

Section 3.13

**State of the Art (SOTA) Manual for
Reciprocating Internal Combustion Engines**

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3.13.1 GLOSSARY

SCR	Selective Catalytic Reduction
NSCR	Non-Selective Catalytic Reduction (3-way catalyst)
SNCR	Selective Non Catalytic Reduction
LEC	Low Emissions Combustion
HAP	Hazardous Air Pollutant
NESHAP	National Emissions Standards for Hazardous Air Pollutants
MACT	Maximum Achievable Control Technology
PM	Particulate Matter
HHV	Higher Heating Value
SI	Spark Ignition
CI	Compression Ignition
HEIS	High Energy Ignition System

3.13.2 SCOPE

The state of the art (SOTA) emission performance levels presented in this manual apply to all stationary reciprocating internal combustion engines (RICE) that are subject to N.J.A.C. 7:27-8.12 or N.J.A.C. 7:27-22.35 and meeting the following criteria:

1. Heat input rate (HHV) less than 100 million BTU/hr, and
2. Combusting commercial fuel.

RICE engines that do not meet the above criteria are required to perform a case by case SOTA analysis.

Compliance with the SOTA performance levels of this manual does not relieve an applicant for an air pollution control permit from the responsibility of complying with the more stringent applicable technology standards established by other New Jersey and federal regulations such as Best Available Control Technology (BACT) for the Federal Prevention of Significant Deterioration Program (PSD) or Lowest Achievable Control Technology (LAER) required for non-attainment new source review if applicable.

The emissions levels and guidance in this manual are provided for air pollution control permit applicants choosing to comply with the New Jersey regulatory requirement, to document advances in the art of air pollution control by the SOTA manual option codified at N.J.A.C. 7:27-8.12, and at N.J.A.C. 7:27-22.35.

3.13.3 SOTA EMISSION PERFORMANCE LEVELS

SOTA performance levels are specified in Table 1. The numerical SOTA levels apply to engines which are currently not authorized to be constructed and to operate under NJ air regulations and which are making a permit application to the Department. The percent reduction SOTA levels apply to existing engines that are currently authorized to operate under NJ air regulations and which are making a permit application to the Department because of a modification or a reconstruction. Achieving SOTA performance levels would require combinations of combustion control, energy efficiency and add on control. These emission control technologies are described in detail further in this manual.

SOTA for an emergency generator application meeting the definition found at N.J.A.C. 7:27-19.1, "emergency generator," is no auxiliary air pollution control.

Table 1
SOTA Emission Performance Levels for
Stationary Reciprocating Internal Combustion Engines

Air Contaminant	Fuel Type	
	Natural Gas, Propane, Gasoline or Dual Fuel	Liquid Fuel (No. 2, Diesel or Kerosene)
Nitrogen Oxides		
Gms/BHP-hr	0.15	0.15
Lbs/Mw-hr	0.5	0.5
Ppmvd @ 15% O ₂	10	10
Percent reduction	90	90
Carbon Monoxide		
Gms/BHP-hr	0.5	0.5
Ppmvd @ 15% O ₂	50	50
Percent reduction	90	90
Volatile Organic Compounds		
Gms/BHP-hr	0.15	0.15
Particulate Matter		
Gms/BHP-hr	No level specified	0.02
Percent Reduction		85
Ammonia Slip		
Ppmvd @ 15% O ₂	10	10
Sulfur Dioxide		
Ppm Sulfur in Fuel	--	30

3.13.4 CONTROL TECHNOLOGIES TO MEET SOTA PERFORMANCE LEVELS

The most commonly used control technologies, to meet the SOTA levels, are presented in Table 2 for various engine types and operational modes. These technologies are described in more detail in this manual. Control technologies may be used singly or in combination to meet the SOTA performance levels. Other control technologies and strategies that may be applied singly or in combination are also presented. The SOTA emissions performance levels apply at +/- 5% of the maximum rated operating load. Engine and control device manufacturer's specifications are required to confirm SOTA claims.

Table 2

Generally Applied Control Technologies to Meet SOTA Performance Levels

Air Contaminant	Spark Ignition			Compression Ignition	
	Natural Gas or Propane <u>Rich Burn</u>	Natural Gas or Propane <u>Lean Burn</u>	Gasoline <u>Rich Burn</u>	Diesel Fuel <u>All liquid fuel</u>	Dual Fuel <u>Diesel plus natural gas</u>
Nitrogen Oxides (NO _x)	NSCR	SCR or LEC	NSCR	SCR	SCR or LEC
Carbon Monoxide (CO)	NSCR	Oxidation Catalyst	NSCR	Oxidation Catalyst	Oxidation Catalyst
Volatile Organic Compounds and Volatile Organic HAPS (VOC)	NSCR	Oxidation Catalyst	NSCR	Oxidation Catalyst	Oxidation Catalyst
Particulate (TSP/ PM-10)	Not Applicable			Particulate Trap plus Catalytic Oxidizer	
Sulfur Dioxide (SO ₂)	Not Applicable	Low Sulfur Fuel		Low Sulfur Fuel	

3.13.5 NATIONAL EMISSION STANDARDS FOR RECIPROCATING INTERNAL COMBUSTION ENGINES

The USEPA has a forthcoming regulation, Maximum Achievable Control Technology (MACT), governing the emissions of HAPs from RICE engines located at major HAP sources (10 TPY any individual HAP, 25 TPY all HAPs combined). This regulation will represent SOTA for HAPs pursuant to N.J.A.C. 7:27-8.12(e) 3 or N.J.A.C. 7:27-22.35(c)3 for RICE engines located at major HAP sources. The SOTA technologies for carbon monoxide and VOC of this manual may achieve compliance with the MACT standards.

3.13.6 BASIS FOR SOTA PERFORMANCE LEVELS

In determining SOTA performance levels for RICE engines, permitting agencies, industry associations, manufacturers of RICE and manufacturers of emissions control equipment were contacted to obtain updated information on emissions and control technologies. Databases for recent permitted and tested engines from New Jersey, California and USEPA were reviewed. The manual was revised based upon this research.

3.13.7 RECIPROCATING INTERNAL COMBUSTION ENGINES (RICE)

RICE are used in industrial applications requiring mechanical work in the form of shaft power, such as oil and gas production, compression, quarrying operations, recycling, construction, and electrical power generation. RICE engines can operate on a variety of fuels at a wide range of speeds and with varying loads.

In a RICE engine, combustion of a compressed fuel-air mixture is used to drive pistons in one or more cylinders with the linear reciprocating motion converted to rotary motion with a crankshaft. There are two basic types of reciprocating engines. Spark Ignited (SI) engines use a spark (across a spark plug) to ignite a compressed fuel-air mixture. Typical commercial fuels for such engines are natural gas, gasoline, and propane. Compression ignition (CI) engines compress air to a high pressure, heating the air to the ignition temperature of the fuel, which then is injected. Diesel fuel oil or a combination of diesel fuel and natural gas 0-90% can be used. Natural gas is compressed with the combustion air, and diesel oil is injected at the top of the compression stroke to initiate combustion in a dual fuel engine.

Reciprocating engines have either 4 stroke or 2 stroke operating cycles. Reciprocating engines are also classified based on air-to-fuel ratio and the exhaust oxygen content. Rich burn engines (which include 4 stroke SI engines) typically operate with an air-to-fuel ratio near stoichiometric

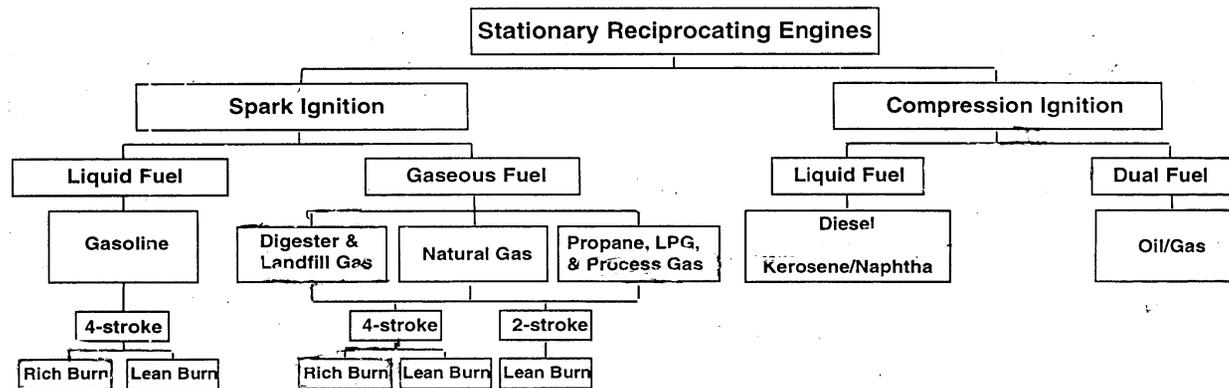
and exhaust oxygen concentrations of one percent or less. Lean burn engines (which include 2 stroke SI engines and all CI engines) have lean (i.e. air enriched) air-to-fuel ratios and typical exhaust oxygen concentration of greater than one percent. Due to higher temperature and pressures in the CI engines, emissions factors for NO_x are typically greater than for other engine types. The available and emerging technologies to control air pollution from each type of RICE are presented and discussed in this manual.

Table 3 shows how RICE engines can be classified. Figure 1 illustrates the hierarchy of types in a general classification of RICE.

Table 3
Reciprocating Internal Combustion Engines Classification

(1)	Ignition of the fuel (spark ignited (SI), and compression ignited (CI)),
(2)	Operating cycle (two stroke, and four stroke)
(3)	Air to fuel ratio and oxygen in the exhaust gas (lean burn, and rich burn).
(4)	Fuel type (natural gas, landfill gas, fuel oil, gasoline, diesel oil and dual fuel)
(5)	Method of fuel addition (carbureted, and fuel injected)
(6)	Charge pressure (naturally aspirated and turbocharged)

Figure 1
**Classification of Stationary
Internal Combustion Engines**



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3.13.8 EMISSIONS REDUCTION WITH INCREASED ENERGY EFFICIENCY- POLLUTION PREVENTION

The New Jersey Air Pollution Control Code, N.J.A.C. 7:27-8 and N.J.A.C. 7:27-22, require inclusion of greenhouse gases resulting from fuel combustion in stationary reciprocating internal combustion engines in air pollution control permits. Greenhouse gases include carbon dioxide, methane and nitrous oxide. Emissions of carbon dioxide can be reduced by favoring higher efficiency processes such as combined cycle operation, combined heat and power cogeneration, and engines which are inherently more efficient. At this time, energy efficiency and the emission rate in lbs/hr and tons per year of each greenhouse gas should be specified. Efficiencies should be reported in terms of the ratio of output over input including any exhaust heat or cooling system heat recovery. DEP is setting a specific energy efficiency goal of 40% at this time with a goal of 65% in the future. These efficiency levels would likely require combined heat and power. The SOTA level for each permit application will be established on a case by case basis. The permit applicants will be required to select the most energy efficient systems, minimizing greenhouse gas emissions and approaching the energy efficiency goals specified above.

Improving the energy efficiency of the system used is the best pollution prevention method. Higher efficiency systems require less fuel to produce the needed power. Improving energy efficiency also results in RICE which emit lesser amounts of the criteria and hazardous air pollutants on an output basis.

3.13.9 NO_x EMISSIONS REDUCTION BY COMBUSTION MODIFICATIONS

Summarized in Table 4.

i. Air-to-Fuel Ratio Adjustment

Rich burn engines

Lowering the air-to-fuel ratio in rich burn engines limits oxygen availability in the cylinder, thus decreasing NO_x emissions. This technique is analogous to the use of low excess air in boilers and has limitation of producing more CO and hydrocarbon emissions. In addition to simple adjustment of the air-to-fuel ratio, the method requires the installation of an automatic air to fuel ratio controller so that changes in load and other operating conditions may be followed to maintain an optimum air-to-fuel ratio.

Lean burn engines

In lean burn engines, increasing the air to fuel ratio decreases the NO_x emissions. Extra air

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dilutes the combustion gases, thus lowering peak flame temperature and reducing thermal NO_x formation. In order to avoid de-rating, combustion air to the engine must be increased at constant fuel flow, requiring a turbocharger. An automatic air-to-fuel ratio controller also will be required. This control method is most effective on fuel-injected engines. Typically, for lean burn engines the air/fuel ratios are increased from normal levels of 50% excess air up to excess air levels of 240%. The upper limit is constrained by the onset of misfiring at the lean limit. This condition also increases CO and VOC emissions. Naturally aspirated engines and engines with fuel injected into the intake manifold plenum do not have identical air-to-fuel ratios in each cylinder, with the result that changes in the ratio are limited.

To maintain acceptable engine performance at lean conditions, high energy ignition systems (HEIS) have been developed that promote flame stability at very lean conditions. (Discussed in more detail later in this manual).

Compression Ignition

Air/Fuel ratio adjustment is not a feasible technique for reducing emissions from compression ignition RICE.

ii. Ignition or Spark Timing Retard

This adjustment lowers NO_x emissions by moving the ignition event to later in the power stroke. Because the combustion chamber volume is not at its minimum, the peak flame temperature will be reduced, thus reducing thermal NO_x formation. Ignition timing retard is applicable to all engines. It is implemented in spark ignition engines by changing the timing of the spark, and in compression ignition engines by changing the timing of the fuel injection. For variable loads, an electronic ignition/injection control system is required.

iii. Prestratified Charge Combustor (PSC)

PSC is a technology for injecting fuel and air into the intake manifold in distinct “slugs” which become separate fuel and air layers upon intake into the cylinders. This creates a fuel rich, easily ignitable mixture around the spark plug, but an overall fuel lean mixture in the combustion chamber. Combustion occurs at a lower temperature, producing less thermal NO_x but without misfire even as the lower flammability limit is approached. Prestratified charge may increase CO and hydrocarbon emissions. The maximum NO_x reduction is determined by the extent to which the air content of the stratified charge can be increased without excessively affecting engine power derate, increased CO emissions and hydrocarbon emissions. Prestratified charge combustion (for stationary engine applications) is limited to 4-cycle natural gas engines.

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iv. Low Emission Combustion (LEC)

LEC is combustion of a very fuel lean mixture. A fuel lean mixture acts as a heat sink, lowers cylinder temperatures and further reduces NO_x formation. Turbochargers and aftercoolers are added to provide the additional combustion air to avoid derate.

Engine manufacturers equipping engines with LEC achieve proper ignition and stable combustion with a combination of improved combustion chamber design, enhanced air fuel mixing and improved ignition systems. Pre-combustion chambers have been utilized for improved mixing and enhanced ignition. Typically a mixture with 75-100% excess air is utilized with pre-combustion chambers. LEC designs offer a redesigned “open” combustion chamber. Excess air levels for open chamber designs are typically slightly above 50%. This technology is not effective on diesel engines but does work for dual fuel engines with pilot liquid fuel reduced to 1% or less, lean burn engines and rich burn to lean burn engine conversions. A high energy spark ignition system (HEIS) is required for ignition of the air fuel charge in the LEC engines.

v. Water Injection and Water/Fuel Emulsions

Water injection or a water in fuel emulsion is a pollution prevention method to reduce combustion temperatures and hence inhibit nitrogen oxide formation. Water is injected into the intake system of a reciprocating internal combustion engine and, due to the latent heat of vaporization of water, the air charge temperature is reduced during the intake stroke. During the combustion process the air/fuel charge is further cooled attributable to the specific heat capacity of water, and the flame speeds are slowed from the adsorption of heat by the water present. Slower flame speeds result in lower peak cylinder temperatures and corresponding lower nitrogen oxides emissions. The use of water injection allows advances of the ignition event and leaner fuel to air mixtures.

vi. High Energy Ignition System (HEIS)

With traditional spark plug ignition, the duration of the spark is very short-occurring over only a fraction of a degree of crankshaft rotation. If the mix of air and fuel in the area of the spark is not exact, there is poor combustion or no combustion at all. With HEIS technology, also known as plasma ignition, a continuous electrical discharge is provided at the gap of a conventional spark plug for 10 to 90 degrees of crankshaft rotation. This extended energy delivery ensures combustion will occur even in the leanest of conditions. High-energy ignition systems can be used only in lean-burn, natural gas-fired SI engines.

With high-energy ignition, a rich mixture is ignited in a small ignition cell located in the cylinder head. The ignition cell flame passes to the cylinder where it provides a uniform ignition source.

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This technique can be retrofit to turbocharged 2 and 4 cycle engines. In most cases, the NO_x reductions have been accompanied by an increase in power output and increased fuel economy.

vii. Exhaust Gas Recirculation (EGR) and Cooled EGR

Exhaust gas recirculation, alone or cooled, is a NO_x control technology to limit the formation of thermal NO_x emissions. Exhaust gases, which contain roughly only 8-9% oxygen, are recirculated to the air intake of the engine. The recirculated exhaust gases act as a heat sink and lower peak combustion temperatures.

viii. After-cooling Following Turbocharging

After cooling is a technology to lower the intake charge air temperature thereby lowering peak cylinder temperatures and NO_x formation. Cooler intake temperatures offer the potential for increased power output and improved fuel economy. A larger more efficient after-cooler would reduce intake air temperatures, but substantial air cooling would require a separate circuit cooling system.

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Table 4

Applicability and Efficiency of NO_x Emissions Reduction Technologies by Combustion Control (percent reduction)

Emissions Reduction Technology	SI Natural Gas or Propane Rich Burn	SI Natural Gas or Propane Lean Burn	CI Diesel Fuel	CI Dual Fuel (diesel plus natural gas)
Air/Fuel Ratio Adjustment	10-40	5-30	N/A	N/A
Ignition or Spark Timing Retard	40	20	20-30	20-30
Prestratified Charge (PSC)	75 - 90	75 - 90	N/A	N/A
Low Emission Combustion (LEC)	85	85	N/A	85
Water Injection	25-35	N/A	25-30	25-30
High Energy Ignition	50-80	50-80	50-80	50-80
Exhaust Gas Recirculation	N/D	N/D	48-80	N/D
Aftercooling	N/D	N/D	N/D	N/D

N/A = Not Applicable

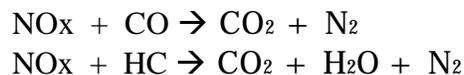
N/D = Not Determined

3.13.10 NO_x EMISSIONS REDUCTION BY ADD ON CONTROL

Summarized in Table 5.

i. Non-Selective Catalytic Reduction (NSCR)

This technology uses three-way catalysts to promote the reduction of NO_x to nitrogen and water. CO and hydrocarbons are simultaneously oxidized to carbon dioxide and water. NSCR is applicable only to rich burn engines (i.e. those with exhaust oxygen concentration below about one percent). NSCR, in addition to the catalysts and catalyst housing, require an oxygen sensor and automatic air to fuel ratio controller to maintain an appropriate air to fuel ratio. Some ammonia can be produced particularly as the catalyst ages. The simplified reactions governing NSCR are as follows:



The exhaust passes over a catalyst, usually a noble metal (platinum, rhodium or palladium) which reduces the reactants to N₂, CO₂ and H₂O. Typical exhaust temperatures for effective removal of NO_x are 800-1200 degrees Fahrenheit. An oxidation catalyst using additional air can be installed downstream of the NSCR catalyst for additional CO and VOC control. This includes 4-cycle naturally aspirated engines and some 4-cycle turbocharged engines. Engines operating with NSCR require air/fuel control to maintain high reduction effectiveness. Extremely tight control of the air to fuel ratio operating range is accomplished with an electronic air to fuel ratio controller.

ii. Selective Catalytic Reduction (SCR)

SCR uses catalyzed reduction of NO_x with injected ammonia or urea solution. This technology is applicable to lean burn engines only (i.e., those with greater than about one percent exhaust oxygen, as oxygen is a reagent in the selective reduction reaction.) SCR may be used with lean burn (SI), dual fuel or diesel engines (CI). SCR produces unreacted ammonia (slip) and monitors are necessary to provide correct control of ammonia injection rates to minimize slip. When used with diesel engines, it is important to use a low sulfur fuel and sulfur resistant catalyst. Sulfur dioxide in the exhaust can be oxidized over the SCR catalyst to sulfuric acid mist, and when combined with unreacted ammonia, produces sulfate particulate.

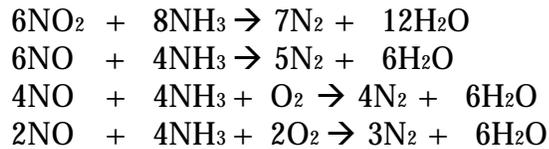
For an SCR system using urea, the first stage of the catalyst bed is the hydrolysis catalyst, which converts the urea to ammonia. In the second stage of the catalyst, the ammonia and NO_x react

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to form nitrogen gas and water with some unreacted ammonia passing through.

Precious metal catalysts can reduce NO_x by 80%. Zeolite catalysts can reduce NO_x by 90% with minimal sulfur dioxide to sulfur trioxide conversion. Exhaust gas temperatures greater than the upper limit (850 F) will pass the NO_x and ammonia unreacted through the catalyst. Ten parts per million ammonia slip is considered technically feasible.

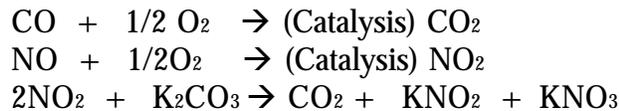
Reactions of NO_x over SCR catalyst:



An SCR system consists of reagent storage, feed and injection system, and a catalyst and catalyst housing. Predictive mapping of engine operating parameters can be used to monitor and control the SCR reaction.

iii. Catalytic Adsorption

This system utilizes a single catalyst and hydrogen regeneration for the removal of both carbon monoxide and nitrogen oxides. The catalyst works by simultaneously oxidizing CO to CO₂ and NO to NO₂ over a precious metal oxidation catalyst. The catalyst surface is treated with potassium carbonate adsorber coating and the NO₂ is adsorbed onto the coating. These reactions are shown below, and are referred to as the "Oxidation/Adsorption Cycle".



Note that during this cycle, the potassium carbonate coating reacts to form potassium nitrites and nitrates, which are then present on the surface of the catalyst. When the surface of the catalyst becomes saturated, the catalyst enters the regeneration cycle. Regeneration occurs by passing a dilute hydrogen reducing gas across the surface of the catalyst in the absence of oxygen to form nitrogen gas and water as the final products.

Parallel adsorbers are typically utilized to allow regeneration of a saturated catalyst while active units adsorb NO_x.

iv. Selective Non-Catalytic Reduction (SNCR)

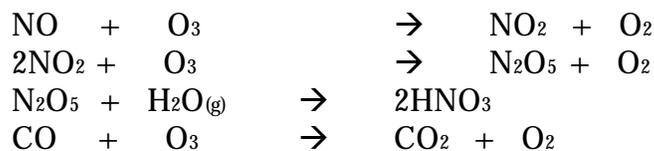
SNCR is applicable to both lean burn natural gas and diesel engines. SNCR involves injecting ammonia or urea into regions of the exhaust with temperatures greater than 1400 – 1500 degrees Fahrenheit. The nitrogen oxides in the exhaust are reduced to nitrogen and water vapor. Additional fuel is required to heat the engine exhaust to the correct operating temperature. Heat recovery from the engine exhaust can limit the additional fuel requirement and concurrent additional emissions from heating exhaust gases. Ten parts per million ammonia (slip) is considered reasonable for SNCR. Temperature is the operational parameter affecting the reaction - as well as degree of contaminant mixing with reagent and residence time. Additional control of particulate matter (up to 85% diesel particulate matter), volatile organic compounds (up to 90 percent) and carbon monoxide (up to 70 percent) may be realized by the afterburning effect of this technology.

v. Lean NOx Catalyst

The lean NOx catalyst works like SCR in that it adds a reducing agent to the exhaust stream to facilitate catalytic conversions. Systems using lean NOx catalysts inject diesel fuel into the exhaust gas to add hydrocarbons. The hydrocarbons act as a reducing agent to facilitate the conversion of NOx to nitrogen and water vapor.

vi. Ozone Injection

Ozone injection, from an on site ozone generator, to a reactor duct oxidizes nitrogen oxides to a higher oxidation state (N₂O₅). A water or caustic scrubber is used to remove the nitrous pentoxide that is highly water-soluble. Typically a heat recovery steam generator and economizer are used to reduce the temperature below 350 F. Temperatures below 350 F inhibits ozone dissociation and ensures that the efficiency of the NOx oxidation is optimal. Ozone is produced on site and on demand for this NOx reduction process. Oxygen supplied to the ozone generator may be evaporation from bulk liquid oxygen or an on-site oxygen generator. The dominant chemical reactions for NOx reduction are as follows (carbon monoxide oxidation is also included):



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Table 5

Applicability and Efficiency of NOx Emissions Reduction Technologies by Add On Control (percent reduction)

Emissions Reduction Technology	SI Natural Gas or Propane Rich Burn	SI Natural Gas or Propane Lean Burn	CI Diesel Fuel	CI Dual Fuel (diesel plus natural gas)
Non-Selective Catalytic Reduction	80-90	N/A	N/A	N/A
Selective Catalytic Reduction (SCR)	N/A	>= 90	90 - 98 *	90 - 98
Catalytic Adsorption	80-90	80-90	80-90	80-90
Selective Non-Catalytic Reduction (SNCR)	50-95	50-95	50-95	50-95
Lean NOx Catalyst	N/A	N/D	>= 90	>= 90
Ozone Injection	85-95	85-95	85-95	85-95

N/A = Not Applicable

N/D = Not Determined

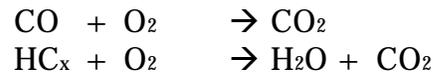
* Catalyst manufacturers have stated willingness to guarantee performance at this level.

3.13.11. CARBON MONOXIDE AND VOLATILE ORGANIC COMPOUND EMISSIONS REDUCTION

Summarized in Table 6.

i. Oxidation Catalyst

An oxidation catalyst can be used to reduce emissions of CO and VOC. For effective reduction of CO and VOC the flue gas must be lean to promote the following reactions:



Rich burn engines require air injection ahead of the oxidation catalyst. The operating temperature window is between 500 °F - 1100 °F. There are several precious metal oxidation catalysts available. Oxidation catalysts can also reduce the organic fraction of particulate.

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Table 6

Applicability and Efficiency of Carbon Monoxide and Volatile Organic Compound Emissions Reduction by Add on Control (percent reduction)

Emissions Reduction Technology	SI Natural Gas or Propane Rich Burn	SI Natural Gas or Propane Lean Burn	CI Diesel Fuel	CI Dual Fuel (diesel plus natural gas)
Oxidation Catalyst	80-95 CO 35-50 VOC	80-90 CO 35-50 VOC	60-85 CO 35-50 VOC 16-35 PM	60-90 CO 35-50 VOC
NSCR	90 CO 50 VOC	N/A	N/A	N/A

N/A = Not Applicable

3.13.12. PARTICULATE EMISSIONS REDUCTION

Summarized in Table 7.

i. Low Sulfur Fuel

Limiting sulfur content of diesel fuel is a pollution prevention method to reduce the sulfate fraction (25-35%) of diesel particulate matter. Current regulations limit diesel fuel sulfur content from an upper limit of 3000 ppmw (0.3 weight percent) in some regions to a lower limit of 2000 ppmw (0.2 weight percent) in other regions. Regulations are under development to limit sulfur content to 15 ppmw. Low sulfur diesel fuel is currently available with a maximum sulfur content of 30 ppmw. Since sulfur is known to poison certain diesel catalyst formulations low sulfur fuel is required for SCR, Lean NO_x and oxidation catalysts.

ii. Fuel Additives.

Additives to diesel fuel are a pollution prevention method to reduce total suspended particulate emissions. The fuel additives are compatible with oxidation catalysts and diesel particulate filters and traps.

Use of the fuel additives was also shown to allow operation of particulate filters without clogging. One formulation is a platinum and cerium catalyst that when mixed with diesel fuel facilitates the combustion of carbon-rich particulate (soot) into carbon dioxide, removing the particulate from the filter. Normally, regeneration of the particulate filter occurs at temperatures greater than the exhaust stream to adequately burn particulate trapped in the filter. The fuel additives allow soot to be burned at typical diesel exhaust temperatures.

iii. Diesel Particulate Trap (DPT)

Trap oxidizer systems consist of a filter positioned in the exhaust stream designed to collect a significant fraction of the particulate emissions while allowing the exhaust gases to pass through the system. Since the volume of PM generated by a diesel engine is sufficient to fill up and plug a reasonably sized DPF over time the filter must be periodically regenerated. Current technologies burn or oxidize the particulate in the trap, thus regenerating the DPF. Numerous methods are utilized to regenerate the DPF as follows:

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1. Catalyst coated filter.
2. Fuel additives to reduce the temperature required for ignition of the accumulated material.
3. Fuel burners, electric heaters, or combustion of atomized fuel by catalyst to heat the incoming exhaust gas to a temperature sufficient to ignite the particulate.
4. Ceramic engine coatings, which will increase the exhaust temperature, thereby increasing the time the exhaust temperature exceeds the required regeneration temperature.
5. Injecting compressed air flowing in the opposite direction of the particulate from the filter into a collection bag which is periodically discarded or burned.
6. Catalyst to oxidize NO to NO₂ which absorbs on the collected particulate, substantially reducing the temperature required to regenerate the filter.
7. Throttling the exhaust downstream of the trap. The method consists of a butterfly valve with a small orifice. The valve restricts the exhaust gas flow, adding back pressure to the engine, thereby causing the temperature of the exhaust gas to rise and initiating combustion.

Some filters are designed with dual filters in which one collects while the other filter is regenerating to avoid bypass of single filter during regeneration.

iv. Catalyzed Diesel Particulate Trap

Catalytic oxidizer systems apply catalytic coatings to the surface of a diesel particulate trap. The catalytic coating preferentially oxidizes the particulate matter and the soluble organic fraction (SOF) by lowering the reaction temperatures necessary for oxidation. Catalyst coating formulations are available that minimize oxidation of sulfur in fuel while oxidizing SOF of diesel particles. Additional benefits are that CO and gaseous organics are also oxidized. The catalyzed diesel particulate trap is not suitable for use with high sulfur fuel since some of the SO₂ is catalytically oxidized to sulfuric acid particulate increasing the particulate emissions. The diesel catalytic oxidizer is primarily used with four stroke engines where exhaust temperatures are typically greater than with two stroke engines. Temperatures up to 700 degrees Fahrenheit, or greater are required for spontaneous regeneration.

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Table 7

Applicability and Efficiency of Particulate Emissions Reduction Control Measures (percent reduction)

Emissions Control Technology	SI Natural Gas or Propane Rich Burn	SI Natural Gas or Propane Lean Burn	CI Diesel Fuel	CI Dual Fuel (diesel plus natural gas)
Low Sulfur Fuel (30 ppmw)	N/A	N/A	25-34	25-34
Fuel Additive	N/A	N/A	1-33	1-33
Catalyzed Diesel Particulate Trap	N/A	N/A	80-90	80-90
Diesel Particulate Trap	N/A	N/A	80	80
Selective Catalytic Reduction	N/A	N/A	15-30	15-30

N/A = Not Applicable

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3.13.13 RECOMMENDED REVIEW SCHEDULE

The next scheduled date for review of the performance levels specified in this manual will be December 2007.

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