CLEANER AIR FOR EVERYONE

PART 1 AN EVOLUTION OF CLEAN AIR IN NORTH AMERICA AND HOW ENGINE EMISSION REGULATIONS AFFECT YOU

One thing is clear — the air we breathe is getting cleaner, thanks to years of work by engine and equipment manufacturers, encouraged by the government, environmental agencies and the Clean Air Act.

A Brief History in Clean Air Developments

Since the middle of the 20th Century, the U.S. government — and other governments around the world — have been working to clean our air. In the United States, it started in 1955 when Congress passed the Air Pollution Control Act. This was the first time the government had formally identified air pollution as a national problem and identified pollution as a risk to the public's health and welfare. It also marked the beginning of funding to research methods to improve air quality.

Eight years later, Congress passed the original Clean Air Act of 1963. It set standards for emissions on stationary sources of pollution (e.g., power plants, steel mills). In 1965, an amendment to the Clean Air Act called the Motor Vehicle Pollution Control Act set the first federal emission reduction standards for automobiles, starting with the 1968 models.

EPA Is Established

Another major milestone for a cleaner environment was the creation of the Environmental Protection Agency, otherwise known as the EPA. That took place in 1970 during the Clean Air Act extension. The EPA was established — in part — to help enforce the regulations set forth by the amended Clean Air Act. The Clean Air Act Extension of 1970 set new national standards for ambient air quality and "new-source" performance standards that strictly regulated emissions of a new source (e.g., automobiles, factories) entering an area.

New standards for hazardous emissions from motor vehicles were also introduced as part of the extension. They included carbon monoxide, hydrocarbons, nitrogen oxides, lead and particulate matter. These emissions are still of primary concern today and are a large part of the emission standards — such as interim Tier 4 and final Tier 4 — that are required for the future.

To combat the hazardous emissions from motor vehicles, the automotive manufacturing industry incorporated the catalytic converter. It made its debut in 1975 as a method to reduce automobile emissions. It soon became a regular part of a vehicle exhaust system, and has since been adopted in other forms of transportation, such as buses, trains and airplanes, to name a few.

1977 Amendment

The next significant update to the Clean Air Act was in 1977. This amendment included the creation of the New Source Review, which was responsible for helping older facilities (power plants, manufacturing plants, etc.) that were previously grandfathered in to the Clean Air Act to undergo environmental testing and install pollution controls during facility expansions. The 1977 amendment also, for the first time, set standards for lead in gasoline used in vehicles, such as passenger vehicles (i.e., cars) and light trucks.

1990 Amendment

The last noteworthy amendment to the Clean Air Act happened in 1990. It placed emphasis on prohibiting leaded gasoline after 1995; it addressed acid rain, ozone depletion and toxic air pollution; and it created a national permits program, known as "emissions trading." This was done to encourage companies to minimize air pollution with incentives for meeting air quality regulations. Companies could purchase emission credits to emit specific volumes of air pollution — or trade permits with other companies — but they were not allowed to exceed a cap.

Shortly after the 1990 amendment to the Clean Air Act, new emission standards were announced for cars and light trucks. It was a two-tier system that started in 1994 and was completed in 2010. Meanwhile, heavy-duty trucks and buses also followed new emission requirements. The final tier for cars, light trucks, heavy-duty trucks and buses is comparable to Tier 4 standards for nonroad equipment, including construction equipment. Nonroad equipment was the last category required to meet the air quality controls, and now the nonroad equipment is entering the final phases of EPA emission standards to significantly reduce any harmful pollutants.

PART 2 UNDERSTANDING EPA STANDARDS FOR NONROAD EQUIPMENT

Understanding exactly how the EPA emission standards impact nonroad equipment — such as Doosan® products — can be difficult and even more challenging is determining what manufacturers — including Doosan — are doing to their equipment to make it compliant with the EPA regulations. The rest of this article will attempt, on a high level, to explain the implications of EPA nonroad emission standards and the technologies available to help companies like Doosan meet interim Tier 4 and final Tier 4 regulations.

Health Benefits

First and foremost, cleaner air is good for everyone. That may sound like common sense, but research shows that remarkable health improvements, especially respiratory, have been made because of changes to clean air standards. Studies show that efforts taken by the EPA have reduced air pollutants, mostly the two worst ones: particulate matter (PM) and nitrogen oxides (NO_x). By the end of 2010, the EPA estimated that NO_x emissions would be reduced by about a million tons per year. That's the equivalent of removing 35 million passenger cars from our roads. Even better, by the year 2030, the EPA estimates that annually, cleaner air will prevent 12,000 premature deaths, 8,900 hospitalizations and 1 million lost work days.

So the health benefits are all positive, but what exactly has the EPA been doing since the first clean air non-road diesel rules took effect in the mid 1990s? The EPA's primary goal was to create a national program designed to reduce harmful emissions from nonroad diesel engines. To do so, they encouraged equipment manufacturers to implement engine and fuel controls to eliminate or minimize PM and NO_x levels from diesel engine exhaust.

Let's take a look at the five individual tiers since they took effect:

Tier 1

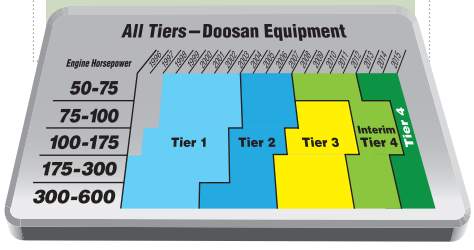
Tier 1 was the first set of emission standards adopted and regulated by the EPA for new nonroad diesel engines. The goal of Tier 1 was to reduce NO_x emissions from nonroad diesel engines by approximately 30 percent. For Doosan equipment, Tier 1 compliancy was ushered in from 1996 through 2000. Actual dates varied by engine horsepower (see chart at right).

Tier 2

Starting in 2001 — through 2006 — the next step in nonroad diesel regulations took effect, again depending on engine horsepower. The goal of these regulations was to reduce NO_x, PM and hydrocarbons. PM reductions were as much as 25 percent on some engines. Those dates, as they apply to Doosan equipment, are shown in the chart below.

Particulate Matter (PM): *Partially composed of leftover fuel that didn't get burned during combustion in the diesel engine. Simply put, it's the black soot you see emitting from a machine's exhaust stack.*

Nitrogen Oxides (NO_x): *Atmospheric pollutants produced in combustion that are invisible, but help form smog.*



Tier 3

In 2006, the EPA Tier 3 regulations first took effect. These were the third set of emission standards adopted and regulated by the EPA for new, nonroad diesel engines. These emission regulations applied to Doosan models with engines with more than 75 horsepower, as shown below. The goal of Tier 3 targeted NO_x again; to reduce it by approximately 39 percent, compared to Tier 2.

Impact on Doosan Equipment

Changes to Doosan equipment to meet the Tier 1 to Tier 3 emission standards varied considerably, depending on the size of engine used. For example, the Doosan excavator product line alone ranges from 51 to 463 horsepower. Major changes to Doosan equipment included turbocharging, improvements to the engine combustion system and use of high-pressure common rail (HPCR) fuel injection systems. Continue reading to learn more about these systems.

Interim Tier 4 (iT4) and Final Tier 4 (T4)

These are the final steps the EPA is implementing as part of its non-road diesel rules to curb emissions. The iT4 regulation for Doosan equipment started in 2008 (50- to 75-horsepower engines) and will continue for larger engines until 2012. T4 will span 2013–2015. Similar to previous emission tiers, further reductions to NO_x and PM will be the primary objective.

Continued on page 8

PART 3 INTERIM TIER 4 AND TIER 4 TECHNOLOGIES

Engine manufacturers identified the fuel injection system as a major focus point to help meet the EPA nonroad diesel engine emission levels for iT4/Tier 4. Fuel injection systems affect the diesel engine's fuel consumption, torque, noise and emission levels.

High-Pressure Common-Rail (HPCR) Fuel System

The fuel injection system is a major area of focus for advancement toward clean-operating diesel engines. HPCR is an advanced fuel-injection design that regulates fuel pressure and injection timing.

Fuel pressure

- The pump applies high pressure to fuel (22,000 to 34,000 psi).
- The common rail stores pressurized fuel.
- The injectors deliver fuel to the engine.

Injection timing

The electronic control unit (ECU) precisely controls injectors to allow multiple fuel injections during each combustion cycle.

HPCR benefits

High pressure transforms fuel into extremely fine mist as it leaves the injectors. Fuel mist combusts (burns) more thoroughly.

1. **Lower operating costs:** When fuel combusts more thoroughly, less is needed to make the engine run. The result is improved fuel economy.

2. **Cleaner exhaust:** When fuel combusts more thoroughly, less of it is left over in the exhaust after combustion. The result is cleaner exhaust.

When fuel is injected multiple times during each combustion cycle, the combustion lasts longer to create more energy and lower peak engine cylinder pressure:

3. **Better performance:** Creating more energy during combustion results in more torque output from the engine.

4. **More operator comfort:** Lower peak engine cylinder pressure reduces engine noise levels.

Interim Tier 4 and Tier 4 After-Treatment Technologies

The good news for non-road engine manufacturers is this: Car and light-duty truck manufacturers complied with EPA regulations years earlier and developed technologies that have been tested in nonroad engines. These after-treatment systems take the diesel engine exhaust that has already been created by the engine and clean it further by using one or a combination of the following:

- Catalytic oxidation
- Heat
- Filtering
- Diesel exhaust fluid (DEF)

DOC/DPF Systems

These after-treatment devices use filtering, heat and catalytic oxidation to lower emissions in diesel engine exhaust. They're commonly combined with one another in a single canister. Together they lower many emissions but, most importantly, they reduce particulate matter.

The diesel oxidation catalysts (DOC)

Engine exhaust is transformed by the DOC to reduce particulate matter. The DOC is a special catalyst that reacts with engine exhaust upon contact. The reaction transforms some of the particulate matter emissions in the exhaust into harmless substances such as water and carbon dioxide.

The DPF (diesel particulate filter)

Engine exhaust is filtered by the DPF to further reduce particulate matter. The DPF is a special "ceramic wall flow" filtration system that further separates particulate matter from the engine exhaust.

DPF regeneration

To keep the DPF clean and working efficiently, the high temperature of the exhaust itself is used to burn accumulated particulate matter off the DPF. This DPF cleaning process is called "regeneration."

Selective catalyst reduction (SCR)

Engine exhaust is transformed by SCR to reduce nitrogen oxides (NO_x). SCR uses an ammonia and water-based liquid called diesel exhaust fluid (DEF). Combining exhaust with DEF causes it to react with a SCR catalyst. This reaction turns harmful NO_x into harmless nitrogen and water vapor.

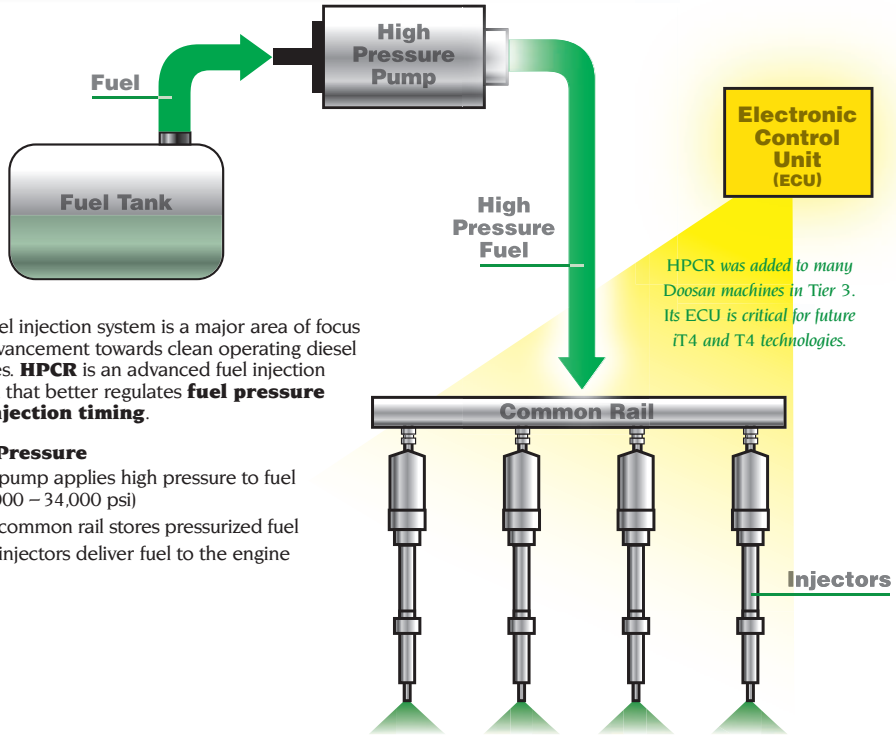
Maintenance requirements

Emission-control systems require maintenance that might include adjustment, cleaning, repair or replacement of components. Check the machine owner's manual or engine owner's manual (if provided) for recommended maintenance of the emission-control system.

The first Earth Day

The first Earth Day was celebrated on April 22, 1970, after U.S. Senator Gaylord Nelson from Wisconsin encouraged Americans to have a better understanding of the environment and the threats it faced from pollution. Today more than 175 countries celebrate Earth Day on April 22.

High-Pressure Common Rail Fuel System (HPCR)



The fuel injection system is a major area of focus for advancement towards clean operating diesel engines. **HPCR** is an advanced fuel injection design that better regulates **fuel pressure** and **injection timing**.

Fuel Pressure

- The pump applies high pressure to fuel (22,000 – 34,000 psi)
- The common rail stores pressurized fuel
- The injectors deliver fuel to the engine

HPCR was added to many Doosan machines in Tier 3. Its ECU is critical for future iT4 and T4 technologies.

Injection Timing

The electronic control unit (ECU) precisely controls injectors to allow multiple fuel injections during each combustion cycle.

HPCR Benefits

High pressure transforms fuel into extremely fine mist as it leaves the injectors. Fuel mist combusts (burns) more thoroughly.

Lower Operating Costs
When fuel combusts more thoroughly, less fuel is needed to run the engine. The result is improved fuel economy.

Cleaner Exhaust
More thorough combustion leaves less leftover fuel in the exhaust. The result is cleaner exhaust.

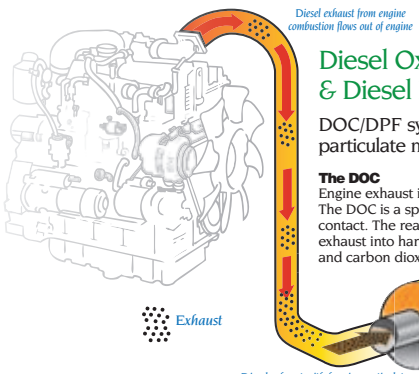
When fuel is injected multiple times during each combustion cycle, the combustion lasts longer to create more energy and lower peak engine cylinder pressure.

Better Performance
Creating more energy during combustion results in more torque output from the engine.

More Operator Comfort
Lower peak engine cylinder pressure reduces engine noise levels.

Visit doosanequipment.com/tier4 for more information

Interim TIER 4 & TIER 4 Technologies (after-treatment)

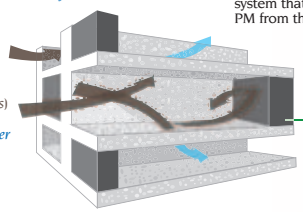


Diesel Oxidation Catalysts (DOC) & Diesel Particulate Filters (DPF)

DOC/DPF systems are highly effective at reducing particulate matter (PM) contained in engine exhaust.

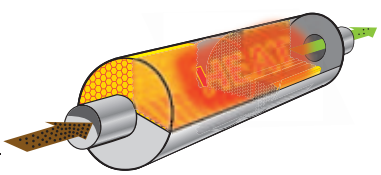
The DOC
Engine exhaust is **transformed** by the DOC to reduce PM. The DOC is a special catalyst that reacts with engine exhaust upon contact. The reaction transforms some of the PM emissions in the exhaust into harmless substances such as water and carbon dioxide.

The DPF
Engine exhaust is **filtered** by the DPF to reduce PM. The DPF is a special "ceramic wall flow" filtration system that further separates PM from the engine exhaust.



Wall Flow Filter
Dirty exhaust (brown arrows) passes through filter walls. PM is left behind and cleaner exhaust (blue arrows) exits.

Barriers exist to ensure exhaust passes through filter walls.

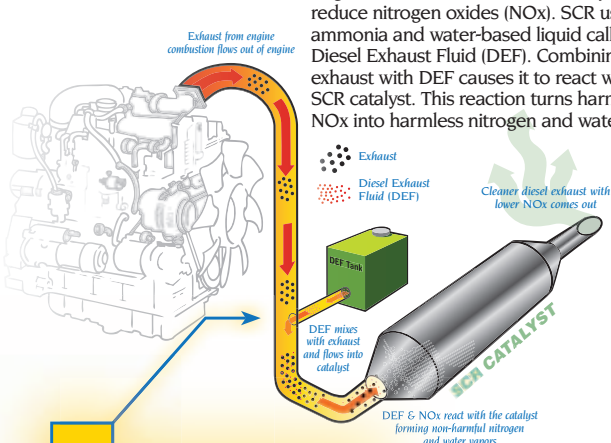


DPF Regeneration

To keep the DPF clean and working efficiently, the high temperature of the exhaust itself is used to burn accumulated PM off of the DPF. This DPF cleaning process is called "regeneration."

Selective Catalyst Reduction (SCR)

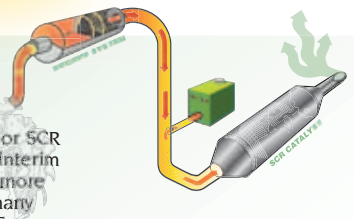
Engine exhaust is **transformed** by SCR to reduce nitrogen oxides (NOx). SCR uses an ammonia and water-based liquid called Diesel Exhaust Fluid (DEF). Combining exhaust with DEF causes it to react with a SCR catalyst. This reaction turns harmful NOx into harmless nitrogen and water vapor.



ECU **HPCR is critical to after-treatment systems.** The ECU controls and monitors **regeneration** and **DEF** mixture.

Teaming Up for Tier 4

In many situations, DOC/DPF or SCR systems are enough to reach Interim Tier 4 requirements. To meet more stringent Tier 4 regulations, many machines will utilize DOC/DPF and SCR together.



Where does **TIER 4** come from?

All emission standards, including Tier 4, are administered as a part of a federal law named the Clean Air Act. The purpose of this law is to reduce air pollution because of its hazards to human health and the environment. The Clean Air Act is managed and regulated by a federal agency known as the Environmental Protection Agency (EPA).

To better understand where the heavy equipment industry is headed, Doosan encourages you to learn about the history of Tier 4–and the technology that makes it a reality.

1996-2015

Heavy equipment evolves to meet tiered emission standards, with Tier 4 being the final step in this process.

1994-2010

Cars and light trucks begin and complete an emissions reduction process. The end result is comparable to what Tier 4 will be for heavy equipment.

1987-2010

Heavy-duty trucks and buses begin and complete an emissions reduction process. The end result is comparable to what Tier 4 will be for heavy equipment.

London's Killer Fog

A toxic mix of fog and coal smoke – kills several thousand over a four-day span. The world changes its view of air pollution.

Donora, PA

For five days, a cloud of air pollution overtakes the industrial town of Donora, Pennsylvania, sickening 40% of the town. 20 die.

1952

The Motor Vehicle Pollution Act sets the first emissions reduction standards for automobiles.

1948

The Air Pollution Control Act of 1955 identifies air pollution as a national problem and provides funding for air quality improvement.

1955

1965

1963

The Clean Air Act of 1963 sets emissions standards for stationary sources (power plants, steel mills, etc.) and recognizes the danger of motor vehicle exhaust.

1970

Emission standards broaden and become more stringent for automobiles and stationary sources, such as factories. Congress creates the EPA in part to assist with the implementation of these expanded standards.

1975

As a result of emissions standards set in 1970, catalytic converters begin to appear on automobile exhaust systems.