



## NO<sub>x</sub> Air Emissions and Drilling Operations

Oxides of nitrogen are a precursor to ozone formation. Nitrogen oxides (NO<sub>x</sub>) are formed when nitrogen (N<sub>2</sub>) and oxygen (O<sub>2</sub>) are combined at high temperatures and pressure during the combustion of fuel. All fuels, such as gasoline, diesel, biodiesel, propane, coal, and ethanol, emit NO<sub>x</sub> when burned. The EPA estimates that 49% of NO<sub>x</sub> emissions come from on-road and off-road vehicles, 27% from power generation (electric utilities) and the remaining 24% from industrial, commercial and residential sources. Due to the many compounds that are a part of NO<sub>x</sub> (predominantly nitrogen dioxide and nitric oxide), the pollutant contributes to a wide variety of health and environmental problems. NO<sub>x</sub> is also a main component of ground-level ozone and contributes to global warming. Since the passage of the Clean Air Act in 1970, all primary air pollutants have decreased - except NO<sub>x</sub>, which has increased by 10%. Due to its serious health and environmental impact, the reduction of NO<sub>x</sub> in our atmosphere has now become a major focus in the fight against air pollution.

Contractual arrangements could be made to ensure that all trucks associated with supplies and services meet specified requirements. Operators could reduce NO<sub>x</sub> emissions by requiring contractors and subcontractors associated with any logistical support or well site operations to either use clean Tier II (or higher) engines for on-road vehicles, or, to use retrofit technology on all on-road vehicles that have Tier I or lower engines.

In 2004 the EPA introduced stringent air emission standards for on-road vehicles. Any pre-existing vehicle is not required to comply with these newer standards. Diesel vehicles from older model years will have higher non-methane hydrocarbon and particulate matter emissions.

Typically, diesel retrofit involves the addition of an emission control device to remove emissions from the engine exhaust. Retrofits can be very effective at reducing emissions, eliminating up to 90 percent of pollutants in some cases. Some examples of emission control devices used for diesel retrofit include diesel oxidation catalysts, diesel particulate filters, NO<sub>x</sub> catalysts, selective catalytic reduction, and exhaust gas recirculation. Devices to control crankcase emissions also exist.

Significant improvement in diesel emission levels, in both light- and heavy-duty engines, was achieved in the 1970 - 2000 period. Particulate matter (PM), NO<sub>x</sub>, and hydrocarbon (HC) emissions were cut by one order of magnitude. Most of that progress was achieved by emission-conscious engine design, such as through changes in the combustion chamber design, improved fuel systems, implementation of low temperature charge air cooling, and special attention to lube oil consumption.

However, more progress was still required, as the NO<sub>x</sub> and PM emissions from diesels remained higher than those from Spark Ignited (SI) engines. A new series of diesel emission regulations was developed with implementation dates around 2005-2010, which require the introduction of exhaust gas

aftertreatment technologies in diesel engines, as well as fuel quality changes and additional engine improvements.

Technology	Emission Impact	Significance
<b>Engine Design Technologies</b>		
Fuel Injection System	~90% PM reduction, ~75% NO <sub>x</sub> reduction, large reductions in HC/CO emissions achieved in the 1980-1990 timeframe	Combination of these engine design techniques was the major source of diesel emission reduction through the end of 1990s; Potential for further emission reductions in the future
Charge Air System		
Combustion Chamber		
Electronic Control		
Exhaust Gas Recirculation	30-50%+ NO <sub>x</sub> reduction	Light duty vehicles; Major heavy-duty engine applications from 2002 (USA)
<b>Fuel, Oil &amp; Additive Technologies</b>		
Fuel & Lube Oil	Only limited direct emission impact in modern engines	Sulfur content remains the critical property due to its effect on catalytic aftertreatment technologies
Alternative Diesel Fuels	Variable, depending on fuel and emission	Short term: emission-driven niche markets; Long term: critical importance due to depletion of petroleum reserves
Fuel Additives	Small emission effect with modern engines and quality diesel fuels	Possible use to assist particulate filter regeneration
Water Addition	1% NO <sub>x</sub> reduction for every 1% added water	Niche markets: marine and stationary engines; centrally fueled fleets (emulsions)
<b>Exhaust Gas Aftertreatment</b>		
Diesel Oxidation Catalyst	High reduction of HC/CO emissions; PM conversion depends on fuel sulfur, usually limited to maximum 20-30%	Widely used on Euro 2/3 cars and on 1994 and later heavy-duty urban bus engines in the U.S.; Will remain a component of future emission control systems
NO <sub>x</sub> Adsorber Catalysts	~90% NO <sub>x</sub> reduction potential	Potential future technology for light duty engines worldwide and for heavy-duty engines in the U.S. (2007/2010)
Urea SCR Catalysts	~90% NO <sub>x</sub> reduction	Future technology for Euro 5 heavy-duty diesel engines; Currently used in stationary engines and other niche markets
Diesel Particulate Filters	70-90%+ PM emission reduction	Expected widespread use for (heavier) Euro 4 cars and heavy duty US2007 engines; Currently used in retrofit programs and voluntary diesel car applications.
Lean NO <sub>x</sub> Catalysts	NO <sub>x</sub> reduction potential of ~10-20% in passive systems, up to 50% in active systems	Uncertain; NO <sub>x</sub> reduction potential insufficient for long-term regulatory objectives
Plasma Assisted Catalysts	NO <sub>x</sub> reduction potential up to ~50%	Uncertain; NO <sub>x</sub> reduction potential insufficient for long-term regulatory objectives.

## Available Diesel Retrofit Technologies

Technology	Emissions Reductions			Fuel Requirements	Additional Information
	HC	PM	NO <sub>x</sub>		
Diesel Oxidation Catalyst (DOC)	50-90%	25-50%	--	500 ppm sulfur	DOC's have an established record in the highway sector and are gaining in nonroad applications. Sulfur in fuel can impede the effectiveness of DOCs; therefore, the devices require fuels with low sulfur levels. Can be combined with other technologies for additional PM and or NO <sub>x</sub> reductions.
Diesel Particulate Filter (DPF)	50-95%	>85%	--	CB-DPF – ULSD; active, non-CB-DPF – 500 ppm	DPF's use either passive or active regeneration systems to oxidize the PM in the filters. Passive filters require higher operating temperature to work properly. Filters require maintenance. Can be combined with NO <sub>x</sub> retrofit technologies.
Flow-through Filter (FTF)	50-95%	30->60%	--	500 ppm sulfur	Filtration efficiency is lower than DPF, but is much less likely to plug under unfavorable conditions, such as high engine-out PM emissions and low exhaust temperatures.
Lean NO <sub>x</sub> Catalyst (LNC) with a DPF	--	>85%	5-30%	ULSD	Verified LNCs are always paired with a DPF or a DOC.
Selective Catalytic Reduction (SCR)	80%	20-30%	80%	500 ppm sulfur	Common in stationary applications. Require periodic refilling of an ammonia or urea tank. Often used with a DOC or DPF to reduce PM emissions.
Exhaust Gas Recirculation (EGR) with a DPF	--	>85%	40-50%	ULSD	Both low-pressure and high-pressure EGR systems exist, but low-pressure EGR is used for retrofit applications because it does not require engine modifications. The feasibility of low-pressure EGR is more of an issue with nonroad equipment than on-road equipment.
Closed Crankcase Ventilation (CCV)	--	5-10%	--	500 ppm	Usually paired with a DOC or DPF.

The array of emission control methods provides the designer with building blocks which need to be chosen and combined into the emission control system, which in turn is integrated with the engine to achieve a given emission target. A system approach is necessary to develop the clean emission diesel engine. There is no miraculous “plug-in” device available which could be installed on a particular engine and effectively clean emissions. An effective emission control strategy has to combine elements of engine design with the use of appropriate fuels and exhaust aftertreatment methods.

Selective catalytic reduction (SCR) of NO<sub>x</sub> by nitrogen compounds, such as *ammonia* or *urea*—commonly referred to as simply “SCR”—has been developed for and well proven in large-scale industrial stationary

applications. The SCR technology was first applied in thermal power plants in Japan in the late 1970s, followed by widespread application in Europe since the mid-1980s. In the USA, SCR systems were introduced for gas turbines in the 1990s, with increasing potential for NO<sub>x</sub> control from coal-fired powerplants. In addition to coal-fired cogeneration plants and gas turbines, SCR applications also include plant and refinery heaters and boilers in the chemical processing industry, furnaces, coke ovens, as well as municipal waste plants and incinerators. The list of fuels used in these applications includes industrial gases, natural gas, crude oil, light or heavy oil, and pulverized coal.<sup>[1]</sup>

SCR is the only proven catalyst technology capable of reducing diesel NO<sub>x</sub> emissions to levels required by a number of future emission standards. Urea-SCR has been selected by a number of manufacturers as the technology of choice for meeting the Euro V (2008) and the JP 2005 NO<sub>x</sub> limits—both equal to 2 g/kWh—for heavy-duty truck and bus engines. First commercial diesel truck applications were launched in 2004 by Nissan Diesel in Japan and by DaimlerChrysler in Europe.

SCR systems are also being developed in the USA in the context of the 2010 NO<sub>x</sub> limit of 0.2 g/bhp-hr for heavy-duty engines, as well as the Tier 2 NO<sub>x</sub> standards for light-duty vehicles.

The technologies and strategies being developed for the 2007/2010 heavy-duty highway diesel engine and Tier 4 nonroad diesel engine standards may be applicable stationary diesel engines provided adequate lead-time is given. The issue is to match the right technologies to the right applications. Reduction of emissions is influenced by the duty cycle of the engine.

## Resources

1. The **Manufacturers of Emission Controls Association (MECA)** is a non-profit association incorporated in Washington, DC. MECA's mission is to provide technical information on emission control technology, thereby facilitating the establishment of strong and effective state, federal, and international air quality programs that promote public health, environmental quality, and industrial progress.
2. **Emission Control Technologies for Diesel-Powered Vehicles, Manufacturers of Emission Controls Association, December 2007:** [www.dieselretrofit.org](http://www.dieselretrofit.org)
3. DieselNet ([www.dieselnet.com](http://www.dieselnet.com)) provides current information about emission standards and regulations.

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<sup>[1]</sup> Cobb, D., et al., 1991. "Application of Selective Catalytic Reduction (SCR) Technology for NO<sub>x</sub> Reduction From Refinery Combustion Sources", *Environmental Progress*, 10, pg. 49.