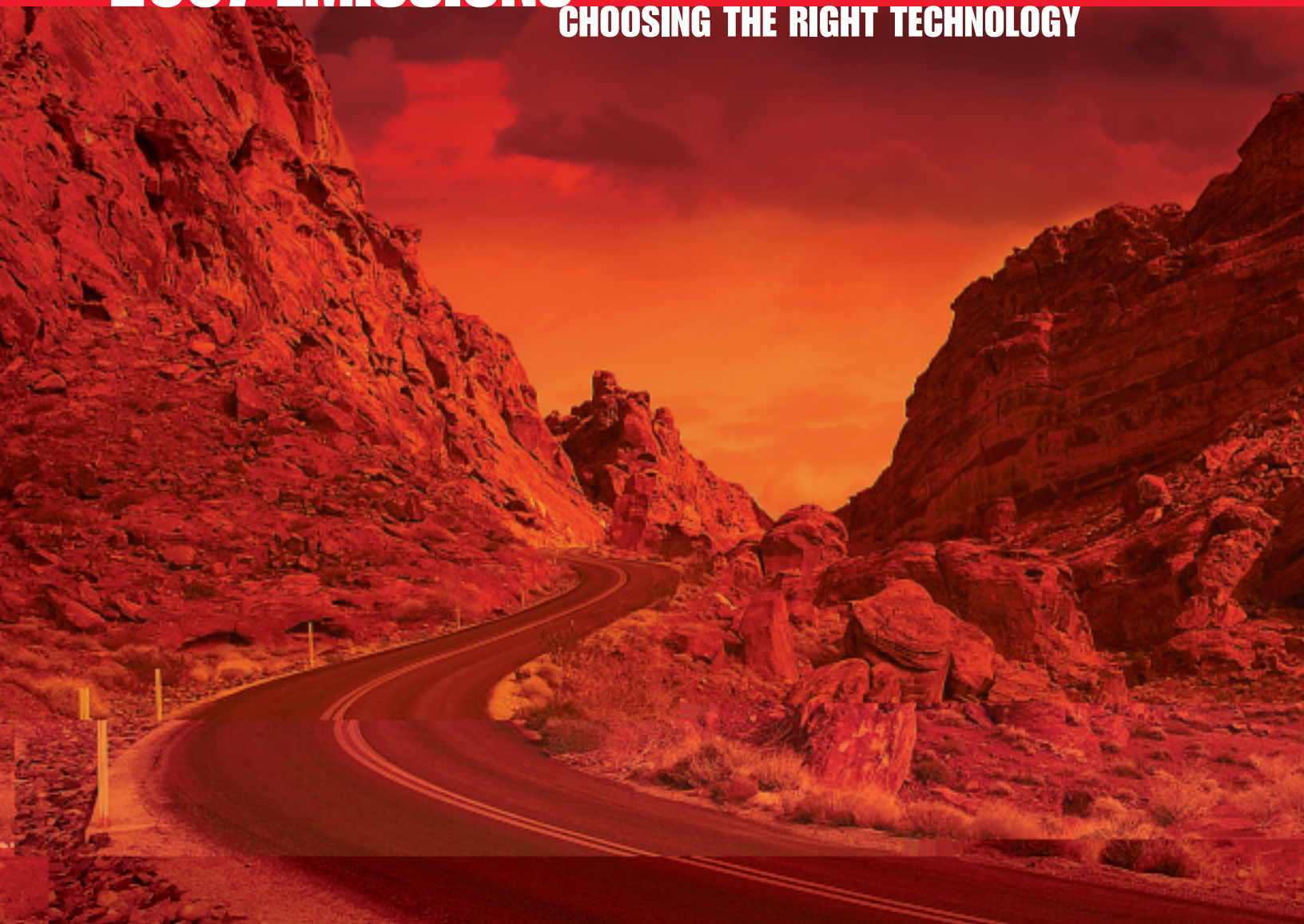




2007 EMISSIONS

CHOOSING THE RIGHT TECHNOLOGY



Cummins 2007-2010 Heavy-Duty On-Highway Emissions Technology

Introduction

Cummins engines are designed to provide customers with the highest levels of performance, durability and dependability at the lowest cost of operation. At the same time, we are committed to meeting or exceeding clean air standards. This document describes the technology options we have explored in order to best meet customer demands and emissions requirements for the on-highway market. Product technologies for industrial, marine, power generation and other markets will be the subject of future papers.

Cummins has long been a pioneer in emissions research and development, investing in critical technologies in order to achieve future emissions standards while meeting the needs of the customer. The emissions solutions we use today are the direct result of a technology plan that was set into motion in the early 1990s, a plan that will carry us through 2010 and beyond.

At the core of this road map was a strategic decision not to limit ourselves to any one approach, but to develop the right technology for each application and market served. Different operating conditions and economic factors can and will influence the technology path most appropriate for each market. While developing multiple emissions solutions requires a broader and deeper investment in Research and Development on our part, it guarantees the Cummins customer that our engines will deliver optimum performance and reliability at the lowest possible cost of operation.

A second, but no less important, part of our strategy has been to involve OEMs as early as possible in the development and integration process. This open exchange of information and technology has been – and will continue to be – instrumental in developing vehicles and equipment that perform at the highest levels of efficiency, durability, reliability and productivity.

Cummins Strategy – The Right Technology Matters

Leadership in combustion research, fuel systems, air-handling systems, controls and aftertreatment allows Cummins to maintain our goal of maximizing customer value by providing the most appropriate emissions control solution for each market served.

In Europe, new on-highway emissions standards (Euro IV) will be introduced beginning October 2005. Cummins will meet these standards using Selective Catalytic Reduction (SCR) aftertreatment. SCR is the best customer solution for this market, because diesel fuel prices are very high in Europe (relative to urea) and the use of urea to reduce fuel consumption makes economic sense.

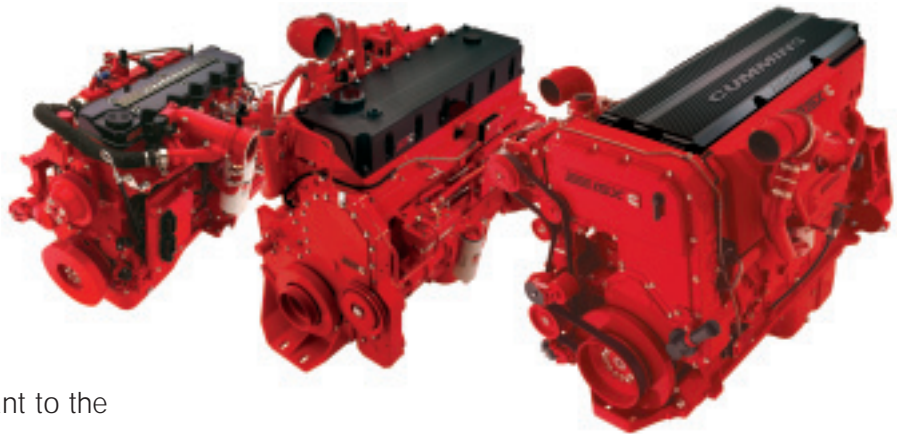
For the U.S. on-highway truck market, Cummins has been the leader in the application of cooled EGR. From April 2002 through December 2003, Cummins cooled-EGR engines accumulated over 1 billion miles of service, providing low cost of operation and reliable operation at 2.5-g/hp-hr NO_x+NMHC emissions levels.

Committed to Customer Needs

While we have taken measures to describe the emissions control technologies of today and the future, our first commitment is to deliver great reliability, durability and cost-effectiveness on all products we produce. In each of these markets, emissions control technologies have been matched to the product duty cycle and the design of the vehicle to deliver the best economic solution for the customer.

Cummins On-Highway Emissions Technology Today

By October 2002,
Cummins had
introduced the
first complete
lineup of engines
that were EPA-



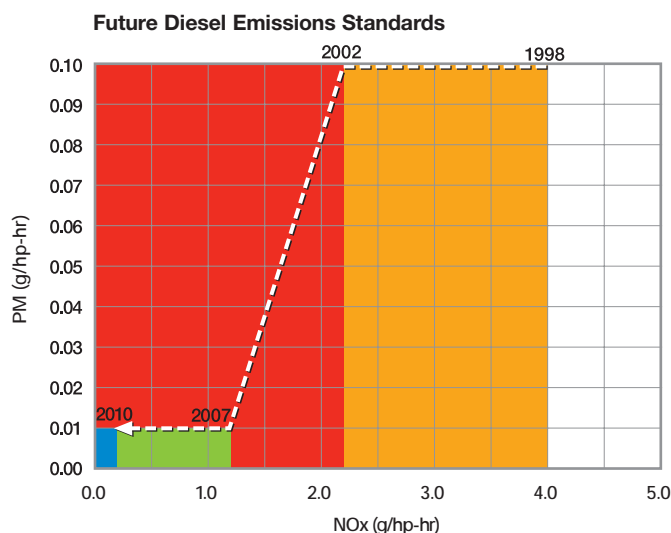
certified and compliant to the

2.5-g/hp-hr NO_x+NMHC standards. These engines feature a combination of advanced combustion, flexible fuel systems and controls, base engine capability, variable geometry turbocharging and integrated cooled exhaust gas recirculation. They have proven highly successful, providing customers with industry-leading fuel economy, performance and reliability. These engines carried over directly for 2004 certification, and they are the foundation for 2007 and beyond.

The 2007 EPA Emissions Rules

Looking ahead to 2007-2010, emissions requirements change dramatically for heavy-duty trucks over this period. Both NO_x and PM (particulate matter) are reduced by 90% from 2004 levels. Specifically, NO_x must be reduced to 0.2-g/hp-hr by 2010, while the particulate standard is reduced to 0.01-g/hp-hr PM beginning in 2007.

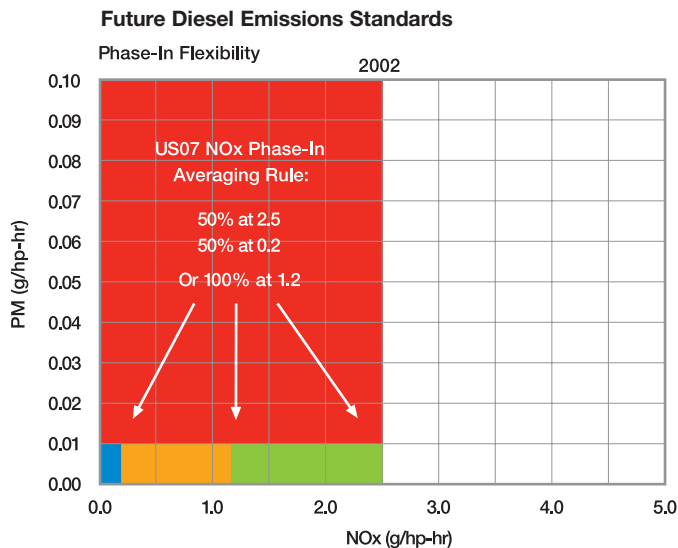
The EPA has allowed for NO_x phase-in from 2007 through 2009. During this time, 50% of the engines produced must meet the 0.2-g/hp-hr NO_x standard, while 50% may continue to meet the 2.5-g/hp-hr NO_x+NMHC standard.



Most engine manufacturers will likely use the NO_x phase-in provisions along with averaging to certify engines to a NO_x value roughly halfway between 2.5-g/hp-hr NO_x+NMHC and the 0.2-g/hp-hr NO_x levels through 2009. This calculates to approximately 1.2 g/hp-hr NO_x.

The PM level is not phased in, and thus all engine production is required to be at 0.01-g PM beginning January 2007.

HD 2007 Rule: Basic Program Requirements							
	2006	2007	2008	2009	2010	2011	2012
PM		100% at 0.01-g/hp-hr					
NO _x		50% at 0.2-g/hp-hr			100% at 0.2-g/hp-hr		
Fuel		80% at 15 ppm maximum sulfur (under voluntary compliance option)				100% at 15 ppm	



In addition to the lower NOx and PM levels, crankcase gases will also be included in the emissions measurements. This requirement will likely drive closed crankcase systems for 2007 or ultra-low emissions from open systems. Open systems allow crankcase gases to be vented into the

atmosphere through a breather tube. Closed systems reroute crankcase ventilation gases from the breather tube back into the engine intake airflow to be used for combustion.

We expect soon to see EPA regulations which will require advanced onboard diagnostics, with additional sensors to monitor the effectiveness of emissions systems on the engine.

Ultra-Low Sulfur Fuel

In addition to new exhaust emissions standards and in support of them, the EPA is also lowering the limit for diesel fuel sulfur from 500 parts per million (ppm) to 15 ppm. The new fuel standard will be phased in beginning September 1, 2006 (80% participation) through September 1, 2010 (100% participation). It is expected that 15-ppm fuel will be widely available. On a volume basis, over 95% of highway diesel fuel produced in 2006 is projected to meet the 15-ppm sulfur standard. On a facility basis, over 90% of refineries and importers have stated that they plan to produce some 15-ppm diesel fuel. It is projected that the additional cost of the new fuel will be less than \$0.05/gallon at the outset.

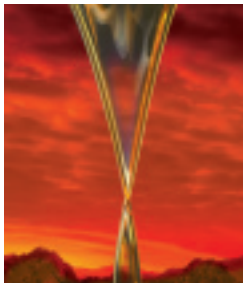
Ultra-low sulfur fuel has several beneficial effects. It inherently produces less PM from combustion, so it is a PM control strategy for all in-use equipment. It enables NOx adsorber technology to be highly effective and reduces the production of sulfuric acid. It also can have a positive effect on oil drain intervals.

However, with two fuels in the marketplace, there will be a risk of misfueling. For engines with NOx aftertreatment this could be a concern, depending on which technology is selected. NOx adsorbers are not tolerant of fuel sulfur. SCR is tolerant of fuel sulfur. PM aftertreatment (particulate filters) may not be permanently damaged from misfueling, but the higher level of sulfur will render the PM filter less effective and may not be emissions-compliant due to sulfates.



2007 Lubricating Oil

New specifications are being developed for lubrication oil compatible with low-emissions solutions for 2007-2010. The primary focus will be to make the oils compatible with



aftertreatment devices. For 2007, the immediate requirement is to reduce ash in order to enable extended maintenance intervals on the diesel particulate filter while maintaining the important lubricity capability of the lubricant.



NOx Reduction Options

Advanced Combustion

Cummins has made a large investment in the development of advanced combustion systems that reduce engine-out emissions at the source – inside the combustion chamber. The combustion system design process uses detailed computer simulation of the combustion event, allowing engineers to study the effects of changes to fuel injection system parameters and combustion chamber geometry. This process accelerates the development process and has allowed Cummins to attain low engine-out NOx and particulates.

Cooled EGR for EPA Heavy-Duty On-Highway In 2007

The introduction of cooled Exhaust Gas Recirculation (EGR) technology in 2002 to meet the 2.5-g/hp-hr NOx+NMHC standards created the foundation for our 2007 products.

Cooled EGR is a very effective NOx control. The EGR system takes a measured quantity of exhaust gas, passes it through a cooler before mixing it with the incoming air charge to the cylinder. The EGR adds heat capacity and reduces oxygen concentration in the combustion chamber by diluting the incoming ambient air with cool exhaust gases. During combustion, EGR has the effect of reducing flame temperatures, which in turn reduces NOx production since NOx is proportional to flame temperature. This allows the engine to be tuned for the best fuel economy and performance at lower NOx levels. EGR can be used to attain the NOx levels being introduced in 2007 and beyond.

In order to control both NO_x and particulate emissions accurately, the amount of recirculated exhaust gas and air has to be precisely metered into the engine under all operating conditions. This has driven the use of advanced Variable Geometry Turbochargers (VG Turbos) that continuously vary the quantity of air delivered to the engine.

The Variable Geometry Turbo by Holset (a subsidiary of Cummins) features a unique patented one-piece sliding nozzle which moves continuously to vary the power of the turbine and the amount of air delivered to the engine. Because of Cummins unique design, it has proven to be the most reliable Variable Geometry Turbocharger in the world.



The VG Turbo is used in concert with an EGR control valve to accurately meter the EGR into the intake system. Customer benefits are increased performance and improved fuel economy.

Simulation, experimental studies and empirical data have shown that cooled EGR continues to offer distinct advantages at 1.2-g/hp-hr NO_x levels in both product cost and fuel economy when compared to other solutions.

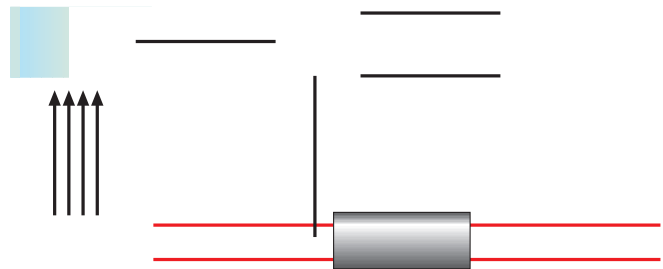
To reach the 2007 phase-in average of 1.2-g/hp-hr NO_x within the engine, we will extend the use of cooled EGR without changing the physical configuration of the engine. A cooled-EGR engine for 2007 will look virtually identical to the ISX or ISM that is being installed today.

Aftertreatment Solutions

While cooled EGR is an “in-cylinder” technology that can reduce NO_x, there are several aftertreatment solutions which can achieve reduced NO_x levels by treating the exhaust gases after they leave the engine. These include Selective Catalytic Reduction, NO_x adsorbers and lean-NO_x catalysts.

Selective Catalytic Reduction (SCR) – The European Heavy-Duty Solution

Selective Catalytic Reduction (SCR) systems use a chemical reductant, in this case urea, which converts to ammonia in the exhaust stream and reacts with NO_x over a catalyst to form harmless nitrogen gas and water. Urea is a benign



substance that is generally made from natural gas and widely used in industry and agriculture. SCR systems are being proposed today for mobile on-highway applications.

In an SCR system, the urea injection rate must be tightly controlled. If the injection rate is too high, not all of the ammonia will react with the NO_x, and some ammonia will “slip” through the catalyst. If the rate is too low, the desired NO_x reduction will not be achieved. Both situations are undesirable and must be avoided.

The urea-SCR system basically consists of three elements:

- **Catalyst** – The catalyst is mounted in the exhaust stream. It can be similar in outward appearance to a muffler, but significantly larger. It contains chemical compounds which, in the presence of ammonia, help transform nitrogen oxides into harmless chemicals.
- **Urea** – Urea is carried on board the vehicle as a water solution in a storage tank with a typical capacity of 20 to 50 gallons. The storage tank is sized to minimize operator filling but within packaging and weight constraints of the vehicle. The storage tank and urea injection system must be protected from freezing, since the urea-water solution solidifies at approximately 12°F.
- **Urea injection and control system** – A sophisticated injection system and controls (including NO_x and urea quality sensors) are required to deliver a precise amount of urea under all environmental conditions. The injection of urea has to be carefully controlled so that the availability of ammonia is closely matched to the amount of NO_x being produced by the engine in real time.

How much urea does an SCR system use? For each 1-g/hp-hr reduction in NO_x, an SCR engine consumes urea at a rate of approximately 1.5% of the amount of fuel used. So for an engine to reduce NO_x output from 6 grams to 1 gram NO_x using SCR (6-1=5 gram reduction), it would take an injection of urea that is roughly 7.5% of fuel used (5 grams x 1.5%/gram = 7.5%).

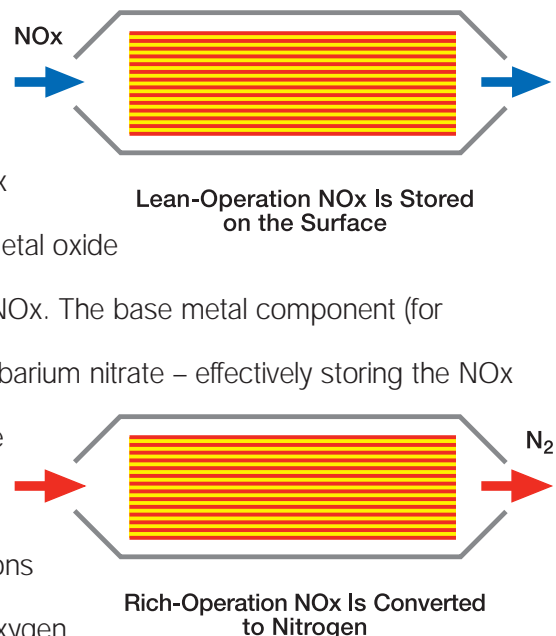
In the U.S., urea is expected to cost about as much as diesel fuel. So for the previous example, diesel fuel economy would have to be improved by at least 7.5% to avoid a negative cost-of-operation impact. The economics of this solution make more sense where diesel fuel costs significantly more than urea – which is true in many countries outside of North America, but is not true in the U.S.

Urea Selective Catalytic Reduction (SCR)



NOx Adsorbers

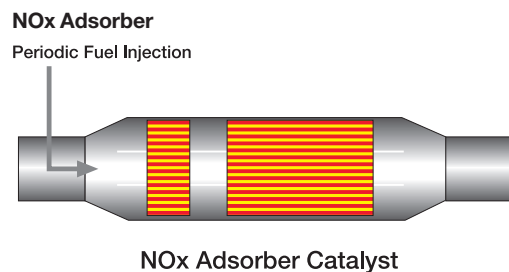
The NOx Adsorber Catalyst (NAC) is a new technology developed in the late 1990s. The NOx Adsorber Catalyst uses a combination of base metal oxide and precious metal coatings to effect control of NOx. The base metal component (for example, barium oxide) reacts with NOx to form barium nitrate – effectively storing the NOx on the surface of the catalyst. When the available storage sites are occupied, the catalyst is operated briefly under “rich” exhaust gas conditions (i.e., the air-to-fuel ratio is adjusted to eliminate oxygen in the exhaust). This releases the NOx from the base metal storage sites, and allows it to be converted over the precious metal components to nitrogen gas and water vapor.



Diesel engines normally operate with an excess ratio of air-to-fuel – so-called “lean” operation. Under lean operating conditions it is extremely difficult to control nitrogen oxides (NO_x) with a catalyst because of the excess of oxygen in the exhaust stream.

Under lean operating conditions, the NO_x is simply stored in the catalyst. Regeneration is required to release and convert the NO_x to nitrogen gas.

Regeneration of the NAC requires elimination of all excess oxygen in the exhaust gas for a short period of time. This can be accomplished by operating the engine in a “rich” mode, or by injecting fuel directly into the exhaust stream ahead of the adsorber to consume the remaining oxygen in the exhaust. Either way, the engine and catalyst must be controlled as a system to determine exactly when regeneration is needed, and to control the exhaust parameters during regeneration itself.



Sulfur poses challenges for NO_x adsorbers. In addition to storing NO_x, the NAC will also store sulfur, which reduces the capacity to store NO_x. Although fuel sulfur levels are being reduced in 2007 to 15 ppm, sulfur at any level poses

challenges and requires the engine design to provide for a periodic de-sulfation process – a process to remove sulfur from the catalyst. This is similar to the NO_x regeneration process, but at higher temperatures.

We expect NO_x adsorbers to appear first in light-duty applications.



Lean-NOx Catalysts

A lean-NOx catalyst uses unburned hydrocarbons to reduce NOx over a catalyst.

The catalyst may contain precious metals such as platinum or other materials such as zeolite. The successful operation of a lean-NOx catalyst requires continuous injection of fuel upstream of the catalyst. The NOx conversion efficiency depends on many factors – but typical values are 10%-25% in use over practical duty cycles. Lean-NOx catalysts do not have adequate NOx reduction capability for 2007 applications. However, lean-NOx catalysts are often an excellent option for retrofits. They are relatively easy to install and integrate with existing engine and vehicle systems.

NOx-Reduction Summary

In summary, key challenges for all NOx aftertreatment technologies (SCR, NOx adsorber and lean-NOx catalyst) include designing and developing integrated systems to:

- Be reliable and durable in all environmental conditions and applications.
- Minimize packaging and weight.
- Control emissions over the life of the product.
- Minimize maintenance.
- Be affordable in both initial price and operational costs.

PM Reduction

The 2007 emissions standards for particulate emissions are 90% lower than the recently introduced 2002 engines, at just 0.01 g/hp-hr. While previous reductions in particulate matter emissions have been achieved through engine combustion improvements and oxidation catalysts, the stringent 2007 particulate standards will require very effective particulate aftertreatment.

The active diesel particulate filter (DPF) is the only current technical option for meeting the U.S. 2007 PM emissions standards. It is expected that all engine manufacturers will use this technology.

Active Diesel Particulate Filters (DPF)

In order to reach the new PM standards on all applications, “active” diesel particulate filters are needed. Filtration of exhaust gas to remove soot particles is accomplished using porous ceramic media generally made of cordierite or silicon carbide. A typical filter consists of an array of small channels that the exhaust gas flows through. Adjacent channels are plugged at opposite ends, forcing the exhaust gas to flow through the porous wall, capturing the soot particles on the surface and inside pores of the media. Soot accumulates in the filter, and when sufficient heat is present a “regeneration” event occurs, oxidizing the soot and cleaning the filter.



challenge of particulate filter design is to enable reliable and consistent regeneration, so that soot is removed under all types of duty cycles. For example, a line-haul truck that is fully loaded and consistently run hot enough for regeneration to take place, the same truck in stop-and-go traffic or running at low speeds may not. EPA requirements for regeneration in every operating condition of this "active" method involve monitoring regeneration events and managing



Filter

engine combustion process in order to allow regeneration to take place. Regeneration is difficult at low temperatures are low, and during

DPF Challenges

Maintenance *may* be required on diesel particulate filters. Metals in lubricant additives will become ash and collect in the filter as oil is consumed and particulate matter is burned off through regeneration. If this is the case, the ash must be cleaned from the filter or plugging will occur. Fleetguard Emission Solutions has recently introduced its first commercial cleaning systems to the field for the retrofit market. However, Cummins long-term goal is to avoid this maintenance altogether.

Cummins is currently working with oil manufacturers on the development of low-ash oils and to understand how different additive components may behave differently with regard to filter plugging. If maintenance of the diesel particulate filter is required, we anticipate that it will be at relatively high-mileage intervals of 185,000-250,000 miles (297,729-402,336 km).

System Integration

Cummins remains focused on providing outstanding customer value, while meeting the toughest emissions standards. Our Research and Development effort is the result of a partnership between Cummins subsidiaries, such as Holset and Fleetguard, key suppliers and customers.

In early 2002, Cummins began operation of a Mobile Emissions Research Laboratory (MERLin) to evaluate the technologies necessary to achieve the 2007 U.S. EPA standard in real-world applications. MERLin has been used to evaluate and develop cooled EGR and all candidate aftertreatment systems.

MERLin is a mobile development environment, which provides comprehensive data acquisition from the emissions control system, computer simulation tools and



control software development tools. Cummins engineers are able to take MERLin on the road and to develop control systems in real-time. MERLin frequently makes road trips to high-altitude, hot, cold and humid locations to develop robust control systems.

In addition, Cummins is deeply involved with our OEM partners and key suppliers in the development and real-world testing of prototype vehicles. These test vehicles are being put into service years in advance of the dates when EPA regulations take effect.

Meeting 2007 Emissions – The Cummins Solution

The Cummins technology plan for on-highway heavy-duty applications in 2007 is straightforward:

- Cummins is well on the way to developing engines to meet the 2007 EPA standards. The proven products in operation today are the base platform for 2007.
- Cummins is the only engine manufacturer with wholly owned subsidiaries providing technology for air-handling (Holset) and aftertreatment systems (Fleetguard Emission Solutions) and so we are able to practice system integration across all critical components and subsystems to a degree that is unmatched by our competitors.

- We will continue to use cooled EGR as the base technology for NOx reduction, as we have consistently stated since 2001. Outward changes to the base heavy-duty engines will be insignificant.
- Cummins will use an active particulate filter to achieve the 90% reduction in particulate matter. We expect all other engine manufacturers to do the same.

The Right Technology Matters.


That is why Cummins has invested in critical components and subsystems across our entire product line. That is why we introduced products in 2002 that are the foundation for a decade of development. That is how we will continue to deliver products that meet the demands of our customers at the lowest emissions levels. Every mile. Every day. Every time.



Glossary

Adsorber Catalyst	An aftertreatment technology that uses a base metal oxide and a precious metal compound as a catalyst to transform NO _x to Nitrogen gas and H ₂ O (water vapor).
Common-Rail Fuel Injection	Fuel delivery system that maintains a high injection pressure regardless of engine speed, using high-pressure fuel stored in a single “common” rail or tube that connects to every fuel injector on the engine.
DPF	Diesel Particulate Filter. Also known as a particulate “trap.” Captures particles of soot in a semi-porous medium as they flow through the exhaust system. Available in “passive” or “active” configurations. Active DPFs use a control system to actively promote regeneration events.
EGR	Exhaust Gas Recirculation. Technology that diverts a small percentage of the exhaust gas back into the cylinder, lowering combustion temperatures and reducing NO _x .
EPA	Environmental Protection Agency. Among many duties, the U.S. government agency responsible for governing heavy-duty engine emissions.
EURO-IV On-Highway Standards	Medium and heavy-duty truck and bus emissions standards which take effect in 2005-2006 throughout Europe.
Exhaust Aftertreatment	Any technology which treats emissions in the exhaust flow, as opposed to inside the power cylinder.
Fleetguard Emission Solutions	A subsidiary of Cummins that is a world leader in the development of advanced emissions and filtration technology.

“Lean” Engine Operation	Using an air/fuel mixture with more air than fuel versus what would occur in a natural (stoichiometric) burning condition.
Lean NOx Catalyst	Uses platinum or zeolite as the reactant. Diesel fuel injected upstream of the catalyst performs a similar function to urea in an SCR system.
MERLin	Cummins Mobile Emissions Research Laboratory, a test vehicle for real-world trial of advanced emissions technologies.
NMHC	Non-Methane HydroCarbons. Primarily unburned fuel in the exhaust stream. With NOx, subject to EPA 2002 emissions controls.
NOx	Nitrogen Oxides. With NMHCs, subject of EPA 2002 emissions controls.
OBD	On-Board Diagnostics. The ability of an engine control system to monitor specific data and determine when systems are not working correctly or trending out of the desired operating range.
PM	Particulate Matter, composed primarily of soot and other combustion byproducts.
“Rich” Engine Operation	Using an air/fuel mixture with more fuel than air versus what would occur in a natural (stoichiometric) burning condition.
SCR	Selective Catalytic Reduction. An aftertreatment technology that uses a chemical reductant (urea) that is injected into the exhaust stream where it transforms into ammonia and reacts with NOx on a catalyst, converting the NOx to nitrogen and water vapor.



Sulfur	A natural element which has been linked to acid formation both inside engines and in the atmosphere.
Tier 3 Off-Highway Emissions Standards	Global emissions standards for industrial markets. Take effect in 2005.
ULSF	Ultra-Low Sulfur Fuel. Diesel fuel which contains less than 15 parts per million by volume of sulfur. Mandated phase-in starting in mid-2006.
Urea	A chemical usually made from natural gas, it is commonly used in fertilizers. Urea breaks down into ammonia (NH_3) and reacts with NO_x in an SCR system.
VG Turbo	Variable Geometry Turbocharger. Turbochargers that constantly adjust the amount of airflow into the combustion chamber, optimizing performance and efficiency.



Cummins Inc.
Box 3005
Columbus, IN 47202-3005
U.S.A.

Phone: 1-800-DIESELS (1-800-343-7357)
Fax: 1-800-232-6393
E-Mail: powermaster@cummins.com
Internet: www.everytime.cummins.com

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