SCR

Volvo Trucks. Driving Success.®

Volvo engines with Selective Catalytic Reduction technology have near-zero emissions and better fuel economy.

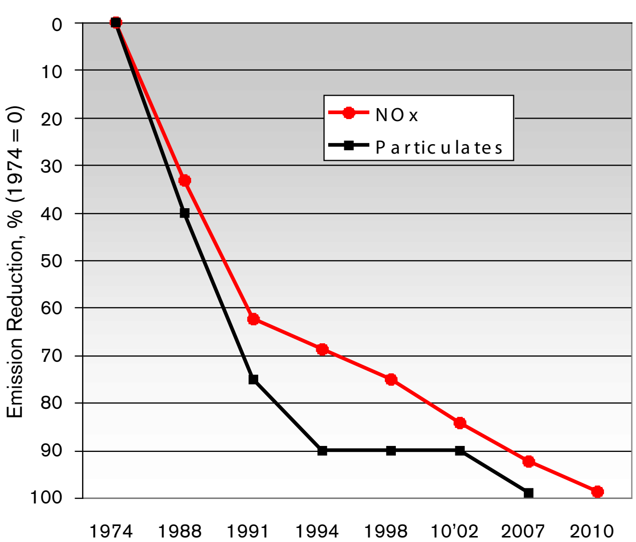
SCR: FOR EPA '10

In 2007, we cleaned the air. In 2010, we'll polish it.

Clean air is a priority for Volvo Trucks. As we have met emissions standards over the years, we've introduced a host of enhancements that help the environment without sacrificing power and fuel economy.

Through innovative applications of EGR (Exhaust Gas Recirculation) and DPF (Diesel Particulate Filter) technology, Volvo's '07 engines effectively reduced oxides of nitrogen (NOx) emissions by 92 percent, and reduced particulate matter (soot) by 99 percent from untreated (1974) levels.

Diesel Emission Standards



By 2010, diesel truck engines will have near-zero output of all regulated emissions.

Now, EPA '10 calls for a further—and final—NOx reduction that is 99 percent lower than 1974. That is good news for the environment, because it means all heavy truck diesel engines meeting 2010 standards will have near-zero levels of all regulated emissions—particulates and NOx, as well as hydrocarbons and carbon monoxide.

To accomplish the reduction in particulate emissions from 90 percent to 99 percent, it took the Diesel Particulate Filter, which is an aftertreatment process that treats the exhaust outside the engine. Similarly, for NOx to make the final step to 99 percent, and at the same time maximize fuel economy, Volvo has decided to use the aftertreatment process known as Selective Catalytic Reduction (SCR).

Volvo diesel engines with SCR offer a wide range of benefits:

- Extremely low emissions
- Less fuel consumption
- A robust, simple and reliable technology
- Unchanged or extended service levels
- Suitable for high engine power outputs

To understand and appreciate why Volvo Trucks has chosen SCR for EPA '10, it's helpful to review the attributes of NOx in the combustion process, and to see how SCR works to reduce NOx levels.

The primary challenge for 2010:
Further reduction of oxides of nitrogen.

The NOx Dilemma.

Approximately 80 percent of the air we breathe is nitrogen gas. Nitrogen is normally inert—in other words, it does not support a flame. However, when air gets extremely hot—as in diesel engine combustion—trace amounts of nitrogen combine with oxygen to form NOx, a pollutant. Over time, an engine creates quite a bit of NOx.

Getting rid of NOx presents a dilemma. Unlike soot or other hydrocarbons—which are reduced by making combustion more efficient—NOx is actually produced in direct proportion to efficient combustion. The more efficient the engine, the more NOx produced.

How Do We Reduce NOx Emissions?

The best way to reduce NOx formation is to reduce the temperature of combustion.

Initially, NOx reduction was achieved with air-to-air charge air coolers that reduce the temperature of the intake air compressed by the turbocharger. Volvo was one of the leaders in this technology, and adopted air-to-air charge air cooling in the 1970s. Today, virtually every light, medium and heavy truck diesel engine sold in North America uses this design.

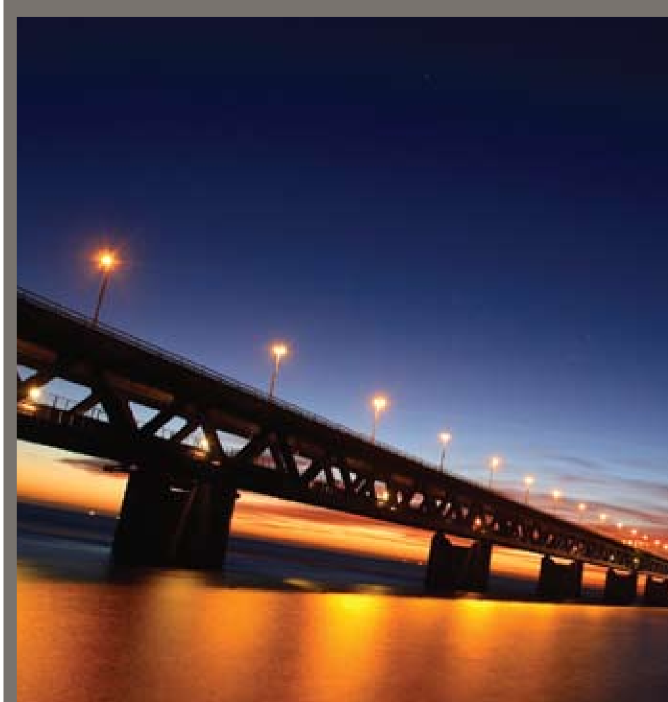
The air-to-air approach uses ambient air as the cooling medium—it's much colder than engine coolant. This provides reduced NOx formation, as well as higher engine power output, better fuel economy and lower internal stresses.

Further reduction in NOx comes via fuel injection improvements:

- Higher fuel injection pressure creates finer atomization for better combustion.
- Shaped fuel injection delivery allows control of rising pressure for best possible release of power.

Volvo Dual-Solenoid Fuel Injector

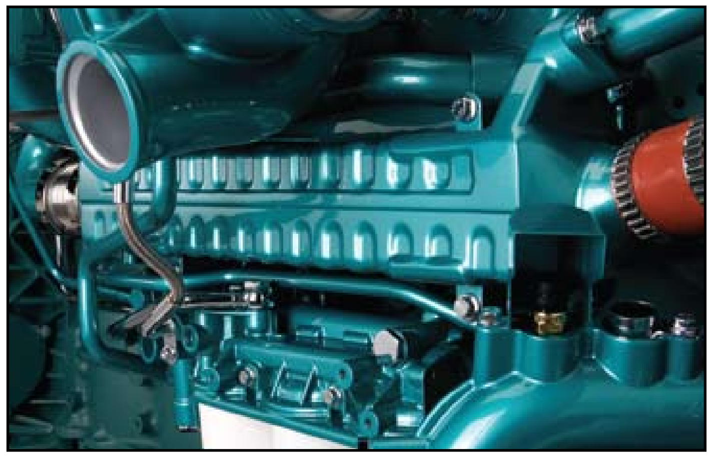
Today's Volvo Truck engines use a dual-solenoid fuel injection system with ultra-high fuel injection pressure. The pressures—currently around 35,000 psi (2400 bar)—are 20 percent higher than our EPA '07 engines. Volvo engineers have used this injection system since 2002 and have maximized its efficiency and performance.



NOx and the EGR process.

In North America, exhaust gas recirculation has been key to the evolution of the low-emission diesel. In EGR, some of the exhaust gas is recycled back through the engine.

The purpose here is not to “re-burn” the exhaust—rather it is to use the spent exhaust to absorb heat. Since it is mostly nitrogen and available in large quantities, re-introducing exhaust back into the engine dilutes the amount of oxygen in the intake charge. This reduces the temperature of combustion and lowers NOx.



EGR Effects

EGR has both positive and negative effects. On the plus side, emissions reduction is excellent. On the negative side, EGR increases heat rejection, decreases engine power density and efficiency, and increases the formation of particulates (soot). However:

- Heat rejection can be solved by using a larger cooling system, as Volvo did in 2002.
- Lower power density means less horsepower can be produced from a given displacement. Greater engine displacement may be needed to maintain horsepower.
- Efficiency can be enhanced by fuel injection improvements.
- Particulates are removed by a DPF.

Different Levels of EGR

There are several levels of EGR that can be incorporated:

- Light EGR (10 – 20 percent)
- Heavy EGR (20 – 35 percent)
- Massive EGR (35 – 50 percent or more)

Volvo used Light EGR with the EPA '02 V-Pulse solution on our D12D engine. Major design changes included the revised cooling system.

For EPA '07, Volvo uses Heavy EGR. Major changes in our engine technology include:

- A variable-geometry turbocharger to provide the higher rates of flow needed.
- Precision EGR flow control using a new EGR valve and closed-loop flow measurement.
- Ultra-high fuel injection pressure from our dual-solenoid fuel injection system.

For EPA '10, Volvo chose to eliminate the NOx using aftertreatment.

NOx aftertreatment: The SCR solution.

Volvo's technique for further reduction of NOx is through the immediate aftertreatment of engine exhaust. If NOx gases are selectively eliminated in a downstream aftertreatment chamber, the level of NOx produced by the engine can be significantly higher. This approach allows the engine to be retuned for maximum fuel efficiency.

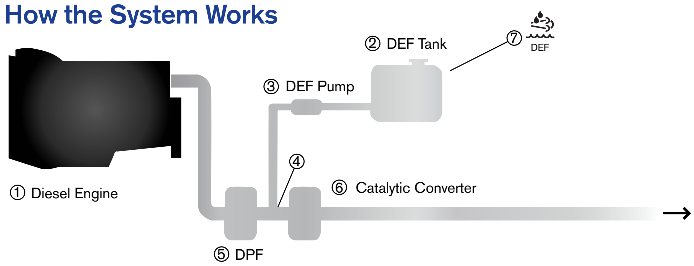
The process for reducing NOx via aftertreatment is called Selective Catalytic Reduction (SCR). It requires a catalytic converter into which is injected Diesel Exhaust Fluid (DEF). The primary component of DEF is water; the active component is urea.

Urea is a nitrogen compound that turns to ammonia when heated. When a urea-and-water solution is injected into the exhaust stream and passed over a catalyst, the urea reacts with the NOx to form nitrogen and water vapor—two clean and harmless components of the air we breathe.

The basic elements of the SCR system:

- SCR catalyst aftertreatment chamber
- DEF tank
    - Pump & lines
    - Heating system
- Control & monitoring system

How the System Works



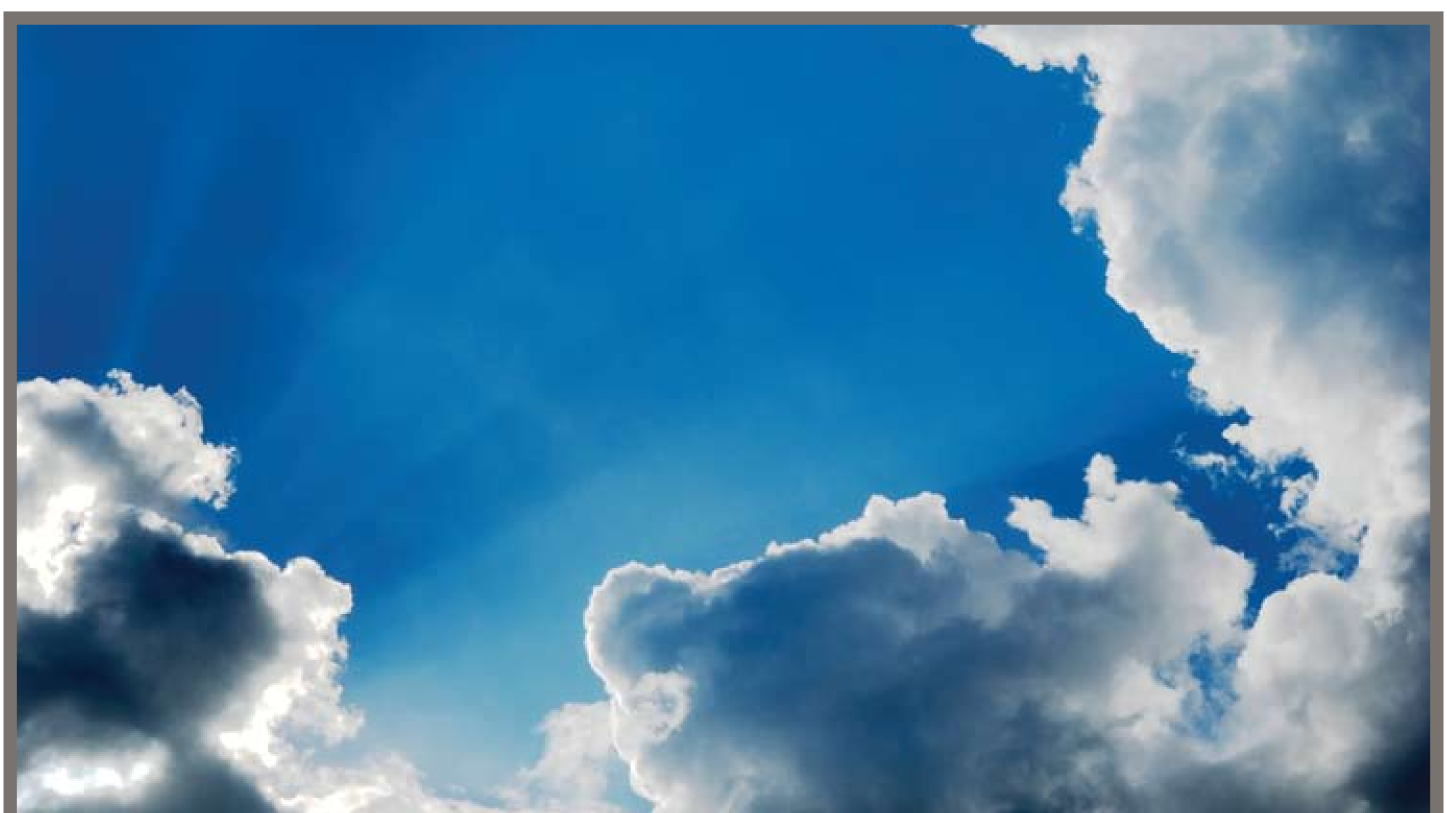
1. Diesel engine optimized for high performance, low particle emissions and low fuel consumption.
2. DEF tank.
3. The DEF tank and injection system's control units continuously vary the amount of DEF injected in response to the engine's current load conditions.
4. DEF is injected into the exhaust gases before they reach the catalytic converter.
5. In the catalytic converter, nitrogen oxides are transformed into harmless nitrogen gas and water.
6. The system notifies the driver when it is time to top off with DEF.

The advantage of using DEF is that it enables the engine to use less EGR—and higher oxygen levels—for better combustion, while easily meeting the EPA's near-zero NOx emissions requirement of 0.2 g/hp-hr NOx. By using DEF, we avoid the disadvantages of increasing EGR to massive levels.

This results in better fuel efficiency from your Volvo Truck engine. With rising crude oil prices, achieving maximum fuel efficiency has become the single most important attribute of modern truck engine design.

SCR vs. Massive EGR

SCR Advantages
The most important benefit of SCR is BETTER FUEL EFFICIENCY. As crude oil tops $100 per barrel, this is now more important than ever.
SCR engines produce less soot than massive EGR. While the soot (particulate matter) will be captured in the DPF, less soot means FEWER ACTIVE REGENERATIONS will be required.
SCR engines allow higher levels of NOx into the DPF (and very low NOx levels out of the SCR catalyst). This also means a higher level of passive regeneration and thus FEWER ACTIVE REGENERATIONS.
Fewer active regenerations of the DPF filter means: 1. Less driver involvement in regeneration issues 2. Improved fuel consumption 3. Increased durability of DPF components due to reduced extreme thermal cycling
SCR engines have lower heat rejection. Today's horsepower range will be available in all chassis. Engines using massive EGR require a new, more costly radiator/charge air-cooling package.
SCR engines have higher power density, not lower. This means today's power levels can be maintained without changes in displacement or increases in cylinder pressure—despite the huge NOx reduction.
SCR allows Volvo to use the same proven base engine we offer today. Same cylinder head, camshaft, fuel injection system.
SCR technology has been proven in Europe and is easy to apply to North American requirements.
SCR engines have longer oil drain intervals.
SCR does not risk base engine durability from unproven pressure dynamics.



AN EMISSIONS GLOSSARY

Active DPF Regeneration
"Active" regeneration refers to the injection of extra fuel to raise temperatures to accomplish DPF regeneration. Active regeneration is used when the engine's exhaust temperature is not hot enough during the work cycle to burn off the soot being collected.

Aftertreatment Device
A device that removes pollutants from exhaust gases after they leave the combustion chamber (e.g., catalytic converters or diesel particulate filters). They are also known as emission control devices or exhaust aftertreatment systems.

Air-to-Air Charge Air Cooler
Designed to reduce the temperature of the intake air compressed by the turbocharger. Air-to-air reduces the inlet charge air temperature by using ambient air as the cooling medium. This allows higher specific power output, with better fuel economy, lower internal stresses and lower NOx formation.

Catalyst
A substance that influences the rate of a chemical reaction but is not consumed or altered in the reaction.

Diesel Exhaust Fluid (DEF)
An aqueous solution of 32.5 percent urea and 67.5 percent deionized water.

Diesel Particulate Filter (DPF)
An aftertreatment device that works in conjunction with the oxidation catalyst to remove NOx and particulate matter (soot) from burned diesel fuel. Inside the DPF is a porous honeycomb structure that catches the soot as exhaust passes through. As soot builds up over time, it is removed through passive or active regeneration.

Exhaust Gas Recirculation (EGR)
A process where some of the exhaust gas is cooled and recycled back through the engine. This dilutes the amount of oxygen in the intake charge, which reduces the temperature of combustion and lowers formation of NOx. There are three levels of EGR:

- Light EGR (10 – 20 percent)
- Heavy EGR (20 – 35 percent)
- Massive EGR (35 – 50 percent or more)

Oxides of Nitrogen (NOx)
When air gets extremely hot—as with a bolt of lightning, or in diesel engine combustion—trace amounts of nitrogen combine with oxygen to form NOx. Oxides of nitrogen are produced in direct proportion to efficient combustion.

Particulate Matter (PM)
Solid particles formed by incomplete combustion.

Passive DPF Regeneration
"Passive" regeneration occurs when the soot in the DPF chemically reacts to form carbon dioxide during the normal work cycle when the exhaust temperatures are sufficiently hot. Passive regeneration is preferable to active because it consumes no extra fuel.

Power Density
The ratio of horsepower to engine displacement decreases with higher rates of EGR.

Regeneration
The process of removing diesel exhaust soot from a diesel particulate filter (DPF) by oxidizing the soot.

Selective Catalytic Reduction (SCR)
A technique for reducing NOx in an aftertreatment device. It features a catalyst which has diesel exhaust fluid injected into it. When DEF is injected into the exhaust stream and passed over a catalyst, the urea in the DEF reacts with the NOx to form nitrogen and water vapor—both clean components of "air."

Soot
The black carbon portion of diesel exhaust particulate matter (PM). It is very similar to "lampblack," the black soot from a smoking candle or kerosene lantern. Soot particles are extremely fine.

Ultra-High Fuel Injection Pressure
Pressure of 35,000 psi (2400 bar). The higher the pressure, the finer the fuel atomization, and the better the fuel economy.

Ultra Low Sulfur Diesel (ULSD)
North American diesel fuel with a maximum of 15 ppm sulfur, introduced beginning mid-2006, as required by the EPA. This fuel is required by many exhaust emissions solutions devices to ensure long-term performance and durability of aftertreatment devices.

Urea
A compound of nitrogen that turns to ammonia when heated. The advantage of using urea in SCR is that it enables the engine to use less EGR and use higher oxygen levels in the combustion, while meeting the near-zero NOx requirement of 0.2 g/hp-hr NOx.

The Most Fuel Efficient Choice for EPA ’10 and Beyond.

Reducing exhaust emissions from diesel engines is important for improving air quality, especially in densely populated areas. It’s clear that for EPA ’10, the operational and economic advantages of SCR make it the most fuel efficient process for maximum emissions reduction.

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