HEAVY IRON RELIABILITY

Volume One | 2007

PUBLISHED BY CHEVRON GLOBAL LUBRICANTS FOR THE CONSTRUCTION INDUSTRY

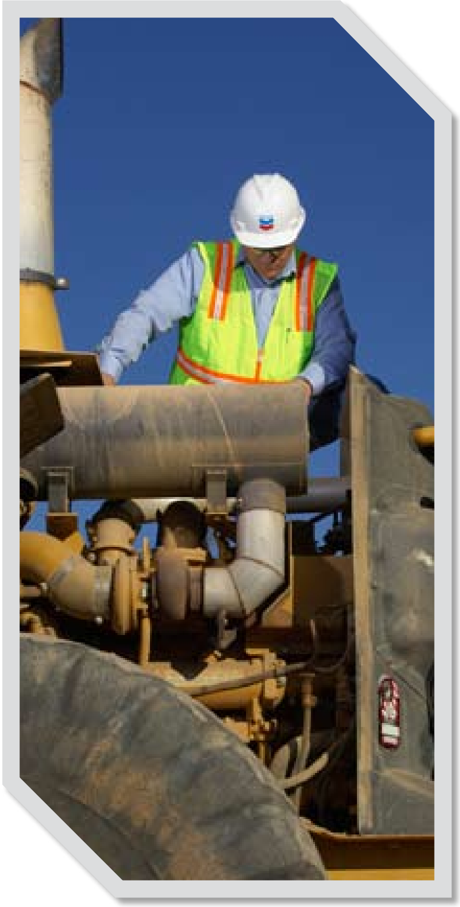
The Effect of Ultra-Low Sulfur Diesel on Off-Highway, Diesel-Powered Equipment

More stringent exhaust emissions regulations are forcing the heavy-duty diesel engine market to undergo a revolutionary transformation. The result is that fundamental changes in the diesel engine and exhaust hardware require engines, exhaust hardware, fuels, and lubricants to work in concert to lower emissions from diesel-powered equipment.

This transformation has already affected the on-highway heavy-duty diesel engine market in 2007 with the introduction of new engine and exhaust hardware, modified engine operations, new fuels, and new engine oils. While the off-highway emissions regulations follow those of the on-highway market by about four years, the impact of these changes will be seen much sooner in the off-highway applications as diesel fuels and engine oils designed for the on-highway engine market are available for the off-highway market. What changes are coming for the off-highway market? How will these changes affect the operations and maintenance practices of off-highway equipment operators? This article answers these questions. The key to making the right choices in business is possessing the right information.

Emissions Regulations are Driving Industry Change

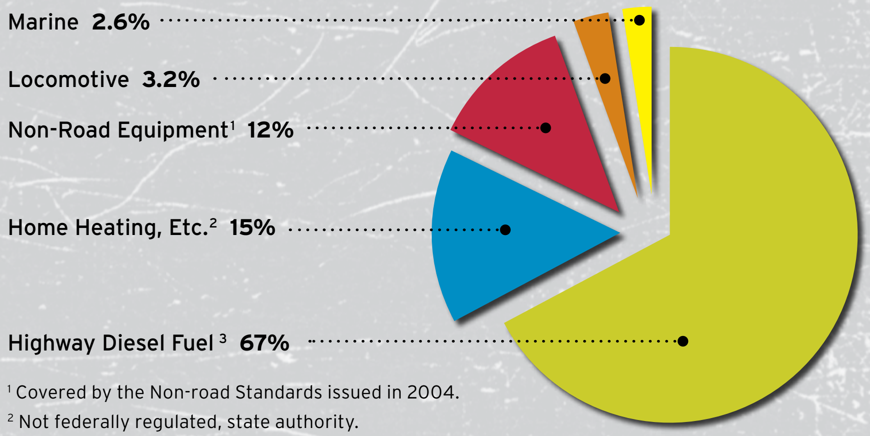
In 2001, the U.S. Environmental Protection Agency (EPA) finalized the *2007 Heavy-Duty Highway Diesel Program,* a comprehensive program to lower the emissions from highway diesel engines. The federally-mandated program included new emissions standards for model year 2007 and later highway diesel engines and lowered the maximum sulfur level for 80% of the on-highway diesel fuel from 500 to 15 parts per million (ppm) starting in June 2006. This new, lower sulfur diesel fuel, *Ultra-Low Sulfur Diesel (ULSD) or S15,* is necessary for the engines to meet the low emissions standards. Fuel sulfur levels directly correlate to sulfate particulate



emissions. Therefore, reduction of fuel sulfur directly reduces particulate emissions in all generations of diesel engines.

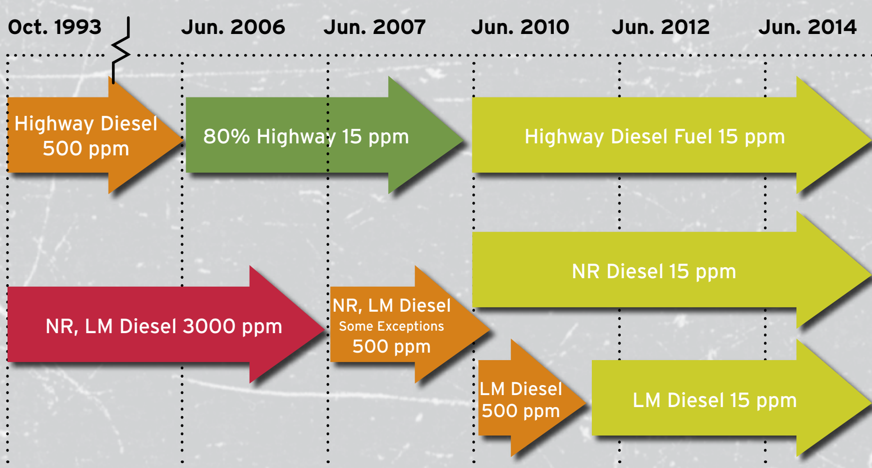
Figure 1: **Distillate Fuel Market Distribution (U.S. Market)**

(Total Market = 59 Billion gallons/year)



[1] Covered by the Non-road Standards issued in 2004.
[2] Not federally regulated, state authority.
[3] Regulated since 1993, new requirements in 2006.

Figure 2: **Diesel Fuel Sulfur Limits**



* This figure is intended to illustrate the timeline for the final highway and non-road diesel fuel sulfur control programs. Not drawn to exact scale. Refer to 40 CFR Part 80 for specific program dates. NR = non-road diesel, LM = locomotive and marine diesel.

In 2004, the EPA issued the Clean Air Non-road Diesel – Tier 4 Final Rule, which extended the emission control program to off-highway diesel engines in these categories:

- Tightened off-highway diesel engine emission regulations starting in 2008
- Lowered off-highway diesel fuel sulfur levels from 3,000 to 500 ppm in June, 2007 and from 500 to 15 ppm in June 2010

Figure 1 illustrates the percentage of the US distillate fuel market used by non-road equipment. Figure 2, Figure 3, and Figure 4 provide more details about the phase-in of the diesel sulfur standards and off-highway diesel engine emissions standards.

While federal regulations do not require ULSD in the off-highway market until 2010, it appeared in some areas as early as 2006 because of the complexity required to manufacture and distribute multiple fuels with different sulfur levels. In a recent survey of refiners and marketers, the EPA discovered that 95% of the highway diesel fuel was ULSD starting June 2006 even though only 80% was mandated. Most refiners will produce only one grade of highway diesel, ULSD. For this reason, it is critical that off-highway equipment managers realize the effect ULSD could have on their operations.

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Figure 3: **Non-Road Emissions Standards Timeline**

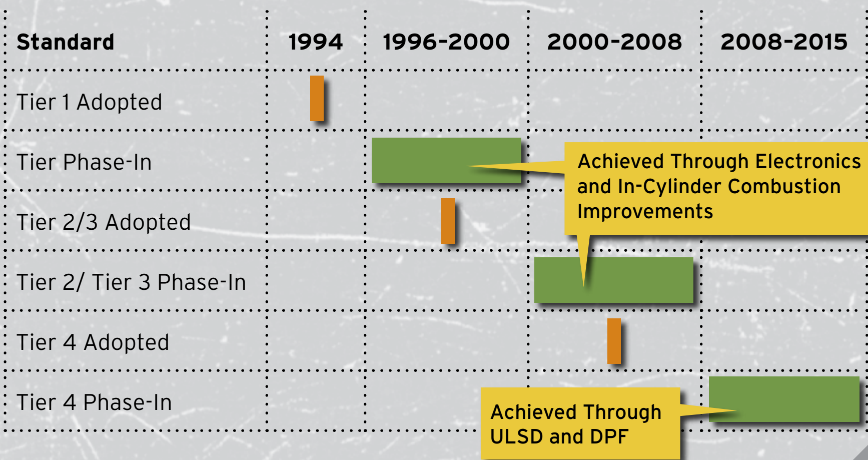


Figure 4: **Non-Road Final Emission Standards**
grams per horsepower hour(g/hp-hr)

Rated Power	First Year that Standards Apply	PM	NOx
hp<25	2008	0.30	–
25<hp<75	2013	0.02	3.5
75<hp<175	2012-2013	0.01	0.3
175<hp<750	2011-2013	0.01	0.3
hp>750	2011-2014	0.075	2.6/0.50 [1]

[1] Applies to gensets over 1200 hp only

Effects of ULSD on Off-Highway Operations

The refinery process used to remove sulfur from diesel fuel also affects its chemical composition, altering several physical and chemical properties of the resulting ULSD. Known as severe hydrotreating, it affects the diesel fuel in these ways:

- Removes the sulfur
- Lowers the aromatic content
- Removes natural lubricity compounds
- Lowers the conductivity
- Increases the cetane number
- Lowers the energy density

An equipment manager needs to know how these changes can affect off-highway operations. These are the risks of which they should be aware:

- Potential fuel leaks
- Lower lubricity
- Increased static discharge
- Improved combustion, lower fuel economy
- Extended drain intervals
- Higher fuel production costs

Potential Fuel Leaks

The most important problem caused

by the lower aromatic content in ULSD is the potential for a fuel leak because of seal failure in the fuel system. Some vehicle owners reported that their vehicles developed fuel leaks since they began using ULSD. Similar leaks were reported in the early 1990s when low sulfur fuel (S500) was introduced federally, and aromatics levels were limited in California diesel fuel. The leaks in the 1990s occurred at points where elastomers (O-rings) are used to seal joints in the fuel system. During 1993-94, the most common were injector fuel pump leaks. This problem is not exclusive to one engine type, one fuel type, or one geographic region. It can affect some engines that are older than ten years, but some newer ones have experienced the problem as well. Should further elastomer failures occur, they are expected to be sporadic.

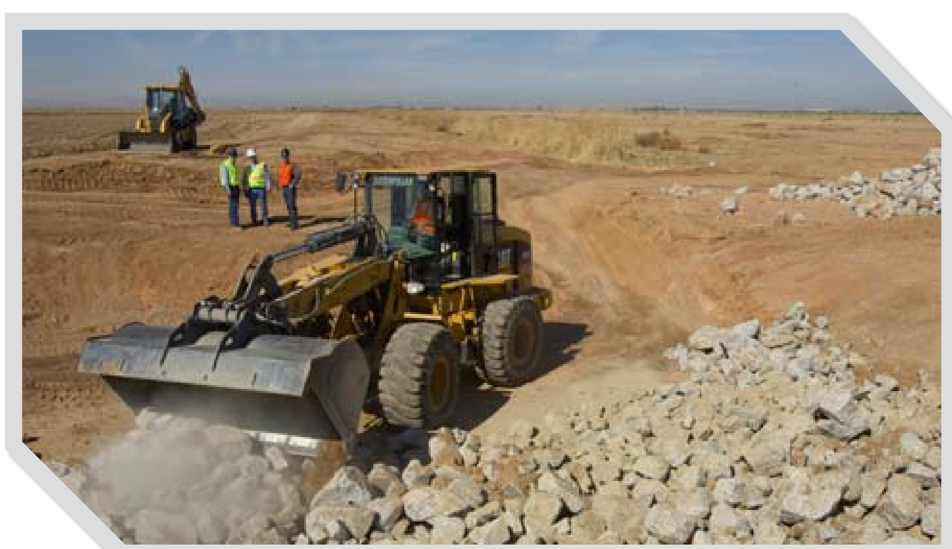
Seals in some vehicles may fail, while similar seals in other vehicles using the same fuel may not. Past experience indicates that the common denominator is Buna nitrile rubber (Buna N) seals that have seen long service at high temperatures. High temperatures have a tendency to accelerate seal aging; the reduction in sulfur content is not responsible for the problem. The change from a higher to a lower aromatics fuel can cause seals to shrink. Aged seals, which do not have the elasticity to adapt to this change, appear to fail sooner.

A leak in your fuel system can be dangerous, potentially causing fires if diesel fuel comes in contact with hot engine parts. It is recommended that you consult with your vehicle manufacturer for advice about maintaining or replacing the fuel system seals in your vehicle. *Newer seal materials have been developed* that can tolerate changes in aromatics levels without leaking. Replacing your fuel system seals will ensure you have the advantage of these new materials.

Lower Lubricity

Severe hydrotreating not only lowers sulfur and aromatic levels in diesel fuel, it also removes the natural lubricity compounds found in diesel fuel that are needed to lubricate the fuel systems. Fuel lubricity has been an issue in other areas for years. The aviation industry dealt with it in the 1960s. Sweden adopted ULSD in 1990 and experienced fuel lubricity problems. California experienced seal and lubricity problems in 1993 after adopting a low-sulfur, low-aromatics diesel fuel.

Fortunately, lubricity additives can be an effective solution; however, like medicine, if used in the wrong dosage or combination, they can be harmful. Equipment managers should not assume the more additive, the better. Test methods have been devel-



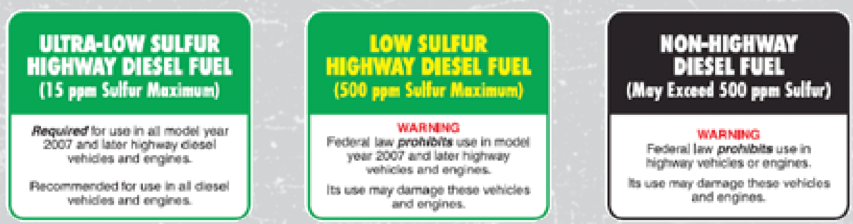
oped to measure fuel lubricity under conditions similar to those found in the diesel injection pump. One test, used in Europe for many years, is the basis for the new specification introduced in the U.S in 2005, well in advance of the appearance of ULSD in the market in June, 2006. The American Society for Testing and Materials (ASTM) has adopted a lubricity specification to protect injection equipment. Since additive use to restore fuel lubricity is common, no field problems are expected. However, more additive will be needed in ULSD to reach the same required lubricity level so equipment will be protected if fuels from reputable and credible suppliers using the proper additive treat level are used. Alternatively, biodiesel is an effective fuel lubricity agent. Use of B2 (2 volume percent biodiesel) will assure proper lubricity and eliminate the need for other lubricity additives. Before using biodiesel, consult the Original Equipment Manufacturer (OEM) owner's manual to ensure their equipment is rated for biodiesel use.

Increased Risk of Static Discharge

Conductivity is the degree to which a material will dissipate an electric charge. All liquids generate a static electric charge as they move through pipes, filters, pumps, etc. Once the charge is generated, liquids with lower conductivities are more likely to accumulate this electric charge. The risk of a static discharge incident increases, therefore, with low conductivity liquids.

Figure 5: **API Suggested Diesel Pump Labels**

Compliant with EPA 40 CFR 80.570



ULSD has a lower conductivity than the conventional diesel fuel that some terminals and truck fleets are accustomed to handling. Other terminals and truck fleets already handle low conductivity products, such as California Low-Sulfur Diesel (CARB LSD) and some jet fuels (supplier-specific). A truck-loading rack flow control system in combination with well-designed truck tank internals

can be used to manage the conductivity risks without the use of conductivity fuel additives.

There is reason to be concerned about the potential increased risk associated with handling ULSD. It is recommended that you ask your product supply terminals and your fleet operators how they are managing conductivity. Industry information is available on this subject from OSHA, including:

(1) Standard 29 CFR 1910.106, "Flammable and Combustible Liquids"

(2) National Fire Protection Association (NFPA) 77, "Recommended Practice on Static Electricity"

(3) American Petroleum Institute (API) Recommended Practice 2003, "Protection Against Ignitions Arising Out of Static, Lighting and Stray Currents" (Refer to Figure 5, API Suggested Diesel Pump Labels.)

Improved Combustion but Lower Fuel Economy

Severe hydrotreating also affects the combustion properties (cetane number and energy density) of the diesel fuel. The cetane number is a measure of the ignition quality of the fuel, and it also affects cold-starting and smoke. Since the diesel engine depends on the fuel to auto-ignite in the absence of spark plugs, the higher cetane number of ULSD provides a benefit. Although it is not widely discussed, the ULSD also has a lower density than LSD, resulting in a lower energy content. Since fuel is purchased and metered in engines by volume, lower energy density lowers the fuel economy achieved using ULSD. *The potential reduction in fuel economy has been estimated at 1%.*

Extended Drain Intervals

ULSD has lower sulfur levels and therefore creates lower levels of acids in the crankcase compared to LSD. Therefore, if all other conditions are held constant and equipment is switched to start with ULSD, oil drain intervals could be extended. As always, conduct a used oil analysis, and consult the OEM to safely extend drain intervals without affecting the useful life of the equipment. In the end, use of ULSD could result in reduced maintenance costs the way the introduction of unleaded gasoline in passenger cars reduced maintenance costs.

Higher Fuel Production Costs

Besides reducing lubricity and increasing cetane, severe hydrotreating also results in lower yields during the ULSD manufacture and, therefore higher production costs compared to LSD. The Environmental Protection Agency (EPA) has estimated the increased production cost at 5 to 7 cents per gallon. However, the actual market price depends on a variety of factors including production costs, distribution costs, and competitive market issues.

In summary, ULSD is coming to the off-highway market. Equipment managers need to take into consideration the effect of ULSD on their operations and maintenance practices and alter them accordingly. Protecting and extending the life of off-highway equipment depends on making the right choices, armed with the most current information.