricants Test Standards Collaboration Team

The presence of multiple standard developing organizations in various global markets has caused similar or even duplicate test methods for oil performance bringing with it a necessity to "translate" the results of test methods when products are marketed internationally. The issue arises when the method of "translation" is not a matter of simply converting results with an equation or unit conversion factors, even then a difference in precision and statistics of test methods can also cause problems. Some test methods, which seem similar on the surface, may be just different enough to invalidate their relevance across jurisdictions of oil standards setters, especially considering the complexity of engine oil formulations. Furthermore, certain performance characteristics such as testing for wear or piston deposits may have multiple different tests in the various specifications, increasing the complexity of testing. Oil companies that intend to be global, to serve the global OEM markets, may face increased time restrictions and complexity to validate their oils and claim the various global specifications. Customers also may have difficulty understanding the applicability of various oils in their engines.

Thus, spearheaded by ASTM International, the Global Lubricants Test Standards Collaboration Team (GLTSCT) was officially formed in September of 2019. This team was formed to find a means to create a more global approach for test standards; ultimately, streamlining the processes involved and saving both time and money by the improvement of technology and the reduction of redundancy among oil test methods. Therefore, the GLTSCT provides an international platform which allows the lubricants industry to share time, materials, intellect, and financial commitments. The GLTSCT will also provide a communication forum to assist with industry issues, specification development timelines, and streamlined test methods, providing annual meetings on a global level, hopefully encouraging collaboration, methods of which are succinctly depicted in the figure below. The GLTSCT is not meant to set specifications and only relays industry needs and discrepancies between industry specification setters to groups such as the ACEA, API, SAE, etc. Similarly, the GLTSCT only conceptualizes standards rather than creating standards. The GLTSCT simply recommends updates, modifications, and new standards that will reduce redundancy and confusion to test standard bodies like CEC, ASTM, IP, or others. To bring about a fruitful collaboration it is then necessary for transparent communication of developments in oil specifications and standards globally.

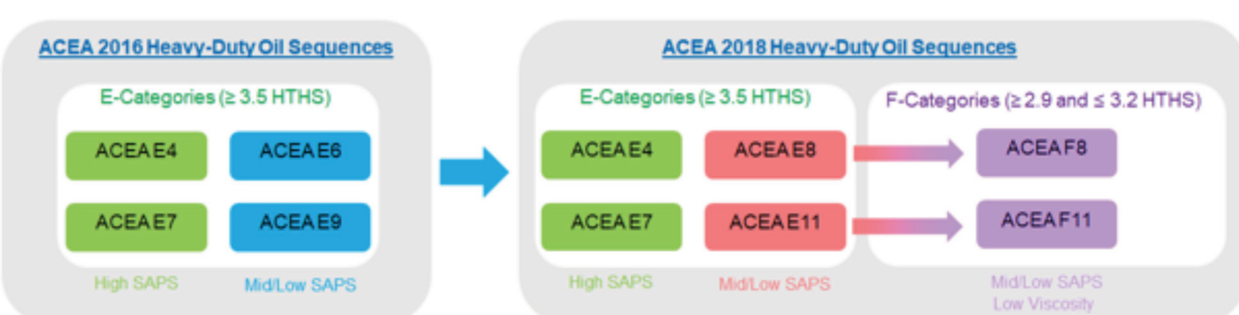
Methods of streamlining collaboration via the GLTSCT

Europe Introduces new ACEA E8, E11, F8, and F11 Oils

In Europe, engine oil standards are set by the Association des Constructeurs Européens d'Automobiles (ACEA) or European Automobile Manufacturers Association. ACEA oil sequences or specifications are divided into classifications for passenger motor oils (A/B class), catalyst compatible motor oils (C class), and heavy-duty diesel engine oils (E class), which are then further subcategorized based on sulfated ash, phosphorus, and sulfur content (SAPS) as well as the HTHS viscosities. The A/B class consists of high SAPS oils designed for older gasoline and light duty diesel engines that do not have emissions reduction-aftertreatment devices. ACEA A3/B3 and A3/B4 require oils with higher HTHS viscosity that provide improved engine protection, while A5/B5 oils have lower HTHS viscosities, possibly sacrificing some wear protection for better fuel economy. The subcategories ACEA A1/B1 were removed from the transition from the 2012 oil sequences to the 2016 oil sequences and were replaced with a new C5 classification. The C class is comprised of catalyst compatible oils for gasoline and light duty diesel engines with aftertreatment devices. C1 and C4 oils have low SAPS content, while C2 and C3 are mid SAPS oils. Additionally, C1 and C2 oils have a minimum HTHS viscosity of 2.9 centipoise, while C3 and C4 have a higher requirement of 3.5 centipoise. As stated previously, ACEA C5 was a new addition in the 2016 oil sequences replacing the original ACEA A1/B1, containing mid SAPS oils with increased fuel efficiency and HTHS viscosities of at least 2.6 centipoise. Every oil under the category of the C class are designed to increase the lifespan of gasoline particulate filters (GPF), diesel particulate filters (DPF), and three-way catalytic converters (TWC), while maintaining a vehicle's fuel economy and protecting the engines. The heavy-duty engines oils that constitute the E class are differentiated from one another by drain interval. Longer drain intervals can be achieved using E4 and E6 oils when recommended, while E7 and E9 oils target medium drain applications.

Recently, in July 2020, the 3rd revision of the ACEA 2016 oil sequences, CEC L-107-19 replaced the Daimler M271 test method for black sludge as indicated in the 2nd revision; however, the Daimler 271 sludge test remains an acceptable alternative test method. However, the most notable change to the ACEA oil sequences is the awaited specifications for the ACEA 2018 engine oil sequences. Yet, the ACEA 2018 engine oil sequences were delayed until 2020 as many of the engine oils in the current European market were deemed adequate for the regulations at the time. Due to rising concerns of low-speed pre-ignition (LSPI) in TGDI engines, ACEA C5 will be upgraded with a newly proposed ACEA C6 to include performance tests for LSPI, chain wear, and turbocharger deposits but the ACEA C5 specifications will most likely remain. Meanwhile, ACEA A5/B5 will be removed and replaced by ACEA A7/B7 with equivalent performance tests to ACEA C6. Similarly, ACEA A3/B3 and C1 will be removed due to their obsolescence, but ACEA A3/B4 is recommended for use in the place of ACEA A3/B3. The ACEA 2018 oil sequences has also proposed upgrades for the E6 and E9 specifications according to established ASTM engine tests, Volvo T13 Engine Oil Oxidation Test (ATSM 8048) and Caterpillar Oil Aeration Test (ATSM 8047), originally developed for API's CK-4 and FA-4 standards to improve extended oil drain capabilities and compatibility with modern engines; as such, ACEA E6 and E9 are anticipated to be replaced by ACEA E8 and E11, respectively. While ACEA E4 and E7 should remain unchanged for older engines. In addition, ACEA introduced a new F sequence, containing F8 and F11, which will require lubricants to have a HTHS viscosity between 2.9 to 3.2 centipoise. These additional classifications should provide a boost in fuel economy and lower greenhouse gas emissions without compromising engine protection.

Although sharing some similarities in performance targets and tests with the United States, Europe's engine oil standards differ because of differences in oil change intervals and emissions regulations. Due to higher oil costs and differing OEM recommendations in Europe, longer drain intervals of 16,000 km (10,000 miles) are much more common for European cars compared to the 5,000 mile benchmark commonly used in the United States. This necessitates the use of drain intervals as a primary factor to categorize European engine oils. Additionally, the European Union's (EU) stricter regulations on carbon dioxide (CO_2) and carbon monoxide (CO) emissions caused a shift in the European market towards diesel-powered vehicles that emit less CO_2. However, diesel engines produce higher levels of nitrogen oxides (NOx) and particulate matter (PM), necessitating the use of DPFs and TWCs to minimize emissions. These emission countermeasures are sensitive to oil composition, especially its SAPS content, which can drastically reduce these devices' effectiveness and longevity. For that reason, the ACEA's specifications include oil classifications for engines using aftertreatment devices (C class) and tend to contain oils that have mid to low SAPS content.



Changes to ACEA Heavy-Duty Sequences

The United States Upgrades to ILSAC GF-6 to Combat LSPI

In 2020, the American Petroleum Institute (API) announced the approval of new performance standards for passenger car engine oils with improved protection and fuel efficiency for automotive gasoline engines. Two of the new standards, GF-6A and GF-6B, are ILSAC specifications that fulfil the performance requirements set by the International Lubricant Specification Advisory Committee (ILSAC). The ILSAC GF-6 standards were primarily implemented to combat LSPI and timing chain wear. Notably, the increased prevalence of TGDI engines, for the purpose of increased fuel economy, has adversely affected modern automobile's susceptibility to LSPI. LSPI is an abnormal combustion event that occurs in TGDI engines when the air-fuel mixture in the ignition chamber combusts before the spark plug fires, which can cause permanent internal engine damage or catastrophic engine failure.

Two examples of piston damage due to LSPI

As such, API introduced a new supplemental service category, API SP, to reduce the occurrence of LSPI, in tandem with the ILSAC GF-6 standards. API SP is backwards-compatible and includes the performance properties of earlier API service categories, such as API SN PLUS, SN, SM, SL, and SJ. The ILSAC standards are split into two categories, GF-6A and GF-6B. GF-6A is backwards-compatible to previous performance standards, while GF-6B is not backwards-compatible and is only used for SAE 0W-16 oils.

The advent of these new standards stems from necessities driven by environmental, market, and technological influences. Due to rising environmental concerns, new EPA regulations under the Clean Air Act limit the maximum greenhouse gas emissions allowed for vehicles. In addition, the National Highway Traffic Safety Administration (NHTSA) implemented Corporate Average Fuel Economy (CAFE) standards that regulate the minimum miles a vehicle must travel per gallon of fuel, amended with the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule. The average American consumer also tends to look for vehicles with higher fuel economy to reduce their carbon footprint and save on fuel costs. Thus, OEMs in North America are driven to reduce emissions and boost fuel economy to meet environmental regulations and fulfill consumer demands. As a consequence, OEMs have turned to adopt strategies to further reduce emissions and improve fuel economy such as the aforementioned TGDI engines.

Other strategies include start-stop engines that removes fuel consumption during idling and utilization of low viscosity oils. The ILSAC GF-6 and API SP standards aim to protect against the LSPI of TGDI engines and reduce sludge formation and varnish deposits for start-stop engines while the GF-6B standard yields higher fuel efficiency with the use of lubricants specifically with low HTHS viscosity oils like 0W-16 grade engine oils.

For diesel engines, API CK-4 and FA-4 are the current oil specifications high-speed four-stroke engines. Originally introduced into the market in December of 2016 as upgrades to CJ-4 generation oils, API CK-4 and FA-4 mark the first time two heavy-duty diesel engine oil categories were developed at the same time. Both oil specifications were designed to maintain engine durability, protect emissions reduction devices, as well as provide improvements to shear stability, oxidation resistance, and aeration control. Both categories have the same limited levels of sulfated ash, phosphorus, and sulfur (SAPS). The main difference between API CK-4 and API FA-4 is the HTHS viscosity, where CK-4 oils retain traditional HTHS viscosity and FA-4 oils require a lower HTHS viscosity focusing on reduction of greenhouse gas emissions via enhanced fuel efficiency for the latest on-highway engine models without sacrificing engine protection. The backwards compatibility of the API CK-4 oil category allows for utilization in older engines, while OEMs and owners of the latest on-road modern engines can benefit from a flexible oil selection and improved fuel economy.

Canada Embraces API CK-4 and FA-4 Standards

As part of North America, it comes as no surprise that Canada has been utilizing API standards for their engine oils as well. Driven by EPA's new emissions legislation and the hazards of LSPI in modern engine designs leading to the development of ILSAC GF-6, Canadian lubricant companies had to ensure that their engine oils could meet the new requirements. Companies like Petro-Canada Lubricants, the biggest oil producer in Canada, began reformulating their repertoire of passenger car motor oils (PCMO) to accommodate new ILSAC GF-6 and API SP category specifications; ultimately, spawning a new generation of oils that provide protection against LSPI, accelerated timing-chain wear, start-stop engines, and enhance fuel economy.

In the field of heavy-duty diesel oils, Canada adapted to the introduction of API CK-4 and FA-4 in 2016. In a manner much like the United States' market, Canada's market shifted towards lower HTHS viscosity oil for use in the latest on-highway engine technologies in favor of the better fuel economy and reduced greenhouse gas emissions. Petro-Canada released oils for the Canadian markets and beyond that are per the API CK-4 and FA-4 categories and appropriate for use in vehicles that are compliant with EPA regulations. Similar to US oils, Canadian CK-4 and FA-4 oils are used in engines with aftertreatment devices such as DPFs with or without Diesel Oxidation Catalysts (DOC), increased rates of Exhaust Gas Recirculation (EGR) and Selective Catalytic Reduction (SCR).

China Progresses Towards Its Own Domestic D1 Standard

Moving away from the Western world, China, historically, has utilized a mix of different foreign oil standards for domestic specification. For the past 30 years, China has adopted the API engine oil specifications and China's diesel engine specification (GB11122) referred to as "National Standards" aligns with API CD to CI-4. In addition, China adopts a vehicle emissions requirement from the European Union's Euro standards. As China's automotive industry continues to experience expedited growth, the needs of the market consequently evolve as well. Concerns surfaced surrounding the inadequacy of the current US and EU standards to comprehensively cover the latest Chinese OEM requirements. In fact, the use of a mix of foreign standards brings about consistency issues and reduced relevance in relation to the domestic market and its demands.

In response to the glaring problems with utilizing standards targeted at a foreign market, China began development for a domestic heavy-duty diesel engine oil specification, D1, that was scheduled for release in 2019. The Chinese Lubricant Specification Development Alliance, consisting of the five leading heavy-duty diesel truck manufacturers (FAW, DongFeng, WeiChai, Foton Daimler and JAC), led discussions for this domestic lubricant standard. Representatives from local lubricant companies, additive companies, independent organizations, and independent test labs also took part in the development process. The new D1 standard adopts the API oil categories' viscosity classifications and bench tests but also includes four additional Chinese diesel engine test methods: The FAW engine test, which focuses on low oil consumption and high temperature detergency; The DongFeng engine test, which determines an oil's resistance to viscosity increase and anti-wear performance from soot contamination; the WeiChai WP13L engine test that measures an oil's total base number (TBN) retention and performance up to 100,000 kilometers due to demand for longer drain intervals from Chinese OEMs; and the Foton Daimler ISGe4 engine test that was designed to assess an oil's ability to maintain normal lubricating conditions for off-road engine use. These tests allow for the assurance of high performance diesel engine oils tailored to Chinese vehicles eliminating the need for oils to undergo engine tests required by API specifications that may be unnecessary for the Chinese market.

India Makes a Jump to BS VI in an Effort to Lessen Emissions

The growing vehicle population in India has continually contributed to the country's escalating pollution problem. Notably, Indian regulations follow similar conditions set by EU emission regulations but have lagged behind EU standards by approximately 10 years nationwide. Consequently, the Indian Ministry of Road Transport and Highways (MoRTH) announced the implementation of the Bharat Stage VI (BS VI) vehicular emission standard over the previous Bharat Stage IV (BS IV) standard completely skipping over Bharat Stage V (BS V). Scheduled for implementation in April 2020, the BS VI standard will restrict vehicle pollution to regulate air quality and bring India's motor vehicle regulations in alignment with the EU's Euro VI standard.

For each vehicle classification and their respective subcategories, proposals were made for mass emission limits, type approval requirements, on-board diagnostic (OBD) systems, and durability levels. In the category of light and heavy-duty vehicles with direct injection and diesel engines, stricter limits will be imposed on hydrocarbons, NOx, and PM and a new particulate number (PN) limit will be introduced. In addition, there will be changes regarding vehicle type procedures for light-duty vehicles through the use of portable emissions measurement systems (PEMS) for in-service conformity testing. BS VI will also replace the European Stationary Cycle and European Transient Cycle used in BS III and BS IV with the use of World Harmonized Stationary Cycle (WHSC) and World Harmonized Transient Cycle (WHTC) test cycles, respectively, for commercial vehicles, as they are more representative of real-world driving conditions. Also, the durability of pollution control devices for commercial vehicles will adopt the requirements outlined in the Euro VI standards. Unique to the BS VI standard, regulations will be proposed for two-wheeled and three-wheeled vehicles as they comprise over 70% of the vehicle population in India including evaporative emissions limits, OBD specifications, and durability standards to ensure that two-wheelers and three-wheelers will pollute no more than a gasoline passenger vehicle at a minimum. This decision will push OEMs to employ a broader range of aftertreatment technology to fulfil the new BS VI requirements such that the use of particulate filters and new fuel injection systems may prove a necessity for passenger cars, commercial vehicles, and two-wheelers to remain under the new emission limits.

The use of reduced SAPS engine oils for all vehicles is a necessity to maintain the performance and integrity of emissions control systems introduced to meet BS VI standards. For passenger car oils, older specifications like API SL will be replaced with newer API SN, ILSAC GF-5, and ACEA C2/C5 quality oils. Specifications like API CK-4 and ACEA E6 plus will experience increased usage as heavy-duty oils for commercial vehicles. API SJ and SL will continue to experience high usage for two-wheeled vehicles, along with API SN, which could be used for enhanced TWC protection due to lower phosphorus content. Despite the use of American and European oil standards, aftertreatment systems in Indian automobiles still suffer from obstacles due to the difference in driving patterns. Indian automobiles typically operate at low speeds with multiple starts and stops in India's cities, which causes an excessive accumulation of particles in DPF aftertreatment systems. This hinders the efficiency of DPF regeneration and results in reduced engine performance, increased fuel consumption, and potentially vehicular failure. At this time, there are no indications that a regional Indian oil standard will be developed to target those conditions.

	CO g/km	HC g/km	HC NOx g/km	NOx g/km	PM g/km	PN #/km
Compression ignition	0.50-0.74	–	0.17-0.215	0.08-0.125	0.0045	$6x10^{11}$
Positive ignition	1.0-2.27	0.10-0.16	–	0.060-0.082	0.0045	$6x10^{11}$

Green = new **Red** = tighter than BS IV

Passenger Vehicle BS VI Proposed Limits

		CO g/kWh	HC g/kWh	NOx g/kWh	PM g/kWh
Two wheelers	SI Engine	1.0	0.1	0.06	0.0045
	CI engine	0.5	0.1	0.09	0.0045
Three wheelers	SI Engine	0.44	0.35	0.085	–
	CI engine	0.22	0.1	0.10	0.025

Green = new **Red** = tighter than BS IV

Commercial Vehicle BS VI Proposed Limits

	CO g/kWh	HC g/kWh	CH4 g/kWh	NOx g/kWh	PM g/kWh	PN #/kWh
WHSC Compression ignition	1.5	0.13	–	0.40	0.01	$8x10^{11}$
WHTC Compression ignition	4.0	0.16	–	0.46	0.01	$6x10^{11}$
WHTC Positive ignition	4.0	0.16	0.5	0.46	0.01	$6x10^{11}$

Green = new **Red** = tighter than BS IV

Two/Three-Wheeler Vehicle BS VI Proposed Limits

Conclusion

The newly developed GLTSCT acts as a platform upon which diverse global oil standard developing organizations may come together in order to bring about not only domestic improvements but global advancement. Test methods can be discussed, and discrepancies can be mediated; ultimately, reducing redundancy and increasing the rate of technological advancement. The outcomes may include faster development process, lower cost for development or even more streamlined standards with low redundancy and higher performance. For end users, the results of collaboration may be the availability of less complex claims and more common oils that better service the global market.

Currently, the engine oil standards developed by API, ILSAC, and ACEA stand at the forefront of the constantly evolving automotive industry around the world. In the United States, the push for smaller, more efficient engines has led to the development of TGDI engines, boasting greater engine performance but increased risks associated with LSPI. Thus, ILSAC GF-6 standards were introduced, reducing the occurrence of LSPI and providing better fuel efficiency. Also, API introduced the CK-4 and FA-4 standards for diesel engine oils that had enhanced engine performance. While FA-4 standards allowed diesel engine oils reduced greenhouse gas emissions to comply with EPA regulations for the first time. Canada's rate of adopting API standards would mirror the United States due to their close proximity and the similarity in vehicle market demands. As such, Canadian engine oils reaped analogous performance and protection benefits in both gasoline and diesel categories. Standards in Europe similarly evolved with ACEA announcing several updates to their specifications. The new ACEA C6, A7/B7, E8, and E11 standards would address LSPI problems and contain performance boosts, with a greater focus on extending drain intervals, utilizing low SAPS oils, and complying with stricter European emissions requirements. On the other hand, China has adopted API engine oil standards, while using European emission standards for a significant portion of their history. However, as China's vehicle market diverges from the operating conditions found in the western market, leading figures in China's automotive industry would come together and begin developing their own domestic heavy-duty diesel oil standard D1. As a developing country, India has been using older API/ACEA standards and has faced a multitude of issues with the low speed, start-stop driving conditions prevalent in urban environments. The implementation of India's BS VI emission standards has pushed the country to adopt updated standards like API CK-4 in an effort to satisfy environmental concerns.

The rapidly developing state of the automotive industry paired with the constant drive for higher performance and efficiency has driven continued technological advancement to engine oils and their standards to match OEM demands. Currently, North America and Europe have been paving the way for developing new standards used in modern vehicles. Countries presently trailing behind have begun establishing their own specifications or modifying current ones in order to better represent their domestic market. Although global engine oil standards may differ in certain aspects, they are all designed to provide the highest quality, optimal viscosity lubricants that yield satisfactory engine protection while maintaining fuel economy where needed and supporting reduction of emissions. The emergence of an international committee dedicated to collaboration has great potential in allowing communication between oil specification setters. The potential to reduce redundancy and expedite development of standards may pave the path to integrate what are currently domestic standards into relatable characterizations of engine oil's on an international scale aiding country's still developing their oil standards and streamlining the development process by hopefully bringing about a concerted effort towards new precedent setting oil standards.

On the horizon, OEMs and oil marketers must still face the emergence of regional emissions standards that may challenge the current OEMs strategies of common engine designs for the global market. Another challenge that remains a consideration as oil standards are developed or become obsolete is the variation of fuels globally that necessitates the need for several oil categories co-existing in the global markets. A global forum for oil standards may ameliorate these trials but only time will tell the results.

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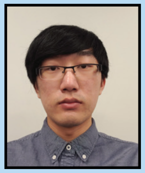

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