CONFIDENCE REPORT:

Low-Viscosity Engine Lubricants

ABSTRACT This report documents the confidence that North American Class 8 trucking should have in Low-Viscosity Engine Lubrication. The study team engaged with the entire industry in generating the findings that are presented here. Thanks to all of those who contributed to this important work.

Trucking Efficiency Trucking Efficiency is a joint effort between NACFE and Carbon War Room to double the freight efficiency of North American goods movement through the elimination of market barriers to information, demand and supply.

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2016 NACFE Fiscal Supporters

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1. Executive Summary

The fuel costs faced by the tractor-trailer industry have been extremely volatile over the past decade. In 2014 diesel fuel costs were $0.58 per mile, costing the industry as much per annum as the costs of drivers' wages and benefits combined. By 2015, through an unexpected combination of global political and economic forces, fuel prices actually dropped to 50% of their 2008 levels. These significant swings in fuel cost are expected to continue into the future, motivating the trucking industry to find solutions that increase its fuel efficiency in order to stay profitable.

Fortunately, myriad technologies that can cost-effectively improve the fuel efficiency of Class 8 trucks are readily available on the market today. Unfortunately, multiple barriers have stymied industry adoption of such technologies, including a lack of data about the true performance gains these technologies offer, and a lack of confidence in the performance testing data that does publicly exist today. To overcome those barriers and facilitate the industry's trust in and adoption of the most promising fuel efficiency technologies, the North American Council for Freight Efficiency (NACFE) partnered with Carbon War Room (CWR) to form Trucking Efficiency. The work of Trucking Efficiency has begun by producing a series of Confidence Reports, of which this report on low-viscosity engine oils is the thirteenth.

Since 2003, fleets have been ramping up their investment in lower viscosity lubricants. However, while 40% of the largest, most efficiency-conscious fleets have adopted these engine oils specifically, the adoption rates for the industry as a whole remain at only about 20%.

> "LOWER VISCOSITY ENGINE OILS DELIVER FUEL SAVINGS, AND CONCERNS OVER LOWER ENGINE PROTECTION ARE SIMPLY NOT VALID ANYMORE."
>
> **Yunsu Park, NACFE Study Manager**

Methodology

This report's conclusions were generated through desk research, conversations at a variety of trucking industry events around the country, and a series of structured interviews with fleets, truck OEMs, engine oil manufacturers, and certifying bodies active in the North American market today.

The goals of this Confidence Report are: (a) to give the industry a foundational understanding of low-viscosity engine oil; (b) to provide an unbiased overview of the benefits and challenges related to low-viscosity engine oil; and (c) to help fleet managers rationalize their investment in low-viscosity engine oil.

FUEL SAVINGS OF LOW-VISCOSITY LUBRICANTS

In engineering terms, viscosity is defined as a measure of a fluid's internal resistance to flow. In a truck's engine, mechanical losses from pumping and friction consume approximately 16% of the total energy input to a vehicle. Lower-viscosity oil will reduce those engine mechanical losses, thereby reducing fuel use.

This report finds that Class 8 over-the-road fleets can realistically expect fuel savings in the range of 0.5% to 1.5% from switching from 15W-40 to 5W/10W-30 engine oil, whether the currently available CJ-4 class or the newer CK-4 class available after December 2016. In addition, switching from 5W/10W-30 oil to the fuel-efficient FA-4 variant of the new PC-11 oils, also available after December 2016, is expected to add a further 0.4–0.7% of fuel savings.

These findings are based on data from multiple sources, as shown in the chart below.

Given that fuel savings of this magnitude can be difficult for fleets to conclusively verify in their own testing, the Confidence Report suggests that fleets considering a switch to lower-viscosity engine oil use a conservative 0.5% in calculating the payback they will earn from switching. If an acceptable return-on-investment is shown with this low level of fuel savings, fleets should be able to confidently make the switch.

Some misperceptions may have hindered the wide-scale adoption of lower-viscosity oils thus far. There is a generally held belief that heavier engine oil affords an engine better protection and therefore increases engine durability. But modern engines subject oil to a variety of temperature and lubricating conditions, and the ability of the engine oil to perform under these conditions depends on many more factors than simply the oil's viscosity. Given the importance and the complexity of an engine oil's performance and function, approval and release of new oils into the market is not taken lightly.

Before any particular engine oil is approved, both the engine OEM and the oil suppliers will have tested it extensively. All approved engine oils meet the durability requirements of every major OEM, regardless of viscosity, and all major North American engine OEMs have approved lower-viscosity 5W/10W-30 engine oil for over-the-road applications. Hence fleet managers should have no concerns that switching to a lower-viscosity lubricant will put their engines at increased risk of damage or failure.

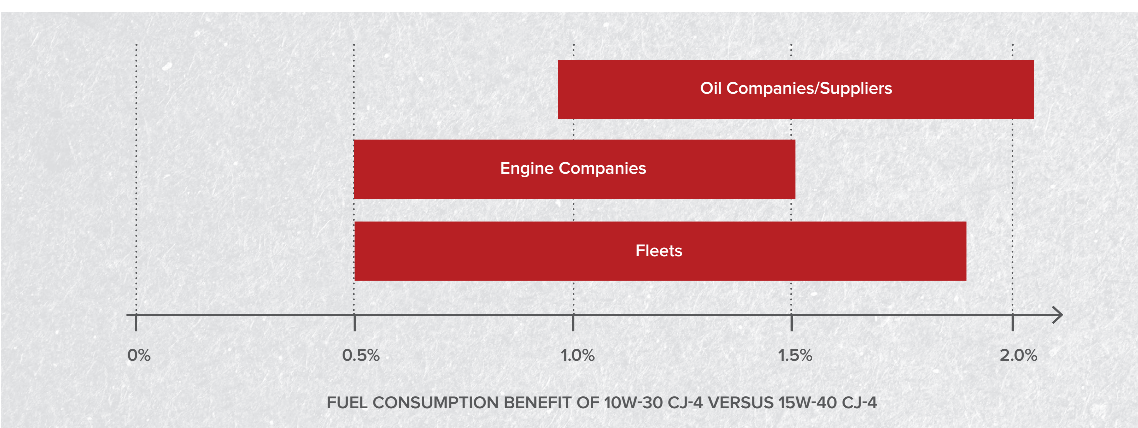
OTHER BENEFITS AND CHALLENGES OF LOW-VISCOSITY ENGINE OILS

As with most technologies, there are both benefits and challenges entailed in adopting the lower-viscosity oils beyond the fuel savings they offer. Fortunately, the benefits are fairly straightforward, while the challenges are limited in scope.

Benefit: Extended Oil Drain

A switch to lower-viscosity oil may allow a fleet to consider an extended drain interval, which can help offset that price premium. Although the ability to extend drain intervals varies greatly by various factors such as duty cycle, and it should always be done in consultation with engine and oil suppliers, one fleet that this study team interviewed extended its drain interval by 20,000 miles by switching to lower-viscosity oil. Extending drain intervals may require

FIGURE ES1: POTENTIAL FUEL SAVINGS IN CLASS 8 OTR APPLICATION AS STATED BY VARIOUS PARTIES



measures such as oil analysis and sophisticated maintenance tracking, which may not be appropriate or accessible for all fleets.

Challenge: Cost

For fleets using non-synthetic 15W-40 oils there is a cost entailed in switching to low-viscosity engine oil. This is largely due to the fact that much of the 15W-40 oil found on the market today is mineral-based, while most xW-30 engine oils are synthetic or synthetic-blends. A change only in viscosity does not result in a significant cost increase, but synthetic and synthetic-blend oils are positioned as premium products and command a premium price. At the retail level, a switch from a mineral-based oil to a synthetic blend typically increases cost by 30–40%, even within the same brand family. Therefore, while adopting this fuel-saving technology does not require an upfront investment, the higher price of the oil will increase maintenance costs over the lifetime of the switch, requiring a proper payback calculation.

Challenge: Compatibility with the Entire Fleet

Every fleet interviewed for this report cited compatibility with the entirety of a fleet's equipment as a basic requirement for adoption of a new engine oil. While lower-viscosity 5W/10W-30 oil versions of CJ-4/CK-4 oil have been approved for engines going back to at least the 2010 model year, the soon-to-be introduced FA-4 oil, which offers the greatest fuel efficiency gains, may have issues with compatibility. Each individual engine OEM must address backward compatibility of FA-4 oil for engines produced prior to 2017. As a result, a switch to FA-4 oil may not be possible for some large mixed fleets or fleets with older vehicles without managing more than one oil type in their maintenance shops.

However, given the fact that all major engine OEMs have approved 10W-30 engine oil, fleet managers are finding there is little risk of losing compatibility with their entire fleet when deciding to switch away from the traditional, high-viscosity 15W-40 to gain an improvement in fuel consumption.

PERSPECTIVES FOR FUTURE SYSTEMS

While low-viscosity engine oil has been on the market for many years, the release of this Confidence Report coincides with an unprecedented change in the choices of engine oils available to trucking fleets. A new category of oils, collectively known as Proposed Category 11 (PC-11), will be available in December 2016. For the first time, engine oil buyers will be faced with a choice of performance categories within a given viscosity—both the CK-4 oils, which will be an update of the currently available CJ-4 performance category, and the brand new type of oils to be known as FA-4.

Mandated fuel-efficiency improvements for heavy-duty highway diesel engines, as well as changes in engine technology, drove the need for these new performance standards. Critical to the development of these standards was the requirement that they maintain all of the existing performance standards as well. As a result, two categories of oil were created, CK-4 and FA-4. Both categories gain improvements in six aspects of oil performance, detailed in the report.

The arrival of the new categories may help raise awareness of the fuel efficiency benefits of some engine oils, but it may also complicate the decision process as fleets assimilate the new information. This Confidence Report is intended to help fleet managers understand how and why the categories differ, and guide their decision-making process to the most cost-effective and fuel-efficient choice for their operations.

TABLE ES1: DECISION GUIDE FOR LOW-VISCOSITY LUBRICANTS

DESCRIPTION OF FLEET AT PRESENT	SUGGESTED FLEET ACTION
Using 15W-40 mineral-based oil	Check with engine OEM(s) for approved 5W/10W-30 oil & work with oil supplier to find acceptable ROI assuming 0.5% fuel savings.
Using 15W-40 synthetic or synthetic-blend oil	Check with engine OEM(s) for approved 5W/10W-30 oil and switch. Fleet should see no significant cost increase.
Single-sourced engine OEM fleet using 5W/10W-30 oil	Work with engine OEM and oil supplier to accelerate backward compatibility of FA-4 to their application.
Multi-sourced engine OEM fleet using 5W/10W-30 oil	Consider isolating any FA-4 approved vehicles to a location where implementation of FA-4 oil could be practical.

CONCLUSIONS AND RECOMMENDATIONS

Given the wide availability of data on the impact of low-viscosity engine oil on fuel consumption, the study team has three key take-aways for fleets:

1. Class 8 over-the-road fleets can realistically expect fuel savings in the range of 0.5% to 1.5% by switching from 15W-40 to 5W/10W-30 engine oil, either CJ-4 or CK-4. The savings from switching to the fuel-efficient FA-4 variant, available after December 2016, can be expected to add a further 0.4–0.7% of increased fuel efficiency.

   In addition, while these efficiency gains are modest relative to some other technologies, this is one of the rare instances where an efficiency technology can be implemented across the entire fleet very quickly, does not require an upfront investment, and does not require any changes in operation or maintenance practices.

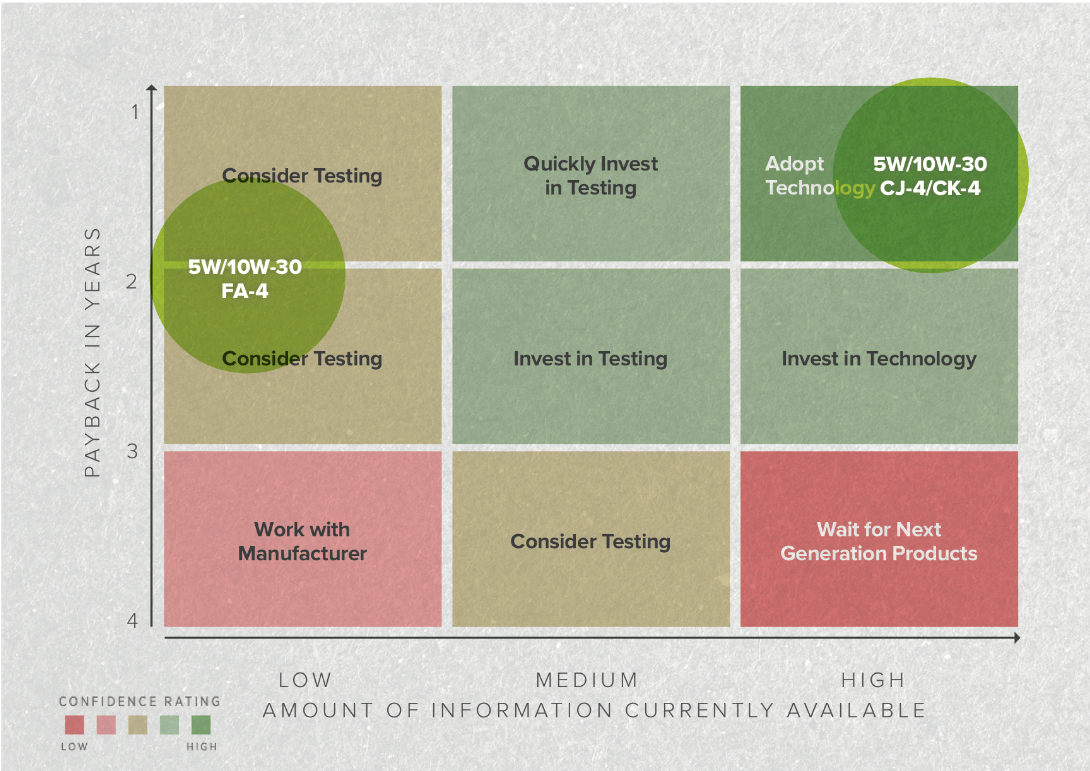
2. All major North American engine OEMs have approved 5W/10W-30 engine oil for over-the-road applications. Approved oils, regardless of viscosity, meet the engine manufacturer's requirements for engine protection.

3. Within the same viscosity grade, the base stock (mineral, synthetic, or synthetic blend) does not directly affect fuel consumption.

Stemming from these conclusions, this Confidence Report recommends that fleets currently using 15W-40 engine oil consult with their engine supplier(s) to identify approved 5W/10W-30 oils for their vehicles. They should then work with their oil supplier to find an acceptable ROI of cost vs. fuel savings, with a conservative assumption for fuel-economy improvement. This could

"THE ARRIVAL OF THE NEW CATEGORIES WILL HELP RAISE AWARENESS OF THE FUEL EFFICIENCY BENEFITS OF THESE ENGINE OILS."
Mike Roeth, Operation Lead, Trucking Efficiency

CONFIDENCE MATRIX LOW-VISCOSITY LUBRICANTS



be done with the ROI calculator included in the report. The decision guide in Table ES-1 can help fleets that want to benefit from the reduced fuel consumption offered by lower-viscosity engine oil.

Along with these recommendations for fleets, the Report gives three key recommendations for other stakeholders involved in engine oils:

1. Oil marketers and other parties that have completed a significant amount of engine oil testing should make that test data available in an open, examinable manner.

2. All engine OEMs should complete the testing required to approve 10W-30 CJ-4/CK-4 for over-the-road applications in all seasons for North America for engines built prior to 2017.

3. Engine OEMs should likewise accelerate the adoption of FA-4 oil in the industry by approving backward compatibility of FA-4 oil, or by helping fleets establish a procedure to test for backwards compatibility of FA-4 oil in their operation for their entire fleet.

CONFIDENCE RATING

For each of the Confidence Reports completed by Trucking Efficiency, the various technologies assessed are plotted on a matrix in terms of the expected payback in years compared to the confidence that the study team has in the available data on that technology—that is, not only how quickly fleets should enjoy payback on their investment but also how certain Trucking Efficiency is in the assessment of that payback time. Technologies in the top right of the matrix have a short payback, usually thanks to their low upfront cost, and moreover are found to have high confidence in those short payback times, usually because the technology is more mature or otherwise has a more substantial track record of results.

Trucking Efficiency is highly confident that all fleets should consider switching from a 15W-40 engine oil to one with lower-viscosity.

TRUCKING EFFICIENCY

Trucking Efficiency is a joint effort between NACFE and Carbon War Room to double the freight efficiency of North American goods movement by eliminating barriers associated with information, demand, and supply.

Worldwide, heavy-duty freight trucks emit 1.6 gigatons of CO_2 emissions annually—5.5% of society's total greenhouse gas emissions—due to the trucking sector's dependence on petroleum-based fuels. With fuel prices still commanding nearly 40% of the cost of trucking, the adoption of efficiency technologies by all classes of trucks and fleets offers significant cost savings to the sector while reducing emissions. These technologies are relatively cheap to implement and widely available on the market today.

Trucking Efficiency provides detailed information on cost-effective efficiency technologies, including data from across a variety of fleets and best practices for adoption. This Confidence Report series from Trucking Efficiency aims to serve as a credible and independent source of information on fuel efficiency technologies and their applications.

In order to generate confidence on the performance claims of efficiency technologies, Trucking Efficiency, via these reports, gathers and centralizes the multitude of existing sources of data about the performance results of different technology options when employed in a variety of vehicle models and duty cycles, and makes all of that data openly accessible and more easily comparable. Furthermore, we assess the credibility of the available data, and provide an industry-standardized ranking of confidence in performance results, including ROI and efficiency gains.

www.truckingefficiency.org

Trucking Efficiency welcomes outside views and new partners in our efforts to help accelerate the uptake of profitable, emission-reducing trucking technologies.

CARBON WAR ROOM

Carbon War Room (CWR) was founded in 2009 as a global nonprofit by Sir Richard Branson and a group of likeminded entrepreneurs. It intervenes in markets to accelerate the adoption of business solutions that reduce carbon emissions at gigaton scale and advance the low-carbon economy. CWR merged with Rocky Mountain Institute (RMI) in 2014 and now operates as an RMI business unit. The combined organization engages businesses, communities, institutions, and entrepreneurs to transform global energy use to create a clean, prosperous, and secure low-carbon future. The combined organization has offices in Basalt and Boulder, Colorado; New York City; Washington, D.C.; and Beijing.

www.carbonwarroom.com

NACFE

The North American Council for Freight Efficiency works to drive the development and adoption of efficiency-enhancing, environmentally-beneficial, and cost-effective technologies, services, and methodologies in the North American freight industry by establishing and communicating credible and performance-based benefits. The Council is an effort of fleets, manufacturers, vehicle builders, and other government and non-governmental organizations coming together to improve North American goods movement.

www.nacfe.org

2. Introduction

This Confidence Report forms part of the continued work of Trucking Efficiency, a joint initiative from the North American Council for Freight Efficiency (NACFE) and Carbon War Room (CWR) highlighting the potential of fuel efficiency technologies and practices in over-the-road (OTR) goods movement. Prior Confidence Reports and initial findings on nearly 70 available technologies can be found at www.truckingefficiency.org.

The fuel costs faced by the tractor-trailer industry have been extremely volatile over the past decade, as shown in Figure 1. By 2015, through an unexpected combination of global political and economic forces, fuel prices actually dropped to 50% of their 2008 levels. These significant swings in fuel cost are expected to continue in the future, and make fuel costs the least predictable aspect of freight operations.

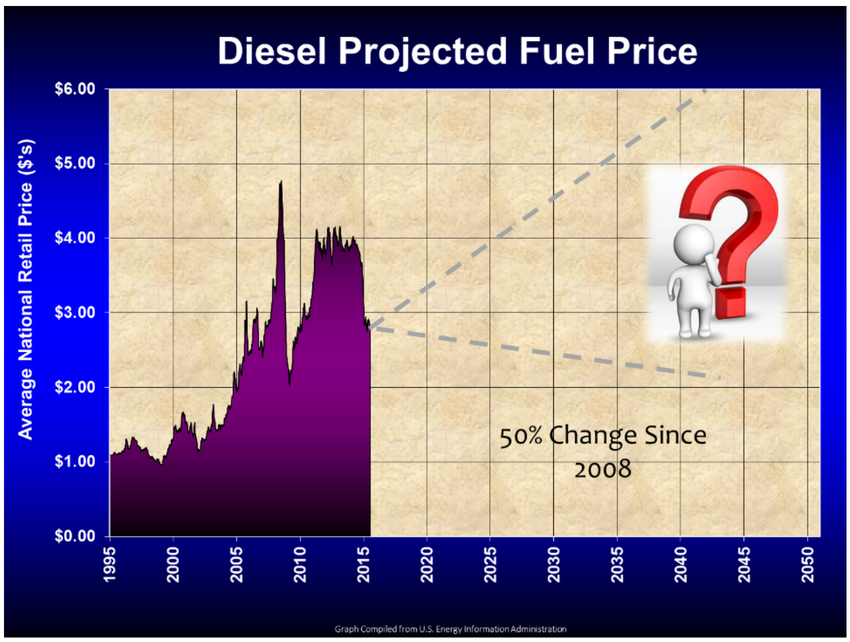


Figure 1: U.S. Diesel Fuel Prices

Truck operating costs have seen steady inflationary increases for labor, but, as Figure 2 shows, in 2013 fuel costs surpassed those for the driver, while in 2014 they began decreasing to $0.58 per mile, on par with the costs for the driver (wages plus benefits). By 2015, through an unexpected combination of global political and economic forces, fuel prices had actually dropped to 50% of their 2008 levels. These significant swings in fuel cost are expected to continue into the future, motivating the trucking industry to find solutions that increase its fuel efficiency in order to stay profitable.

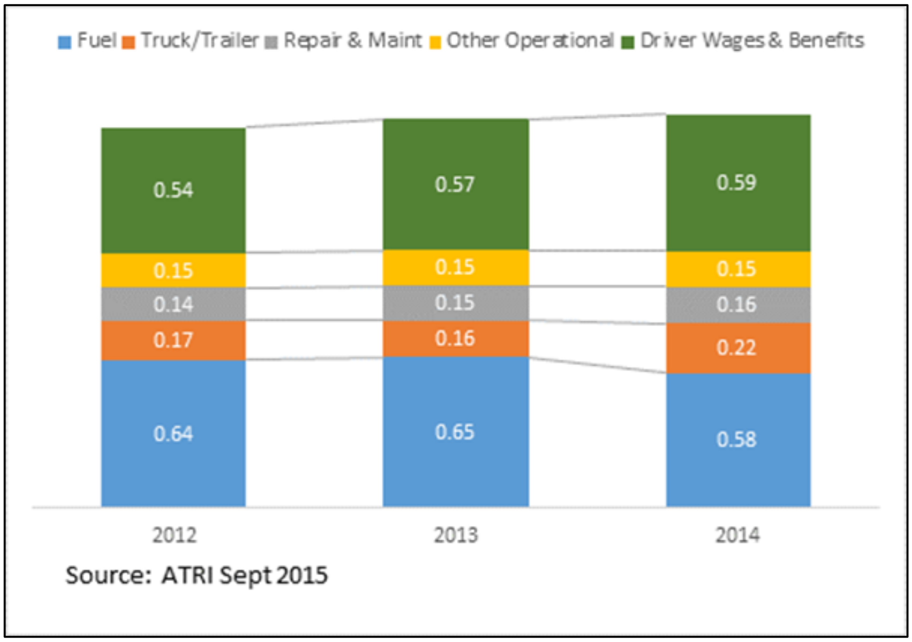


Figure 2: Trucking Operational Costs per Mile

Investment into proven technologies and practices that allow a truck or fleet to increase their fuel efficiency – meaning that they can do the same amount of business while spending less on fuel – is a hugely promising option for the industry in light of this trend of volatility.

To understand, and thereby better facilitate, the uptake of such technologies, NACFE conducts an annual review, the "Fleet Fuel Study," of the industry-wide adoption rates of nearly 70 fuel efficiency technologies currently available for Class 8 tractors and trailers. This work, available on the www.nacfe.org website, has been called "the most comprehensive study of Class 8 fuel efficiency adoption ever conducted." (Truck News, 2012)

Figure 3: Fleet Study Participants

The overriding take-away from the most recent Fleet Fuel Study, completed in 2015, is that fleets are enjoying dramatic improvements in their fuel efficiency by adopting combinations of the various technologies surveyed — savings of about $9,000 per tractor per year compared to a fleet that has not invested in any efficiency technologies. It found that these fleets have fleet-wide fuel economy of just under 7.0 mpg, while the U.S. average, for the approximately 1.7 million tractors in over-the-road goods movement, is 5.9 mpg. This finding was drawn from research into the use of fuel efficiency products and practices by 14 of the largest, most data-driven fleets (Figure 3). Those fleets represent both regional and long-haul tractors and trailers, in both dry goods and refrigerated cargo movement, and boast a combined inventory of 53,000 tractors and 160,000 trailers. The 2015 study reviewed twelve years of adoption decisions by these ten fleets, and describes their specific experience with the nearly 70 technologies. Each fleet shared the percentage of their new purchases of tractors and trailers that included any of the technologies. They also shared twelve years' worth of annual fuel economy data for the trucks in their fleet. With these two pieces of information, which will be updated every year, NACFE is able to generate insights into the following aspects of the industry:

- Adoption curves for each of the technologies, indicating which technologies have the steepest adoption rates, which are being adopted steadily but slowly, and which are not being purchased at all. These curves also show how uniformly (or not) fleets are acting in their adoption patterns.
- Identification among the various fleets of the innovators, early-majority, late-majority, and even laggards, in new technology adoption.
- Comparison of technology adoption rates to overall fuel efficiency.
- Identification of three key insights: that the adoption of automated manual transmissions has reached high levels, that aerodynamics are now available for natural gas tractors, and that the optimization of engine parameters is being pursued more widely as a fuel-saving strategy by large, medium, and small fleets.

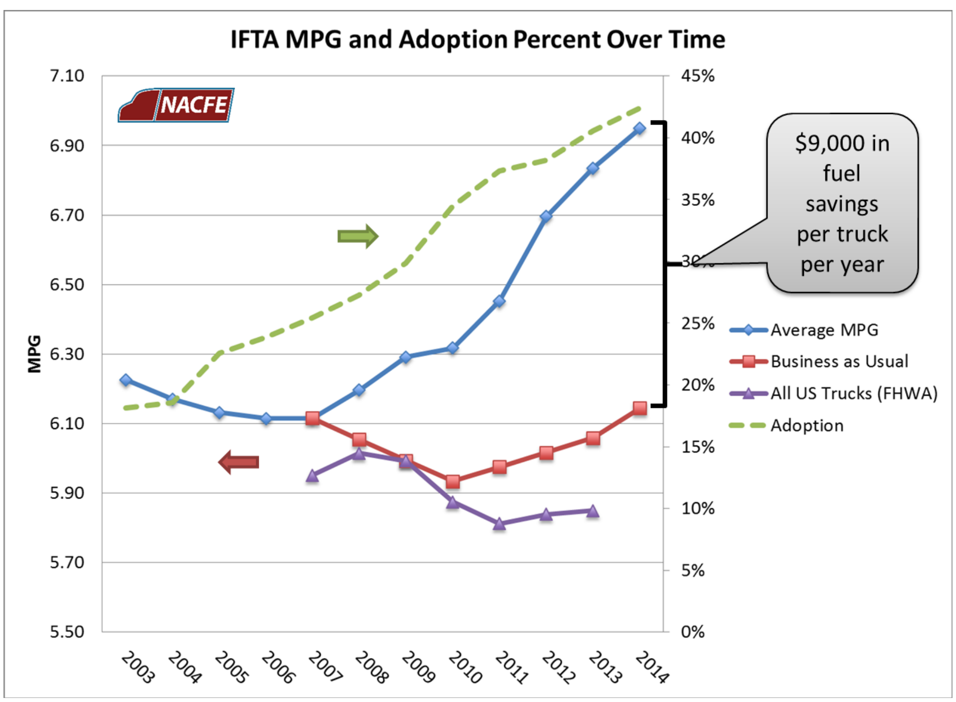


Figure 4: Fuel Savings per Truck – Blue line represents fleets surveyed by the Fleet Fuel Study

1.1. Trucking Efficiency's Confidence Reports

NACFE's Fleet Fuel Studies provide useful insights into adoption trends in the industry, as well as into the specific practices of different major fleets. NACFE hopes that this information could alone spur additional investment, particularly by fleets that may be lagging behind the overall industry when it comes to certain widely-adopted technologies. However, in the course of conducting the studies, it became clear that some technologies are still only adopted by the most progressive or innovative fleets in spite of their strong potential for achieving cost-effective gains in fuel efficiency. In order to facilitate the wider industry's trust in and adoption of such technologies, NACFE and CWR formed Trucking Efficiency and began this series of reports, called "Confidence Reports," which will take an in-depth look at those most-promising but least-adopted technologies one-by-one.

Confidence Reports provide a concise introduction to a promising category of fuel efficiency technologies, covering key details of their applications, benefits, and variables. The reports are produced via a data mining process that combs public information and collects otherwise-private information (which is shared with Trucking Efficiency for the purpose of the reports), in order to centralize an unparalleled range of testing data and case studies on a given technology set.

Low-viscosity lubricants represent one such technology set. The most recent Fleet Fuel Study found that, since 2003, fleets have been ramping up their investment in lower viscosity lubricants. However, adoption rates, even among the most efficiency-conscious fleets, only recently crossed 40% (Figure 5) while remaining much lower in the industry as a whole

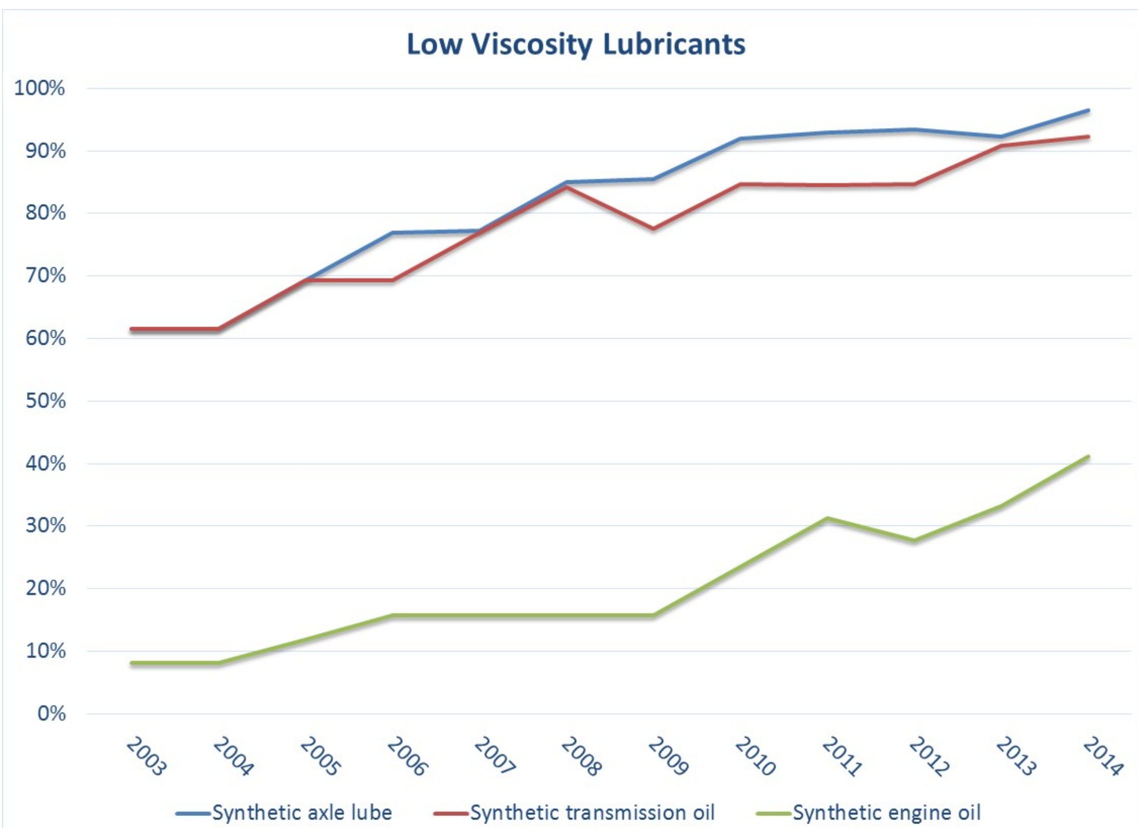


Figure 5: Low-viscosity Lubricant Adoption by Category (NACFE)

The goals of this Confidence Report are: (a) to give the industry a foundational understanding of low-viscosity engine oil; (b) to provide an unbiased overview of the benefits and challenges related to low-viscosity engine oil; and (c) to help fleets rationalize their investment in low-viscosity engine oil.

This NACFE Confidence Report on Low-Viscosity Engine Lubricants is one in a series of NACFE-focused reports on configuring vehicles and operations to improve their fuel efficiency. Visit www.truckingefficiency.org to view this and other completed reports on tire pressure systems, 6x2 axles, idle reduction, electronically controlled transmissions, electronic engine parameters, low rolling resistance tires, lightweighting, downspeeding, preventative maintenance, trailer and tractor aerodynamic devices, and efficiency testing methods.

1.2. About this Report

The scope of this report is limited to engine oils and does not address transmission oils or axle lubrication. This report's scope also excludes aftermarket oil additives, which may be addressed in a separate Confidence Report at a later date.

NACFE's and other industry surveys indicate that the use of synthetic transmission oil and axle lube is very high already in the industry, while use of low-viscosity engine oil, remains at less than 20%. within the industry as a whole. As stated above, NACFE's Fleet Fuel Study finds that even among the fleets most aggressive in their adoption of efficiency technologies, only 40% are pursuing low-viscosity engine oil. Important to note, NACFE's Fleet Fuel Study does not ask about viscosity, but rather about whether fleets have switched from mineral-based oil to synthetic or synthetic blend oil, which are often but not exclusively the same thing as "low-viscosity oil." The 20% figure represents usage of synthetic and/or synthetic blend oil; it is thus a close-but-not-exact picture of usage of low-viscosity oil.

While low-viscosity engine oil has been on the market for many years, the release of this report coincides with an unprecedented change in the choices of engine oils available to trucking fleets. A new category of oils, collectively known as Proposed Category 11 (PC-11) during its development phases, (to be sold as CK-4 and FA-4) will be available in December 2016. For the first time, engine oil buyers will be faced with a choice in performance categories within a given viscosity, and resultant issues of backward compatibility with older equipment. The arrival of the new category may help raise awareness of the fuel efficiency benefits of some engine oils, but it may also complicate the decision process as fleets assimilate the new information. This report is intended to help fleets understand how and why the categories differ, and guide their decision-making process to the most cost-effective and fuel-efficient choice for their operations.

As will be discussed in the report, low-viscosity engine lubrication has the potential to increase fuel efficiency by about 1% in Class 8 over-the-road applications. While the efficiency gains are modest relative to some other technologies, this is one of the rare instances where an efficiency technology:

- can be implemented across the entire fleet very quickly
- does not require an upfront investment
- does not require any changes in operating or maintenance practices following implementation.

2. Background

Many people have an intuitive understanding of the purpose of engine oil and the importance of viscosity in oil's ability to perform its function. However, a deeper explanation of how oil is formulated, how oil functions in various parts of the engine, and how viscosity is measured will help in understanding the benefits, challenges and conclusions reached by the study team behind this Confidence Report.

2.1. Components of Oil

Broadly speaking, modern engine oil is made up of two components: the base stock, and additives. As the performance of engines have increased over the years, the oil companies manipulate the mixture of additives combined with the various base stocks in order to develop ever-higher-performing oils capable of meeting the demands of modern engines.

The base stock (or "base oil") makes up approximately 80% (by volume) of engine oil and serves several functions:

- Provides the physical separation of mating parts
- Serves as the heat transfer agent
- Acts as the medium for the additive package

Base stock can be refined from crude oil (petroleum), or produced through chemical processes. There are five groups of base stock, each a product of a specific refining or production process that results in unique properties.

- *Group I* base stocks are mineral oils that are refined by treating them with solvents. They have more sulfur than other grades, and less than 90% of the liquid consists of "saturates," which are resistant to oxidation.
- *Group II* base stocks are refined through hydrocracking, which removes impurities more effectively than solvents. These oils are composed of 90% saturates, making them more stable, and they contain less sulfur than group I base oil.
- *Group III* oils are more highly refined than Group II oils, with more intense heat and pressure used in the hydrocracking process. This more intense refining gives them a viscosity index above 120[1], meaning that their viscosity changes less with temperature.
- *Group IV* oils are not the result of refining crude oil but rather are composed of polyalphaolephins (PAO), which are made by polymerizing an alpha-olefin molecule, a process that results in a very stable, highly purified ethylene derivative. In the U.S., engine oil made with group III or IV base oil is considered synthetic. In other parts of the world, only group IV base oils are categorized as synthetic.
- *Group V* base oils are other non-petroleum based oils made from various raw materials such as silicone, phosphate esters, etc. This group is typically not relevant to a discussion of engine oils.

[1] Viscosity index is an arbitrary measurement of the degree of change in a lubricating oil's viscosity with variations in temperature. The higher the index, the lesser the change; an index above 110 is considered very high.

[2] Though the "meanings" of the letters such as the C and J were discussed in section 2.4, it is not known what, if

Category	% Sulfur		% Saturates	Viscosity Index
Group I	**>0.03**	**And/or**	**<90**	**80 to 120**
Group II	**≤0.03**	**And**	**≥90**	**80 to 120**
Group III	**≤0.03**	**And**	**≥90**	**≥120**
Group IV	**All polyalphaolefins (PAOs)**			
Group V	**All others not included in Groups I, II, III, or IV**			

Table 1: Base Stock Groups courtesy of API

A combination of additives, composed of chemicals and crude oil derivatives, must be added to these base stocks, no matter which group, in order to give engine oil its desired performance. Some common categories of additives are:

- Antioxidants – delay the oxidation of the engine oil that is caused by the combustion process
- Anti-wear agents – chemicals that form localized protective layers to reduce metal-metal wear in the engine
- Corrosion inhibitors – elements to prevent rust from forming on engine components
- Detergents – agents that keep the engine clean and neutralize corrosive acids
- Dispersants – chemicals that combine with soot and sludge and keep it suspended in the oil, rather than sticking to the engine parts
- Pour point depressants – polymers designed to lower the temperature at which the oil will flow
- Viscosity modifiers – temperature-dependent polymers that counteract some of an oil's natural tendency to thicken when cold and thin when hot. These polymers make multi-grade oils possible.

2.2. Functions of Engine Oil

Most people are aware that engine oil lubricates the internal parts of an engine to protect them from wear. Along with lubrication, oil serves two additional functions in a diesel engine: cooling and cleaning. These three functions mean that interaction between engine oil and the engine is complicated, and a change in one desired characteristic, such as an improvement in fuel consumption, must be balanced by many other requirements.

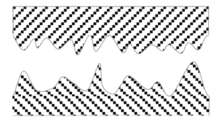
2.2.1. Lubrication

The primary function of engine oil is to lubricate moving parts. The oil forms a hydrodynamic film between metal surfaces, preventing metal-to-metal contact and reducing friction. When the oil film is not sufficient to prevent metal-to-metal contact, three negative impacts result:

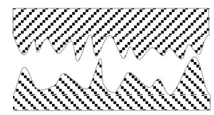
- Heat is generated through friction
- Local welding occurs
- Metal transfer results in scuffing or seizing

There are three basic regimes of lubrication used in engine protection. These are known as boundary lubrication, hydrodynamic (or full fluid film) lubrication and mixed (with both hydrodynamic and boundary conditions), and are shown in Figure 6.

Hydrodynamic
Metal surfaces are completely separated by a thick fluid film. No asperity contact.



Mixed
A partial fluid film separates all but the tallest asperities and prevents most contact.



Boundary
High metal to metal contact, very little or no fluid film separates components.

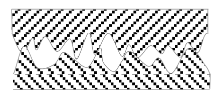


Figure 6: Lubrication Regimes descriptions courtesy of Lubrizol

Hydrodynamic conditions exist in a component such as a journal bearing that is pressure fed from a source of oil, as the operation of that component creates a high-pressure film by wedging the oil between the bearing and the shaft. Examples of these are crankshaft bearings, camshaft bushings, or accessory driveshaft bushings.

Boundary lubrication is typical of any component that is lubricated during start-up and shut-down by residual oil around the component, but that does not have a constant source of pressurized oil. An example is the cam follower roller to camshaft lobe interface, which relies on the ability of the oil to cling to the parts and lubricate until oil flow is established. Many fuel systems contain parts that are initially lubricated in a boundary condition.

A mixed lubrication condition can exist in components where the motion is more complex such as at the piston skirt/ring to cylinder bore or sleeve interface. Some hydrodynamic lubrication occurs mid-stroke in these components, while boundary lubrication dominates at top and bottom, dead center of the stroke where the piston momentarily stops.

Attention to component geometry, including surface finish and texture, along with lubricating oil characteristics are important to keep damage from occurring every time the engine is stopped or started.

A diagram called the Stribeck Curve (Figure 7) depicts the friction coefficient between the engine parts versus the lubricating condition. As illustrated, the friction coefficient increases at both ends of the curve and is impacted differently as oil viscosity changes, a challenge for engine oil designers working to improve fuel consumption.

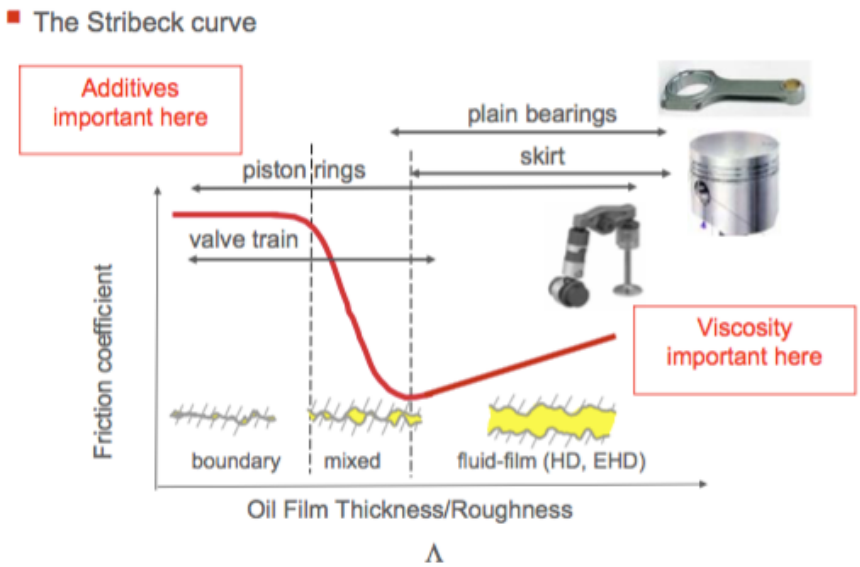


Figure 7: Stribeck Curve courtesy of Shell

2.2.2. Cleaning

Oil acts as a cleaning agent in the engine by flushing contaminants from critical internal components. The build-up of sludge, varnish, and oxidation onto pistons, rings, valve stems, and seals will lead to severe engine damage, so additives in the oil are designed to hold such contaminants in suspension until they are either removed by the oil filtration system or during the course of an oil change.

Typically, these contaminants include fuel, coolant, and soot. While engine and oil design are major factors, the level of contamination is usually heavily influenced by of the quantity of fuel that has been consumed by the engine, more so than the number of miles or hours of operation that a truck has traveled. An example is a truck that is operated at a weight considerably less than the maximum allowable, or with a decreasing payload, versus a truck operated at close to the vehicle weight limit. The lighter-weight truck will consume less fuel, and will therefore have less oil contamination through combustion.

The viscosity of the engine oil changes as contaminants accumulate in the oil. Soot concentration will increase viscosity, while fuel dilution (which happens in limited degrees in normal operation) will decrease it. However, for most engines operating under normal conditions (i.e. minimal fuel dilution), used oil will be more viscous than new oil. Therefore, while longer drain intervals offer a productivity increase for truck fleets, they will typically come with a fuel consumption penalty.

2.2.3. Cooling

Engines designers use lubricating oil to cool internal components that do not come in close contact with the vehicle's cooling system, as oil provides an excellent heat transfer medium. Heat is transferred to the oil as it comes into contact with various components, and that heat is then transferred to the primary cooling system at the oil cooler.

There are several examples of lubrication-cooled components in an engine. One of them is the piston, where oil jets spray directly at the bottom of the piston crown or into a gallery cast into the piston. Another example is the bearing housing of a turbocharger, which often use the turbo's lubricating oil to carry away the extremely high temperatures seen in the component.

While the amount of cooling the engine oil performs does not directly correlate to fuel consumption, it is a consideration for oil designers who must balance the temperature effect and their impact on additives with other desirable properties.

2.3. Viscosity

Most people who purchase engine oil recognize that oil comes in different viscosities, indicated by viscosity grades on the packaging. The importance of oil viscosity was recognized in the earliest days of automotive engine development, leading the Society of Automotive Engineers (SAE) to develop the classifications system in use today. Not as apparent is the meaning behind those grades, and how they relate to measured oil viscosity.

In engineering terms, viscosity is defined as a measure of a fluid's internal resistance to flow. Resistance to flow generally equates to fluid friction, and results in pumping losses that affect an engine's fuel consumption. The viscosity of engine oil is commonly measured or defined in two ways:

1. Kinematic viscosity (KV) is a measure of the fluid's resistance to flow due to gravity. It is typically determined by measuring the time required for oil to flow through an orifice at a certain temperature (ASTM D445). Kinematic viscosity at both 40 °C and 100 °C is often shown on oil analysis reports. The unit of measurement is centistokes (cSt), equivalent to 1 mm^2/second in SI units. In everyday terms, a difference in KV can be observed by pouring a liquid out of a jar – maple syrup, for example has a higher KV than coffee at room temperature, and therefore pours much more slowly.
2. Dynamic viscosity (DV), also known as absolute viscosity, is a measure of a fluid's resistance to deformation by shear stress, and is given in centipoise (cP) or milliPascal·second (mP·s). Unlike KV, dynamic viscosity characterizes viscosity under higher shear forces than gravity, such as in a pump or bearing.
3. High temperature high shear (HTHS) viscosity is an example of a measurement of a fluid's dynamic viscosity under high shear and at elevated temperature. Per ASTM D4683, HTHS viscosity is measured by filling the area between a rotor and a stator at a test temperature of 150 °C (302 °F) and measuring the torque needed to turn the rotor at a given speed. Within a diesel engine, the HTHS viscosity of an oil relates to the environment at the ring/liner interface.

2.4. API Oil Service Categories

Figure 8: API Donut courtesy of API

While awareness of the concept and importance of oil viscosity is high, fewer people are familiar with the performance categories currently used to classify engine oil, which capture not only viscosity but other important facets of an oil's performance as well. In 1970 the American Petroleum Institute (API) along with the Society of Automotive Engineers (SAE) and the American Society for Testing and Materials (ASTM) established the present day API service classification system in order to define and label performance standards of lubricating oils. The service categories and performance requirements have been updated on a regular basis as engine and lubricating technology has advanced. Today, the API service 'Donut' (Figure 8) is recognized as the symbol for lubricating oils that meet these performance requirements, and engine OEMs often reference the API performance standard level when specifying oils suitable for their engines.

The API service Donut indicates that an oil has been tested and proven to meet the labeled viscosity grade and performance standard. In the example in Figure 8, the oil is a multi-grade 15W-40 oil, as shown in the center of the donut. The letters following the words 'API Service' in the upper ring portion of the donut indicate the specific performance standards that the oil meets.

Each letter signifies the following:

- The first letter, C – in CJ-4 and CI-4 – indicates suitability for diesel engines. S – in SM - indicates suitability for gasoline engines.
- The next letter – I, J, or M – indicates the performance level as defined and agreed upon by the standard setting bodies. Standards are designated in alphabetical order. For diesel engines, J is the most recent (until Dec 2016) while N is the latest for gasoline engines. New performance levels are created when either standards become stricter or additional requirements are added.
- Finally, the number – 4 – indicates suitability for four stroke diesel engines.

Performance categories are not only updated; old ones are also phased out over time. API currently considers three diesel engine oil categories to be current for their respective applications.

CJ-4 — The latest performance standard for high-speed four-stroke diesel engines designed to meet EPA 2010 on-highway emissions standards using ultra-low sulfur diesel (ULSD). CJ-4 meets or exceeds earlier performance criteria given for CF-4, CG-4, CH-4 and CI-4/CI-4 Plus.

CI-4/CI-4 Plus: For high-speed four-stroke diesel engines designed to meet EPA 2004 on-highway emissions standards implemented in 2002. Compatible with four-stroke engines specifying CD, CE, CF-4, CG-4, CH-4, and CI-4/CI-4 Plus.

CH-4 For high-speed four-stroke diesel engines designed to meet EPA 1998 on-highway emissions standards.

The process of defining a performance category, not to mention of producing and testing lubricating oils that meet the requirements of the category, is extensive. However, results from a survey conducted by API and shared with NACFE indicate that while the effort put into defining and testing the categories is high, awareness of the categories and their meaning, even by fleet maintenance professionals, is not. Since, to date, many category updates have been backwards compatible, this lack of awareness of the evolution of performance categories has not been an issue. Moreover, since oils meeting the newest standards are backwards compatible to engines produced over the last two decades, it is rare for oils meeting only older standards to be found on the shelves. However, with the pending release in December 2016 of two new performance categories where cross-compatibility is uncertain, the oil industry and engine OEMs are racing to increase awareness of the performance categories and their meanings among the industry.

2.4.1. Viscosity Grades

While in engineering terms viscosity is measured by kinematic or dynamic viscosity (as discussed in section 2.3), automotive oil viscosity is typically referred to by its viscosity grade (also commonly called its weight). SAE's system of classifying viscosity is based on a numerical grade system defined in SAE J300, with corresponding kinematic viscosity shown in Table 2. Important to note, the numbers used in determining viscosity grades are *grades*, and do not corresponded to measurements in any set units

Viscosity Grade	Kinematic Viscosity (mm^2/s @ 100 °C) Min	Max	HTHS Viscosity (mPa·s @150 °C) Min
OW	3.8		
5W	3.8		
10W	4.1		
15W	5.6		
20W	5.6		
25W	9.3		
20	5.6	<9.3	2.6
30	9.3	<12.5	2.9*/3.5**
40	12.5	<16.3	3.7***
50	16.3	<21.9	3.7
60	21.9	<26.1	3.7

*** New API FA-4 service category**
**** xW-30 oil HTHS lower limit for performance categories other than FA-4**
***** The SAE lower HTHS limit for some grades is 2.9 but the current API performance category requires 3.7 or higher for all SAE 40 grades.**

Table 2 SAE J300 Viscosity Specifications by Viscosity Grade

At one time, engine oil was only mono-grade, typically designated by "SAE" followed by a number, such as SAE 40. These mono-grade oils were graded according the ranges of kinematic viscosities shown in Table 2. However, because oil viscosity is impacted by ambient temperatures, fleets had to switch between different grades of oil with the changing of the seasons. In response, multi-grade (or multi-viscosity) oil was developed, and such oils are designated by two numbers, the first followed by a W for winter such as in 15W-40. Multi-grade oil is therefore able to counteract oil's natural tendency to thicken in cold conditions. For automotive applications in regions where temperatures can vary widely, engine OEMs almost exclusively specify multi-grade oil to prevent cold start issues.

In automotive applications, winter grades always appear as part of a multi-viscosity fluid such as 15W-40 and are defined by their cold-cranking and other borderline pumping requirements (not shown in Table 2) rather than their kinematic viscosities. For OTR applications, the winter grades have a minimal bearing on fuel consumption since engines are at their normal operating temperatures nearly all of the time. Hence, in this Confidence Report, the viscosity grades are often referred to as xW-30 or xW-40, capturing every variety of winter grade available in that viscosity category.

One more thing that is important to note is that viscosity grades will start counting down by four rather than five. The next lower grade below SAE 20 will be designated as SAE 16, followed by SAE 12 and so on. This is in order to avoid confusion with winter grades going forward. When the grades were first developed, oil with a viscosity as low as an SAE 20 was not available, so the winter grades were able to use those lower numbers. Additionally, SAE viscosity grades are designated by application using different scales to avoid misapplication of fluids. Therefore, gear oil with a SAE grade of 75W-140 does not necessarily have a higher viscosity than 15W-40 engine oil.

As seen in Table 2, each SAE grade covers a range of viscosities. For OTR applications characterized by a high percent of operation time spent at highway speeds, an oil's impact on fuel consumption is most highly correlated to its HTHS viscosity, for reasons that will be addressed in a later section of this report. The variation in the HTHS viscosity that is possible among oils of the same grade in part explains the varying impact a switch from 15W-40 to 10W-30 can have on fuel consumption. Some 15W-40 oils may be formulated closer to the lower HTHS limit of 3.7 mPa-s, while others may be above 4 mPa-s. Therefore, a change from 15W-40 oil with an HTHS of 3.7 mPa-s to a 10W-30 with an HTHS of 3.5 mPa-s will have a minimal impact on fuel consumption, while a switch from a 15W-40 oil with an HTHS viscosity of 4.2 mPa-s will have a greater impact. The following chapters will discuss the meaning of all of these terms in more detail.

As previously discussed, various components within the engine operate under different lubricating conditions. These relate to different types of frictional losses; boundary friction, where parts are in contact, hydrodynamic losses, where the parts are floating on a rapidly moving fluid film, and a mixed region, where parts experience both boundary friction and hydrodynamic losses. Even though a more-viscous lubricant can reduce boundary friction, the parts in heavy-duty diesel engines that see the greatest frictional losses are predominantly operating under conditions of hydrodynamic and mixed losses, both of which will be reduced through a lower-viscosity lubricant. Thus, reducing the viscosity of the lubricating oil will consistently reduce the overall engine friction, and thereby the fuel consumed by the engine.

This is confirmed in real-world testing. Every oil supplier and engine company interviewed by the study team confirmed the correlation between decreasing oil viscosity and fuel consumption, in particular between HTHS viscosity and fuel consumption. One major oil supplier shared data with this study team indicating that the correlation can be as high as 96%. In other words, their data found that when the HTHS viscosity of oil is reduced, in the particular engine considered, there is a 96% probability that fuel consumption will decrease. Not every oil or engine supplier presented such data to the study team, but all agreed the correlation between viscosity and fuel is 80% or more. In the world of statistics, an 80% correlation is considered a near certainty.

For truck fleets, this boils down to a choice between the viscosity grades. HTHS viscosity is not always shown in a product specification, although oil manufacturers typically will provide the information when asked. While the SAE HTHS viscosity specification for SAE 40 engine oil is a minimum of 3.7 mPa-s, this study team found that many 15W-40 oils have an HTHS viscosity in the range of 4.0 – 4.2 mPa-s, while CJ-4 5W/10W-30 are at 3.5 – 3.7 mPa-s. (The new PC-11 CK-4 oils should have similar ranges). It is this reduction in HTHS viscosity that primarily accounts for the reduction in engine friction that results in improved fuel consumption when changing from a 15W-40 to a 5W/10W-30 oil.

2.4.2. Proposed Category 11 Oil

On December 10, 2015, the standard setting bodies approved new standards for new categories (Proposed Category 11, or PC-11) of engine oil for commercial vehicles, to be labeled CK-4 and FA-4[2], and which will replace the current CJ-4 standard that were introduced in 2006. This approval marked the culmination of four years of work in defining, developing, and testing oils according to the new standards agreed to by the many industry participants and standard setting bodies involved in the process.

The need for these new performance standards was driven by mandated fuel-efficiency improvements for heavy-duty highway diesel engines, as well as changes in engine technology. Critical to the development of these standards was the requirement that they maintain all of the existing performance standards as well. As a result, two categories of oil were created, CK-4, the successor to CJ-4 and FA-4, a new fuel-efficient category. Both categories gain improvements in:

- Oxidation stability
- Aeration control
- Shear stability
- Scuffing/Adhesive wear control
- Compatibility with bio-diesel blends

The importance of HTHS viscosity in influencing fuel consumption explains the gains in fuel economy offered by this new category of oil. The difference between the two new types of PC-11 oil is that CK-4 preserves the historical heavy-duty viscosity criteria for KV and HTHS, while FA-4 offers fuel efficiency benefits through lower HTHS viscosity. As illustrated in Figure 8, xW-30 CK-4 oil will maintain a lower limit in HTHS viscosity of 3.5mPa-s (same as the current CJ-4 oil), which places it at the upper end of SAE

[2] Though the "meanings" of the letters such as the C and J were discussed in section 2.4, it is not known what, if anything, the new designation of "F" means, while the letter "A" indicates that it is first round of performance requirements for the "F" oil category.

30 weight oils (shown by the dark gray bar at bottom left). However, the fuel-efficient variant, FA-4 xW-30, is near the bottom of SAE 30 weight oils, with a HTHS viscosity between 2.9 to 3.2 mPa-s. CK-4, like CJ-4, will be available as both xW-40 and xW-30 variants, while FA-4 will only be available in xW-30 viscosity.

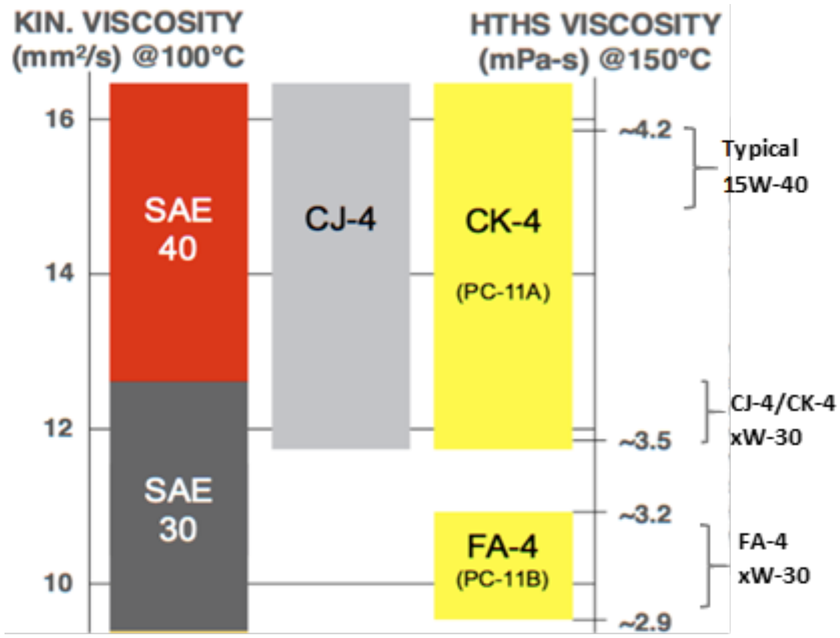


Figure 8: Relationship between kinematic viscosity and HTHS viscosity is approximate. HTHS scale not linear. Figure courtesy of Shell.

In conjunction with the more stringent performance criteria of PC-11, for both CK-4 and FA-4, additional testing methodologies have been approved as well. Specifically, changes to the limits for the shear stability test have been implemented, along with new oxidation and aeration tests.

Since this is the first time that two new service categories are launched at the same time and will be available side by side (xW-30 CK-4 and xW30 FA-4), much consideration has been given to the labeling and marketing of these variants. To minimize confusion, various naming and labeling conventions have been tested, but only one will be chosen before any of the new oils enter the market on December 1, 2016. Additionally, major oil suppliers as well as industry groups have stepped up their marketing communications to introduce several new websites explaining the benefits of the new oils. These include websites by Shell, Chevron, Lubrizol as well as others.

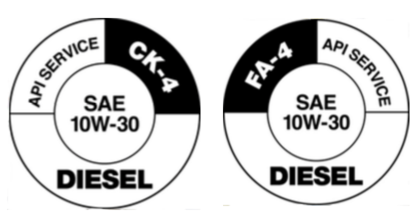


Figure 9: Labeling Concepts tested by API (Courtesy of API)

An open question that will likely not be completely addressed by the time the new oils enter the market is the backward compatibility of FA-4 oils to engines older than model year 2017. On the one hand, major oil companies have been testing FA-4 equivalent oils in fleets for a number of years, and have accumulated evidence through oil analysis and engine tear-downs to show that no harm is done to older engines by using FA-4 oil. However, the engine OEMs will only be able to confirm compatibility and determine warranty policy implications based on the results of their own testing. Since the final formulations of FA-4 have not been available to the OEMs yet, it may take some time before sufficient data exists for backward compatibility to be confirmed.

2.5. Compatibility

There is a generally held belief that heavier engine oil affords an engine better protection and thereby increases engine durability. An oft-cited example used to back up this belief is that water, which has lower viscosity than oil, does not lubricate or protect an engine. True, water will not lubricate an engine, but the relationship between engine oil, viscosity, and performance is much more complicated than this example claims, and comparing between water and oil is not a valid analogy with comparing between two approved engine oils.

As discussed, modern engines subject oil to a variety of temperature and lubricating conditions, and the ability of the engine oil to perform under these conditions goes far beyond the oil's viscosity. Engine oils would not meet the performance requirements of these engines without a sophisticated balance of base oil and additives, the combination of which must be tested under prescribed conditions to meet the API classification requirements. In addition to the API requirements, engine OEMs conduct rigorous engine tests to ensure their engines pass internal durability requirements. This sometimes generates additional manufacturer specifications that engine oils must meet in order to be approved for their engines.

The study team reviewed each of the engine OEM's recommendations and found that all have similar oil viscosity and API oil classification requirements; some also have additional test requirements for oil manufacturers to meet. What this all means is that before any particular engine oil is approved for an engine, both the engine OEM and the oil suppliers will have conducted extensive testing on the oil. While testing cannot preclude all oil-related failures, it does indicate that approval and release onto the market is not taken lightly. The engine OEMs interviewed by this study team consistently stated that all approved engine oils meet their durability requirements, regardless of viscosity.

Important to note for fleets considering a switch to lower-viscosity oils, all major North American engine OEMs have approved 5W/10W-30 engine oil for over-the-road applications, along with other oil grades sometimes predicated by ambient temperature. Approved oils, regardless of viscosity, meet the engine manufacturer's requirements for providing engine protection and performance. One major North American engine manufacturer even found that, based on inspection and measurement of an engine following a 500k mile field test, the 10W-30 oil actually showed less wear to the engine.

Table 3 is a synopsis of the current recommendations for the major North American Class 8 engine manufacturers. Note that where the engine manufacturer lists a specification, only oils meeting those specs are approved. Also key to note, although none of the engine companies are likely to require FA-4, all of the OEMs interviewed by the study team expect it to be compatible. However, it may be some time before it can be certified as backwards-compatible with a range of older engines, which may present a barrier to adoption for some fleets. This issue is discussed in more depth in Chapter 4.

Company	Model	Model Year[1]	SAE Viscosity	API Class.	Mfg Spec.
Cummins	ISX12, ISX15	2010 -2016	xW-30 xW-40	CJ-4, CK-4	CES 20081
		2017[2]	xW-30 xW-40	CK-4, FA-4[3]	TBD
Detroit Diesel	DD11, DD13, DD16	2010 -2016	xW-30 xW-40	CJ-4, CK-4	PGOS 93K214
		2017[2]	xW-30 xW-40	CK-4, FA-4[3]	TBD
Mack	MP7, MP8, MP10	2010-2016	xW-30 xW-40	CJ-4, CK-4	EO-O Premium Plus
		2017[2]	xW-30 xW-40	CK-4, FA-4[3]	TBD
Navistar	N13	2010 -2016	xW-30[4] xW-40	CJ-4, CK-4	None
		2017[2]	xW-30 xW-40	CK-4, FA-4[3]	TBD
Paccar	MX-11, MX-13	2010 -2016	xW-30 xW-40	CJ-4, CK-4	None
		2017[2]	xW-30 xW-40	CK-4, FA-4[3]	TBD
Volvo	D11, D13, D16	2010 -2016	xW-30 xW-40	CJ-4, CK-4	VDS-4
		2017[2]	xW-30 xW-40	CK-4, FA-4[3]	VDS-4.5

Table 3: Recommendations of major North American engine manufacturers

1. The study team limited the scope of this report to model years 2010 and later.
2. 2017 oil recommendations are anticipated based on discussions and have not yet been published by the engine OEMs.
3. None of the engine companies are likely to require FA-4, however all OEMs interviewed by the study team expect it to be compatible.
4. Currently limited to ambient temperatures below 90 °F for engines produced prior to 2017.

3. Fuel Savings

Given the many facets of engine oil, especially with the new PC-11 oils soon to be released, this report discusses the impact of oil viscosity on fuel in terms of two considerations:

1. Switching from a higher-viscosity 15W-40 oil to a lower viscosity xW-30 oil within the same service category (i.e., CJ-4, which will become CK-4 after December 2016)
2. Switching from existing oil varieties, whether 15W-40 or xW-30, to the new PC-11 oil varieties of xW30 FA-4

In the first consideration, fleets that switch to lower-viscosity engine oil will enjoy improvements in their fuel consumption. In fact, there is considerable evidence, both theoretical and practical, that using lower-viscosity oils will make a noticeable improvement in heavy truck fuel economy. For just one example, according to an analysis presented by the Argonne National Lab in 2011, engine mechanical losses from pumping and friction consume approximately 16% of the total energy input to a vehicle.

Lower-viscosity oil will reduce those engine mechanical losses, thereby reducing fuel use. Discussions and literature indicate that fuel savings in the range of 0.5% to 1.5% are realistic for Class 8 over-the-road fleets when switching from 15W-40 to currently available xW-30 engine oil.

For the second consideration, switching to the fuel-efficient FA-4 variant of the new PC-11 oils, available after December 2016, is expected to add a further 0.4-0.7% of fuel savings (discussed in more detail below), but data on the performance of these oils is more limited than it is for existing lower-viscosity lubricants

Looking in more detail at the first consideration, the impact on fuel consumption resulting from a change from 15W-40 CJ-4 to 10W-30 CJ-4 oil for class 8 over-the-road fleets, was cited in interviews by the study team as ranging from just under 1% to about 2%. Some oil suppliers pointed to data that had a slightly more favorable result, while engine suppliers, who at times also pointed the team to external studies, tended to be more cautious in their figures.

One such credible external study, released in 2010, entailed work by Argonne National Lab that measured the fuel-saving potential of various lower-viscosity oils compared to 15W-40 in a Volvo VD-12 on-highway test. Contrasting 15W-40 with 10W-30, in conditions designed to duplicate typical on-highway operation, the improvement was measured at 0.9%. Under hilly conditions, the percentage improvement was found to be 0.7%. The difference was attributed to the fact that friction becomes a smaller percentage of total fuel consumed in hill climbing. With 5W-30 oils, the improvement under highway cruise conditions was found to be 1.10%.

Similar results were revealed when Chevron tested a 12-liter Volvo engine running the D12D Volvo test procedure. The test was conducted on a dynamometer with five measurements taken at 13 different speed and load operating modes. A base measurement was taken with 15W-30 oil and compared with 15W-40, 10W-40, 10W-30, and 5W-30 oils. They reached the following conclusions:

1. When comparing 10W-30 to 15W-40, the fuel economy improvement is roughly 1% at low rpm, high load, and 3.5% at a high rpm, low load.
2. Friction modifiers, part of the additive package for most oils, do have an effect. The savings is about 0.5% at moderate load and rpm, which resembles highway cruise conditions.

Unfortunately, fleets, with their varied operational conditions and the wide array of factors that influence fuel economy, have difficulty measuring fuel changes of these magnitudes in their own operations. Some fleets interviewed by the study team accepted the fact that the improvement was below their level of measurement, and were comfortable in assuming it to be at least 0.5%. Others, primarily the very large fleets, shared that they were in fact able to observe an improvement of between 1-2% after switching from 15W-40 to 10W-30 oil.

Taken as a whole, the data appears to converge on a conservative range of 0.5–1.5% as the savings an OTR fleet should experience when changing from CJ-4 15W-40 to CJ-4 10W-30 oil. Industry participants and fleets interviewed by the study team generally agreed that this was a realistic range that fleets could confidently expect to achieve by switching. The FA-4 oils are not included on this chart, as data on their fuel savings is limited.

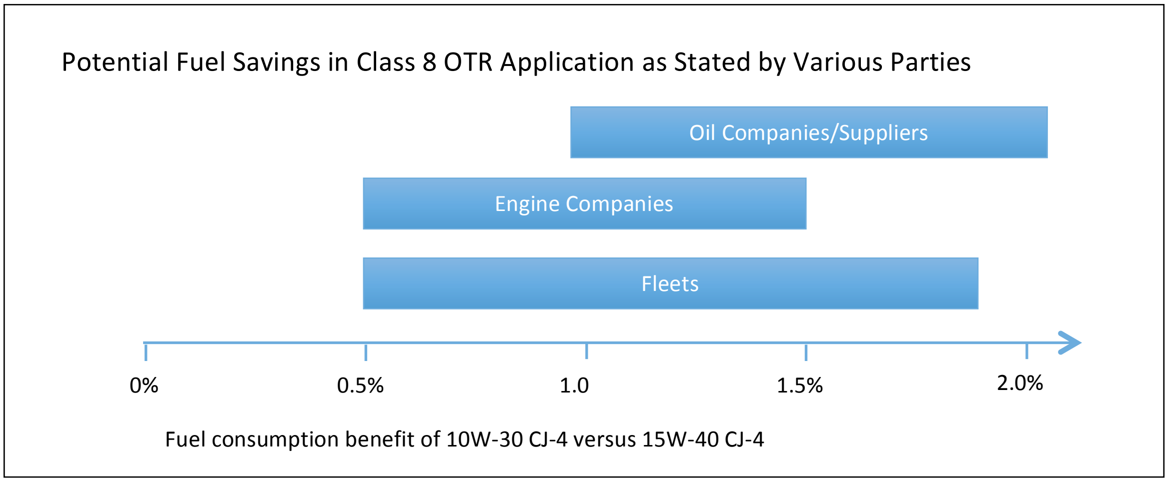


Figure 60: Summary of Fuel Savings potential

In addition to viscosity, additives can also have an effect on the fuel consumption caused by engine oil. The aforementioned Argonne National Laboratory report, as well as one of the industry suppliers interviewed by the study team, both indicated that the impact of additives can be in the range of less than 0.5% to over 1.0%. One reason that additives have an impact on fuel consumption is that friction modifiers, combined with a lower-viscosity base stock, can actually reduce boundary friction, even though the reduced viscosity of the oil overall would otherwise tend to slightly increase that particular type of friction. This can augment the fuel-saving performance of low-viscosity oils, and may in part explain the different fuel savings experienced by fleets when using oils with different additive packages.

3.1. Fuel Savings from PC-11 Oils

At the end of 2016, fleets will have more choices when considering lower viscosity oil. The lower HTHS viscosity FA-4 oil is being developed specifically to reduce fuel consumption below the level of CJ-4 (and future CK-4) xW-30 oil. Engine companies interviewed by the study team were reluctant to share any data on the benefits of FA-4 oil. However, two major oil industry participants did provide the study team with some preliminary data. While one set of data was based on a two-truck test and the other was measured on a test rig, they were consistent in their findings that switching from CJ-4/CK-4 xW-30 to FA-4 xW-30 will yield an additional savings of 0.4-0.7%. (Note that a simple calculation of the potential benefits based on the decrease in HTHS viscosity suggests that the savings may in fact be a bit greater.) Additional test data from the engine OEMs and fleets will eventually help the industry understand the true benefit of FA-4.

There are some stumbling blocks that prevent this study team from reaching a firm conclusion on the benefits of the new oil:

- The data demonstrating the fuel economy benefit is still limited.
- Pricing for the new FA-4 oil has not been revealed at this time although one oil supplier indicated that a price premium should be expected, a reasonable assumption given the incremental investment oil companies are making in the new oil.
- Backward compatibility to older engines remains an open question that the engine OEMs must address. None of the major engine OEMs interviewed by this team indicated that the lower

viscosity oil resulted in any design changes to the engine. While at least one OEM indicated that backward compatibility to some extent is likely, all OEMs remain cautious until further testing is completed.

3.2. Impact of Base Stock

Within the same viscosity grade and API performance category, the base stock (mineral, synthetic or synthetic blend) of the oil chosen does not directly affect fuel consumption.

There is a general assumption that synthetic oils (and thereby synthetic blends) have better performance than mineral-based (conventional) motor oil. This may in part be based on the fact that synthetic oil costs considerably more than its conventional counterpart. A quick check of local retailers confirms that the price difference is considerable (Table 4) although fleet pricing may vary substantially from retail.

	Shell Rotella Triple T (15W40, gallon)	Shell Rotella T5 Synthetic Blend (15W40, gallon)	Shell Rotella T6 Full Synthetic (5W40, gallon)
Major Discount Retailer	$12.97	$16.71	$21.36
Major Auto Parts Retailer	$13.99	$19.99	$24.99
Average versus Conventional		+36%	+53%

Table 4: Retail prices of mineral, synthetic and synthetic blend oil

A commonly stated explanation for this price differential is that, since synthetic oil is a manufactured product, as opposed to the result of refining petroleum, it offers greater control over achieving the desirable properties for a lubricant.

Another commonly held set of perceptions are around the benefits of synthetic oils vs. conventional. In general, these perceived benefits include the ability of synthetic oils to withstand greater temperature ranges, the fact that they are 'slippier,' resulting in greater engine performance and fuel economy, and several others. This study team did not attempt to validate any of these common performance claims, and only assessed the potential impact of synthetic engine oil on fuel economy.

Any discussion with a major oil company on the benefits of synthetic oil typical starts with a definition of synthetic versus mineral oil. As discussed in an earlier section of this report, oil is made up of base stock (~ 80%) and additives (~20%) and it is in regards to the base stock that the distinction is made. In the U.S., of the five base stock categories, oil made with group I and II base stock is considered mineral oil while oil made with group III and IV base stocks are synthetics (group V is a catch-all for anything which does not fall into group IV and is generally not relevant for engine oil lubricants). Initially, only oil made with group IV base stock was considered synthetic, but the definition was diluted in the U.S. after some industry participants successfully argued during the regulatory process that the processing required to create group III base stock in fact meets the definition of a synthetic oil.

Further diluting the definition of synthetic oil is that there is no industry standard on what is considered a “full synthetic” versus a mineral and synthetic blend. A typical 10W30 CJ-4 oil could contain up to 30% group III base stock and still be labeled a mineral oil. Some “full synthetic” oils may be formulated with only group IV base stock, while others may be a blend of group III and IV or even only group III. Each is likely to have different additive packages, resulting in varying characteristics and which, depending on the desired positioning within the oil brand, may all be labeled differently.

Given these blurry definitions, what this all means with respect to the fuel economy performance of synthetic vs. mineral oil remains unclear. A major industry participant could only go so far as to say that any two oils in the same viscosity grade, and with similar HTHS viscosity and additive packages, should have very similar fuel economy impacts, regardless of whether they are categorized as synthetic or as mineral oils. Even this statement was accompanied with a caution for the study team that this assumption only applies to freshly serviced oils. This begs the question of whether synthetic oil will offer improved fuel economy performance over the entire drain cycle, as the ability to maintain a certain performance over the life of the oil is one of the oft-stated benefits of synthetic oils.

No matter what, it is certain that the largest predictor of the fuel economy of an engine oil is the oil’s HTHS viscosity. Assuming no significant dilution (such as from fuel leaks), HTHS viscosity will increase as the oil ages due to thermal oxidation and soot loading. However, not all oils oxidize in the same manner, and every engine creates different types of soot that can have varying impacts on viscosity. Therefore, viscosity changes in oil over its life will vary depending on the oil’s chemistry, the operating conditions of the engine, and the type of soot, amongst other factors. An example of this varying impact is illustrated in Figure 11, which shows the soot concentrations and viscosities of oil in two engines checked at various intervals during a drain cycle.

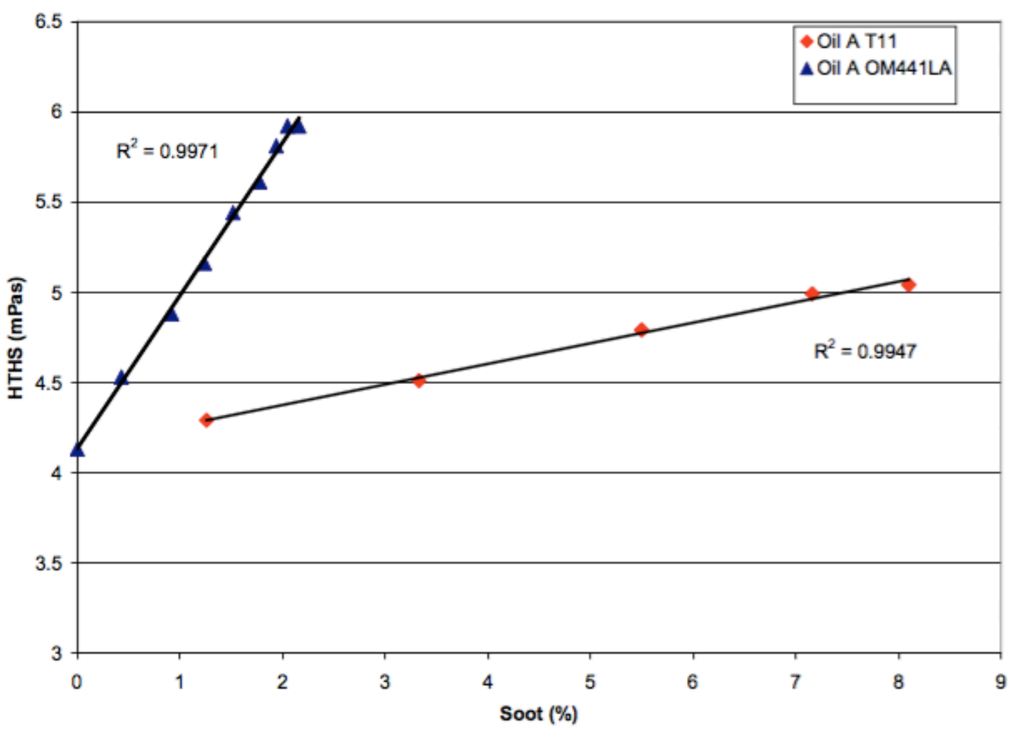


Figure 11: Impact of soot concentration on HTHS viscosity over life of oil

Note that, while most post-2010 engines create much less soot than ones manufactured during the high-EGR, pre-2010 era, the impact from soot on viscosity can be much higher in the newer engines, though the study team was unable to find clear data as to why this is. In the above chart, the engine represented by the blue dots had an increase in HTHS viscosity of nearly 2.0 mPa-s, at a soot concentration level of ~2% (a common concentration in modern SCR-equipped engines at the end of a drain cycle), while the oil in the engine represented by the red points, with a soot concentration that was four times higher at the end of the drain cycle, had an HTHS viscosity increase of less than 1.0 mPa-s. While these exact figures are only true for this particular engine pair, they demonstrate the magnitude that variables such as the type of soot, and not only the amount of it, can have on HTHS viscosity, and thereby fuel consumption. Simply put, this chart illustrates that the relationship between viscosity and soot is not always a direct correlation as many assume.

What is certain is that engine oil will have an increasingly negative impact on fuel consumption as it ages due to its increasing viscosity. Unfortunately, the magnitude of this impact will vary dramatically by engine and possibly by oil brand and type. In sum, it is not possible for the study team to make a general statement on whether synthetic oils will provide a fuel consumption advantage over the life of the oil when compared to mineral oils, given the large impact of other factors such as the type of soot created and the blurry definition of what counts as a synthetic.

Does this mean that all claims regarding synthetic oils are invalid? No, as the focus of the study team is mostly on fuel consumption, and is analyzing categories of technologies, not any one brand or product. Therefore, a particular brand may very clearly define what it labels as synthetic oil, and its offering may outperform the mineral-based oil in the same viscosity category in all manner of performance measures, including fuel consumption. The conclusion of this Confidence Report is simply that there is no categorical benefit of synthetic oil compared to mineral oil when it comes to fuel consumption.

4. Additional Benefits and Challenges

As with most technologies, there are both benefits and challenges entailed in adopting the lower-viscosity oils beyond the fuel savings they offer. Fortunately, the benefits are fairly straightforward, while the challenges are limited in scope.

4.1. Benefit: Extended Oil Drains

15W-40 oil is currently the most commonly sold viscosity grade in the heavy-duty class 8 market. Most 15W-40 engine oils are mineral oil based, and positioned with a lower price point than the lighter viscosities. In contrast, many 5W-30 and 10W-30 engine oils are made from synthetic or synthetic-blend base stocks, and priced as premium products. The synthetic base stocks may give the lower-viscosity oils some favorable characteristics such as resistance to oxidation, and moreover their premium pricing will sometimes translate to a more sophisticated additive package, which can lessen the impact of the factors that typically deteriorate engine oil. In sum, due to these reason, a switch to lower-viscosity oil may allow a fleet to consider an extended drain interval, which can help offset that price premium.

Although the ability to extend drain intervals varies greatly by various factors such as duty cycle, and it should always be done in consultation with engine and oil suppliers, one fleet that this study team interviewed extended their drain interval by 20,000 miles by switching to lower-viscosity oil. Extending drain intervals may require measures such as oil analysis and sophisticated maintenance tracking, which may not be appropriate or accessible for all fleets. In sum, fleets should do their own research to determine whether this benefit will be available to them or not.

4.2. Challenge: Cost

As with most fuel saving technologies, for many fleets there is a cost entailed in switching to low-viscosity engine oil. This is namely for fleets using mineral-based 15W-40 oils; those currently using 15W-40 synthetic oils will not see much of an increase in price, as shown via the quick survey of retail prices in Table 5, which finds little cost difference between two viscosities of synthetic oil within the same brand family, even though the additive packages and even the base stock may vary. (Table 1).

Outlet	Brand/Type	Quantity	xW-40	xW-30	Diff
Major Retailer	Shell Rotella T5	1 Gallon	$16.47	$16.71	1.5%
Online Oil Retailer	Mobil Delvac Elite	4x1 Gallon	$88.92	$90.00	1.2%

Table 5: Retail Prices within same brand family

However, while only a change in viscosity does not result in a significant cost increase, as mentioned, most 15W-40 oil found on the market today is mineral-based, while nearly all xW-30 engine oils are synthetic or synthetic blends. Synthetic and synthetic blend oils are positioned as premium products and command a premium price. At the retail level, a switch from a mineral-based oil to a synthetic blend typically increases cost by 30-40%, even with the same brand family, as shown in Table 4 from section 3.2. Fleets interviewed by this study team did not discuss the exact prices that they receive from their suppliers, but several verified this range of increase. All fleets indicated that prices for synthetic blends are higher than the price for mineral; some also indicated that the price premium has decreased in recent years. Therefore, while this fuel-saving technology does not require an upfront investment to adopt, the higher prices of the oils will increase maintenance costs over the lifetime of the switch, and requires a proper payback calculation by a fleet considering a change.

4.3. Challenge: Compatibility with the entire fleet

Fleets do not want to add any additional sources of complexity in their maintenance shops, or any other part of their operation. So when it comes to engine oil, compatibility with the entirety of a fleet's equipment was cited a basic requirement for adoption by every fleet the study team interviewed.

Every major North American engine OEM has approved lower-viscosity 5W/10W-30 oil versions of the current CJ-4 oil types for their engines going back to at least the 2010 model year.[3] With the introduction of FA-4 oil, compatibility will be a larger issue. Each individual engine OEM must address backward compatibility of FA-4 oil with engines produced prior to 2017. As a result, some large mixed fleets or fleets with older vehicles may find that a switch to FA-4 oil is not possible for their fleet without managing more than one oil type in their maintenance shops.

Of the major fleets interviewed by the study team, while some had switched to 10W-30 and others remained on 15W-40, each fleet was consistent in its requirement that their engine oil had to be compatible with 100% of the vehicles in the fleet. For some fleets this meant compatibility across

[3] The cautionary note is that Navistar limits xW-30 oil to ambient temperatures below 90°F for engines produced prior to the 2017 model year, although the study team was informed that this limitation is historical and not based on any known issues.

several model years, while for others it included compatibility across engine manufacturers and even to lighter-duty gasoline engines. Large fleets may have the physical ability to accommodate more than one oil type, but from an operational perspective, the potential benefit offered by optimizing oil for one particular group of vehicles is outweighed by the risk of filling other engines with the wrong oil.

Fortunately, most manufacturers currently have available a 10W-30 oil that meets current API requirements and the specifications of all major North American engine OEMs for commercial as well as light-duty gasoline engines. The study team even spoke with a fleet that operates a variety of diesel and gasoline-powered equipment, some of it more than ten years old, and who found a 10W-30 oil that met the requirements of its entire fleet.

Some examples of oils that meet current API requirements as well as all major heavy-duty engine OEM specifications are listed in Table 6. Fleets should always check with their engine OEMs to ensure an oil meets their requirements.

Engine Oil Brand/Type	Viscosity	API Class.	Mfg Specifications
Chevron Delo 400 XLE Mobil Delvac Elite Shell Rotella T5 Valvoline Premium Blue	10W-30	CI-4/CI-4 Plus CJ-4 SM	Caterpillar ECF-3 Cummins CES 20081 DDC 93K214 Mack EO-O Premium Plus Volvo VDS-4

Table 6: Examples of engine oils that meet all major heavy-duty engine OEM specifications.

Finally, the study team asked each of the Truck OEMs interviewed for this Confidence Report which viscosity grade of oil they are currently filling and will be providing in their engines in 2017. With the exception of Cummins, every major engine OEM currently ships their engines with a 10W-30 oil that meets their specification, and expects to continue to do so in 2017 with the CK-4 classification. Cummins, which only ships some of their engines pre-filled with engine oil, has not yet determined whether they will switch to 10W-30 from the 15W-40 they currently use.

The OEMs are not expecting to ship engines pre-filled with the FA-4 oil because the OEMs do not anticipate needing the gain in fuel economy that it offers to meet their requirements under the U.S EPA's Phase 2 Greenhouse Gas regulations. The study team speculates that the likely price premium of FA-4 oil compared to CK-4 is also dissuading OEMs from adopting. Fleets which are highly conscious of fuel efficiency may still choose to explore FA-4 on their own, given the additional fuel savings it should offer.

Given the fact that all major engine OEMs have approved 10W-30 engine oil, and the wide availability of oil that meets all major manufacturer specifications, fleets are finding that there is little risk of losing compatibility with their entire fleet when deciding to switch away from the traditional, high-viscosity 15W-40 and the higher fuel consumption that oil causes.

5. Insights from Fleets

Fleets considering a change in engine oil typically approach this decision with a bit of caution, and for good reason. Fleets should discuss any considered change in oil with their engine OEM(s) and oil suppliers, as every fleet interviewed by the study team for this report did before switching. The ones that do decide to switch will find that engine issues arising from adopting an approved lower-viscosity oil are no more common than with a 15W-40, and that engine OEMs will stand behind their products whenever an approved oil is used. There are rare examples where a change in engine oil had disastrous consequences for seemingly the most minor of reasons; however none of the fleets interviewed by the study team for this report attributed a single engine issue to a change to lower-viscosity engine oil.

The following two case studies illustrate the experience of two different fleets in analyzing the benefits and challenges of switching from higher-viscosity 15W-40 to lower-viscosity 10W-30 engine oil.

5.1. Case Study #1 – National Truckload Carrier

Fleet Description

- National truckload carrier with some dedicated operations
- Operating in the lower 48 states and Canada
- Average annual miles: 115,000 miles
- Mixed Class 8 fleet
- Average vehicle age: ~ 2 years

This particular fleet tests a variety of fuel economy improvement measures on an ongoing basis. As most fleets, they had been using a well-known brand of 15W-40 mineral-based engine oil for many years. Given their reputation as a fleet dedicated to fuel efficiency, their oil supplier approached the fleet about testing 10W-30 engine oil. In comparison to some of the other fuel saving technologies they explored and adopted, the expected savings from switching to a lower engine oil viscosity were fairly modest: just 1-2%. However, unlike many other technologies, this change did not require an upfront investment or a change in their practices, though it did increase the cost of their oil on an ongoing basis.

Benefits & Cost

There were two main reasons the fleet decided to test the lower-viscosity oil. One was to improve cold-start during winter in their northern locations, the other was to improve fuel efficiency.

A no-start due to cold weather is relatively rare in modern heavy-duty trucks, but fleets are nonetheless keen to prevent them as they result in lost productivity and a potential road-service call. When it does occur, most often the cause is a weakened battery or some other extenuating circumstance. Long cold starts also have an effect on fleets; though the cost is less apparent, they may result in accelerated starter wear over time, and cause a reluctance by drivers to turn off their engines, resulting in fuel loss from idling. Therefore, a reduction of no-start or long cold start issues was difficult to quantify but expected to be a benefit for this fleet from switching to lower-viscosity engine oil.

With regards to the fuel savings, the fleet was similarly realistic about their ability to measure the benefits of adoptions. Even in their dedicated operations, there is enough variability from temperature, tire wear, different trailers, driver behavior, and other factors that makes detecting an improvement of less than 2% very difficult. Rather than dedicating the significant resources needed to run a controlled fuel economy test, the fleet decided to accept the science behind low-viscosity engine oil and assumed a fuel consumption benefit of 0.5% in their planning.

Since this fleet was switching from a mineral-based 15W-40 oil to a synthetic blend 10W-30 oil, it faced a significant cost increase in its ongoing oil purchase price. However, the fleet calculated that they would earn an acceptable ROI on their increased oil cost even using the conservative 0.5% fuel savings, and felt confident in implementing the change.

Implementation

This fleet performs about 50% of its oil changes in-house with most of the balance of their oil changes occurring at major truck stop chains. They negotiated an acceptable price for their bulk in-house oil purchases but, continue to use 15W-40 oil for oil changes performed outside of their facilities.

The implementation itself was very simple for the fleet. Drain intervals were kept the same, and no other changes were required to use the lower-viscosity oil. It has been nearly two years since they made the switch. They continued to conduct occasional random oil analysis, as they had prior to the change, and they have found no issues related to the lower-viscosity engine oil.

Looking Forward

This fleet continues to look for further advances in technology that will improve their efficiency. The new PC-11 oil of FA-4 will offer another such opportunity for them to enjoy better efficiency from their engine oil. They expect improves in fuel consumption over their current 10W-30 oil, of around 1%, still an amount that will be difficult for them to measure. Pricing of FA-4 also remains an unknown, and there are potential issues related to compatibility with their existing fleet that must be addressed with their engine OEMs. However, these are all addressable issues, and the fleet intends to study their options when the new oils appear on the market.

5.2. Case Study #2 – Carrier with Dedicated Operations

Fleet Description

- National truckload carrier with some dedicated operations
- Operating in the lower 48 states and Canada
- Average annual miles: 80,000 - 110,000 miles depending on operation
- 90% Class 8 fleet from a single OEM Class 8
- Average vehicle age: less than 2 yeas

This fleet is also well-known for continuously testing and implementing fuel savings measures. Management recognizes that validating and implementing fuel-saving investments takes time, but is a high priority in this era of fluctuating fuel prices.

The fleet tracks their oil performance and manages their oil drain interval very closely, and they perform the majority of oil changes in-house. Of the remaining oil changes, many are performed at large truck-stop chains with which the fleet has contracts, and specifies their own oil type and brand. This gives the fleet fairly good control of the oil used in its vehicles.

The fleet had considered a switch to 10W-30 oil for about a year prior to actually testing. During that year they closely consulted with their engine supplier about their oil options, and also requested and received a considerable amount of information and data from their oil supplier on the potential fuel savings. The experience of an individual fleet will be specific to their unique operations, but the availability of the data at least assured them that their expectation of fuel savings was realistic.

Testing

While the change from a mineral-based 15W-40 oil to a synthetic blend 10W-30 was motivated by the fuel savings opportunity, this fleet's engine OEM and oil supplier agreed that an extension in the oil drain interval was also possible thanks to the switch. Therefore, even though the extended drain intervals was considered a side benefit, much of the testing of the new oil was focused on validating the longer oil drain interval.

Thirty vehicles were chosen for testing. Oil sampling was conducted every 5,000 miles, up to the desired oil change interval, requiring approximately half of a year of testing to validate the longer drain cycle. Validating fuel savings did not take as long, and the fleet conducted an SAE-type test to quantify the fuel savings.

Benefits & Cost

The fleet's fuel testing indicated a reduction in fuel consumption of 1.5-1.8%, a result that was high enough to allow for some conservatism in their ROI calculations, to allow for variance in the fleet's operations. When synthetic blend 10W-30 oils first entered the market, the price premium was significant – enough to keep most fleets from even testing them. That premium has diminished over the years, and this fleet found that an acceptable ROI could be achieved using even a more conservative fuel savings assumption than the amount suggested by their tests.

Implementation

Once the decision was made, the new lower-viscosity oil was rolled out to the maintenance facilities and implemented at the fleet's offsite facilities quickly. The fleet uses maintenance management software to track and manage the oil drain interval for each vehicle specifically, so an update to the standard drain interval was easy to implement and transparent to much of the organization.

Prior to committing to the change, the fleet asked for and received guarantees from their oil supplier against any engine failure that could be attributed to the new engine oil. Fortunately, in the two years since implementation, there has not been an engine failure related to either the engine oil or the new drain interval. With many more vehicles and miles, the fleet has also confirmed that the fuel savings match the higher results shown in their initial test of around 1.5%.

Looking forward

This fleet also intends to test the new FA-4 oil as soon as is practical. Given the rapid turnover of older vehicles they anticipate the ability to implement the new oil very early if tests confirm an additional fuel savings, even without backward compatibility, thus giving this fleet a further edge in fuel consumption.

5.3. Insights from Interviews

In conducting the research for this Confidence Report the study team spoke with fleets, engine OEM, oil manufactures, and others about the fuel savings available from lower-viscosity engine oil, and the challenges and benefits of adoption. The following quotes offer a sample of insights from these interviews:

- "The price of fuel will eventually increase and we won't be able to make changes (to reduce fuel consumption) fast enough when we have to." – VP, fleet maintenance
- "It would be a pain to try to maintain two engine oils." – VP, fleet maintenance
- "Most people associate higher viscosity with better engine protection, but that sentiment is breaking down." – Engineer, Oil co.
- "Most fleets and buyers of oil point to the viscosity as the primary identifier of an oil." – Engineer, Oil co.
- "Studies that we have commissioned indicate that the on-highway segment is about 67%-75% 15W-40 and about 20% 10W-30, with the percentage of 10W-30 increasing as the fleet size increases." (On oil types used by the industry today) – Marketing manager, Oil co.
- "At some point, the cost of the increased fuel consumption will more than offset the benefit of an extended oil drain interval." (That is to say, extending a drain interval by too much could offset the fuel economy benefit of switching to a lower viscosity oil.) – Chief Engineer, Oil co. supplier
- On the fuel consumption benefit of 10W-30 vs 15W-40: "Own-truck testing indicates achievable improvements of ~ 1%. Span of improvements increases in applications with more stop-and-go." – Senior engineer. Oil co.
- "There is a quantifiable fuel savings with lower viscosity oils in controlled engine tests. In most cases, the improvement is bigger when measured in the field. Field testing may exceed what we see in the test cell .5-1%, and even 1.5%. Depends on the duty cycle, of course." – Engineer, Engine OEM
- On the reason for using 15W-40 vs 10W-30: "People used to believe that the higher number is critical in determining engine protection. This is not true anymore." – Engineer, Engine OEM

6. Conclusions

Given the wide availability of data on the impact of low-viscosity engine oil on fuel consumption, the study team has arrived at three conclusions:

- Interviews and literature indicate that Class 8 over-the-road fleets can realistically expect fuel savings in the range of 0.5% to 1.5% from switching from 15W-40 to currently available 5W/10W-30 engine oil. The savings from switching to the fuel-efficient FA-4 variant, available after December 2016, can be expected to add a further 0.4-0.7% of increased fuel efficiency.
- All major North American engine OEMs have approved 5W/10W-30 engine oil for over-the-road applications. Approved oils, regardless of viscosity, meet the engine manufacturer's requirements for engine protection.
- Within the same viscosity grade, the base stock (mineral, synthetic or synthetic blend) does not directly affect fuel consumption.

6.1. Recommendations

In addition to the above three conclusions, the study team's research has produced the following four recommendations for the industry regarding accelerating adoption of lower-viscosity engine oil and unlocking the fuel efficiency benefits it offers:

- Fleets currently using 15W-40 engine oil should consult with their engine supplier(s) to identify approved 5W/10W-30 oils for their vehicle(s). They should then work with their oil supplier to find an acceptable ROI of cost vs. fuel savings, with a conservative assumption for fuel economy improvement. This Confidence Report was published along with an ROI calculator from that fleets could use for this.
- Oil marketers, and other parties that have completed a significant body of testing an engine oil, should make that test data available in an open, examinable manner.
- All engine OEMs should complete the testing required to approve 10W-30 CJ-4/CK-4 for over-the-road applications in all seasons for North America for engines built prior to 2017.
- Engine OEMs should likewise accelerate the adoption of FA-4 oil in the industry by approving backward compatibility of FA-4 oil, or by helping fleets establish a procedure to test for backwards compatibility of FA-4 oil in their operation for their entire fleet.

6.2. Decision Guide

The study team has compiled the following guide to help fleets that want to benefit from the reduced fuel consumption offered by lower-viscosity engine oil.

Description of Fleet at Present	Suggested Fleet Action
Using 15W-40 mineral based oil	Check with engine OEM(s) for approved 5/10W-30 oil & work with oil supplier to find acceptable ROI assuming 0.5% fuel savings
Using 15W-40 synthetic or synthetic blend oil	Check with engine OEM(s) for approved 5/10W-30 oil and switch. Fleet should see no significant cost increase
Single sourced engine OEM fleet using 5/10W-30 oil	Work with engine OEM and oil supplier to accelerate backward compatibility of FA-4 to their application
Multi-sourced engine OEM fleet using 5/10W-30 oil	Consider isolating any FA-4 approved vehicles to a location where implementation of FA-4 oil could be practical

Table 7: Decision Guide for Lower-Viscosity Engine Oils for Class 8 Trucks

6.3. Confidence Rating

For each of the Confidence Reports completed by Trucking Efficiency, the various technologies assessed therein are plotted on a matrix in terms of their expected payback in years compared to the confidence that the study team has in the available data on the performance of that technology – that is, not only how quickly fleets should enjoy a payback on their investment, but how certain Trucking Efficiency is in the assessment of that payback time. Technologies in the top right of the matrix have a short payback, usually thanks to their low upfront cost, and moreover are found to have enough perforamnce data that fleets can be highly confident in those short payback times, usually because the technology is more mature or otherwise has a more substantial track record of results.

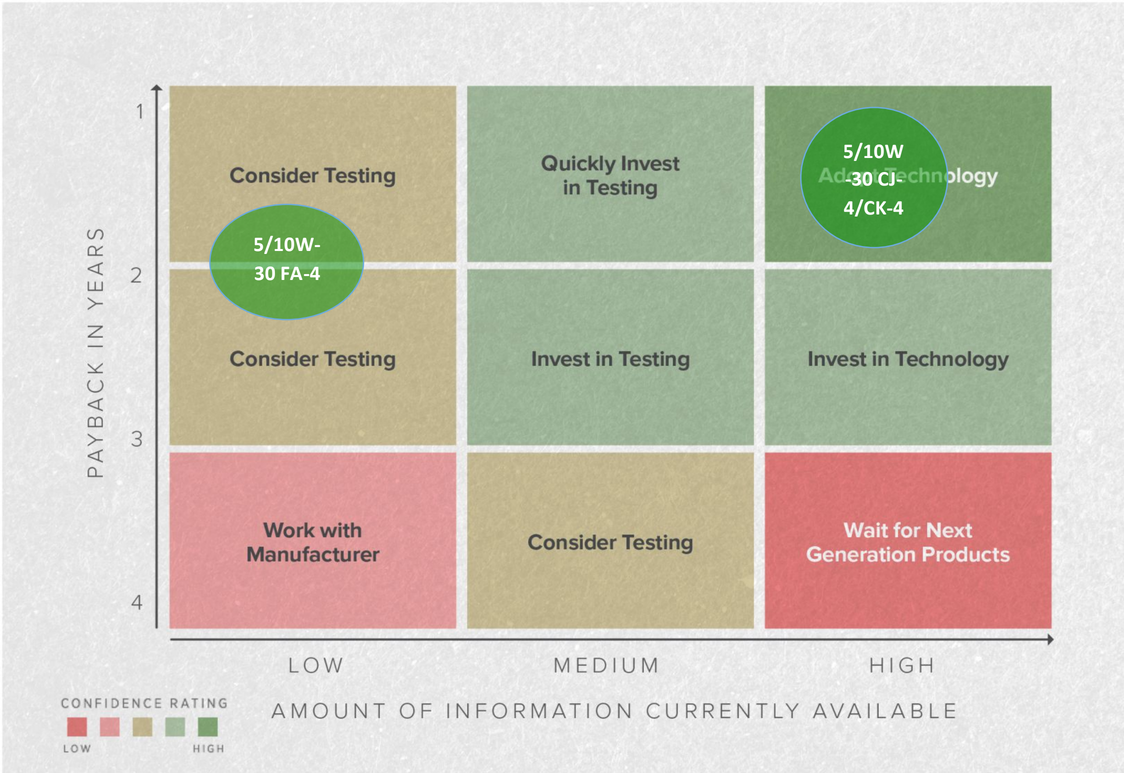


Figure 12: Confidence Matrix of Lower-Viscosity Engine Oils for Class 8 Trucks

Appendix A – References

First Occurrence	Reference	Source
Section 2.1	API Base Oil Interchangeability Guidelines for Passenger Car Motor Oils and Diesel Engine Oils	http://www.api.org/certification-programs/engine-oil-diesel-exhaust-fluid/~/media/files/certification/engine-oil-diesel/publications/appendix-e-rev-09-01-11.ashx
Section 2.2	Cummins Engine Oil and Oil Analysis Recommendations (Service Bulletin 3810340)	Cummins, Inc.
Section 2.4	API Service Categories	http://www.api.org/products-and-services/engine-oil/eolcs-categories-and-documents/oil-categories#tab_diesel
Section 2.4.1	SAE Viscosity Grades	http://www.viscopedia.com/viscosity-tables/substances/sae-viscosity-grades/
Section 2.4.1	What is PC-11	http://www.whatispc-11.com
Section 2.4.1	Beyond CJ-4: Introducing PC-11, the new HDDEO Performance Category	http://hddeo.com/IntroducingPC-11.html
Section 3	Argonne National Laboratory, Lubricants – Pathways to Improving Fuel Efficiency of Legacy Fleet Vehicles	http://energy.gov/sites/prod/files/2014/03/f8/deer11_fenske.pdf