2010 EMISSIONS

CHOOSING THE RIGHT TECHNOLOGY

Cummins 2010 On-Highway Emissions Technology.

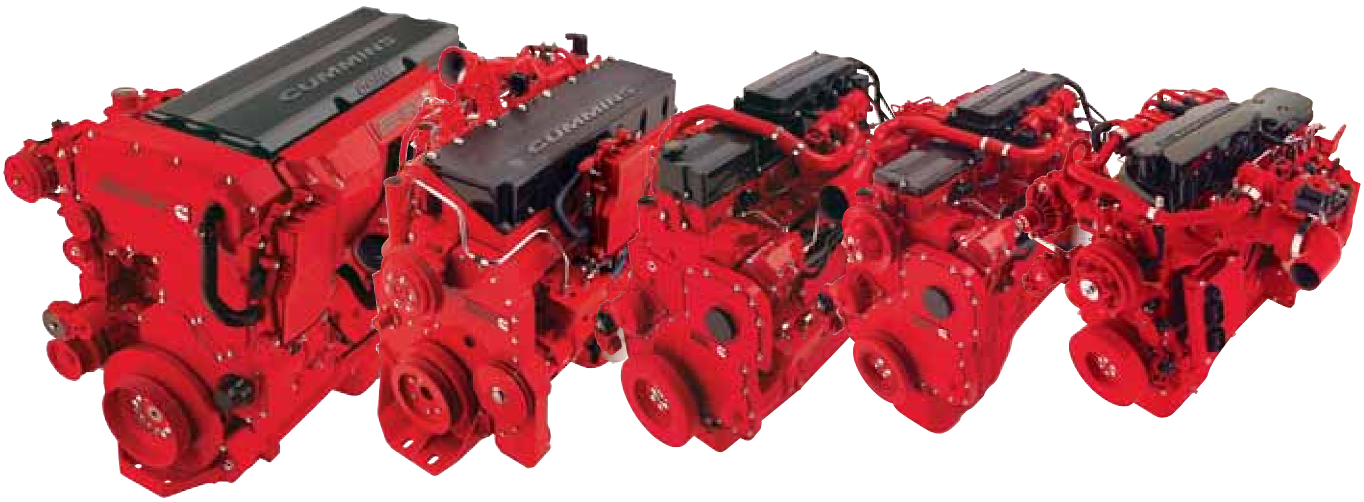
Introduction.

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.

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 fuel economy and reliability at the lowest possible cost of operation.

A second, but no less important, part of our strategy has been to involve OEM customers 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, filtration, controls and exhaust aftertreatment allows Cummins to achieve 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) were introduced beginning October 2005. Cummins met these standards using Selective Catalytic Reduction (SCR) aftertreatment on our MidRange engines. 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 at the 2.6-g/hp-hr NOx level required by Euro IV.

For the U.S. on-highway truck, bus, RV and emergency vehicle markets, Cummins has been the leader in the application of cooled EGR. From April 2002 through December 2006, Cummins cooled-EGR engines accumulated over 40 billion miles of service, providing low cost of operation and reliability at 2.5-g/hp-hr NOx+NMHC emissions levels.

Beginning in January 2007, all Cummins on-highway engines utilize exhaust aftertreatment for particulate control as well as a crankcase coalescing filter to control crankcase emissions, which are now included in the emissions certification procedure. In addition, the Cummins Turbo Diesel used in the Dodge RAM Heavy Duty pickup truck already meets the 2010 emissions levels utilizing a close-coupled catalyst and NOx adsorber technology and a diesel particulate filter. The combination of engine design and aftertreatment and OEM integration enables a package that produces the strongest, cleanest and quietest pickup truck in its class.

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 performance and fuel economy, 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.

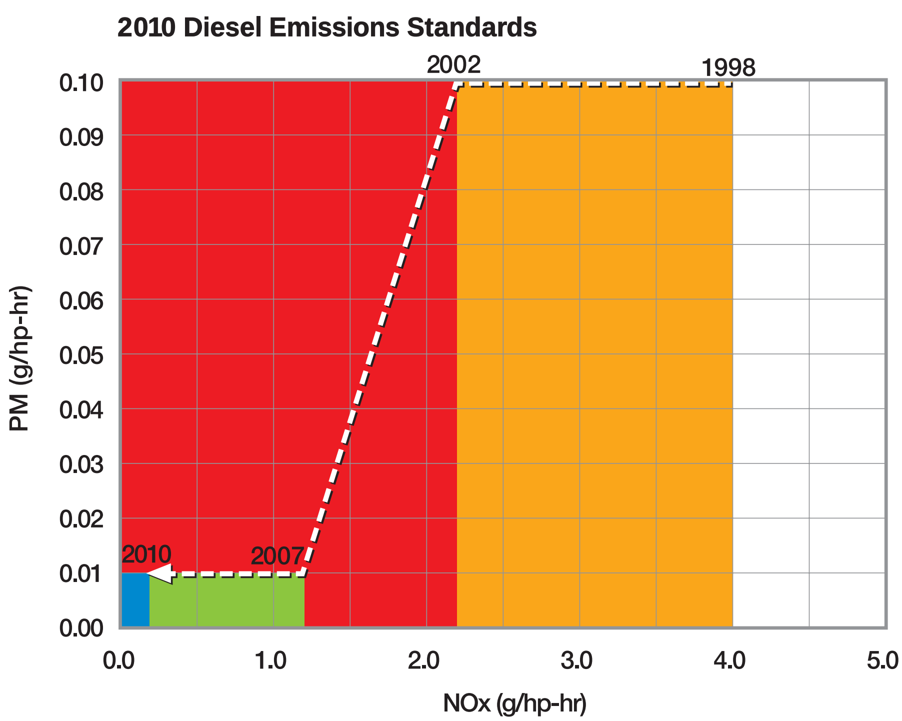
Beginning in October 2002, Cummins introduced the first complete lineup of engines that were EPA-certified and compliant to the 2.5-g/hp-hr NOx+NMHC standards. And in 2007 these engines feature a combination of advanced combustion, flexible fuel systems and controls, base engine capability, Variable Geometry Turbocharging and integrated cooled Exhaust Gas Recirculation. They have proven to be highly successful, providing customers with industry-leading fuel economy, performance and reliability.

The 2010 EPA Emissions Rules.

Looking ahead to 2010 and beyond, emissions requirements change dramatically for on-road vehicles. Both NOx and PM (particulate matter) are reduced by 90% from 2004 levels. Specifically, NOx must be reduced to 0.2-g/hp-hr by 2010, while the particulate standard was reduced to 0.01-g/hp-hr PM beginning in 2007.

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

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



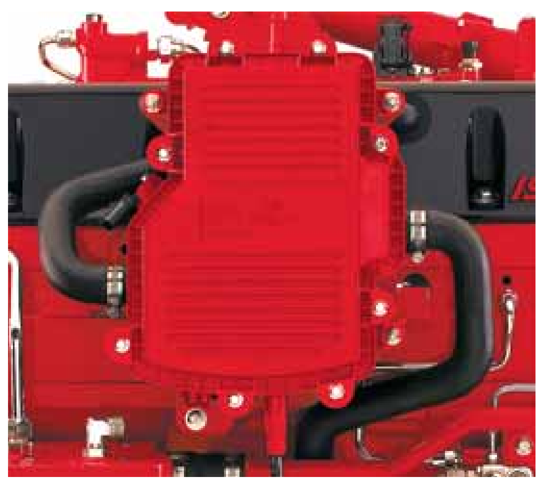
2007 Rule: Basic Program Requirements

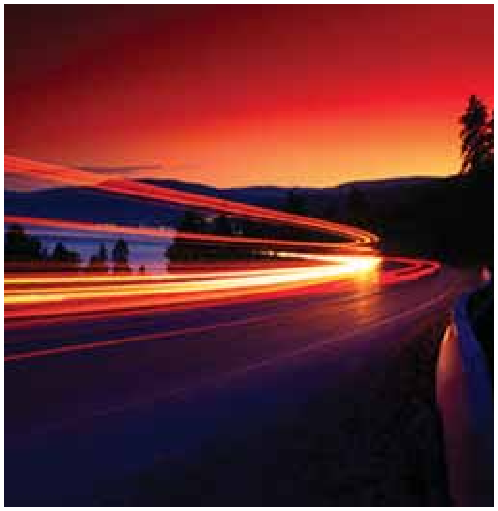
	2006	2007	2008	2009	2010	2011	2012
avPM		100% at 0.01-g/hp-hr					
NOx		50% at 0.2-g/hp-hr			100% at 0.2-g/hp-hr		
Fuel		80% at 15-ppm maximum sulfur (under voluntary compliance option)				100% at 15 ppm	

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

In addition to the lower NOx and PM levels, crankcase gases are also included in the emissions measurements. This requirement has driven 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/filter tube arrangement. Closed systems reroute crankcase ventilation gases from the breather tube back into the engine intake airflow to be used for combustion.





On-Board Diagnostics (OBD).

Beginning in 2010, the California Air Resources Board (CARB) will require engine manufacturers to phase in On-Board Diagnostics (OBD) on their highest-volume heavy-duty engines. By 2013 all engines produced will have to be OBD-compliant per CARB requirements. It is expected that the Environmental Protection Agency (EPA) will have the same OBD requirements as CARB beginning in 2013.

The CARB is also requiring engine manufacturers to comply with a new Service Information Regulation (SIR). In essence, the Service Information Regulation requires that engine manufacturers provide the necessary troubleshooting, maintenance and service information to third-party channels as well as to their own service channel. This approach should allow customers to have access to proper diagnosis and repair of their engine to ensure that the engine remains in emissions compliance for the life of the engine.

The OBD system detects emissions-related malfunctions, alerts the operator of the vehicle to the detected malfunction, stores diagnostic records of the malfunction and supports off-board communications to a diagnostic service tool (e.g., scan tool) to allow the efficient service and maintenance of the vehicle. The Service Information Report makes it possible for the aftermarket service channel as well as the engine manufacturer's service channel to service and maintain the emissions control systems to their proper performance levels.

Fuel And Lubricating Oil Requirements.

The EPA has lowered the limit for sulfur in diesel fuel from 500 parts per million (ppm) to 15 ppm. The new fuel standard was phased in beginning October 1, 2006 (80% participation) through September 1, 2010 (100% participation). In 2007, all indications are that 15-ppm Ultra-Low Sulfur Diesel (ULSD) fuel is widely available.

Use of ULSD fuel is critical for proper performance of exhaust aftertreatment systems. Beginning in 2007, all heavy-duty, mid-range and light-duty diesel engines are required to operate using ULSD fuel.

Biodiesel is growing in popularity and use in North America. Cummins is fully committed to assisting and supporting the industry in developing the appropriate quality standards and specifications for the proper use of this fuel. In addition, Cummins is committed to developing our products to be fully capable to operate on B20 biodiesel today and into the future.

New specifications have been released for lubrication oil compatible with low-emissions solutions for 2007-2010. The primary focus has been to make the oils compatible with exhaust aftertreatment devices (e.g., diesel particulate filter). For 2007, the requirement has been to reduce ash in the oil in order to enable extended maintenance intervals on the diesel particulate filter while maintaining the important lubricity capability of the lubricant. The new low-ash oil classification (CJ-4) that was released for 2007 on-highway engines will also be used in 2010. A new oil classification will not be required for 2010.

NOx Reduction Options.

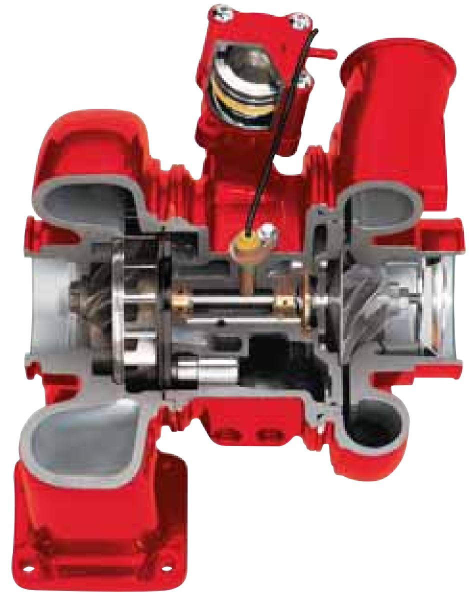
Advanced Combustion.

Cummins has made a large investment in the development of advanced combustion systems and flexible fuel 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 (e.g., injection timing, injection rate and shape) and combustion chamber geometry. This process accelerates the development process and has allowed Cummins to attain low engine-out NOx and particulates.

Integrated Cooled EGR.

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 EPA '07 and future EPA '10 products.

Cooled EGR is very effective at 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 was used to attain the NOx levels introduced in 2007 and beyond.



In order to control both NOx 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 Cummins Turbo Technologies 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.

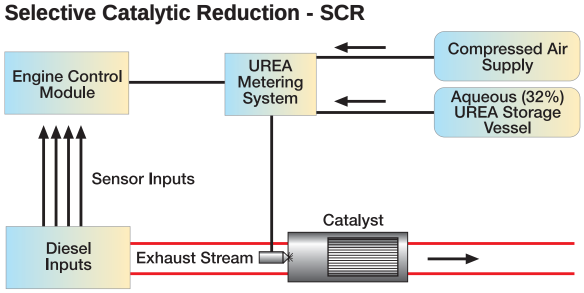
Simulation, experimental studies and empirical data have shown that cooled EGR continues to offer distinct advantages at 1.2-g/hp-hr NOx levels in both product cost and fuel economy when compared to other solutions.

To reach the 2010 NOx standard within the engine, we will extend the use of cooled EGR. A cooled-EGR engine for 2010 will look very similar to the Cummins on-highway engine installed today.

Aftertreatment Solutions.

While cooled EGR is an "in-cylinder" technology that can reduce NOx, there are aftertreatment solutions which can achieve reduced NOx levels by treating the exhaust gases after they leave the engine. These include Selective Catalytic Reduction (SCR) and NOx adsorbers.

Selective Catalytic Reduction - SCR



Basic Principal – Spraying UREA into the exhaust stream to promote NOx–reducing catalyst activity.

Selective Catalytic Reduction (SCR).

Selective Catalytic Reduction (SCR) systems use a chemical reductant – in this case urea – which converts to ammonia in the exhaust stream and reacts with NOx 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 used today in Europe.

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 NOx and some ammonia will "slip" through the catalyst. If the rate is too low, the desired NOx 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 5 to 30 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 12ºF.
- **Urea injection and control system –** A sophisticated injection system and controls (including NOx 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 NOx being produced by the engine in real time.

How much urea does an SCR system use? For each 1-g/hp-hr reduction in NOx, an SCR engine consumes urea at a rate of approximately 1.5% of the amount of fuel used. Assuming a NOx reduction from 1.2-g/hp-hr to .2-g/hp-hr and for an engine to consume 100 gallons of diesel fuel in 600 miles (6 mpg), the urea consumption for this period would be 1.5 gallons.

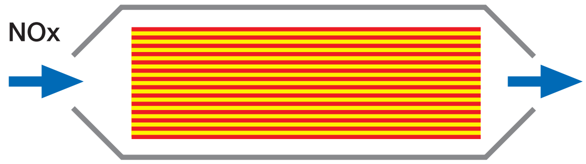
In the U.S., urea is expected to cost about as much as diesel fuel. Preparing for 2010, an infrastructure will need to be developed and implemented for commercial availability of urea.

NOx Adsorbers.

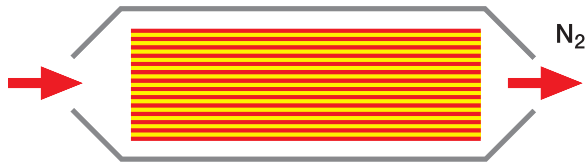
The NOx Adsorber Catalyst (NAC) is a new technology developed in the late 1990s. The NOx Adsorber Catalyst uses a combination of base metal oxide and precious metal coatings to effect control of NOx. The base metal component (for example, barium oxide) reacts with NOx to form barium nitrate – effectively 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 (NOx) with a catalyst because of the excess of oxygen in the exhaust stream.

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



Lean-Operation
NOx Is Stored on the Surface



Rich-Operation
NOx Is Converted to Nitrogen

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. 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 NOx adsorbers. In addition to storing NOx, the NAC will also store sulfur, which reduces the capacity to store NOx. Although fuel sulfur levels were 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 NOx regeneration process, but at higher temperatures.

Cummins is using NOx adsorber technology beginning in model year 2007 Dodge Ram Heavy Duty pickup trucks. The Cummins Turbo Diesel for the Dodge Ram already meets 2010 emissions levels.

NOx-Reduction Summary.

In summary, key challenges for all NOx aftertreatment technologies (SCR, NOx adsorber) 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.

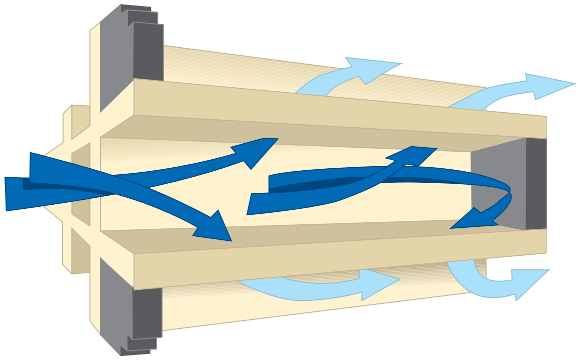
PM Reduction.

The 2007 emissions standards for particulate emissions are 90% lower than 2002 engines, from .1 to .01-g/hp-hr. While previous reductions in particulate matter (PM) emissions have been achieved through engine combustion improvements and oxidation catalysts, the stringent 2007 particulate standards 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. All engine manufacturers use this technology in one form or another.

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 microscopic-sized particulate matter 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 particulate matter on the surface and inside pores of the media. Particulate matter accumulates in the filter, and when sufficient heat is present a “regeneration” event occurs, oxidizing the particulate matter and cleaning the filter.



Wall-Flow Filter

The challenge of particulate filter design is to enable reliable and consistent regeneration, so that particulate matter is removed in all types of duty cycles. For example, while a line-haul truck that is fully loaded will consistently run hot enough for regeneration to take place, the same truck in stop-and-go traffic or running from Duluth to International Falls in the middle of winter may not. EPA requirements state that every engine has to achieve the required reduction in every operating condition, which is why active controls are needed. The use of this "active" method involves monitoring the particulate filter backpressure and regeneration events and managing the temperature entering the filter.

There are several methods to control or raise the exhaust temperature to "actively" manage the DPF. The methods chosen for EPA '07 engines are management of the combustion process in combination with an additional oxidation catalyst. This will allow regeneration to take place under low-ambient/low-load conditions when exhaust temperatures are low, and during normal operation as well.

DPF Challenges.

Maintenance will be required on diesel particulate filters. Additives in lubricating oils will become ash and collect in the filter as oil is consumed and particulate matter is oxidized through regeneration. Ash must be cleaned from the filter or plugging will occur. The Cummins Particulate Filter cleaning interval for all on-highway engines is 200,000 to 400,000 miles. The actual cleaning interval will be dependent on duty cycle and engine oil consumption. Cummins has introduced a commercial cleaning system to the field for the North American market. Cummins will provide two cleaning methods:

- Cleaning of particulate filters at Cummins distributor branch locations.
- Factory exchange ReCon® program.

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 Business Units, such as Cummins Fuel Systems, Cummins Turbo Technologies and Cummins Filtration, and 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 Future Emissions – The Cummins Solution.

The Cummins technology plan for on-highway applications for 2010 and beyond is straightforward:

- Cummins is well on the way to developing engines to meet the 2010 EPA standards. The proven products in operation today are the base platform for 2010.
- Cummins is the only engine manufacturer providing technology for air-handling (Cummins Turbo Technologies) and aftertreatment systems (Cummins Emission Solutions) and filtration (Cummins Filtration), enabling us to execute 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.
- SCR systems will be introduced into the North America market beginning in 2010, depending on engine model and vehicle application.
- Cummins uses an active particulate filter to achieve the 90% reduction in particulate matter. The Cummins Particulate Filter is a proven technology.

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 NOx to nitrogen gas and H_2O (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.

Cummins Emission Solutions — A Business Unit of Cummins that is a world leader in the development and production of advanced emissions technology.

CCC — Close-Coupled Catalyst. Same design concept as a DOC, but located as near as possible to engine-out exhaust.

Coalescing Filter — Unique filter design from Cummins Filtration that enables an open crankcase ventilation system that meets the EPA emissions requirements for 2007 and beyond for the on-highway market.

DPF — Diesel Particulate Filter. Captures particulate matter 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.

DOC — Diesel Oxidation Catalyst. Promotes the chemical reaction from NO (Nitric Oxide) to NO_2 (Nitrogen Dioxide) which is required for oxidation of particulate matter in the diesel particulate filter (regeneration).

EGR	Exhaust Gas Recirculation. Technology that diverts a small percentage of the exhaust gas back into the cylinder, lowering combustion temperatures and reducing NOx.
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 took effect in 2005-2006 throughout Europe.
Exhaust Aftertreatment	Any technology which treats emissions in the exhaust flow, as opposed to inside the power cylinder.
"Lean" Engine Operation	Using an air/fuel mixture with more air than fuel versus what would occur in a natural (stochiometric) burning condition.
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.
OEM	Original Equipment Manufacturer.
PM	Particulate Matter. Composed primarily of soot and other combustion by-products.
“Rich” Engine Operation	Using an air/fuel mixture with more fuel than air versus what would occur in a natural (stochiometric) 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. Took effect in 2005.
ULSD	Ultra-Low Sulfur Diesel. Fuel which contains less than 15 parts per million by volume of sulfur. Mandated phase-in started in October 2006.

Urea A chemical, usually made from natural gas, that is commonly used in fertilizers. Urea breaks down into ammonia (NH_4) and reacts with NOx in an SCR system to produce N_2 and H_2O.

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
Internet: everytime.cummins.com

Bulletin 4971141 Printed in U.S.A. 9/07