Mobile Off-Highway Emissions.

Choosing The Right Technology For Tier 4.

Cummins Off-Highway Emissions Technology

Introduction

Cummins engines are designed to provide customers with the highest levels of reliability, durability, performance and dependability at the lowest cost of operation. At the same time, we are committed to meeting or exceeding clean air standards worldwide. This document describes the technology options Cummins is developing to meet emissions requirements for the off-highway market. It discusses several technologies as well as their advantages and challenges.

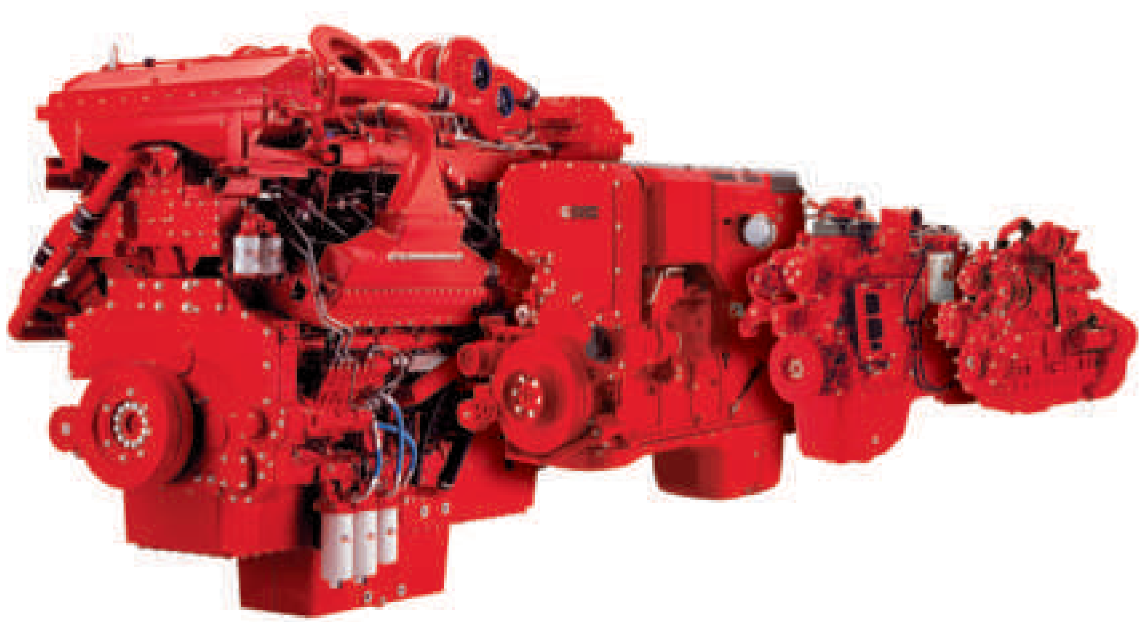
Cummins has long been a pioneer in emissions research and development. We have invested in critical technologies to achieve current and future emissions standards and meet the needs of our customers. The emissions solutions we use today are the direct result of a technology plan that was put in place in the early 1990s. It is a plan that will carry us through 2015 and beyond. At the core of this technology road map is a strategic decision to involve original equipment manufacturers as early as possible in the development and integration process. This open exchange of information and technology has been – and continues to be – instrumental in developing solutions for the future.

Our objective is very clear. It is to deliver products that meet emissions standards with the best reliability, fuel economy, durability, performance and the lowest cost of operation.

Cummins Strategy – The Right Technology Matters

Cummins is a leading global manufacturer and supplier to very diverse worldwide markets and customers. As emissions regulations are becoming more stringent worldwide, Cummins leadership in combustion research, fuel systems, air handling, aftertreatment, filtration and control systems becomes more significant. It means we can achieve the goal of maximizing customer value by providing the most appropriate emissions solution integrated into each equipment type and market.

Cummins component technology companies, joint ventures, customer partnerships and our relationships with universities and national laboratories uniquely position us to design, manufacture and implement the best solutions for off-highway markets. Today and in the future, Cummins will continue to deliver power uniquely matched and integrated into every application through advanced customer engineering.



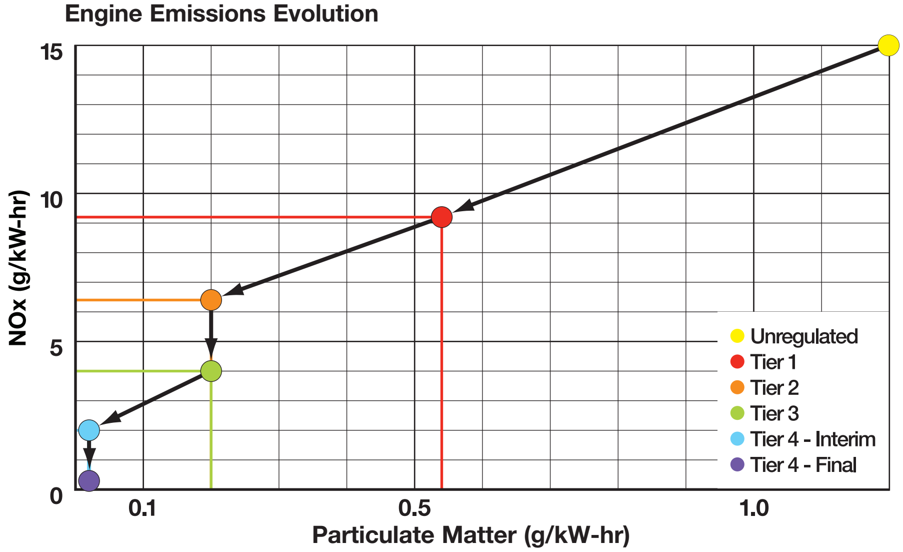
Evolution of Mobile Off-Highway Standards

In 1996, the first EPA emissions regulations, known as Tier 1, went into effect for diesels used in mobile off-highway applications in the United States. This was mirrored three years later in Europe with EU Stage I regulations. Since then, the U.S. EPA and its counterparts in Canada, Europe and Japan are closing the gap between the on-highway and off-highway emissions limits.

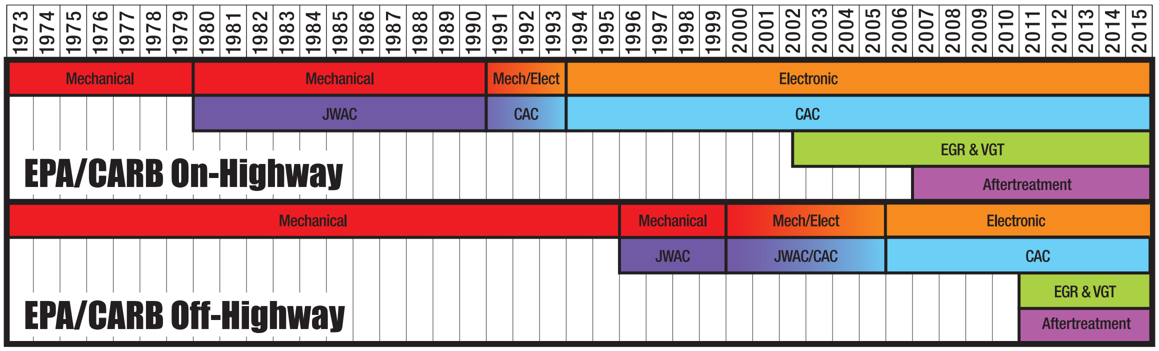
Regulatory agencies have primarily focused on the reduction of particulate matter (PM) and oxides of nitrogen (NOx). Carbon monoxide (CO) and hydrocarbons (HC) are also regulated but are inherently low from diesel engines.

By 2014, EPA Tier 4 Final, EU Stage IV and Japanese off-highway regulations call for PM and NOx levels to be reduced more than 90% from current levels for most power categories. The use of advanced engine technology and exhaust aftertreatment will be required to achieve these near-zero emissions levels in off-highway equipment.

Engine Emissions Evolution



Emissions Technology – Cummins MidRange and Heavy-Duty Diesel Engines

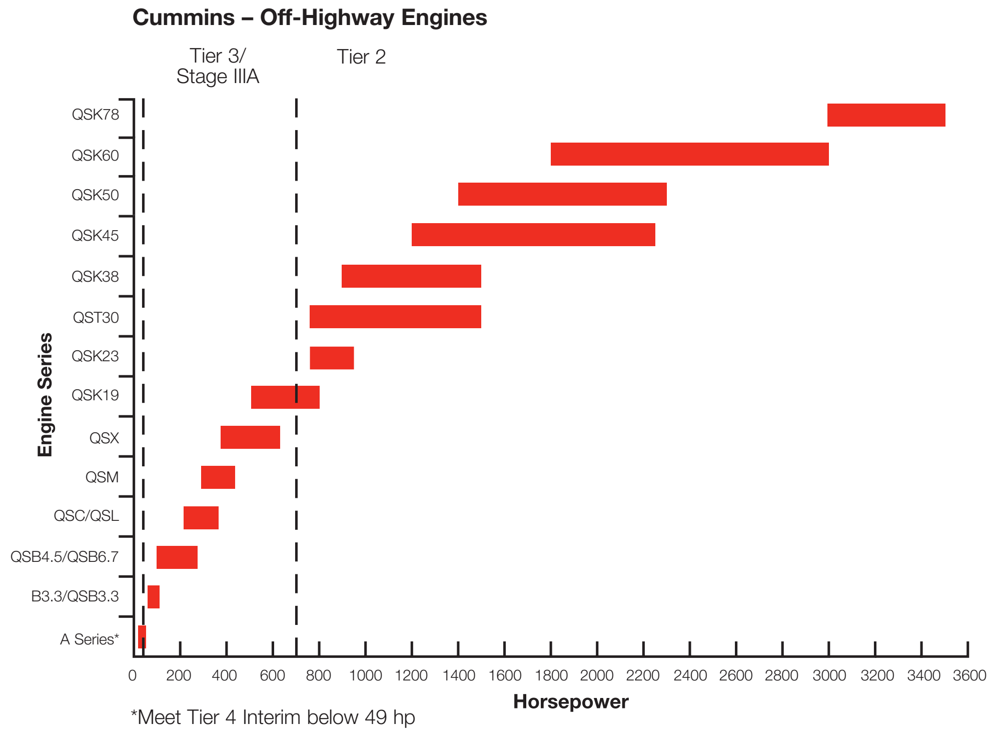


- Fuel System/Controls (mechanical to electronic)
- Charge Air Temperature Control (jacket-water aftercooled [JWAC] to air-to-air aftercooled [CAC])
- EGR (cooled Exhaust Gas Recirculation) and VGT (Variable Geometry Turbocharging)
- Exhaust Aftertreatment

While the gap between on- and off-highway emissions is closing, the effect dates for equivalent off-highway emissions levels generally lag on-highway by a few years. This chart illustrates the types of technology driven by on- and off-highway emissions and how the off-highway implementation has followed the on-highway market.

While the technologies shown in the chart above were developed for earlier on-highway applications, the requirement for later off-highway utilization was very much in the initial design profile. This approach has enabled Cummins to deliver the right emissions solution by leveraging our on-highway experience and then optimizing the technology for off-highway applications.

For more information regarding on-highway emissions regulations and technology approaches, please read Cummins 2010 On-Highway Technology brochure (Bulletin 4971141).

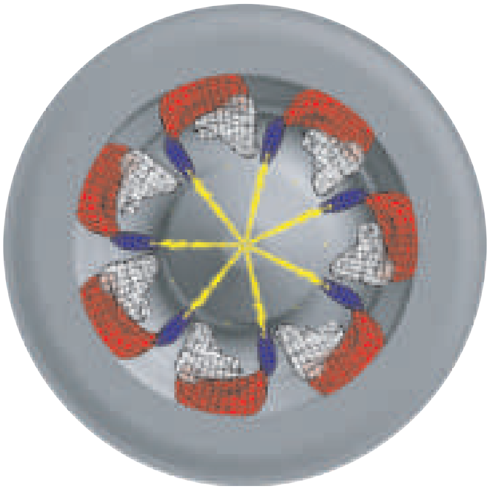


Current Emissions Standards

Cummins has a broad product line of certified off-highway diesel engines providing power from 31-3500 hp (23-2610 kW).

Today 49-751 hp (37-560 kW) engines must meet the third Tier or Stage of emissions standards, which began in 2005 and have been phased in by power categories. Larger engines above 751 hp (560 kW) must meet Tier 2 standards in North America. A close examination of the chart on pages 10 and 11 reveals that current emissions levels are similar in Europe, Japan and the U.S. While emissions levels are similar, differences do exist – such as unique standards and procedures for measuring smoke emissions during engine acceleration. Certification and labeling requirements also vary. These differences cause additional work for manufacturers, but the standards are close enough to permit the sale of common products in these countries. This is important for both engine and equipment manufacturers.

Engine Combustion Simulation



Particulate Matter
Fuel-Rich Region
NOx
Liquid Fuel

The primary focus of the Tier 3/Stage IIIA standard has been NOx reduction. Cummins advanced in-cylinder solution, electronic controls and advanced fuel systems for Tier 3/ Stage IIIA provide a key building block as we move forward to the next level of off-highway emissions.

The same expertise with advanced in-cylinder combustion and high-pressure common-rail fuel systems has been applied to Cummins range of high-horsepower engines over 751 hp (560 kW) to achieve Tier 2 emissions levels, introduced in January 2006 for applications in North America.

Next-Generation Standards

Tier 4 Interim and Stage IIIB

Tier 4 Interim regulations take effect in North America in January 2011 for engines above 173 hp (129 kW). Equivalent EU Stage IIIB regulations begin at the same time for European Union countries, while similar regulations commence in October 2011 for Japan. A maximum of 15-ppm sulfur content in diesel fuel will be regulated for these off-highway applications in North America and 10 ppm in Europe and Japan.

As detailed in the chart on pages 10 and 11, the EPA Tier 4 Interim and EU Stage IIIB emissions standards and effect dates vary by power category.

The regulations require a major reduction of particulate matter (PM) and also require significant oxides of nitrogen (NOx) reductions. The most stringent reductions apply across the 174-751 hp (130-560 kW) power categories with 90% PM and 45% NOx reductions. These reductions drive the need for PM exhaust aftertreatment and enhanced engine technology. In the 75-99 hp (56-74 kW) power category, PM aftertreatment will also be required to achieve over 90% PM reduction, although NOx reductions are less severe than higher-power engines.

For engines less than 49 hp (37 kW), Tier 4 began in January 2008 and required a PM reduction of 50%. For this power category, Cummins has achieved Tier 4 emissions reductions using advanced in-cylinder combustion without the need for exhaust aftertreatment.

Tier 4 Interim standards begin in 2011 for engines greater than 751 hp (560 kW) in the U.S. and Canada, but are not applicable in Europe or Japan. Emissions levels are less severe than those of engines in the 174-751 hp (130-560 kW) power category, recognizing the challenge of retaining power density for these larger displacement engines. For large engines used in portable power generation applications, the regulated NOx emissions levels are set lower than for mobile machines.

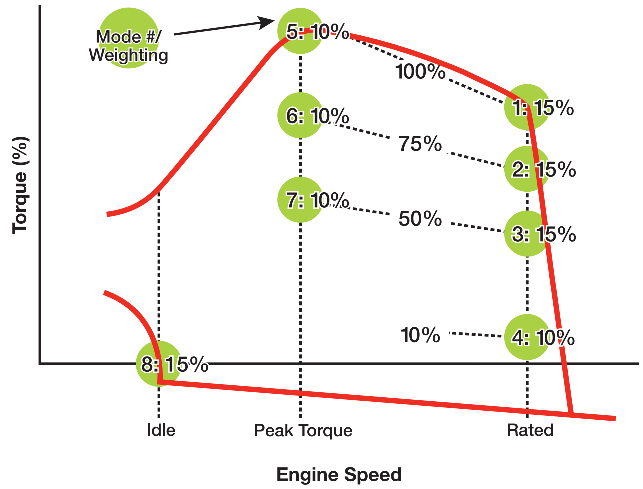
Tier 4 Final and Stage IV

In January 2014, EPA Tier 4 Final and EU Stage IV reduce NOx emissions by an additional 45% for engines above 173 hp (129 kW).

Similar NOx reductions will also be required for engines above 74 hp (55 kW) in January 2015. Japanese regulations will closely align with the EPA and EU emissions standards.

At this point, both NOx and PM emissions will be at near-zero levels, comparable with the most stringent on-highway applications. With only a three-year gap between the introduction of Tier 4 Interim/Stage IIIB and Tier 4 Final/Stage IV, engine and aftertreatment design architecture for 2011 will need to be capable of incremental emissions reduction for the 2014 solution.

Steady-state test characterizes emissions at eight isolated points typical of engine operation. Emissions are measured under a hot-stabilized engine condition.



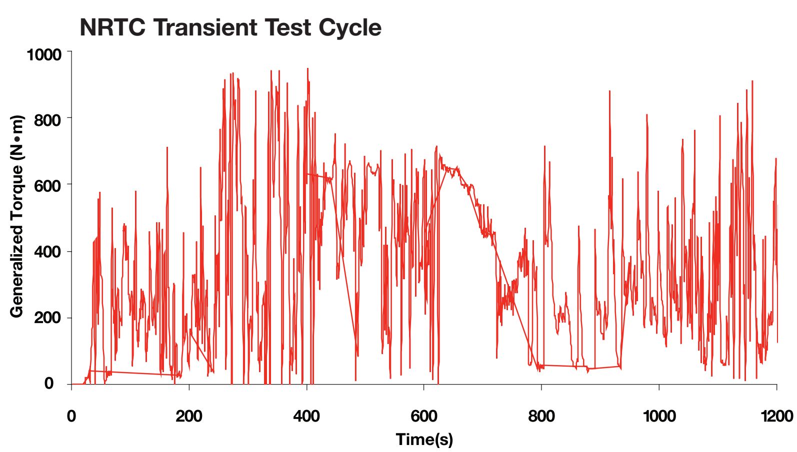
Test Certification

2011 EPA, EU and Japanese off-highway emissions regulations will require both engine and aftertreatment to be certified compliant as a single emissions system, replacing engine-only measured emissions with tailpipe-measured emissions.

Engine test certification becomes more rigorous for the 2011 regulations with a new non-road transient composite (NRTC) test cycle. The new test cycle will be in addition to the current Tier 3 steady-state eight-mode emissions test cycle.

This transient test cycle is more representative of actual non-road engine operation in service. Emissions, particularly PM, are more difficult to control in the transient cycles.

A further addition to the test certification is that engine crankcase emissions (blowby gasses) have to be accounted for in EPA Tier 4 tailpipe emissions measurement. Crankcase emissions consist of hydrocarbon gas that escapes from the cylinder through the piston rings into the crankcase.



Transient test operation captures emissions across a broad range of engine speed and load combinations attained during actual-use conditions. The procedure requires measurement of both cold-start and hot-start emissions over the transient duty cycle.

U.S. EPA

kW	(HP)	1996	1997	1998	1999	2000	2001	2002	2003	2004
0 - 7	(0 - 10)					(10.5) / 8.0 / 1.0				
8 - 18	(11 - 24)					(9.5) / 6.6 / 0.80				
19 - 36	(25 - 48)				(9.5) / 5.5 / 0.80					
37 - 55	(49 - 74)			9.2 / – / – / –						
56 - 74	(75 - 99)									
75 - 129	(100 - 173)		9.2 / – / – / –						(6.6) / 5.0 / 0.30	
130 - 224	(174 - 301)	9.2 / 1.3 / 11.4 / 0.54							(6.6) / 3.5 / 0.20	
225 - 449	(302 - 602)	9.2 / 1.3 / 11.4 / 0.54					(6.4) / 3.5 / 0.20			
450 - 560	(603 - 751)	9.2 / 1.3 / 11.4 / 0.54						(6.4) / 3.5 / 0.20		
>560	(>751)					9.2 / 1.3 / 11.4 / 0.54				

EUROPE

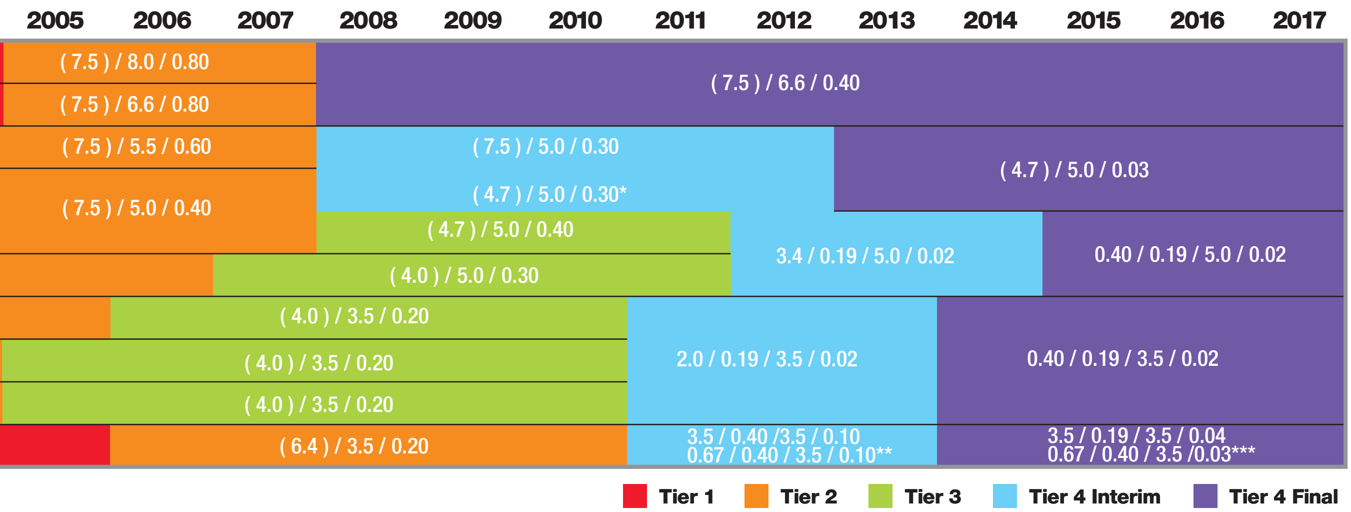
kW	(HP)	1996	1997	1998	1999	2000	2001	2002	2003	2004
18 - 36	(24 - 48)						8.0 / 1.5 / 5.5 / 0.8			
37 - 55	(49 - 74)				9.2 / 1.3 / 6.5 / 0.85					
56 - 74	(75 - 99)									
75 - 129	(100 - 173)				9.2 / 1.3 / 5.0 / 0.70					
130 - 560	(174 - 751)				9.2 / 1.3 / 5.0 / 0.54			6.0 / 1.0 / 3.5 / 0.2		

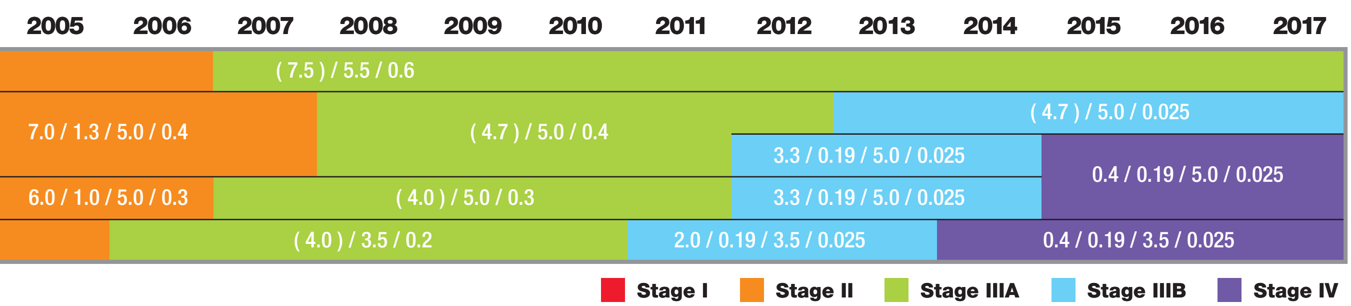
JAPAN (Introduction dates are October of year listed.)

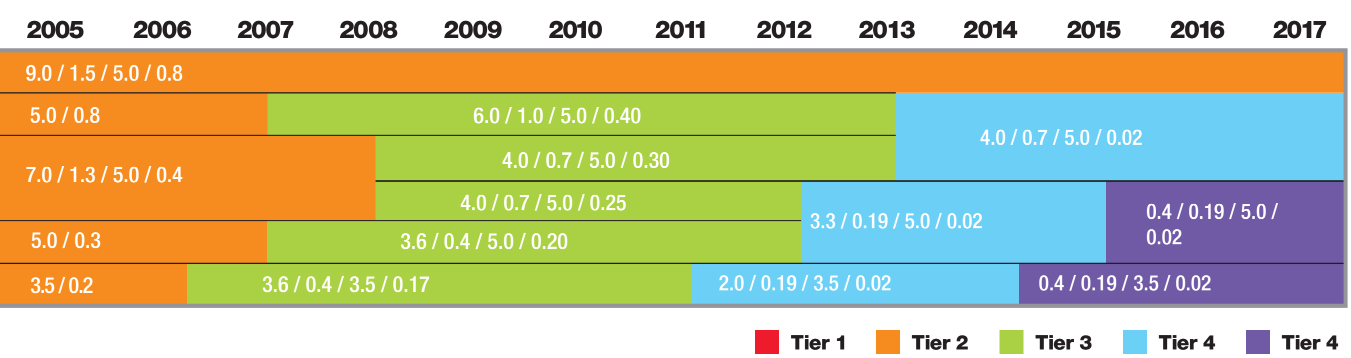
kW	(HP)	1996	1997	1998	1999	2000	2001	2002	2003	2004
8 - 18	(11 - 24)	Tier 1 standards are application-specific								
19 - 36	(25 - 48)								8.0 / 1.5 /	
37 - 55	(49 - 74)	9.2 / 1.3 / 5.0 --, Tier 1 standards are application-specific and apply to engines 30-260 kW								
56 - 74	(75 - 99)									
75 - 129	(100 - 173)	Tier 1 standards are application-specific							6.0 / 1.0 /	
130 - 560	(174 - 751)								6.0/1.0/	

NOx/HC/CO/PM (g/kW-hr)
(NOx+HC)/CO/PM (g/kW-hr)
(Conversion: [g/kW-hr] x 0.7457 = g/bhp-hr)

The chart above is displayed for reference purposes only and does not depict the various options available to engine and equipment manufacturers. See the appropriate regulations for specific details and options related to that region's emissions standards and implementation dates.







*Tier 4 Interim Option 1 PM Standard
**Applies to portable power generation >1200 hp
***Applies to portable power generation >751 hp

ULSD Fuel Standards

In meeting the 2011 emissions requirements, diesel fuel is a critical part of the solution. Ultra-Low Sulfur Diesel (ULSD) is necessary for most aftertreatment technology as high levels of sulfur will render the aftertreatment less effective and may not be emissions-compliant due to the increased production of sulfates. The sulfur level in diesel fuel for non-road engines in North America will be lowered from the current 500-ppm maximum limit to 15 ppm.

The automotive market in North America introduced ULSD fuel ahead of the EPA 2007 regulations. With the infrastructure already in place, this will ease the transition to 15-ppm sulfur content diesel for the off-highway market. The EU is expected to introduce ultra-low sulfur diesel fuel in 2009 ahead of the Stage IIIB regulations in 2011. In Japan, ULSD fuel is already available for on-highway and some specialized off-highway applications.

The introduction of ultra-low sulfur diesel fuel provides other beneficial effects beyond ensuring effective operation of aftertreatment. It inherently produces less PM from combustion and will also enable a major reduction in sulfur dioxide (SO_2) emissions from off-highway engines.

Biodiesel fuel is gaining significant attention by offering environmental advantages. Cummins is fully committed to assisting and supporting the industry in developing the appropriate quality standards for the correct use of this fuel. In addition, Cummins is committed to developing our engines to be fully capable to operate on B20 biodiesel blend today and into the future.

Emissions Reduction Technology

The Tier 4/Stage IV emissions standards drive NOx and PM to near-zero limits. At 2011 Tier 4 Interim/Stage IIIB, the focus is on 90% PM reduction and 45% NOx reduction for the 174-751 hp (130-560 kW) power category. At 2014 Tier 4 Final/Stage IV, the focus is on an additional 45% NOx reduction. Cummins will apply an incremental technology approach that will expand on our Tier 4 Interim solution to meet Tier 4 Final in the most effective way. To achieve this, Cummins has evaluated the various technology options shown:

Engine Strategies

- Combustion optimization
- Cooled Exhaust Gas Recirculation (EGR)
- Variable Geometry Turbocharging (VGT)
- High Pressure Common Rail (HPCR) fuel systems
- Electronic controls
- Crankcase filtration
- Direct Flow air filtration system

Aftertreatment Strategies

- Catalyzed Diesel Particulate Filter (DPF)
- Diesel Oxidation Catalyst (DOC)
- Selective Catalytic Reduction (SCR)
- NOx adsorbers

Cummins Tier 4 Interim/Stage IIIB technology development began in 2004 and involved evaluating various combinations of these emissions reduction strategies. One scenario is the use of SCR aftertreatment for NOx reduction and in-cylinder combustion for PM control together with some particulate aftertreatment. The other scenario is to use combustion optimization and cooled EGR for NOx reduction along with a catalyzed Diesel Particulate Filter (DPF) for PM control. Key engine systems such as VGT, HPCR and electronics are critical components in all scenarios.

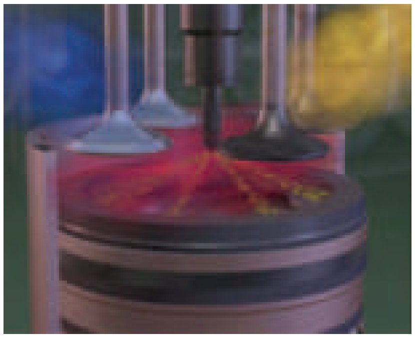
The starting point is to meet Tier 4 emissions levels – but equally important to Cummins is to achieve the best value solution for our customers by focusing on the need to minimize installation impact and achieve the lowest cost of operation. This process led to Cummins defining a Tier 4 Interim/Stage IIIB solution for the 174-751 hp (130-560 kW) power band utilizing cooled EGR for NOx reduction and Cummins Particulate Filter aftertreatment for PM control. Engine technology enhancements also include Cummins Variable Geometry Turbochargers, High Pressure Common Rail fuel systems, integrated electronic controls, crankcase filtration and Direct Flow air filtration.

This technology route was announced in 2007 as common architecture for all Cummins six-cylinder MidRange and Heavy-Duty products for 2011 emissions compliance. These various engine and aftertreatment technologies will be discussed on the following pages.

Cummins has a unique advantage in that we design and manufacture all the critical engine subsystems and aftertreatment. We can integrate them more efficiently and optimize them as a total system.

2012 Emissions Phase-In

Tier 4/Stage IIIB emissions will take effect for the 75-173 hp (56-129 kW) power category in January 2012, a year later than those in the higher power categories. Cummins continues to develop and refine a technology solution for products within this power range. Depending on power output, the Diesel Particulate Filter (DPF) and Diesel Oxidation Catalyst (DOC) are under evaluation for PM aftertreatment.



Optimized 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 has been optimized to attain low engine-out emissions with fuel-efficient operation by fine-tuning the key variables: valve events, swirl intake ports, fuel injection pressure, timing and spray angle, turbocharger and inlet manifold design.

Using analysis-led design, our engineers can model detailed computer simulation of the combustion event and optimize the results by controlling or modifying critical design parameters. We can analyze thousands of combinations before committing to a design and have developed great correlation between analysis and empirical tests. Cummins combustion design led to the in-cylinder solution for Tier 3/Stage IIIA and is a key building block in achieving Tier 4 Interim/Final and Stage IIIB/IV emissions compliance.

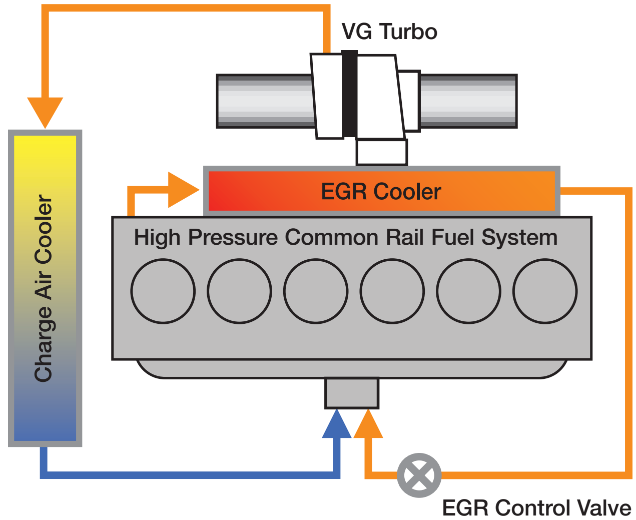
Cooled EGR

Cooled Exhaust Gas Recirculation (EGR) technology is very effective at controlling NOx. The EGR system takes a measured quantity of exhaust gas and 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 gas. During combustion, the lower oxygen content has the effect of reducing flame temperatures, which in turn reduces NOx, since NOx production is exponentially proportional to flame temperature. This allows the engine to be tuned for the best fuel economy and performance at low NOx levels. Cooled EGR will be used by Cummins to attain the NOx levels being introduced in 2011 for 174-751 hp (130-560 kW) off-highway applications.

In EGR engines, exhaust gasses are cooled by engine coolant which raises the cooling system requirement. For on-highway applications,

Cummins short-loop EGR system routes the exhaust gas directly back to the cylinder.

Cooled-EGR Schematic



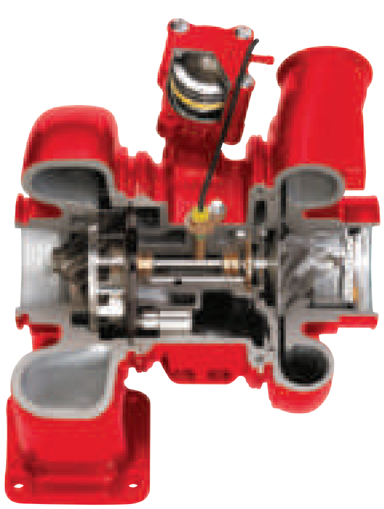
this is managed well with vehicle ram air and slightly larger cooling packages. For off-highway equipment, where ram air is not available, upgraded cooling fan and radiator/charge air packages are required to reject the additional heat. This increased heat rejection is a necessary consequence to achieve major emissions reductions. However, the impact on cooling systems can be mitigated by Cummins working with the equipment OEM and cooling system suppliers to achieve more efficient packaging and integration techniques. With hundreds of thousands of on-highway EGR engines in service, Cummins offers a unique degree of experience in this area.

Variable Geometry Turbocharging

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. For Cummins Tier 4/Stage IIIB 174-751 hp (130-560 kW) products, this has driven the use of variable geometry turbochargers used in concert with an EGR control valve to accurately meter the cooled exhaust gas into the intake system. Customer benefits are increased performance and improved fuel economy.

Cummins Variable Geometry Turbocharger, with a unique patented one-piece sliding-nozzle design, continually varies the airflow delivered to the engine. This combines the benefits of a small and a large turbocharger in a single unit. The sliding nozzle varies the exhaust gas flow into the turbine wheel to provide rapid boost at low engine rpm and then maintain high boost at higher rpm.

Cummins Turbo Technologies



Variable Geometry Turbocharger

HPCR Fuel Systems

High-pressure common-rail fuel systems have been, and will continue to be, a critical element in the emissions reduction recipe. There are many injection characteristics that must be balanced and tuned with all other critical engine subsystems (base engine, air handling, aftertreatment and controls). Full electronic control over fuel timing, quantity, pressure, delivery rate shape and the number of injection events is a must for optimum emissions solutions and performance.

Cummins capability to design and manufacture its High Pressure Common Rail fuel systems offers a major resource to both achieving emissions standards and enhancing engine performance. Most of Cummins product platforms, from the 3.3-liter to the 78-liter engine, already incorporate HPCR fuel systems, and for Tier 4 Interim/Stage IIIB emissions in 2011 this key technology will be utilized for all engines.

Fuel Systems

High Pressure Common Rail Fuel System

Cummins latest-generation ECMs have the capability to manage EGR, VGT, fuel injection and exhaust aftertreatment as a single integrated emissions control system.

Highly flexible control of fuel injection offered by these systems results in better atomization of the fuel with a corresponding reduction in unburnt carbon and more efficient combustion.

Electronic Controls

The electronic control of engine systems is a vital element in meeting emissions standards. More stringent emissions regulations require very precise control of fuel injection, air handling and aftertreatment systems. At the same time, the extreme operating environments in off-highway applications require a robust electronic system for reliable operation.

Common architecture is applied across all Cummins electronic engines – small or large – in the area of control modules, software, sensors/harnesses and tools such as PowerMatch and INSITE™ to assist in equipment integration, power optimization and diagnostics for all types of equipment and applications.

To meet Tier 4/Stage IIIB 2011 off-highway emissions levels requiring exhaust aftertreatment, Cummins engine electronic control modules will utilize higher capacity and faster processing speeds. Cummins has the in-house capability to design the core programs and algorithms needed to precisely control engine and aftertreatment as a single integrated system.

Equipment manufacturers are increasingly looking to CANbus common area networks for integrating electronic subsystems, enabling them to “talk” to each other along a serial datalink. The Cummins ECM is already CANbus compatible for J1939 and ISO multiplexing. For Tier 4, this connectivity will be extended to incorporate aftertreatment via the engine ECM.

Filtration

Direct Flow Filtration System for Tier 4

Enhanced Engine Filtration

Tier 4 engines will require higher levels of filtration efficiency and protection for air intake systems, engine lube oil and fuel, as well as eliminating crankcase emissions. Cummins Filtration has already developed a range of Fleetguard® products well in advance of the 2011 off-highway emissions introduction to meet these requirements.

Ultra-Low Sulfur Diesel (ULSD) and biodiesel blends present new fuel filtration challenges for high-pressure common-rail fuel systems. While ULSD fuel is a key enabler for exhaust aftertreatment, the very low sulfur content can lower the resistance of the fuel to oxidation which can lead to plugging the fuel filter. Biodiesel fuel blends require highly efficient fuel/water separation filters to protect the fuel system.

Cummins Filtration has introduced superior fuel-conditioning products to ensure the HPCR system operates correctly to very fine tolerance levels. Fuel filtration to 7-micron, see-through components, compact filter-in-filter two-stage designs, and water separation capability to below 200 ppm will make an important contribution to Tier 4 filtration technology.

A range of Cummins coalescing filters were first introduced for EPA ’07 engines to meet the need for eliminating crankcase emissions, also known as blowby gasses.

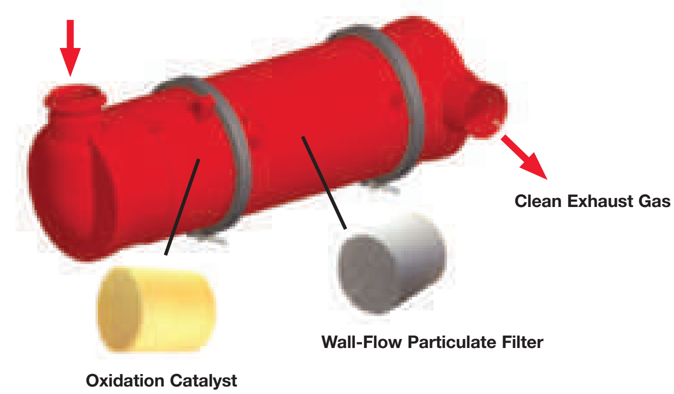
Cummins coalescing filter for eliminating crankcase emissions

As this requirement is also part of the Tier 4 test certification, the crankcase filters will be utilized as part of the Cummins technology solution to meet 2011 emissions. These highly efficient filters return all the oil to the crankcase and provide the added benefit of removing oil mist and tiny oil droplets, ensuring that the engine and power train remain clean.

Cummins Direct Flow air filtration by Fleetguard has been specifically developed for Tier 4 platforms to provide a smaller, more flexible installation package and higher air filtration efficiency. This is accomplished by creating a direct-flow path through the filter media which is packaged in a rectangular configuration rather than a conventional cylindrical shape.

The Direct Flow housing includes a sensor to monitor temperature and pressure, which sends data to the engine electronic control module to ensure optimum air intake system operation.

Combined with the Cummins Particulate Filter aftertreatment system, the Direct Flow air filtration system and crankcase filter complete the packaging integration to fully manage total airflow in meeting stringent Tier 4 emissions standards.



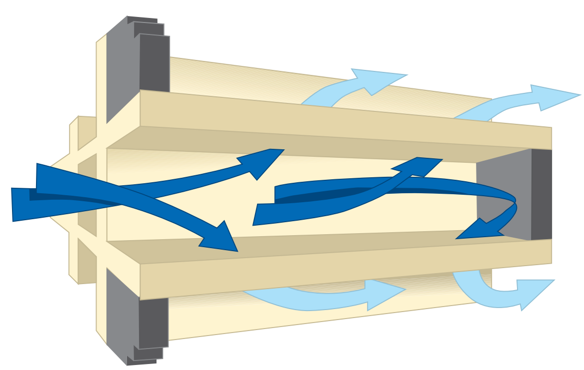
Cummins Particulate Filter

In a catalyzed diesel particulate filter, the particulate matter is collected on the filter. The PM is oxidized gradually by passive regeneration or by active regeneration when the exhaust temperature is increased, typically by injecting small amounts of fuel. Cummins successfully utilized this aftertreatment technology to meet EPA '07 on-highway regulations and has leveraged this expertise to develop a particulate filter specifically tailored for off-highway environmental factors and duty cycles. The catalyzed Cummins Particulate Filter will be part of an integrated engine and aftertreatment solution for the 174-751 hp (130-560 kW) Tier 4/Stage IIIB emissions power category.

The Cummins Particulate Filter for Tier 4 replaces the muffler in the exhaust stream and is designed to provide the necessary acoustic attenuation. The housing incorporates an oxidation catalyst and the ceramic particulate filter.

- Wall-Flow Filter – A porous ceramic wall-flow particulate filter captures up to 90% of the PM. This consists of an array of small channels through which the exhaust gas flows. Adjacent channels are plugged at opposite ends, forcing the exhaust gas to flow through the porous wall, capturing the PM on the surface and inside pores of the media before it can exit.

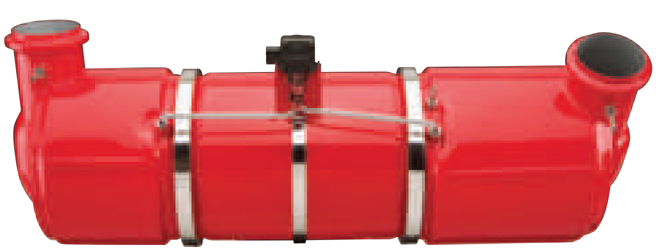
Filter media captures PM from the exhaust gas flow



Wall-Flow Filter

- Passive Regeneration – The primary purpose of the Cummins Particulate Filter is to trap the particulate matter for a sufficient period of time to allow oxidation of the PM.

  At higher temperatures, the oxidation is accomplished through direct reaction with oxygen (O_2). At lower temperatures, the primary method of PM oxidation is through reaction with nitrogen dioxide (NO_2) developed in the oxidation catalyst incorporated within the filter housing.



- Active Regeneration – Initiated when particulate filter operating conditions result in a PM accumulation rate that exceeds the oxidation rate, and the PM loading exceeds a predetermined level. The active regeneration prevents filter plugging by removing the excess PM buildup. This involves monitoring the PM backpressure and regeneration events, and managing the temperature of the exhaust entering the filter. When needed to raise the temperature and actively manage the DPF regeneration, a small quantity of fuel is injected from a doser or through the High Pressure Common Rail fuel system.

  The design challenge is to enable reliable and consistent regeneration events, so that PM is removed in all types of duty cycles. The active regeneration control is designed so that it can take place under low ambient temperature/low load conditions when exhaust temperatures are low. This is the area where Cummins in-house expertise has been successfully applied to developing core programs and algorithms for controlling the aftertreatment from the engine ECM.

Filter Cleaning

The buildup of incombustible ash will eventually require the filter to be cleaned to prevent plugging. The service event is anticipated at very long intervals extending to several thousand hours, depending on duty cycle. The ash is part of the oil additive package and is intended to absorb acids in the oil resulting from combustion. During engine operation, trace amounts of ash collect in the filter as engine oil is consumed during normal operation. Low-ash oils, which maintain the important lubricity capability of the lubricant, are specified to reduce ash buildup in the filter. In North America, it is likely that today's on-highway API CJ-4 will be used.

Designed for Off-Highway

Cummins Particulate Filter for Tier 4 has been specifically designed and developed as an integrated system with the engine to meet the most challenging demands of off-highway equipment:

- Operate reliably and durably in all environmental conditions and applications – capable of off-highway shock loads, vibration and angularity requirements
- Minimize packaging and weight
- Control emissions over the life of the product
- Extend filter-cleaning maintenance

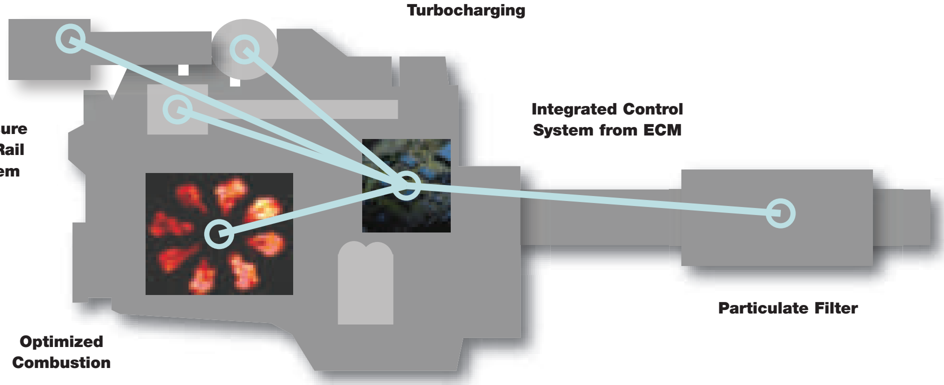
Looking Toward Tier 4 Final and Stage IV

Cummins Tier 4 Interim/Stage IIIB technology path for 2011 across the 174-751 hp (130-560 kW) power category will combine cooled EGR, variable geometry turbocharging and a High Pressure Common Rail fuel system with integrated Cummins Particulate Filter aftertreatment and Direct Flow air filtration. With just three years before the introduction of Tier 4 Final/Stage IV in 2014, Cummins will apply an incremental technology approach which will be more easily incorporated on the Interim product platforms and help to reduce installation complexity.

Most of this incremental technology approach is focused on advanced combustion engineering and the potential use of incremental aftertreatment to reduce oxides of nitrogen.

Selective Catalytic Reduction (SCR), NOx adsorbers and other options are part of this evaluation underway. As the technology leader, Cummins will continue to leverage our core competencies to deliver the right technology with the lowest cost of ownership for our customers.

Tier 4/Stage IIIB demands new levels of system integration



Every™ System. Integrated.

Every System. Integrated.

Cummins remains focused on providing outstanding customer value while meeting the toughest emissions standards. We have invested significantly in a broad technology portfolio which extends from air intake to exhaust aftertreatment. This means we can fully integrate all the key subsystems more effectively.

Because of our investment in all the critical technologies, we are able to leverage our broad experience in other markets where exhaust aftertreatment systems are already in production.

This stable technology base enables Cummins to focus on achieving the lowest initial cost for the OEM and on the lowest cost of operation for the equipment owner.

Cummins is deeply involved with our OEM partners in the machine integration and testing of Tier 4 engines and aftertreatment in off-highway equipment. This test equipment is being evaluated years in advance of the dates when EPA Tier 4 regulations take effect. That is how we will continue to deliver products that meet the demands of our customers at the lowest emissions levels.

Glossary

Advisor	A Cummins proactive tool for OEMs and technical support to select and design installations that maximize engine-to-machine performance for the end customer.
B20	A fuel blend of 20% biodiesel and 80% diesel.
CARB	California Air Resources Board. Implements and enforces air pollution control rules and regulations in the state of California.
CO_2	Carbon Dioxide. Classified as the major greenhouse gas and emitted proportional to amount of fuel consumed. With inherently higher fuel efficiency, diesel engines produce lower levels of CO_2. The EPA does not regulate CO_2 emissions from diesel engines.
CO	Carbon Monoxide. A regulated diesel emission produced by incomplete combustion. CO is emitted at very low levels from diesel engines.
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 that connects to every fuel injector on the engine.
Cummins Emission Solutions	A world leader in the design and manufacture of catalytic exhaust aftertreatment systems, including DPF, SCR and DOC systems.
Cummins Filtration	A world leader in the design and manufacture of filtration and exhaust systems, including Fleetguard and Nelson products.
Cummins Turbo Technologies	A world leader in the design and manufacture of turbochargers for diesel engines, including the Holset VGT™.
Cummins Fuel Systems	Develops and manufactures advanced fuel systems and electronic controls.

DOC	Diesel Oxidation Catalyst. Consists of a catalytic coating on a honeycomb substrate for oxidizing particulate matter (PM). Operates in a passive-only mode without active regeneration, so is less efficient at PM reduction than the DPF.
DPF	Diesel Particulate Filter. Captures particulate matter (PM) 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 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 is responsible for governing engine emissions.
Exhaust Aftertreatment	Any technology which removes emissions in the exhaust flow.
HPCR	High Pressure Common Rail fuel system.
INSITE™	Diagnostic software tool with real-time monitoring of everything from fuel burned to boost pressure and coolant temperature. Reads fault codes, provides rapid repair directions, and enables adjustable parameters and calibrations.
NMHC	Non-Methane Hydrocarbons. A regulated diesel emission which is primarily unburned fuel in the exhaust stream. Commonly described as Hydrocarbons (HC).

NOx	Oxides of Nitrogen. A regulated diesel emission which is a collective term for gaseous emissions composed of nitrogen and oxygen.
NOx Adsorber	Aftertreatment technology that uses a catalyst to capture and then convert NOx to harmless nitrogen gas and water vapor.
NRTC	Non-road transient composite test cycle introduced for Tier 4 emissions certification.
PM	Particulate Matter. A regulated diesel emission composed primarily of carbon soot and other combustion by-products.
PowerMatch	A Cummins calibration delivery system allowing quick and easy tailoring of electronic calibrations for a new application.
SCR	Selective Catalytic Reduction. An aftertreatment technology that uses a chemical reductant (urea) injected into the exhaust stream where it transforms into ammonia and reacts with NOx on a catalyst, converting the NOx to harmless nitrogen gas and water vapor.
Sulfur	A natural element in diesel fuel which has been linked to particulate matter and acid formation in the atmosphere.
Terms for Approximately Equivalent Standards	U.S. EPA .... EU (European Union) Tier 1.......................... Stage I Tier 2.......................... Stage II Tier 3.......................... Stage IIIA Tier 4 - Interim............ Stage IIIB Tier 4 - Final............... Stage IV

ULSD Ultra-Low Sulfur Diesel. Diesel fuel which contains less than 15 parts per million by volume of sulfur. Mandated October 2006 for EPA on-highway, September 2010 for EPA off-highway and expected in 2009 in the EU.

Urea A chemical usually made from natural gas, which is commonly used in fertilizers. Urea solution used for SCR aftertreatment breaks down into ammonia and reacts with NOx in the SCR system to produce harmless nitrogen gas and water vapor.

VGT Variable Geometry Turbocharger. Turbochargers that constantly adjust the amount of airflow into the combustion chamber, optimizing performance and efficiency.

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