

Enhancing Fuel Standards for Gasoline Direct Injection (GDI) Engines



In today's rapidly evolving automotive industry, fuel quality is a critical concern for both manufacturers and consumers. The TOP TIER™ program, established two decades ago by leading auto manufacturers, has been instrumental in ensuring higher fuel detergency standards to enhance engine performance and longevity. As we move into 2025, the program has introduced the TOP TIER+™ standard, specifically designed to address the unique challenges posed by Gasoline Direct Injection (GDI) engines. This new standard aims to mitigate issues such as fuel injector deposits and abnormal combustion events called Stochastic Pre-Ignition (SPI), ensuring cleaner, more efficient, and environmentally friendly fuel.

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The Birth of TOP TIER™

Twenty years ago, a consortium of auto manufacturers created the TOP TIER™ program to address the insufficient fuel detergency in the marketplace. OEMs were concerned that low-quality fuel contributed to engine issues, negatively affected customers, and increased warranty costs. The TOP TIER™ program is voluntary and links higher-quality gasoline to a defined engine cleanliness performance standard.

Fuel marketers must provide standardized engine and laboratory test data on their deposit control additives to comply with this voluntary standard. The program also prohibits organometallics additives in gasoline, although this is rarely done today. The performance data provided must show a higher level of deposit control for intake valves without causing intake valves to stick. Additive companies typically conduct the testing of these additives.

The Evolution of GDI Engines

As we fast forward to 2025, new challenges have emerged. OEMs have increasingly adopted Gasoline Direct Injection (GDI) technology to lower carbon emissions and improve fuel economy. GDI engines inject fuel directly into the combustion chamber, allowing for downsizing and turbocharging, which leads to higher compression ratios, improved efficiency, lower fuel consumption, and reduced CO₂ emissions.

However, GDI engines face two main concerns: fuel injector deposits and SPI. Injector deposits can degrade the fuel spray pattern, resulting in a loss of fuel economy and increased particulate emissions. These particulates may contribute to SPI, a severe pre-ignition event (abnormal combustion) that can cause severe engine damage. Early investigations identified fuel and lubricant formulation properties and potential additive effects at very high treat rates that could contribute to SPI.

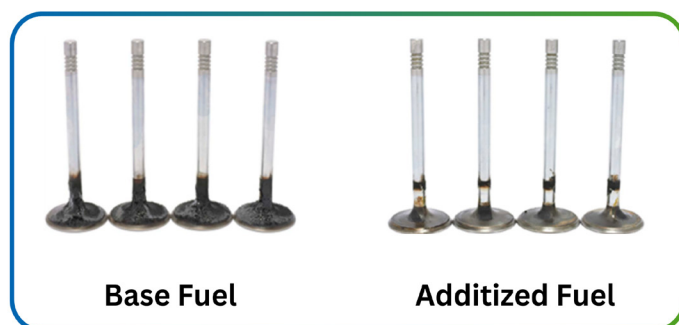
Introducing the TOP TIER+™ Standard

To address these new concerns, the TOP TIER™ program has released a revision to enhance the performance standard. Fuel marketers who meet these new requirements can use the TOP TIER+™ label in the marketplace. The intention is to phase out the old standard, giving fuel marketers two years to transition to additives that meet the revised standard.



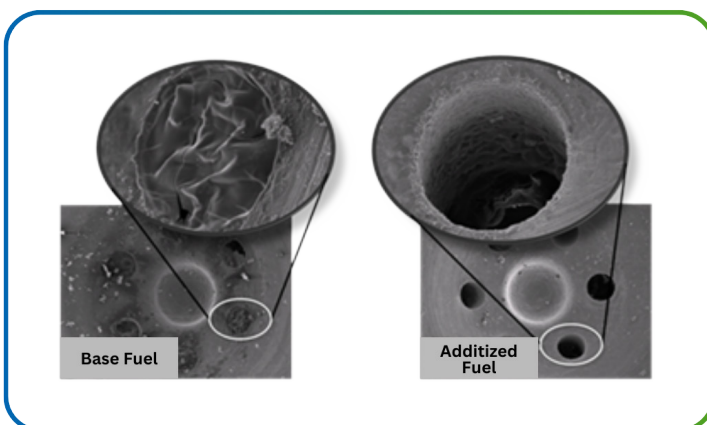
TOP TIER+™ Program Highlights

IVD Control: Requirements remain unchanged. The Ford 2.3L Test for intake valve deposit (IVD) control is standardized as ASTM D6201. A base gasoline with specific properties and without a detergent additive is tested, and a minimum of 500 mg average IVD per cylinder must be attained. The same fuel is then additized and tested, with an average IVD of no greater than 50 mg for a pass.



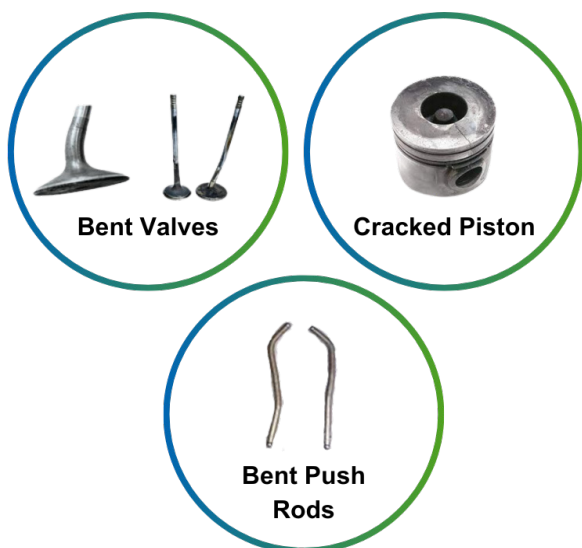
GDI Fuel Injector Cleanliness: NEW REQUIREMENT. This steady-state 120 hour engine dynamometer test evaluates the accumulation of deposits in injector nozzles, which can lead to poor fuel delivery, reduced fuel economy, and increased emissions. The test engine is a 2012-2013 GM LHU, a turbocharged four-cylinder inline engine with a 2.0-liter displacement.

The test involves a 60-hour "dirty-up" phase using Haltermann HF2208 dirty-up reference fuel without additives, aiming to induce at least a 5% increase in injector pulse width (IPW). After this phase, the same fuel is treated with a deposit control additive, and the test is restarted. The objective is to reduce deposits, with a successful outcome defined as a 50% or greater reduction in IPW within 60 hours.



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Intake Valve Sticking No-Harm: Requirements remain unchanged. This test ensures that no valve sticking is observed in sensitive engines, with no sticking observed in the VW Wasser Boxer or GM 5.0L valve stick test at three times the additive concentration that passed the IVD requirement.



GDI Particulates No-Harm: NEW REQUIREMENT. Particulates are measured continuously during the injector cleanliness test, ensuring no increase in particulate emissions from additives. A 20% margin of soot increase is acceptable early in the clean-up phase, but soot emissions at the end of the test must be equal to or lower than those at the end of the dirty-up.

SPI No-Harm Demonstration: NEW REQUIREMENT. This test uses the same GM 2.0L LHU engine as the deposit control test and examines the frequency of abnormal combustion events indicative of SPI. The test fuel required is Gage Products Test Fuel TTG-1-002 TOP TIER™ SPI Test Fuel. An acceptable performance demonstration occurs when the SPI frequency from the additized phases is statistically equivalent to or better than the base fuel phases at a p-value level of 0.05 (95% confidence level).

Combustion Chamber Deposit Control: Requirements remain unchanged. The effect of additives on combustion chamber deposits is evaluated, with the additized fuel test showing no more than a 40% increase in CCDs over the base run.

The new standard, revision G, was released in January 2025 - [click here](#).

Transition to TOP TIER+™

TOP TIER™ will allow a two-year window for compliance with the new standard. During this period, two levels of TOP TIER™ performance in the marketplace will be differentiated by names and decals. Compliance with the old standard will be designated as TOP TIER™, while compliance with the new standard will be designated as TOP TIER+™. After the two-year window, only TOP TIER+™ certified fuels will remain in the marketplace.

The test requirements are summarized below.

Test	Limit	Fuel Type
Ford 2.3L – IVD	Base - 500 mg. Additized - 50 mg	Meet TOP TIER™ fuel properties
Ford 2.3L – CCD	Additized CCD < 140% of base	
GM LHU – injector fouling	Base fuel - 5% or more increase in injector PW Additized – 50% reduction in that increase	Haltermann HF2208 LHU test fuel
GM LHU – PM no harm	End of clean-up PM must be no more than at of end of dirty-up	
GM LHU – SPI no harm	Statistically, there is no harm to SPI count for three base runs versus three additized runs	Gage products TTG-1-002 TOP TIER™ SPI Test Fuel

TOP TIER™ Standard is available outside the United States, including fuel marketers in Canada, Mexico, Puerto Rico, Japan, Colombia, Peru, El Salvador, Guatemala, Honduras, Panama, and Argentina.