

# CLEAN DIESEL TECHNOLOGY FOR OFF-ROAD ENGINES AND EQUIPMENT: *TIER 4 AND MORE*

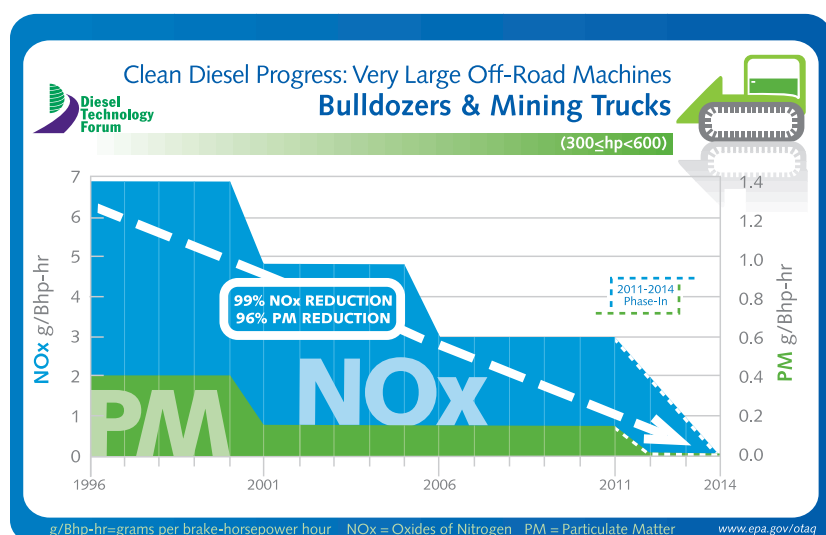
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Clean diesel technology is now the standard for all new technology, everything from new passenger cars and pick-up trucks to highway commercial trucks. Clean diesel is a system of three key parts: cleaner diesel fuel, advanced engine technology and aftertreatment. Now, starting in 2011, this new generation of clean diesel technology for off-road engines and equipment known as Tier 4 will be making its way onto the construction and industrial jobsites and farm fields around the country. This paper describes the milestones and technology and what it means for dealers, distributors, mechanics and those involved with operating diesel engines and equipment.



## WHAT IS TIER 4?

Tier 4 refers to a generation of federal air emissions standards established by the U.S. Environmental Protection Agency (EPA) that apply to new diesel engines used in off-road equipment. Essentially it requires manufacturers to reduce the levels of particulate matter and oxides of nitrogen (NOx) to a level that is 50-96 percent lower than existing generation of diesel engines. It is important to note that Tier 4 emissions requirements apply to new products only and do not apply retroactively to any existing machines or equipment. **(See section on retrofit).** EPA and California have adopted the same standards, so there are no unique Tier 4 diesel emissions standards that apply in California.



> **FIGURE 1:  
Emissions  
Standards  
for  
Bulldozers**

## WHY ARE THESE CHANGES BEING MADE?

Through the Clean Air Act, EPA establishes national clean air standards that determine levels of allowable emissions (ozone, fine particles, etc.) in the air. From that, sources of these emissions (cars, trucks, tractors, power plants, other industry) are regulated by EPA and the California Air Resources Board to control the volume and types of emissions. Each state or regional area with levels of emissions that exceed the standards must develop a plan to improve air quality and meet the clean air requirements established by EPA. Introducing new cleaner diesel engines will aid in state and regional clean air compliance.

## HOW WERE THE “TIERS” ESTABLISHED? WHAT ARE THE OTHER TIERS?

The “tiered” series of emissions regulations has been in effect over the last 13 years governing new off-road engines and equipment. These standards establish progressively lower allowable emissions of nitrogen oxides and particulate matter. It is complex system and its compliance dates are based on the size of engine (in hp and /kW-hr) and other factors. The Tier 4 standards provide manufacturers with a flexibility provision and include an interim step - Tier 4 interim - which requires substantial reduction in PM emissions and flexibility in lowering oxides of nitrogen. A Tier 4 final step includes additional reductions in NOx and HC emissions). **A detailed table (Figure 3) of these standards along with a graphical display is in the Appendix.**

A Tier 0 engine has basically no modern emissions controls and may be referred to as unregulated and is likely to be a mechanically controlled engine rather than electronic. Each progression of standard level - Tier 1, Tier 2, Tier 3 engines all are lower in emissions and more advanced technologically than the previous generation. The use of electronic engine controls, new higher pressure fuel injection systems and advanced turbocharging are all technologies that reduce emissions and aid performance.

## ONCE THE TIER 4 ENGINES COME ON THE MARKET, CAN I STILL ORDER A TIER 3 ENGINE?

According to federal law and EPA regulations, depending on the machine, manufacturers will typically only be able to produce the Tier 4 engines after the established deadlines. However, equipment dealers can sell inventories of engines and equipment from the previous generation technology (Tier 3) until the inventory is depleted. Each engine and equipment OEM may have different technology and transition plans, so it will be important to understand these requirements for each machine and horsepower rating of each engine and each manufacturer. Under the EPA rules, manufacturers are provided with flexibility in meeting the requirements. Also, machines slated for export outside the U.S. are treated differently.

## DO THE NEW TIER 4 ENGINES REQUIRE DIFFERENT FUEL?

Yes! New Tier 4 generation engines and equipment will **require** the use of ultra-low sulfur diesel fuel (ULSD) which has no more than 15 ppm sulfur. This fuel has been used since 2006 in on-highway vehicles. Older off-road machines and engines can continue to use the higher sulfur fuels which will be available in diminishing quantities nationwide until December 2011. Supplies of the old “higher sulfur” diesel fuel will be diminishing rapidly beyond 2010, but still may be available in some more remote locations and areas of the country. **(For more information on clean diesel fuel requirements visit [www.clean-diesel.org](http://www.clean-diesel.org))**

## WE KNOW THE NEW TIER 4 ENGINES WILL BE DIFFERENT FROM PREVIOUS ENGINES BUT HOW WILL THEY BE DIFFERENT?

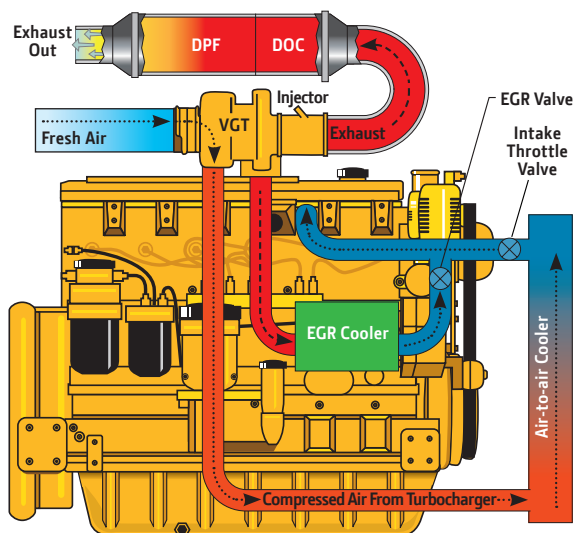
While each manufacturer will pursue their own technology path and emissions compliance strategy, there are a number of new technologies coming on many Tier 4 engines and equipment. For the equipment, the changes likely to be most noticeable are in the packaging and placement of the aftertreatment system and the increased size of the air intake system to accommodate the needs for increased airflow and cooling. New changes to the engine will likely mean that engine compartments may be reworked to manage the new systems. Some OEMs have indicated they will package any new exhaust system configuration inside reworked sheet metal skin while others will place the systems in their traditional locations with additional shielding and routing hardware to accommodate the heavier exhaust system components.

Most Tier 4 engines will be electronically controlled, meaning that a computer will monitor and adjust the fuel and air mixture to optimize emissions and performance for the engine on a real-time basis. In addition, changes in the engine will include new and different systems to accommodate the increased heat rejection of the new engines. For the first time, most off-road equipment will likely incorporate emissions control technology in the exhaust system, such as a catalytic converter and/or particulate filter, typically in place of the existing muffler and exhaust system. Some of these new exhaust aftertreatment systems mean that the pipes and placement of the muffler and exhaust may be different than previous generations of equipment, or potentially larger in size to accommodate the new functions and in some cases hotter temperatures of the exhaust. There are two primary technology pathways for meeting the Tier 4 requirements; exhaust gas recirculation (EGR) or selective catalytic reduction (SCR).

Some Tier 4 engines will include use of cooled exhaust gas recirculation (EGR) (Figure 2). EGR is a technique that recirculates a portion of the exhaust gases back into the combustion chamber which has the effect of lowering the combustion temperature and reduces formation of NOx. This system will add additional manifolds and plumbing around the engine.

One of the biggest changes for engine and equipment dealers is that some engines/machines will utilize a new emissions control technology system known as selective catalytic reduction (SCR) (Figure 3). This technology is also designed to reduce emissions of nitrogen oxides. Widely used in Europe on heavy duty trucks and in some U.S. stationary industrial and power generation settings, SCR technology is new to the U.S. for mobile

## PowerTech PVX Interim Tier 4 technology



**FIGURE 2:**  
Schematic of  
Interim Tier  
4 technology  
using EGR.

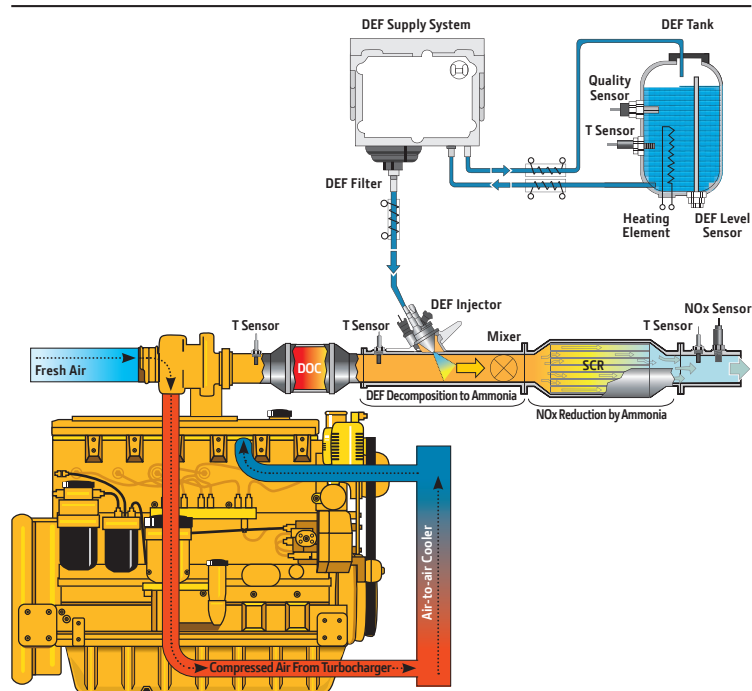
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on-road and off-road applications in 2010. The majority of heavy-duty truck manufacturers began using SCR technology in their 2010 products, along with a number of light-duty diesel car manufacturers, and some manufacturers will use this in their off-road equipment offerings.

In this SCR system a special catalyst is positioned in the exhaust stream/muffler system downstream from an active spray dosing system that periodically sprays a mist of a chemical reagent called diesel exhaust fluid (DEF), or aqueous urea - to react with the exhaust nitrogen oxides and lower tailpipe emissions. Depending on its size a machine will have a storage tank holding anywhere up to 15 gallons of liquid DEF. The DEF dosing system, supply and return tubing and control and monitoring functions are all integrated into the engine electronic controls. DEF consumption is dependent on equipment utilization, load factors, idle time etc. Manufacturers are optimizing SCR technology and DEF tank sizes such that DEF tanks need to be replenished in conjunction with key maintenance intervals. Indicator lights on the dash will warn the operator when the DEF supply is running low and should be replenished. If it is not replenished, upon a series of start-ups, the machine will eventually revert to a "limp" mode where engine performance is de-rated until the DEF fluid is replenished and the integrity of the emissions control system is restored. DEF supply has been growing for the on-highway vehicle market. It is generally expected to be more widely available as more engines and vehicles that require it are produced.

Tier 4 engines and machines may have other differences depending on manufacturer. These could include changes in horsepower ratings, smaller engine displacements, and differing power and torque performance, higher fuel economy and other factors.

## Interim Tier 4 with DOC and SCR



**FIGURE 3:**  
**Schematic**  
**of Tier 4**  
**technology**  
**using SCR.**

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## HOW WILL TIER 4 ENGINES AFFECT THE VALUE OF MY TRADE-INS?

Anytime a new engine or machine is introduced into the market, it sets a new standard for potential purchasers who weigh the costs and benefits of upgrading to the new technology with keeping their older technology. General economic conditions and the demand for new technology versus “older” technology influence the resale and equipment trade in markets. It is unknown whether or not introduction of the Tier 4 emissions technology will have any particularly different impact on the value of pre-Tier 4 equipment and engines.

However, equipment owners considering acquiring older/used engines and equipment should be aware that future construction projects and bids may include consideration of the ages and or emissions performance of the fleet of machines used on the prospective project. Emissions performance of both new and existing equipment should be evaluated together as contractors consider trade and resale options.

## WHAT ADDITIONAL TECHNICIAN TRAINING AND CERTIFICATIONS ARE GOING TO BE NEEDED?

Reducing emissions down to near zero levels will introduce a number of changes in engine and equipment design to accommodate the new technologies into the equipment. Each manufacturer will determine their own product compliance strategy. These changes could include devices such as particulate filters, oxidation catalysts, lean-NO<sub>x</sub> traps, or SCR that are integrated into the existing exhaust and muffler systems.

Technicians will need to have a general familiarity with electronically controlled engines, exhaust aftertreatment control devices, the concept and practice of measuring backpressure, along with the general exhaust equipment maintenance and operation. New operator warning lights and dashboard indicators will likely be included by some manufacturers to denote levels/conditions of new diesel exhaust fluid, or the indication of an active particulate filter regeneration event that might require special attention. Some Tier 4 engines/machines may use particulate filter technology that could require periodic maintenance and cleaning and/or removal. This may also involve some new equipment in a service facility such as an oven or cleaning cabinet to fully service the filters. Some of these functions can be performed by vendors off-site.

For manufacturers that utilize SCR technology, service employees will need to be trained in the general aspects of SCR technology including the basic SCR components on the machine (SCR catalyst, storage tank, spray nozzle and plumbing systems), fluid flows and pressures and

troubleshooting. Training on the safe handling, storage, disposal and dispensing of diesel exhaust fluid, including its material safety data sheet (MSDS) is also strongly suggested.

## WHAT ADDITIONAL DEALER DIAGNOSTIC EQUIPMENT WILL BE NEEDED?

No specific diagnostic equipment requirements can be speculated at this time. However, if a manufacturer uses an SCR emissions control technology on their engine or machine, this will require that service facilities maintain supplies and dispensing equipment for DEF, commonly known as aqueous urea, in quantities to service Tier 4 engines with this technology.

## WILL THERE BE A PHASE-OUT FOR ENGINES OR WILL MY ENGINE BE GRANDFATHERED FOR AT LEAST A WHILE?

*If there is no grandfather clause, will consideration be given to compensate user with older equipment and dealers with used stock?*

The Tier 4 requirements apply only to NEW engines—including those sold in California and all other states. There is no federal requirement to upgrade any existing engine to the new Tier 4 standards. California is pursuing separate state law requirements for the modernizing and upgrading of off-road machines and equipment in that state. **(For more information see [www.arb.ca.gov/diesel](http://www.arb.ca.gov/diesel)).**



## IS THIS THE LAST STEP IN REDUCING EMISSIONS?

Diesel engine emissions have been moving progressively toward zero levels for several years (See Figures 5 and 6 in the Appendix.) and Tier 4 Final emissions are near zero. However, EPA establishes future standards based on air quality considerations and technical feasibility. New efforts are underway to establish fuel economy requirements for on-highway trucks, focusing on carbon dioxide (CO<sub>2</sub>) emissions as part of a broader climate change policy. Consideration of CO<sub>2</sub> emissions from off-road engines and equipment is possible in the future.

## WILL THESE NEW GENERATION ENGINES BE AS DURABLE AS CURRENT ENGINES?

Manufacturers will strive to make sure that new engines will have equal or greater durability than the previous generations of engines.

## WILL THE NEW ENGINES HAVE THE SAME POWER AND PERFORMANCE CHARACTERISTICS OF THE OLD TECHNOLOGY?

Manufacturers are working to produce products that are not only lower in emissions but also ones that maintain or increase previous engine performance. Because most manufacturers are building Tier 4 technology off of Tier 3 platforms, they have been able to maintain or improve

performance in requirements such as cold-weather starting, transient response time, power bulge, peak torque, and low-speed torque. Some new generation engines may have different power characteristics and/or fuel consumption rates.

## DO THE NEW TIER 4 ENGINES REQUIRE ADDITIONAL MAINTENANCE?

Some new Tier 4 engines may have additional or different maintenance requirements as compared to previous generations of equipment. These new requirements could include changes in the types of engine oil, the frequency of recommended oil changes, and changes in air filters and fuel filters and routine maintenance on the exhaust particulate filter systems. For engines that use SCR technology, they will have to be periodically filled with DEF which could occur at a maintenance interval or while on the job site, depending on manufacturer design, machine use and other factors. Equipment that uses diesel particulate filters will require exhaust filter maintenance at intervals typically of 3,000 to 4,500 hours.

## CAN I USE BIODIESEL IN THE NEW TIER 4 EMISSIONS ENGINES/EQUIPMENT?

Manufacturers currently allow for/warrant the use of a blend of anywhere from 5-20 percent blend of biodiesel (fatty acid methyl ester) meeting certain ASTM quality requirements in regular diesel fuel to be used in existing diesel engines and equipment. However, for new Tier 4 engines, it remains to be seen what the policies will be. Biodiesel blends alter combustion



and exhaust temperatures and may impact the performance or durability of some new emissions control technologies when used in a Tier 4 engine. Equipment owners are advised to check carefully with their OEMs regarding permitted fuel blends and use in Tier 4 emissions equipment.

## HOW WILL EMISSIONS PERFORMANCE FACTOR INTO OUR CUSTOMERS CONSIDERATION?

In addition to the typical considerations of maintenance, productivity, resale and the cost of total cost of ownership, there are new reasons why users of diesel engines and equipment need to become more fluent with engine emissions requirements.

Because of new national clean air standards and growing pressure for “greening” of government and private industry, it is projected that equipment owners will increasingly encounter contract specifications, job bids and project riders and contingencies that take into consideration the emissions profile of their equipment in the project bidding and award process.

For example, on public projects such as transportation facilities or infrastructure, some local and state governments have in recent years begun to require contractors to provide detailed information on the numbers and types of equipment to be used on a project and the emissions profiles of the equipment, along with an indication of whether the equipment has been “retrofitted” with exhaust aftertreatment controls or other technology, along with other factors. Some contracts had previously required that as a condition of bidding on a contract, that contractors would have retrofitted all their machines and

equipment, used only cleaner diesel fuel on the prospective job site, or other similar emissions-reducing conditions. One of the first and most visible national projects to have such a requirement was the “big dig” project - building a central artery and tunnel through Boston, Massachusetts. More recent examples include the Cook County Illinois green construction specifications and the Illinois Executive Order. Emissions profiles of a contractor’s equipment is becoming a new aspect of competitive bidding and can make the difference in winning or losing future jobs.

Outside of California there are presently no state laws requiring the mandatory retrofitting of existing, privately owned diesel engines or equipment. However, there are a growing number of states, including Illinois, New Jersey, New York and Rhode Island which require the retrofitting of state-owned equipment or that which is under contract to the state.

## IMPORTANT ISSUES AND THE FUTURE

### WHAT ARE THE OTHER EMISSIONS-RELATED ISSUES WE’RE LIKELY TO BE HEARING ABOUT IN THE FUTURE?

Whether you are an equipment dealer, owner or operator of diesel machines and equipment, there are a number of important trends to watch:

**More State and Local Requirements:** More than any point in the past, the number of state and local laws regulating the use of diesel engines and equipment are growing. This constantly changing environment requires that equipment owners and dealers stay abreast of state and local laws and regulations which can regulate emissions, idling times and fuel use.

**Owners and Operators Have More Responsibility:**

The responsibility for reducing diesel emissions is moving more toward owners and operators rather than manufacturers. Historically, reducing emissions from diesel engines and machines has been totally an issue between engine makers and EPA regulators, where new clean air standards were set and manufacturers made design changes to meet the standards. Owners and operators simply purchased the new model engines and equipment, and over time, newer engines replace older ones and the overall emissions levels improve as the fleet gets newer. However, this trend is changing.

Since Tier 4 emissions will be near zero, the amount of research and development has increased and is more complex compared to previous Tier transitions. Since diesel engines are known for their durability, many older machines will remain in use for years to come and begin accounting for a larger share of diesel emissions. Some of the oldest engines and machines have 20-40 times the emissions levels of a new Tier 4 engine. As new ozone and PM standards are adopted over the next five years, state and regional officials will be looking for cost-effective, near-term ways to reduce emissions through requirements or aggressive incentives to accelerate the modernizing and upgrading of existing engines and machines ("aka retrofitting") to lower emissions levels

**New Emphasis on Reducing Equipment Idling:** Depending on age and condition, an idling diesel engine can consume one-half to one gallon of fuel per hour. Many job sites have multiple machines operating at various intervals that

are left idling when not in use. Unlike retrofit regulations, idle reduction measures virtually always have benefit environmental as well as engine benefits and so there will likely be more efforts to raise the awareness about diesel idling and the economics of shutting off engines when not in use; saving money for owners and reducing emissions in the air.

**Climate change, fuel economy and CO<sub>2</sub>:** Efforts are underway in the Congress and at EPA to regulate emissions of CO<sub>2</sub> which is directly related to the fuel consumption of an engine/vehicle or machine. For cars, EPA is establishing both a CO<sub>2</sub> emissions standard and higher fuel economy requirements by 2017. In the highway truck market, EPA and DOT are currently working on establishing what will ultimately be standards for heavy truck fuel economy and CO<sub>2</sub> emissions in the next few years. While fuel economy and CO<sub>2</sub> standards have not been proposed for off-road machines and equipment to date, this is always a possibility for consideration by policymakers.

**Hybridization:** Could a hybrid drive loader or dozer be in your future? These options are already available on select machines by some manufacturers, but expect to see more hybridization as technology evolves and costs are reduced to allow the more widespread use of electric motors, batteries and storage systems on off-road machines and equipment.

**For more information on diesel issues and technology visit [www.dieselforum.org](http://www.dieselforum.org).**

## APPENDIX

### US EPA Non-Road Regulations (130-560kw)

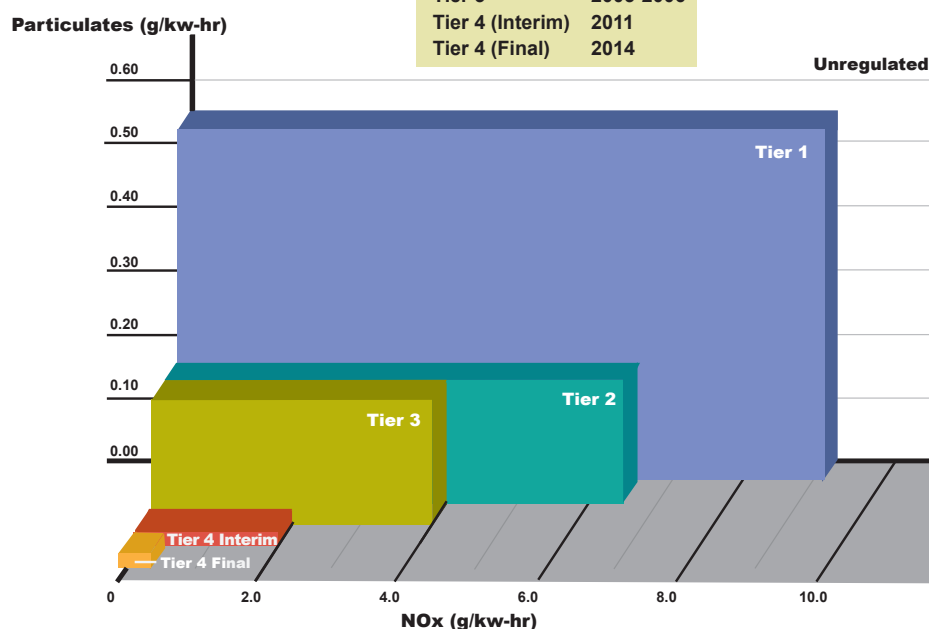


FIGURE 4

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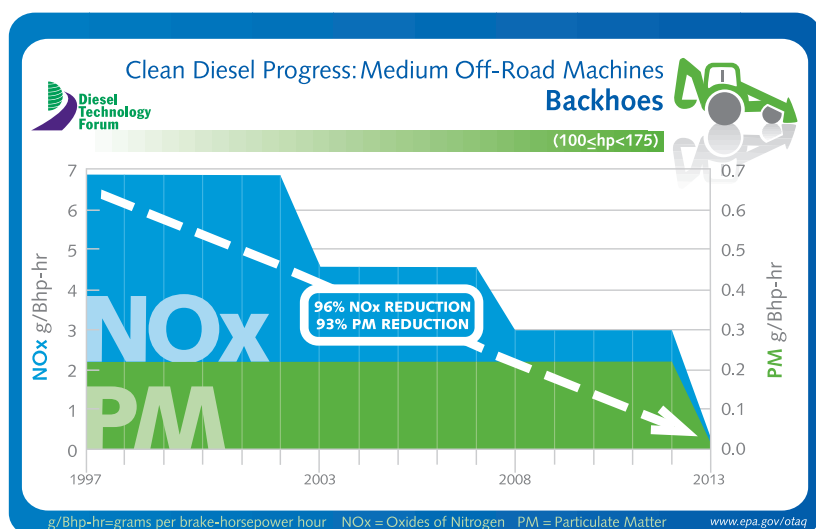
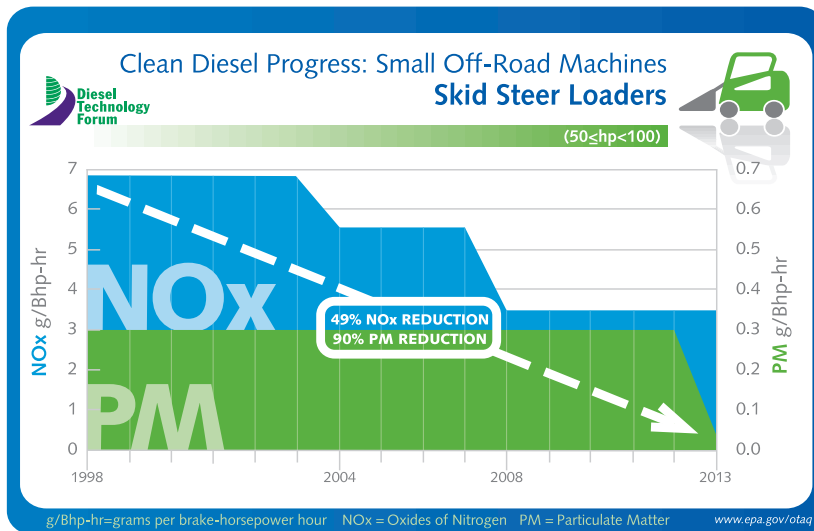


FIGURE 5:  
Emission  
Standards  
for Backhoes

## APPENDIX



**FIGURE 6:**  
**Emission**  
**Standards**  
**for**  
**Skid Steer**  
**Loaders**

### Additional Resources:

- [www.dieselforum.org](http://www.dieselforum.org)  
General info on off-road diesel engines, equipment, retrofitting, etc.
- [www.clean-diesel.org](http://www.clean-diesel.org)  
Diesel fuel standards and timeframes
- [www.epa.gov/nonroad-diesel/regulations.htm#5](http://www.epa.gov/nonroad-diesel/regulations.htm#5)  
U.S. EPA, Regulations for Non-road engines
- [www.cat.com/technology/acert-technology](http://www.cat.com/technology/acert-technology)
- [www.johndeere.com/tier4](http://www.johndeere.com/tier4)
- [www.tier4.info](http://www.tier4.info)  
Cummins
- [www.mtu-online.com/mtu-northamerica/products/diesel-engines-overview/](http://www.mtu-online.com/mtu-northamerica/products/diesel-engines-overview/)