LINKING LUBRICANTS TO FUEL ECONOMY AND CARBON DIOXIDE EMISSIONS

AN ON-THE-ROAD DEMONSTRATION OF THE FUEL ECONOMY ADVANTAGE OF USING LOW-VISCOSITY OILS

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“THE STARSHIP TRUCK ACHIEVED NEARLY TWO AND A HALF TIMES GREATER FREIGHT TON EFFICIENCY THAN THE NORTH AMERICAN AVERAGE.[1] ”

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In 2018, the Starship truck made a six-day journey across the USA and achieved nearly two and a half times greater freight ton efficiency (FTE) than the North American average.[1] To achieve this substantial carbon dioxide (CO_2) emission reduction and fuel saving, the truck combined many technologies, including low-viscosity lubricants, all of which had to be currently available, affordable and accessible. This paper describes the link between lubricants, fuel economy and CO_2 emissions.

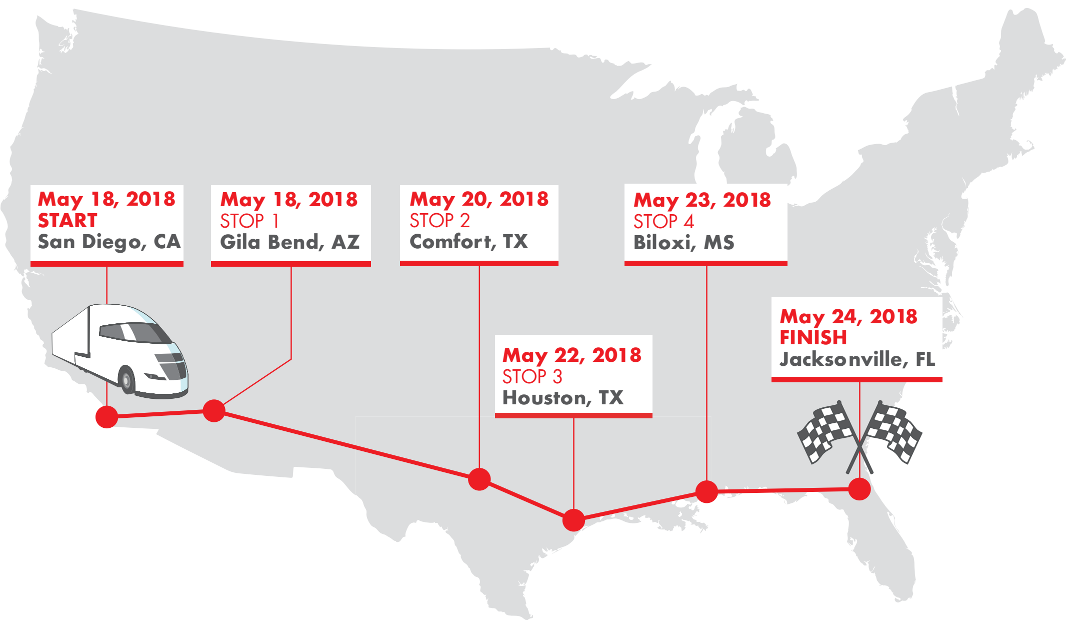

FIGURE 1. The Starship truck's six-day transcontinental route.

During its coast-to-coast crossing (Figure 1), the Starship truck carried 19.95 tons of freight, yet still managed a fuel economy of 8.94 mpg for an FTE of 178.4 ton-mile/US gal.[2] In comparison, the average North American truck has a fuel economy of 6.4 mpg[1] and carries 11.25 tons for an FTE of 72 ton-mile/US gal.

Carrying a full load contributed significantly to the impressive results. If every truck in the USA were to carry its maximum load, 871,000 fewer trucks would be necessary. If the remaining trucks achieved the Starship truck's 8.94-mpg fuel efficiency, then the fleet's CO_2 emissions would be cut by 60%.[3]

Maximizing every load is challenging and new technologies can take decades to penetrate the global fleet, but there are fuel economy improvements that can be made quickly and inexpensively – and with substantial financial benefits for fleet operators. For example, if every US truck increased its fuel economy by just 1%, the total saving for fleet owners and operators would be $3 million a day.

Fleet operators can achieve fuel-economy improvements of a few percent almost instantly through driver behavior training and using low-viscosity engine oils.

> **LOW-VISCOSITY OILS** CAN IMPROVE FUEL ECONOMY WITHOUT COMPROMISING ENGINE PROTECTION TO KEEP TRUCKS ON THE ROAD.

The Starship Initiative

The Starship Initiative set out to design an exceptionally energy efficient Class 8 truck by combining current technologies to reduce the energy used to transport goods in an affordable and accessible way – so no new concepts or wildly expensive solutions. The truck was co-engineered by AirFlow Truck Company and Shell.

The idea was to demonstrate how good today's trucks could be if promising energy efficiency concepts, including aerodynamic features such as truck and trailer side skirts and boat tails, and low viscosity fuel economy lubricants, were to be drawn together in one place. Each of the major truck, driveline and operating features that contribute to energy use was considered.

Although modifications like streamlining bodywork are highly visible and their fuel economy benefits are intuitive, the truck's lubricants are hidden and their role in fuel efficiency is, perhaps, less obvious.

OIL VISCOSITY, FUEL ECONOMY AND CO_2 EMISSIONS

Imagine the effort required to wade through water compared with walking through air. Pushing through water would use up your energy more quickly, make you breathe harder (and emit more CO_2) and, eventually, make you hungry (wanting to replace spent fuel).

As in the analogy, the engine requires less engergy to pump a low-viscosity lubricant. This leaves a little more energy to drive the truck along the road and, thus, slightly reduces the fuel demand and the associated CO_2 emissions.

Viscosity is the resistance to flow. Thicker fluids have a greater resistance to flow than thinner fluids. Different test methods and conditions are used to measure viscosity.

For heavy-duty diesel engine oils, one method for measure of flow resistance or thickness during engine operation is known as the high-temperature, high-shear (HTHS) viscosity.

The HTHS viscosity has a linear correlation with fuel economy: the lower the HTHS, the higher the fuel economy benefit (Figure 2). In other words, thinner oils improve fuel economy. However, the relationship is not quite so simple, as lubricants need to perform many functions, not least reducing friction between components moving past each other and protecting these parts from wear.

Engine oils as fuel economy enablers

Engine oils are also enablers for other technologies that are essential for high engine efficiency. For example, engines operating at high torque and low speed tend to be more fuel efficient. While nearly all heavy-duty diesel engines are turbocharged and intercooled to allow high torques to be developed, the bias towards up-torqueing and down-speeding exaggerates the role of these devices, driving them to operate at higher temperatures and pressures. Modern lubricants therefore need to withstand this hotter, more hostile, environment if the possibilities of higher torque operation are to be realized. Thus, although in this example, the lubricant is not improving fuel economy directly, its robustness facilitates engine operating styles which do improve engine efficiency.

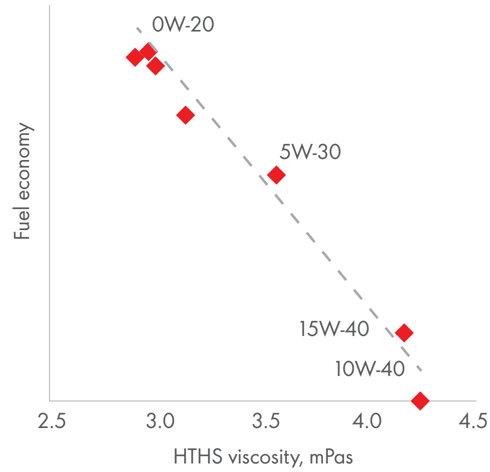

FIGURE 2. The relationship between HTHS viscosity and fuel economy.

LOWERING VISCOSITY WITHOUT COMPROMISE

Low-viscosity oils help to improve fuel economy and thus reduce CO_2 emissions and fuel consumption. However, simply lowering the viscosity is not enough. A hyper-fuel-efficient oil would be useless if it led to overly frequent maintenance or premature engine failure. Low-viscosity oils need to improve fuel economy without compromising engine protection to keep trucks on the road and operating costs down.

The latest fuel-efficient engines require oil to provide protection under harsh operating conditions. Operators also expect longer oil-drain intervals and lubricants must work in the presence of biofuels. In short, low-viscosity oils must work harder, under more severe conditions and for longer.

By expertly combining synthetic base oil and advanced additive technologies, Shell has created a portfolio of low-viscosity oils that do not compromise protection.

Shell Lubricants has a long history of developing and deploying low-viscosity engine oils for heavy-duty diesel engines. More than 20 years ago, it was the first company to launch a 10W-30, low sulfated ash, phosphorus and sulfur (low-SAPS) oil. The protection provided by these low-viscosity engine oils, for example, Shell Rotella T5 Ultra, has been proven in millions of miles of field trials and in the market.

FROM PROTECTING LOCAL AIR QUALITY TO LOWERING GLOBAL EMISSIONS

Driven by the need to improve local air quality, regulations in the USA and Europe have led to tighter particulate matter and nitrogen oxide (NOx) limits (Figure 3). The introduction of diesel particulate filters to help meet the particulate limits had implications for engine oils. The additives used to boost an oil's wear protection and cleansing abilities can form ash when burned. This ash is captured along with soot in the diesel particulate filter. The diesel particulate filter must be cleaned periodically to remove the ash that has accumulated.

To help maximize diesel-particulate-filter service life, Shell Lubricants developed diesel engine oil formulations that contain lower levels of ash-forming components and help to control oil consumption.

With the growing acknowledgment that the world is facing a climate emergency, the focus is now shifting to improving fuel economy to reduce CO_2 emissions.

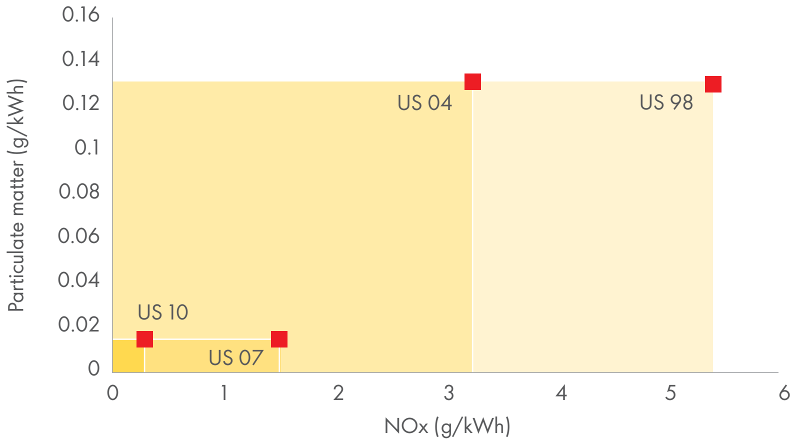

FIGURE 3. Tightening particulate matter and NOx limits.

> **BY EXPERTLY COMBINING** SYNTHETIC BASE OIL AND ADVANCED ADDITIVE TECHNOLOGIES, SHELL HAS CREATED A PORTFOLIO OF LOW-VISCOSITY OILS THAT DO NOT COMPROMISE PROTECTION

CREATING A FLEET OF FULLY LOADED STARSHIP TRUCKS COULD CUT THE US FLEET'S CO_2 EMISSIONS BY 60%.

NEW SPECIFICATIONS FOR LOWERING EMISSIONS

In 2016, the American Petroleum Institute (API) completely redesigned heavy-duty diesel engine oil specifications with the introduction of the API CK-4 and FA-4 performance categories.

Both CK-4 and FA-4 categories target improved oxidation stability, aeration control and shear stability compared with API CJ-4 oils. CK-4 oils have a minimum HTHS viscosity of 3.5 cP (similar to API CJ-4 products) and are designed for current engine technologies and are backwards compatible.

FA-4 oils have lower HTHS viscosities (2.9–3.2 cP) that offer the potential for improved fuel economy while providing the same protection benefits as CK-4 formulations. These oils are intended for newer engines.

The trend for lower viscosity synthetic and synthetic-blend heavy-duty engines oil is expected to continue with potential SAE 5W-20 and 0W-20 oils in the not-so-distant future. These lower viscosity oils will provide additional improvements in fuel economy and reductions in CO_2 emissions.

PROVING THE FUEL ECONOMY ADVANTAGE OF LOW-VISCOSITY OILS

From laboratory to road

The fuel economy benefits of low-viscosity oils that do not compromise oil durability and wear protection have been demonstrated using the precision of laboratory testing and real-world field trials. At Shell, developing a fuel-efficient, heavy-duty engine oil has four basic steps:

1. Significant **laboratory work** using friction or rig tests evaluates the effects of oil formulation on component friction. Many formulations can be screened quickly to assess the effects of different base oil and additive properties.
2. Fired **engine tests** measure an engine's fuel efficiency using different lubricant formulations. In an engine test cell, parameters such as engine speed, load, engine coolant temperature and duty-cycle can be precisely controlled. And, accurate fuel consumption and emissions can be measured.
3. **Chassis dynamometer tests** evaluate vehicle performance with different lubricant or fuel formulations. Simulations of different driving cycles and terrains can be controlled and accurately repeated. Many aspects of vehicle performance can be standardized to enable precise measurements of small differences in vehicle speed, load and temperature, for example. Sophisticated experiments can even use robot drivers to minimize the effects of human variability or errors.
4. The final step is **field trials** on fleets of vehicles at third-party sites. Such field trials enable Shell scientists to test lubricants under real-world conditions: on the road with driving conditions and loads representative of urban and/or highway driving.

Real-world results

Fleet owners and operators want to know that the fuel economy benefits proven in laboratories translate to on-the-road savings. Field evaluation is difficult because many factors influence real-world fuel economy. To isolate the lubricant effect, Shell ran a large-scale field trail that minimized the number of variables to be controlled and standardized those variables that could not be controlled. This approach eliminated bias to give trustworthy results.

Six different oils were tested, including a reference CK-4 SAE 15W-40 oil, an FA-4 5W-30 oil and a test formulation with a viscosity as low as SAE 0W-20.

The field trial was conducted in the USA using six different trucks meeting 2010 emission standards and equipped with diesel engines from Cummins, Detroit, Paccar, Navistar and Mack. The Society of Automotive Engineers' industry-standard drive cycles designed to represent urban (J1321) and highway (J1526) conditions were used.

To give confidence in the results, the measurements were repeated and averaged over 24 days at a certified independent test house. The experiments were carefully designed to minimize variables that could not be controlled such as weather and humidity, and each truck and lubricant was tested on every test day. The lubricants were allocated to trucks on a careful statistical design basis to ensure that differences in fuel use between the different engine oil formulations were statistically significant at the 95% confidence level.

Shell Rotella 10W-30 synthetic-blend CK-4 lubricant gives a 2% fuel economy benefit compared with a standard 15W-40 oil.[4]

A prototype 0W-20 oil showed even stronger fuel economy benefits: a gain of more than 3.7% compared with the 15W-40 oil and almost a 2.9% gain on the 10W-40 oil. Although a 0W-20 grade will not be viable until manufacturers co-engineer their engines for such a low-viscosity oil, it illustrates the potential gains.

THE STARSHIP TRUCK'S OIL

The Starship truck used a used Shell Rotella® T6 Ultra full synthetic 5W-30 oil which meets API FA-4 performance standard and has demonstrated outstanding engine protection over millions of miles of real-world service. The fuel economy benefit is likely to be higher than the 2% gain from switching from a 15W-40 to a 10W-30 oil demonstrated in the field trial.

The truck also used synthetic Shell Spirax® S6 GXME 75W-80 transmission fluid, Shell Spirax® S6 ADE 75W-85 axle oil and advanced Shell Spirax® S6 GME 40 wheel hub oil to improve its drivetrain efficiency.

A QUICK WIN

Creating a fleet of fully loaded Starship trucks could cut the US fleet's CO_2 emissions by 60%. This kind of transformation would take time, but there are fuel- and CO_2-saving measures that fleet operators can implement quickly and inexpensively. One of these is to use low-viscosity lubricants in newer engines where the engine manufacturers' specifications allow. This is because low-viscosity lubricants take less power from the engine, which leaves a more power to drive the truck and thus uses less fuel for the same distance.

Unlike many fuel-efficiency technologies which cannot easily be retrofitted, lower viscosity oils can be added anytime in a truck's life and can be applied across a fleet. As such, using lower viscosity engine oil can pay back quickly.

In field trials, Shell Rotella® T5 synthetic blend 10W-30 oil demonstrated a 2% fuel economy benefit compared with a standard 15W-40 oil. A 1% improvement in fuel economy would save US fleet owners and operators $3 million a day!

The Shell Starship initiative also demonstrated some of the other things that fleet operators can do. In addition to using low-viscosity lubricants, they could also consider driver training and using low-rolling-resistance tires and aerodynamic devices to help reduce emissions and cut costs.

[1]North American Council for Freight Efficiency: "Run on less report," (2018): nacfe.org/run-on-less-report

[2]North America Council for Freight Efficiency data verification report for Starship truck coast-to-coast test drive

[3]Reductions in annual CO_2 emissions calculated as if all trucks in the USA operated at the same FTE (ton-miles/US gal) as the Starship and the scale of the fleet was reduced to balance the increased loading. CO_2 emissions refer to those from the combustion of diesel fuel alone with a standard emission rate of 22.4 lb of CO_2 per US gallon of diesel fuel.

[4]Clevenger, S.: "Low-viscosity engine oils will support push for improved fuel economy, Shell says," TTNews (2018): www.ttnews.com/articles/low-viscosity-engine-oils-will-support-push-improved-fuel-economy-shell-says.com