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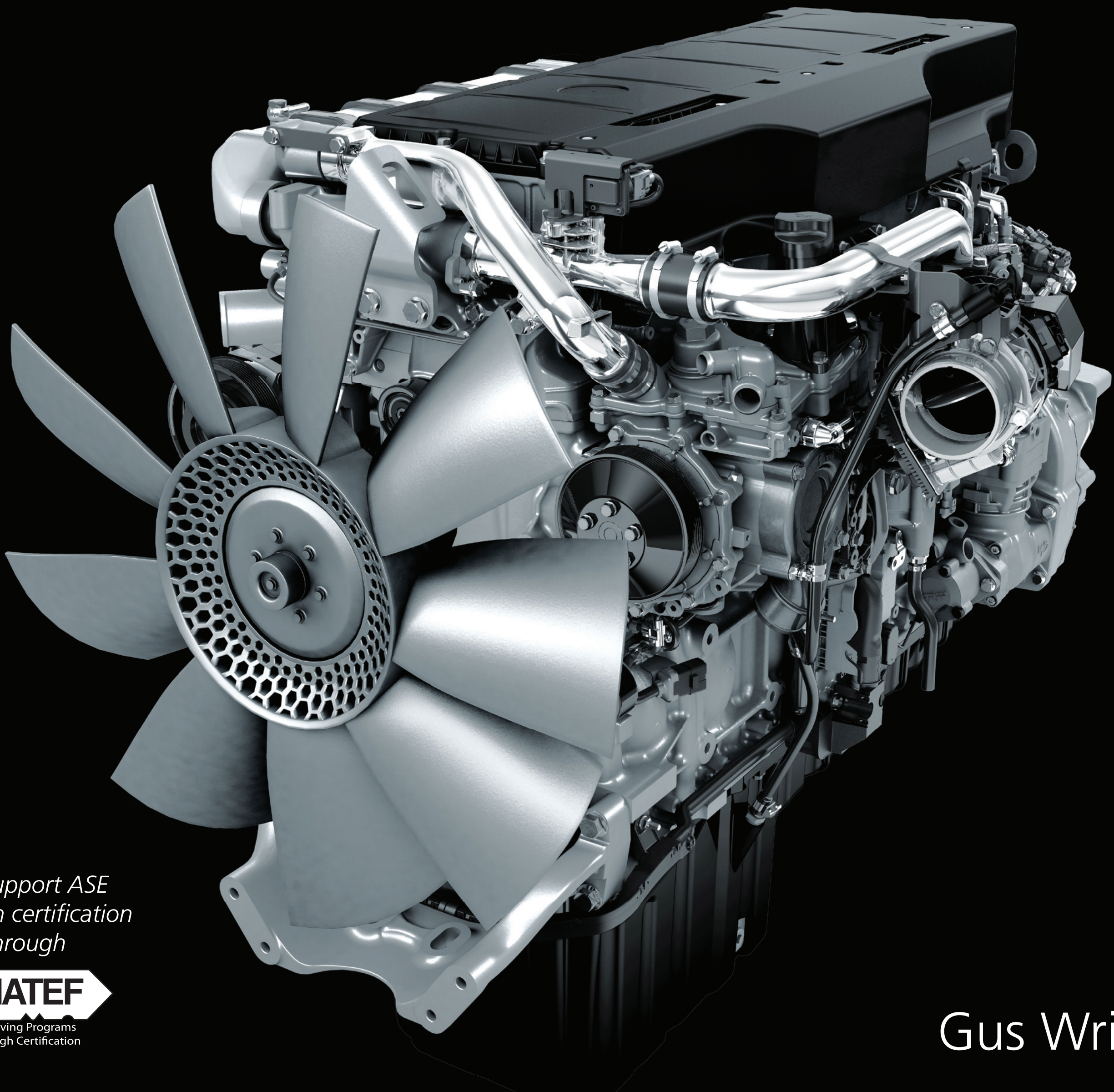
CDX Automotive

SAMPLE CHAPTER
DIESEL ENGINE EMISSIONS

Fundamentals of
Medium-Heavy Duty Diesel Engines



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BRIEF CONTENTS

CHAPTER 7

NATEF Tasks

There are no NATEF Tasks for this chapter.

Knowledge Objectives

After reading this chapter, you will be able to:

1. Identify and describe the categories of noxious emissions from diesel engines. (pp. 103–106)
2. Describe the mechanisms that form noxious emissions in diesel engines. (pp. 106–112)
3. Explain common strategies used to reduce noxious emissions from diesel engines. (pp. 106–112)
4. Describe emissions standards for diesel engines. (pp. 112–118)
5. Identify and describe the major emission monitoring and control systems used to reduce noxious emissions from diesel engines. (pp. 118–120)

Diesel Engine Emissions

Skills Objectives

There are no Skill Objectives for this chapter.

Introduction

Technological innovations in today's diesel are driven by emissions legislation. These legal standards aim to reduce and eliminate the production of noxious substances from all internal combustion engines, including diesel-powered vehicles FIGURE 7-1. Technological advances made to meet these standards have not sidelined diesels but instead have produced cleaner engines that are more efficient and powerful. Today's engines also have greater driving refinement and noise reduction than any previous generation of engines.

Emissions reduction is a crucial part of engine technology. Identifying the emissions unique to diesels, and how those emissions are formed, enables technicians to better understand engine and emission system operation. Emissions standards also have implications for service practices and procedures because technicians are required to maintain vehicles in compliance with emissions standards. Familiarity with emissions legislation that outlines standards for engine durability, service tool capabilities, on-board communication between electronic control modules, and self-diagnostic capabilities of emission control system operation is also helpful to technicians.

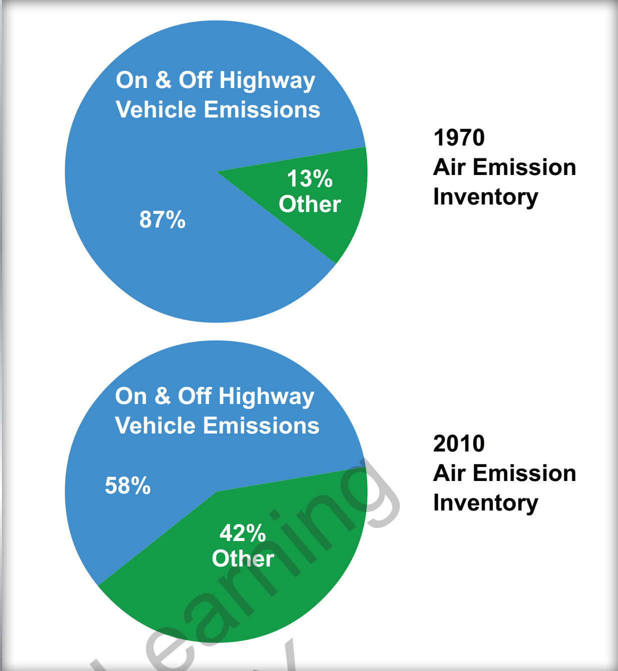

FIGURE 7-1 Technological innovations that reduce and eliminate emissions have led to a substantial drop in pollution from motor vehicles.

Is Diesel Dirty?

The public perception of dirty diesel is not without foundation FIGURE 7-2. Emissions legislation for diesel engines has lagged behind legislation for gasoline engines. Although passenger vehicles were equipped with emissions controls beginning in the late 1950s, the first emissions standards for heavy-duty diesels were not established until the 1970s. One reason for lagging emission standards is that the number of diesel engines in use is small compared to the number of gasoline engines in use. In fact, diesel engines are used primarily in heavy-duty buses and trucks and make up approximately 5% of the vehicle registrations in North America. Emission standards for diesel engines began to become more noticeable

You Are the Truck Technician

A 2005 truck arrives at your shop with the complaint that the exhaust is blowing excessive black smoke and the engine has low power. The driver has also received a fine for the excessive emissions and has an order to have the vehicle's emission-related defects repaired. You begin to prepare a repair estimate by identifying and diagnosing the possible causes of the power loss and black smoke. One concern you have is whether the engine is too worn out to repair and needs rebuilding. You investigate this possibility by performing a crankcase pressure test according to the manufacturer's recommendations. It turns out that the engine does have excessive crankcase blow-by and the engine is likely too worn to perform any repairs that would reduce the emission- and power-related problems.

1. What parts would you replace during an engine overhaul to minimize blow-by emissions from the crankcase?
2. What other parts would you recommend replacing or testing that may also impact the emissions and power complaints?
3. How are the emissions-related problems possibly related to the reduced power output from the engine?

FIGURE 7-2 Diesel engines have long been associated with black soot or "rolling coal" emissions from exhaust stacks.

as emissions from gasoline-fueled vehicles dropped which made the proportion of emissions produced by diesels rise. Data estimates from the 1980s and 1990s show that diesel contributed more than 50% of the emissions in overall emissions inventories—a disproportionate amount when you consider that diesels are only 5% of the vehicles on the road.

These numbers do not paint the whole picture, however. Actual measurements showed that diesel exhaust made up only 24% of overall air emissions, far lower than estimates predicted by EPA models. Longer distances are traveled by heavy-duty diesels; 40% of total accumulated trip distances are made by diesel-powered commercial vehicles such as buses, heavy trucks, and delivery vehicles. Also, diesel-powered vehicles carry much heavier loads than gasoline-fueled vehicles. And, since 2005, there has been a dramatic increase in the use of diesel-fueled vehicles used for transportation. For instance, according to statistical data, in the US in 2011, 23% of the vehicles used for transportation were

TECHNICIAN TIP

Diesel engines built after 2010 are approaching near zero emissions in real-world measurements. More particulate is left on the road by a truck's tires than is emitted from its exhaust. One study of late-model diesel engine emissions found that the number of particles in the air of the average living room is higher than in late-model diesel exhaust. A recent study completed by the University of California found that more particulate is produced by charbroiling a single hamburger patty than by driving a MY2007–2010 diesel truck. The study noted that a fully loaded 18-wheeler diesel-engine truck would have to drive 143 miles (230 km) at highway speed to produce a mass of particulate equivalent to that produced by cooking a single charbroiled hamburger patty.

diesel powered. When all of these factors are brought together, the full picture shows that diesels travel much farther, carrying heavier loads, while using less fuel. A diesel-powered vehicle will produce lower emissions than gasoline-powered vehicles for every ton of weight transported per mile. Today's diesels are in fact as clean as, if not cleaner than, gasoline engines. In fact, modern diesels emit close to zero emissions; sensitive, research-grade instruments are now required to even measure emissions emitted from today's diesel vehicles.

Classification of Emissions

All internal combustion engines produce emissions, which are by-products of the combustion of fuel FIGURE 7-3. Close to 2,000 substances are identified as

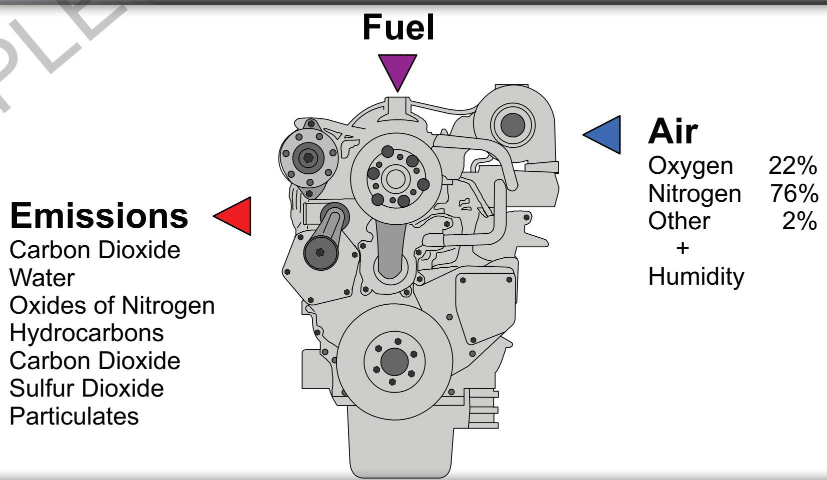

FIGURE 7-3 Hydrocarbons, carbon monoxide, oxides of nitrogen, particulate matter, and carbon dioxide are regulated emissions from diesel engines.

engine emissions. Not all of these emissions are harmful to humans or plant life. Emissions that are hazardous to human or plant life are identified as noxious and classified into four main categories: hydrocarbons (HCs), carbon monoxide (CO), oxides of nitrogen (NO_X), and particulate matter (PM). These categories of noxious emissions are referred to as regulated emissions because legislation limits their production from motor vehicles and equipment. Other emissions are not referred to as noxious, but some do fall into the category of **greenhouse gases (GHG)**. GHGs are believed to trap heat in the atmosphere which contributes to global warming FIGURE 7-4.

Carbon Dioxide

An additional emission, carbon dioxide (CO_2), has also been garnering attention recently.

Until 2009, **carbon dioxide (CO_2)**, a by-product of normal combustion, was not a regulated emission because it was not considered toxic to animal or plant life. However, much attention has been given to its role as a GHG, so much so that public interest in reducing the production of CO_2 has turned to regulating CO_2 emissions. Beginning in the US in January 2009, legislation passed imposing mandatory limits on carbon emissions from all motor vehicles TABLE 7-1 and TABLE 7-2. The European Union's EURO standards have had direct limits on carbon dioxide since 2007 but only for passenger vehicles and not trucks. In North America, however, carbon dioxide limits are indirectly regulated by fuel-economy standards. Because carbon dioxide is a normal by-product of combusting carbon-based fuels, reducing fuel consumption will in turn lower CO_2 output.

Hydrocarbons

Hydrocarbon emissions are formed from unburned fuel. Fuels are classified as hydrocarbons because they are made of mostly hydrogen and carbon atoms. Hydrocarbons in the atmosphere will react with NO_2, an oxide of nitrogen, in the presence of sunlight to form **photochemical smog**, which is a form of air pollution resembling a hazy brown or reddish fog in the atmosphere. Exposure to hydrocarbons is also associated with human health problems, including cancer.

Carbon Monoxide

Carbon monoxide is a colorless, odorless, and tasteless gas that is poisonous in concentrations of as little as 0.3%. Carbon monoxide is created as a result of incomplete combustion of carbon-based fuels. This gas was once

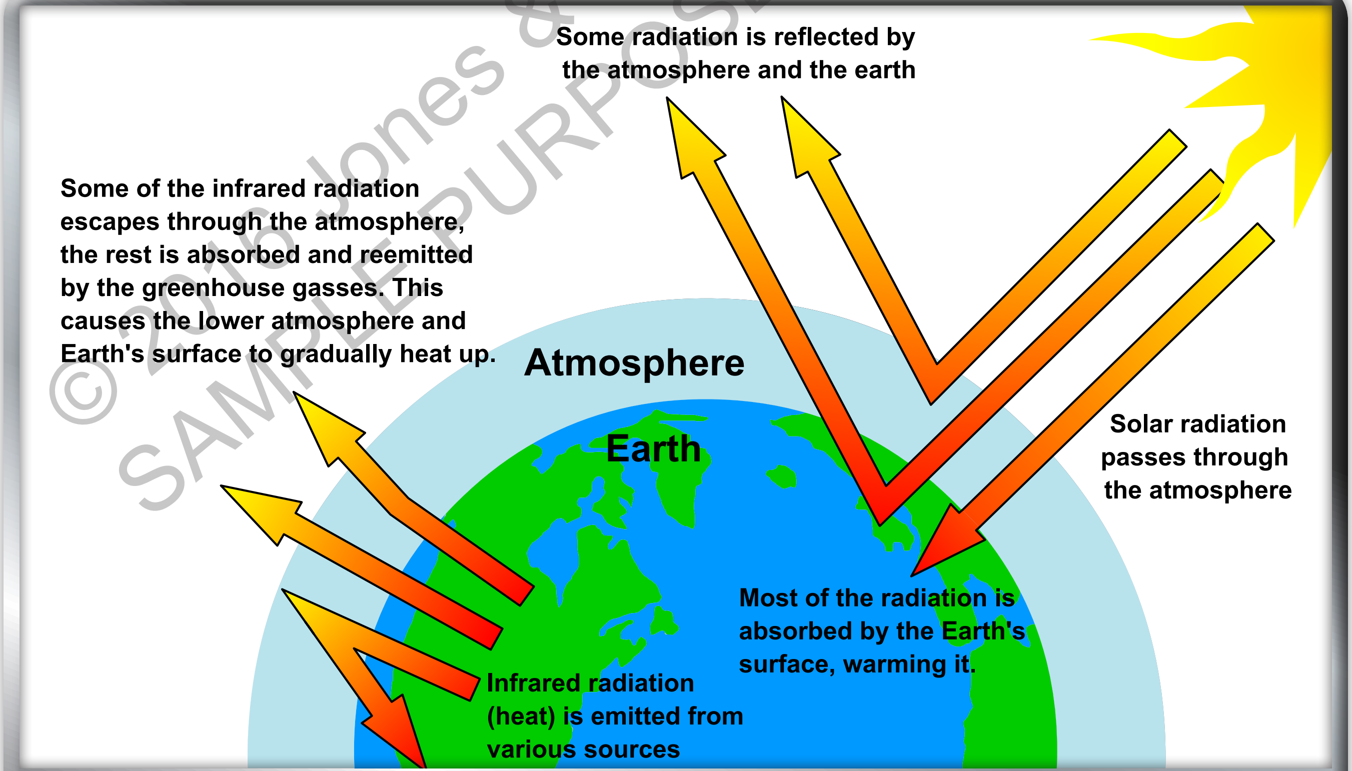

FIGURE 7-4 The cause of global warming is attributed to large amounts of CO_2 emissions produced by burning fossil fuels.

TABLE 7-1: GHG Standard for Carbon Dioxide Emissions from On-Highway Diesel-Powered Vehicles

Category	Year	EPA CO_2 Emissions (grams/ton/mile)	National Highway Traffic and Safety Administration (NHTSA) Gallons/1,000 miles/ton
Medium-Duty	2014	502	4.93
Medium-Duty	2017	487	4.78
Heavy-Duty	2014	475	4.67
Heavy-Duty	2017	460	4.52

TABLE 7-2: 2007 GHG Standard for Carbon Dioxide Emissions from Vocational Applications of Diesel-Powered Vehicles

Category	EPA CO_2 Emissions (grams/ton/mile)	NHTSA CO_2 Emissions Gallons/1,000 miles/ton
Light Heavy-Duty Classes 2–5	373	36.7
Medium Heavy-Duty Classes 6–7	225	22.1
Heavy Heavy-Duty Class 8	222	21.8

prevalent in vehicle exhaust gas, in particular when lead was used as a fuel additive. Contrary to common belief modern gasoline-powered vehicles still produce carbon monoxide (even those using electronically controlled combustion systems and catalytic converters) and can still cause severe poisoning and even death if a person is exposed to exhaust gases in confined spaces where the exhaust gases cannot escape freely into the atmosphere.

Higher compression pressures and excess air used in diesel combustion limits carbon monoxide formation in diesels. Under most conditions, fuel is able to find enough oxygen molecules to react with, and higher compression pressures push molecules more closely together which increases the likelihood of chemical reactions.

Oxides of Nitrogen

Oxides of nitrogen and NO_X are terms for the same category of emissions formed from combining nitrogen with oxygen. There are several different oxides of nitrogen, which the x in NO_X designates, but two are most commonly found in engine emissions. The first is nitric oxide (NO), a colorless, odorless, and tasteless gas that quickly converts to nitrogen dioxide (NO_2) in the presence of oxygen. NO_2 is a reddish-brown, poisonous gas, and it is a major contributor to smog. These gases should not be confused with nitrous oxide (N_2O)—also known as laughing gas—which is used as an anesthetic. Nitrous oxide is also used to boost engine performance when delivered to the combustion chamber through the intake manifold.

NO_X and Smog

Oxides of nitrogen are particularly harmful engine emissions for a couple of reasons. First, NO_X is an essential ingredient to the formation of smog. On warm days in the presence of sunlight, **volatile organic compounds (VOCs)**, which are chemically reactive molecules containing carbon, cause NO_X to break down and form ground-level **ozone (O_3)**, a noxious gas molecule. Like NO_X, ozone can damage lung tissue, sting eyes, irritate the nose, and aggravate respiratory problems such as asthma and bronchitis. In addition, NO_X emissions can also form nitric acid, contributing to acid rain. Without NO_X emissions from the engine, photochemical smog would simply not form.

Particulate Matter

As the name suggests, **particulate matter** refers to the combination of liquids and solid particles emitted from the exhaust pipe and crankcase of a diesel engine. Particulate matter originating from the exhaust is observed as soot particles emitted during engine acceleration **FIGURE 7-5A**. Black carbon mostly makes up this emission. In newer diesel-powered vehicles, particulate emissions are almost undetectable **FIGURE 7-5B**. Though less visible, liquids in the exhaust, such as oil droplets and sulfate compounds, are also considered to be particulate matter. Oil droplets make up the bulk of particulate matter originating from the engine crankcase.

Particulate matter is regulated and classified by particle size **FIGURE 7-6**. Four categories exist: PM-50, PM-10, PM-2.5, and ultrafine PM. PM-50, which is particulate matter smaller than 50 microns in diameter, is the only particulate matter visible to the naked eye, and it falls quickly to the ground. PM-10 is particulate matter smaller than 10 microns in diameter, and PM-2.5 is particulate matter smaller than 2.5 microns in diameter. PM-2.5 is a subset of PM-10, but it is categorized separately because it is considered more hazardous and requires separate accounting. Ultrafine, or nano, particles are those between 5 and 50 nanometers (nm) in diameter. While ultrafine PM accounts for 50–90% of the number of particles in diesel exhaust, it is only 1–20% of the total particulate mass. Fine particles (PM-10 or smaller) remain airborne for days or even months.

Airborne particulate matter has many sources; it is estimated that transportation produces nearly a third of total particulate matter. Particulate matter in the atmosphere is responsible for the hazy appearance of the sky on smoggy days. However, the largest proportion of exhaust, ultrafine PM and PM-2.5, is not even visible to the eye because it is microscopic. The small size of these particles is what makes diesel particulate hazardous.

Safety

Exhaust particles smaller than 10 microns are especially dangerous because they remain airborne for a long time and can penetrate into the deepest parts of the lung when breathed in. These small particles within the lungs aggravate respiratory conditions such as asthma and bronchitis. Particulate matter is also believed to carry other toxic, combustion-formed compounds with it into the lungs and bloodstream. Compounds found in soot such as polycyclic aromatic hydrocarbons (PAHs) are carcinogenic; in fact, diesel soot itself is classified by many government agencies as either a probable or known cancer-causing agent. According to reports by the California Air Resources Board (CARB) diesel soot has been responsible for a significantly high level of risk of cancer caused by air pollution.

Sulfates

When diesel fuel is refined from petroleum oil that is pumped from the ground, varying quantities of sulfur naturally combine with oil. Burning sulfur contained in fuel produces sulfate (SO_x) emissions, which can contribute to air pollution and acid rain. The biggest hazard of burning fuel containing sulfur is that it reacts with other combustion by-products to increase the formation of particulate matter.

Formation of Emissions

Understanding where and how emissions are formed provides helpful insight into the design and operation of various engine systems and strategies that manufacturers

FIGURE 7-5 **A.** Particulate emissions appear as black soot emitted from the exhaust of older or malfunctioning diesel engines. **B.** Emissions produced by the diesel engine in this 2010 bus are nearly undetectable.

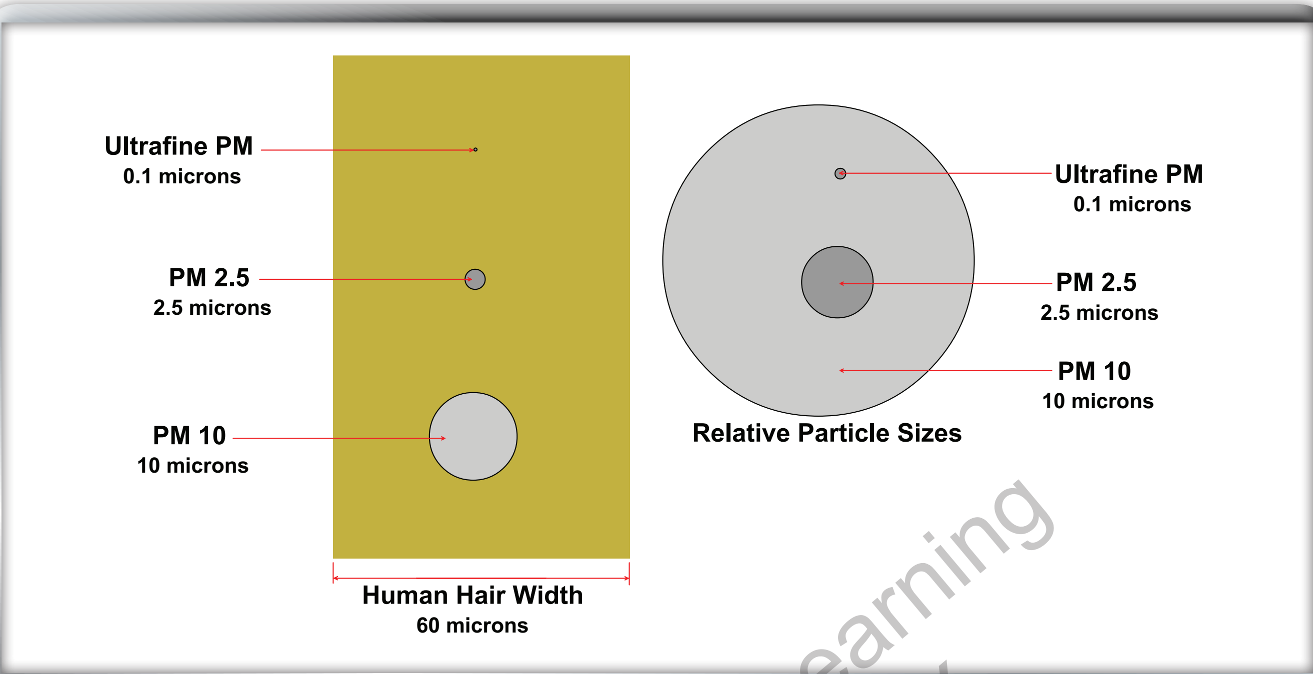

FIGURE 7-6 Particulate matter is categorized by its size.

have developed to reduce and eliminate emissions from diesel engines. Manufacturers attempt to either prevent the formation of emissions by altering combustion conditions that lead to the production of emissions, or clean up emissions after they are produced. Crankcase controls and exhaust aftertreatment systems are examples of systems used to prevent noxious emissions from entering the atmosphere after they are formed. Most other engine and fuel system technologies are designed to target in-cylinder formation of emissions.

Emission Sources

Diesel vehicles produce emissions from two sources: the exhaust system and the crankcase. Regulatory attention until recently has been given only to exhaust emissions. There are no regulations for evaporative emissions from diesels because negligible emissions are produced from the evaporation of diesel fuel. Crankcase emissions from diesels were regulated beginning under EURO 5 and EPA 07 emission standards, about 40 years after similar regulations began for gasoline engines. This delay in regulations was because emissions from this area of the engine are different and have a smaller environmental impact compared to gasoline engines.

Exhaust Emissions

Exhaust emissions, also occasionally referred to as tailpipe emissions, consist of waste combustion gases **FIGURE 7-7**. Water, carbon dioxide, and nitrogen make up the bulk of the exhaust content, but harmful carbon monoxide,

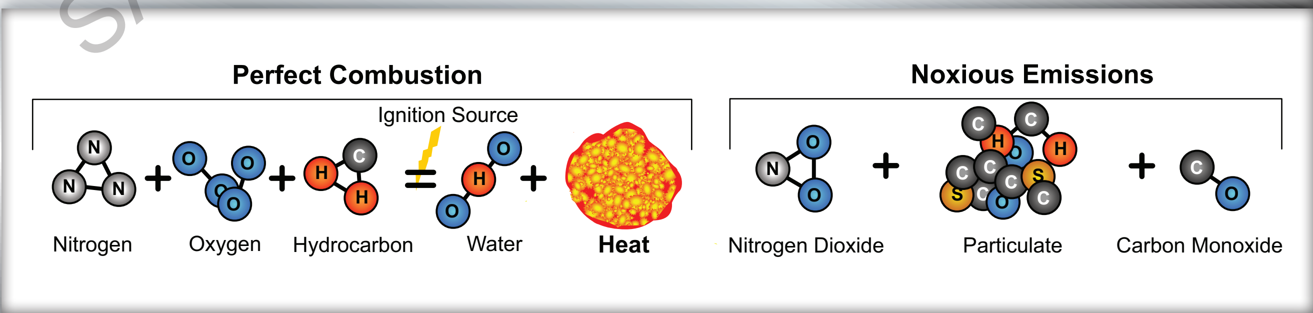

FIGURE 7-7 Perfect combustion compared to imperfect combustion. Imperfect combustion produces harmful emissions.

hydrocarbons, oxides of nitrogen, and particulates accompany the relatively harmless substances. Noxious emissions from diesel exhaust make up 0.2–0.3% of all combustion by-products. In comparison, untreated emissions from spark-ignition engines burning gasoline comprise 1–3%. Exhaust emissions are formed during the combustion process. Injector spray characteristics have a major influence on combustion quality, which in turn influences the types and quantities of emissions produced FIGURE 7-8. Diesel-engine exhaust emissions are unique due to the higher combustion temperatures and pressures produced through turbocharging and high compression ratios. Diesel fuel properties and the nature of compression ignition operation also change the type of emissions formed and the processes forming them.

Crankcase Emissions

Crankcase emissions are mainly composed of cylinder blow-by gas and oil droplets FIGURE 7-9. Blow-by is the leakage of air past the piston rings into the crankcase. In any engine, blow-by occurs mostly during the compression stroke. This happens because the piston rings cannot form a perfect gas-tight seal, which permits some air to leak past the rings. In diesels, only air is present in the cylinder during the compression stroke. This means most

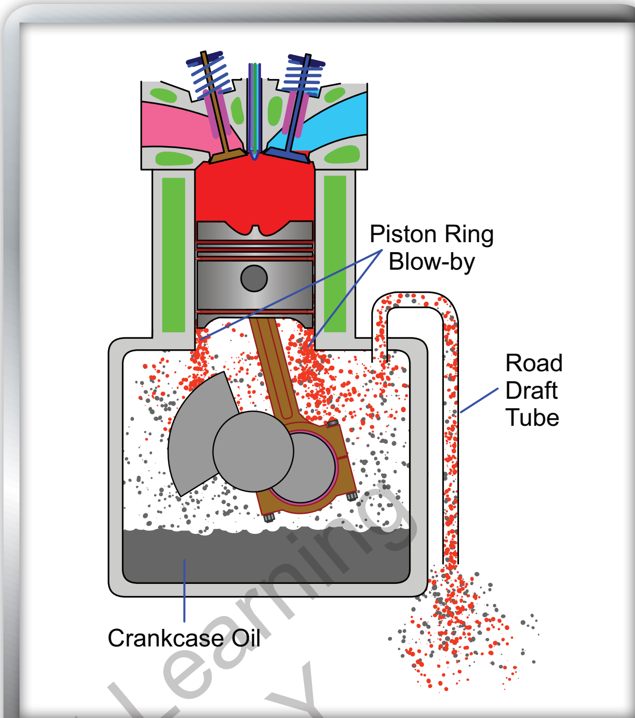

FIGURE 7-9 Blow-by from diesel engines consists mostly of air leaking past the piston rings and mixing with fine oil droplets picked up from the crankcase.

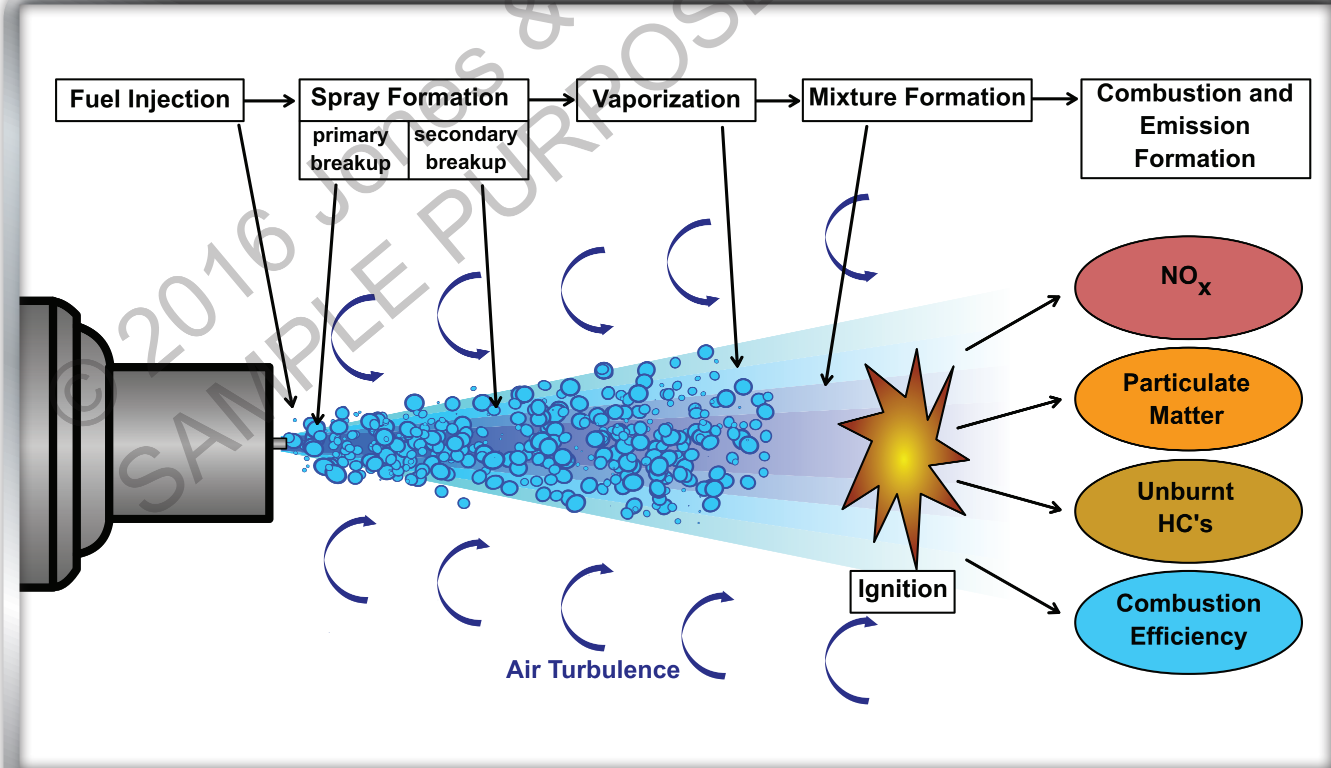

FIGURE 7-8 Formation of gaseous emissions takes place in the combustion chamber.

blow-by consists of air. During the power stroke when cylinder pressure is highest, little blow-by takes place because the compression rings are tightly sealed. Almost no blow-by takes place during the exhaust and intake strokes. While some blow-by is normal, the volume of blow-by will increase as cylinder walls and piston rings wear FIGURE 7-10. In fact, measuring crankcase pressure to evaluate the volume of blow-by is one of the best measurements of engine wear. Engines with excessively high crankcase pressure typically have a poor piston ring-to-cylinder wall seal, which in turn increases blow-by.

Unless vented to the atmosphere, blow-by gases built up in the crankcase would cause seals and gaskets to leak oil from the engine. Blow-by only becomes a problem when it travels through the crankcase to the atmosphere and picks up droplets of oil thrown from the crankshaft and piston cooling jets. Blow-by containing liquid oil droplets is categorized as a particulate emission. Until 2006, diesel engines could vent crankcase blow-by directly to the atmosphere FIGURE 7-11A. Today, diesels are equipped with crankcase controls FIGURE 7-11B. Crankcase controls are covered in more detail later in the book.

Hydrocarbon Production

Hydrocarbon emissions are composed of unburned fuel and are produced from the evaporation of fuel or from incomplete combustion. Diesel engines produce comparatively little hydrocarbon emissions in contrast to gasoline-fueled engines. With almost no evaporative fuel vapors, hydrocarbon emissions due to fuel evaporation are drastically lower from diesels than from gasoline-fueled vehicles. Diesel cold-start emissions are also negligible in comparison to gasoline engines. Excess air and higher combustion temperatures and pressures ensure more complete combustion of fuel in a diesel.

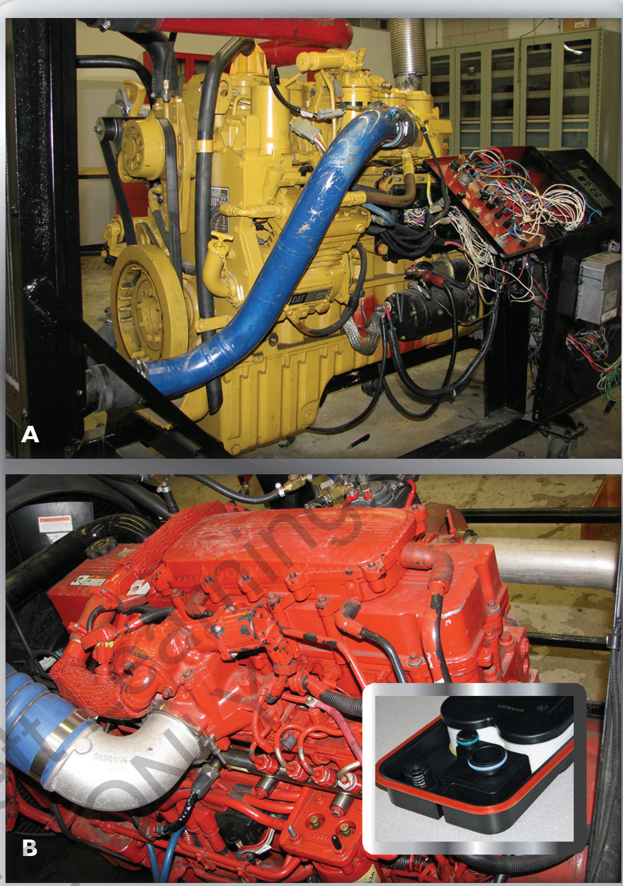

FIGURE 7-11 **A.** An open crankcase ventilation system used by a 3126B Caterpillar engine. **B.** This Cummins "C"–series engine uses a crankcase ventilation system that separates oil from air using a coalescing filter located inside the housing over the valve cover.

FIGURE 7-10 This 7.3L turbocharged IDI diesel engine has excessive blow-by due to cylinder wear.

Evaporative Emissions

Fuel evaporation, such as from a fuel tank, can be a major source of hydrocarbon emissions from gasoline vehicles. However, diesel fuel vaporizes at a higher temperature than gasoline. Diesel fuel's low volatility means little evaporation of fuel takes place from diesel fuel tanks FIGURE 7-12. When diesel fuel does evaporate, it exerts very little pressure in comparison to gasoline. For these reasons, there is no requirement for evaporative emissions controls on diesel engines. Diesel fuel does not easily vaporize. This tendency can be easily observed at fuel-pump islands where spilled fuel lingers for days and weeks before disappearing. Lighter, more volatile fractions of the fuel evaporate more quickly. Heavier, more viscous fuel molecules linger on pumps and concrete surfaces longer than spilled gasoline molecules do.

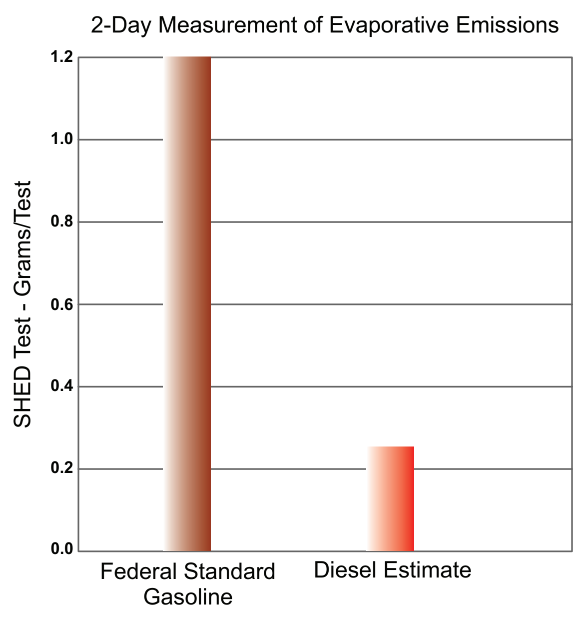

FIGURE 7-12 Levels of evaporative emissions in gasoline versus diesel engines.

FIGURE 7-13 Crevice volume.

Incomplete Combustion

Incomplete combustion is responsible for the majority of hydrocarbon emissions from diesels. The most common causes for incomplete combustion are:

- Inadequate combustion time
- Improperly mixed air and fuel
- Coarse spray droplets
- Insufficient combustion heat and pressure

Fuel can also sometimes avoid combustion in certain areas around the combustion chamber. One major area where hydrocarbons and carbon monoxide form is above the top compression ring between the piston crown and the cylinder wall in an area called the **crevice volume** FIGURE 7-13. Manufacturers' research has discovered that close to 50% of hydrocarbon emissions from diesels originate from fuel trapped in this region. This region prevents proper heating and mixing of fuel with air. The gap between the cylinder head gasket, block deck, and cylinder head is another region contributing to hydrocarbon emissions. In today's diesels, manufacturers have moved the top compression ring closer to the piston crown, and made other modifications to piston design, to minimize crevice volume. The fire ring of the head gasket has also been moved closer to the cylinder in modern engines.

Difficult-to-burn fuel molecules called aromatic molecules cause a characteristic smell from diesel exhaust at idle and low speed. These molecules are complex hydrocarbons which are unusually shaped and sometimes not completely combusted, especially during low speed and load conditions when cylinder pressure and temperatures are reduced FIGURE 7-14. Diesel fuel aromatic content is limited by legislation to reduce hydrocarbon emissions and carbon monoxide production.

> **TECHNICIAN TIP**
>
> Oxidation catalysts help reduce and eliminate diesel exhaust smell. Damaged, missing, or cold catalytic converters are common causes for the strong odor from exhaust and fuel with high aromatic content.

Carbon Monoxide Production

Carbon monoxide is formed when fuel has only partially reacted with oxygen. With adequate heat, pressure, and combustion time, carbon monoxide would change into carbon dioxide. Low combustion temperatures and pressure, lack of oxygen, or insufficient burn time typically contribute to increased carbon monoxide production from an engine.

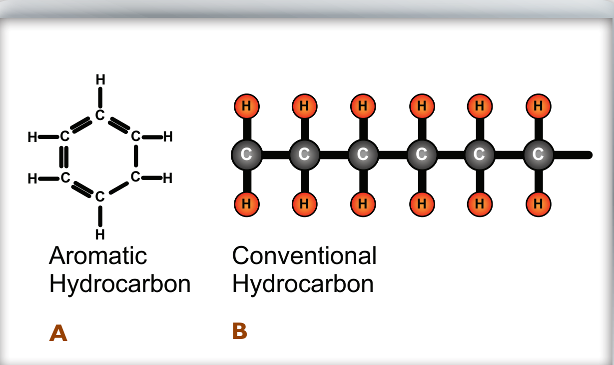

FIGURE 7-14 **A.** Aromatic hydrocarbon molecule. **B.** Conventional hydrocarbon molecule.

Diesel engines produce only very small amounts of carbon monoxide compared to gasoline-fueled engines. Unlike gasoline-fueled engines, diesel-fueled engines do not operate near stoichiometric air-fuel ratios. Generally, diesel combustion uses excess air, which means a greater likelihood of complete reactions between fuel and oxygen; this limits carbon monoxide production. High compression ratios and turbocharging, which increase combustion pressure and push molecules closer together in the diesel combustion chamber, also enable greater likelihood of chemical reactions between oxygen and fuel.

Oxides of Nitrogen Production

Nitrogen is a relatively inert gas and has many industrial applications where that property is useful (e.g., shock absorbers, welding shielding gas, AC leak detection). In engines, however, high combustion temperatures and pressures eventually cause reactions between nitrogen and oxygen FIGURE 7-15. Because nitrogen makes up 78% of air, its sheer volume means a great potential exists to enter combustion reactions. Even though diesel engines produce relatively low levels of HCs and CO emissions, diesel engines have a natural capability to produce far more NO_X than gasoline-fueled engines. Combustion temperatures above 2,500°F (1370°C) contribute to NO_X formation. Because diesel fuel burns at close to 4,000°F (2200°C), increases in temperatures above 2,500°F (1370°C) are easily achieved. Combustion temperature increases above 2,500°F (1370°C) also cause NO_X production to increase exponentially. The three main reasons that diesel engines produce higher levels of NO_X are their higher compression ratios, cylinder pressures, and temperatures which accelerate the speed of chemical reactions.

Particulate Matter Production

Particulate matter is formed in the diesel combustion chamber from the tiny drops of fuel sprayed into the chamber near the end of the compression stroke. It's important to remember that these are liquids and not vapors. Vapors—not liquids—burn. Time and heat are needed to convert diesel fuel into vapor. The low volatility of diesel fuel promotes poor vaporization, but vaporization is needed for complete combustion. In diesel combustion there is a limited amount of time for vaporization to take place because fuel is injected near the end of the compression stroke. Because diesel fuel vaporization is poor, liquid fuel burns from the outside in FIGURE 7-16. Burning fuel from the outside in, with limited time, heat, and air, will produce a small carbon nucleus; this is the primary component of particulate.

Diesel fuel chemistry also contributes to particulate formation. Carbon, rather than hydrogen, tends to be

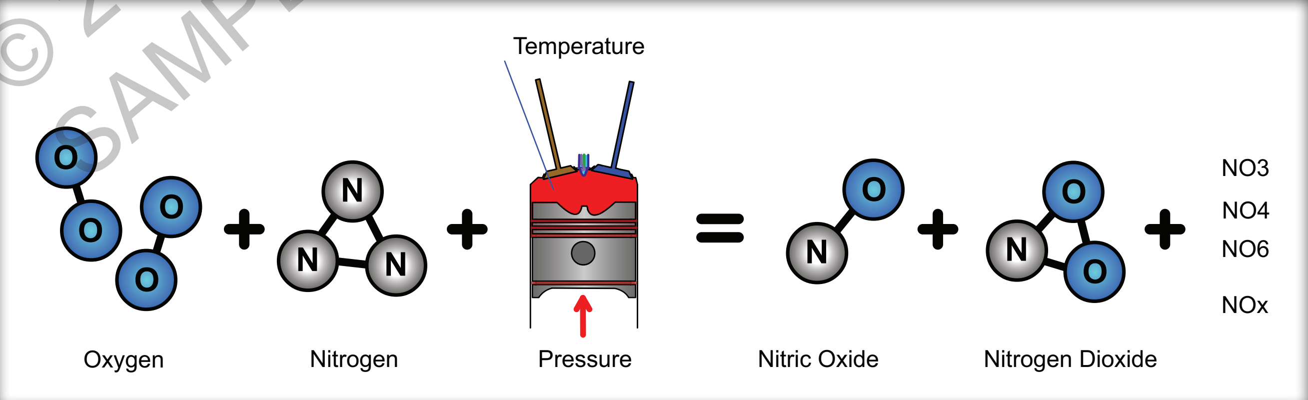

FIGURE 7-15 Under the high pressure and temperature in the combustion chamber, nitrogen will react with air to produce various oxides of nitrogen collectively referred to as NO_X.

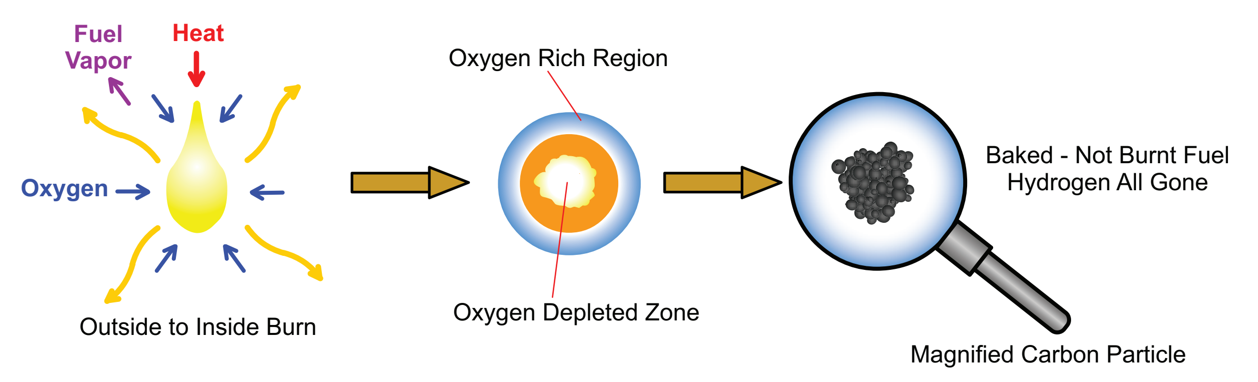

FIGURE 7-16 The lack of oxygen surrounding the fuel droplet after the air around the droplet is used up causes the droplet to burn incompletely.

left over after combustion because it reacts more slowly with oxygen due to the greater number of bonds in a carbon atom. Four bonds are formed by carbon atoms in comparison to a single bond formed by hydrogen. The carbon-to-carbon bonds are especially strong and difficult to break. When carbon-to-carbon bonds are unbroken, black carbon will agglomerate, or chain together, to form black sooty particulate.

The short amount of time to inject, vaporize, distribute, mix, and burn the fuel at the end of diesel's compression stroke means particulate matter production is higher from a diesel engine than in a gasoline engine. Gasoline will vaporize and mix with air quickly during the intake and compression strokes, which also permits more time for improved mixture preparation. A common strategy to reduce particulate formation is to make fuel droplets smaller by using finer atomization. This is done by using higher pressurization of fuel through an injector with smaller, more numerous spray holes. Particulate matter production can also be reduced by using higher combustion pressures and temperatures to accelerate the burn rate, which causes more complete oxidation of the carbon content of diesel fuel.

Sulfate Production

When diesel fuel is refined from petroleum that is pumped from the ground (mineral petroleum), varying quantities of sulfur naturally combine with the oil. When sulfur burns in the combustion chamber, sulfate (SO_X) emissions are formed. Since the mid-1990s, in North America and around the world, sulfur content has been progressively reduced to minimize SO_X production. In 2007, sulfur content in North America dropped from a high of 500 parts per million (ppm) to a low of 15 ppm. This change followed the use of ultra-low-sulfur fuel used for many years in Europe. Further reductions are scheduled for 2015. No exhaust emission standard currently exists for sulfur compounds alone. Instead, sulfur content in fuel is limited. Regulating sulfur content out of fuel enables the use of sophisticated exhaust emissions aftertreatment systems such as particulate filters, selective catalyst reduction, and NO_X adsorbers. High fuel-sulfur content destroys the ability of these devices to convert noxious emissions into other harmless combustion by products **FIGURE 7-17**.

Particulate Emissions and Engine Speed

Maximum engine speed is part of the emissions information on diesel engines. Tachometers in diesel-powered vehicles have a lower maximum engine speed limit than gasoline-fueled engines. Diesel engines cannot turn as fast as gasoline engines because they will not completely burn fuel at high speed. The pre-combustion processes

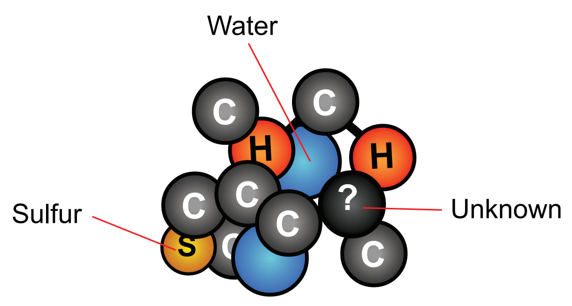

FIGURE 7-17 Composition of a typical particle of soot found in diesel exhaust prior to 2007.

of atomizing, distributing, vaporizing, and mixing fuel with air in the few degrees of engine rotation near the end of the compression stroke requires time. If an engine's piston is rotated too fast through the cylinders top dead center (TDC), not enough time is available to properly complete the pre-combustion mixture preparation stages. In that situation, the engine simply runs out of time to properly prepare and burn the fuel air mixture. If the maximum engine speed limits are exceeded, diesel engines will produce excessive noxious exhaust emissions FIGURE 7-18. This is why diesel emission decals have a maximum rated speed and the fuel system governor must limit top engine speed.

TECHNICIAN TIP

The maximum engine speed listed on the emission decal is part of the regulatory emission certification for an engine family. Technicians are required to ensure that engine speeds cannot be exceeded through any fuel system malfunction, tampering, service practices, or procedures.

Carbon Dioxide Production

As with all exhaust emissions that can damage the atmosphere and the environment, carbon dioxide is best known as a greenhouse gas. Internationally, legislation requires vehicle manufacturers to limit CO_2 emissions from their vehicles. Carbon dioxide is a normal byproduct of combustion of carbon-based fuels. Diesel engines offer a good solution to meet both fuel mileage standards and reduce overall CO_2 emissions. Typically, CO_2 emissions from diesels are 30–40% lower than an equivalently powered gasoline-fueled engine. Factoring in the use of biodiesel, a 100%-renewable fuel source, the environmental footprint of the diesel engine can be even smaller.

Emissions Standards

Around the world, concerns about the negative environmental and health impacts of vehicle emissions have produced legislated standards for noxious emissions. The European Union (EU) and the United States have developed two emission standards adopted by most other countries in the world. The greatest number of countries use emission legislation made law by the European Parliament which was phased in between 1993 and 2014. In the EU, there are six progressive stages for reducing emissions beginning with EURO 1 until the most current EURO 6 from 2014. In the US, the Environmental Protection Agency (EPA) has developed emission standards. The US and Canada use US EPA standards. China has developed its own standards that closely approximate EURO standards. Japan follows Japanese Ministry of Land, Infrastructure and Transportation (JMLIT) standards FIGURE 7-19.

Both EPA and EURO standards regulate nearly the same noxious emissions; the only difference is the classification of hydrocarbons into several different subcategories. GHG emissions, which are vehicle emissions believed to contribute to global warming, are a recent EPA

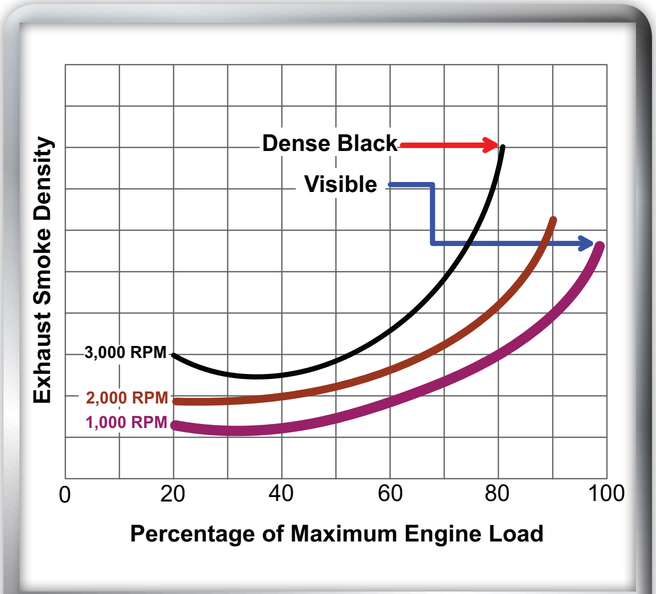

FIGURE 7-18 Relationship of exhaust smoke density and maximum engine load at 1,000, 2,000, and 3,000 RPM.

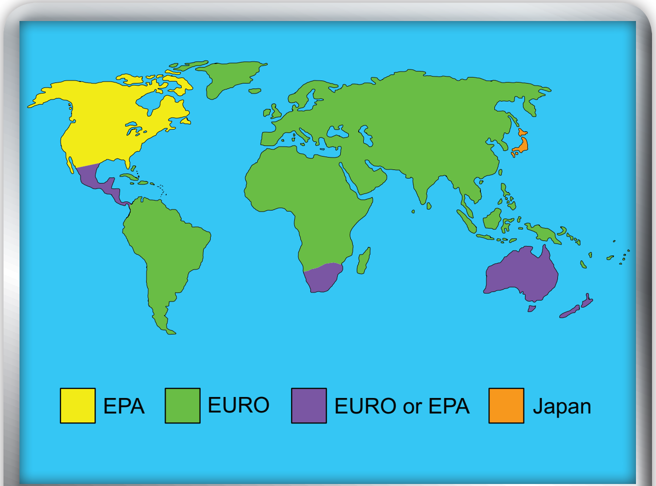

FIGURE 7-19 Two major emission legislation standards are the EPA and EURO.

regulation. The EPA has set fuel economy standards for heavy-duty vehicles to reduce carbon dioxide emissions, a major GHG gas, while the EURO standard currently limits carbon dioxide only in light-duty vehicles. While both standards vary in the regulation of light-, medium-, and heavy-duty vehicles, the EPA and EURO emission standards for off-road engines are harmonized with identical standards applying to engines used in heavy equipment, mining, locomotives, and other no-road vehicle applications.

Emission limits and testing procedures are the significant differences between EURO and EPA standards. For heavy-duty engines, EURO and EPA emissions are measured on a dynamometer, which runs the engine only through a precise sequence of changing speed and load conditions to simulate driving in urban and on-highway conditions. Heavy-duty emissions are measured in grams per horsepower per hour, while light-duty emissions are measured in grams per mile or kilometer. Engine testing only, rather than testing the entire vehicle, is necessary because a heavy-duty engine may go into a wide variety of chassis, such as a truck or bus. A more comprehensive and rigorous test procedure performed by the EPA measures emissions under a wider variety of operating conditions with slightly lower maximum emission threshold than the EURO standards.

Sometimes, within an individual country, multiple emissions standards are in force. For example, two sets of emissions standards are used in the United States—a federal standard and a state standard (California). Federal standards are set by the EPA; California standards are set by the California Air Resources Board (CARB). California standards are stricter than federal standards; this is due in part to high population density and geographical factors that contribute to poor air quality in California. California is the only US state permitted by federal law to enact vehicle emissions standards stricter than those set by the federal government. Other states can choose to adopt California's standards, but only California can be the first to surpass standards set by the federal government. The following sections will detail the development of North American emissions standards, applied to diesel vehicles sold there (such as emissions decals and useful life requirements), and specialized standards for different types of diesel-fueled vehicles.

Standards Development

Emissions standards for diesel-fueled vehicles are constantly evolving with emission reductions required by each new standard, causing the development of new technology to reduce emissions. The first emissions standards for diesels were not established until 1970. These first standards limited peak smoke opacity for heavy-duty diesels. A diesel emissions standard for oxides of nitrogen followed in 1984, and a particulate matter standard was first established in 1988.

In 1993, a new standard required that diesel fuel's typical 5–7% sulfur content be reduced to less than 1%. Reducing fuel's sulfur content helped reduce particulates and minimize corrosion and deposit formation in fuel system components. Maximum aromatic content was limited simultaneously in 1993. European manufacturers reduced sulfur content much earlier and introduced **selective catalytic reduction (SCR)** systems. SCR allowed optimization of engine power output while reducing particulate emissions close to North American standards without a fuel penalty. Because sulfur content in fuels can poison the most recent converter substrates, ultra-low-sulfur fuel was introduced for the 2007 emission systems; this dropped sulfur content. European manufacturers reduced sulfur content much earlier and introduced selective catalyst reduction (SCR) systems, an exhaust aftertreatment system for removing NO_X emissions, before using particulate filters. SCR allowed optimization of engine power output while reducing particulate emissions to levels close to North American standards without the fuel penalty in this market which is sensitive to higher fuel prices.

Minimizing the production of emissions produced in the cylinders, rather than exhaust-based reduction, was the traditional control strategy until 2007. Until that point, the problem of diesel exhaust's relatively cool temperatures and air-rich output prevented the use of conventional catalytic converter technology, which is used in automobiles. However, when **diesel particulate filters (DPFs)**, another exhaust aftertreatment system designed to filter soot particles from the exhaust, were introduced for all on-highway heavy-duty diesels, exhaust-based reduction became a major strategy for reducing diesel emissions.

Until 2009, carbon dioxide (CO_2), a by-product of normal combustion, was not a regulated emission because it is was not considered toxic to animal or plant life. However, because of its role as a GHG, public interest in reducing the production of CO_2 has turned to regulating CO_2 emissions. Rather than regulate CO_2 standards directly, which the EURO standard does only on light-duty vehicles, fuel economy standards are established to indirectly limit CO_2 production. The reasoning is that with reduced fuel consumption, less CO_2 is produced.

Fuel economy standards targeting CO_2 for 2014–2017 are the most recently scheduled emission standards. For tractor-trailer combinations, vehicle emissions standards for 2014–2017 target 7–20% reduction in CO_2 emissions over the 2010 baselines. Vocational vehicles, heavy-duty

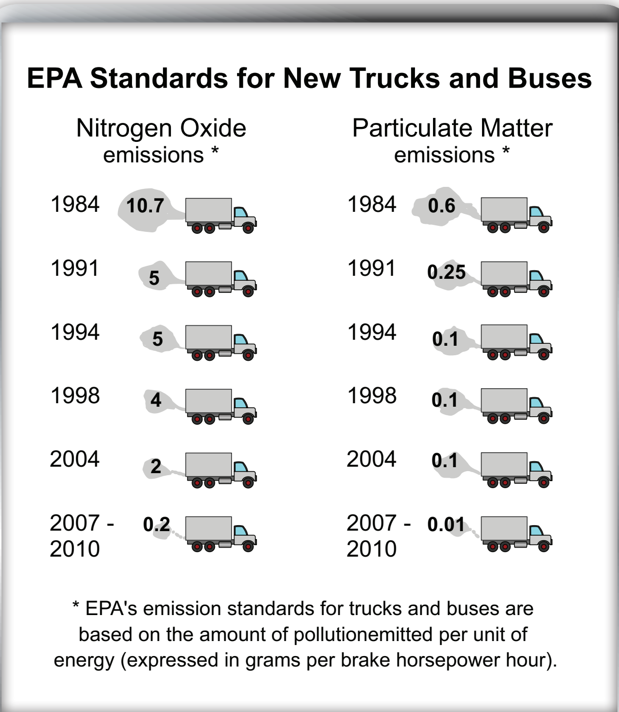

FIGURE 7-20 A comparison between old and new clean diesel technology.

pickup trucks, and vans must achieve at least a 10% reduction in CO_2.

To meet the 90% reduction in NO_X output for 2010, several SCRs were introduced **FIGURE 7-20**. The most common SCR systems on heavy-duty trucks and buses is liquid SCR. This system uses a urea molecule dissolved in water to break down NO_X. A few light- and medium-duty vehicles manufacture urea molecules in a uniquely designed catalyst.

Emissions Decals

One way that countries ensure compliance to emissions standards is by issuing decals. For example, vehicles and equipment sold for on- or off-highway use in North America must have an emissions decal affixed to the vehicle or engine **FIGURE 7-21**. The decal contains emissions information indicating to what standard the vehicle or engine is certified. The decal also includes important information for the technician about part replacement and adjustment procedures, software calibration files, and other relevant data that could affect emissions production. For example, on a diesel engine, the decal will contain information about valve lash settings, injection timing, fuel rates, and the presence of emissions system

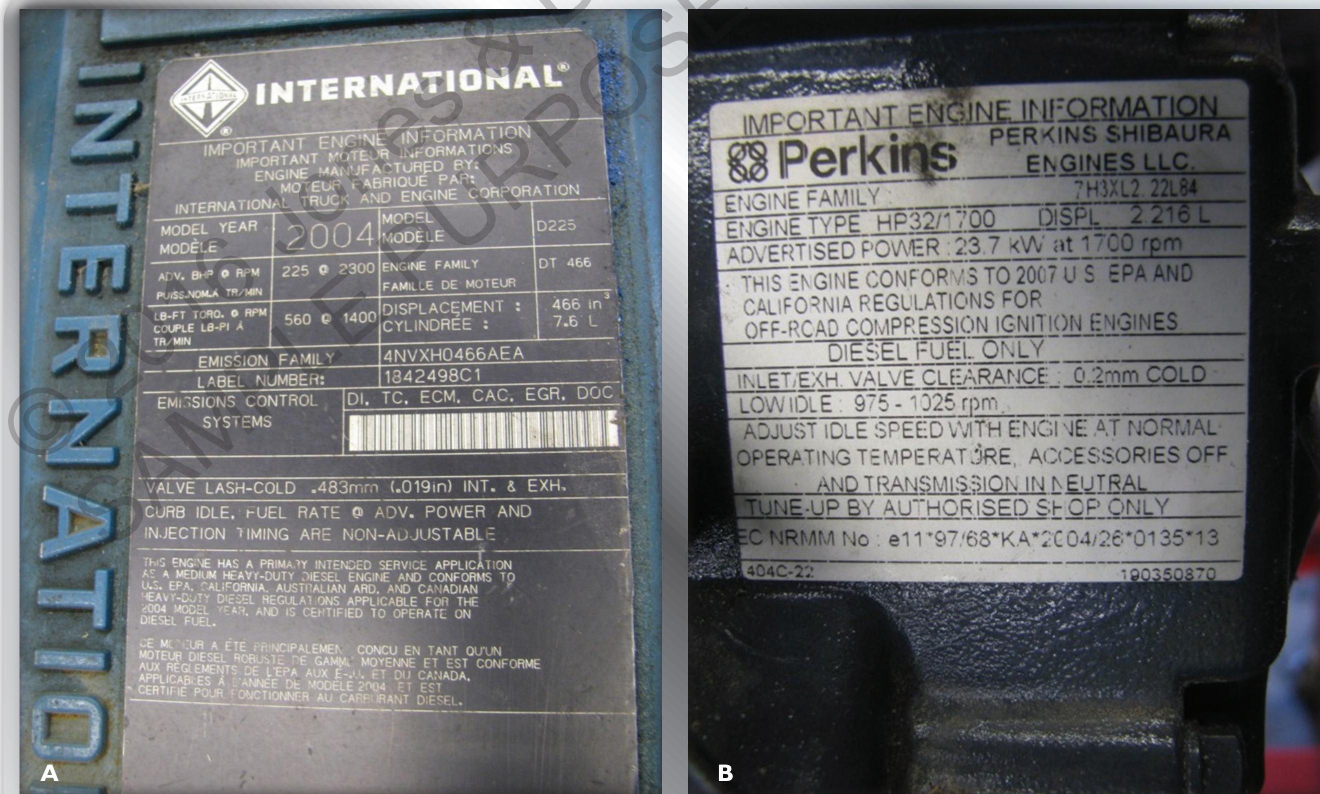

FIGURE 7-21 **A.** An emission decal from a heavy-duty diesel engine. **B.** An emission decal from an off-road diesel engine.

components. Because heavy-duty engines are certified for emissions output in grams per horsepower-hour, decals are affixed to the engine. These engines are used in a variety of chassis configurations, so measuring emissions for distance traveled is impractical. Light-duty vehicle emissions are certified by vehicle type, and emissions are measured in mass units for every mile or kilometer traveled. Emissions decals for light-duty vehicles are placed on the chassis in the vicinity of the engine compartment.

Useful Life Requirement

Starting in 2004, diesel engines must meet emissions standards over what is termed the "useful life" of the engine. The definition of "useful life" depends on the type of engine. In 2004, useful life was defined as:

- Light-Duty: 110,000 miles (177,000 km) or 10 years
- Medium-Duty: 185,000 miles (297,728 km) or 10 years
- Heavy-Duty: 435,000 miles (700,065 km) or 10 years

Useful life now includes not only regulated emissions, but CO_2 as well, so engines must be built more durably to meet these standards. Adaptive strategies must be used to compensate for deterioration factors which could push an engine out of compliance.

Heavy-Duty Standards

Emissions milestones for heavy-duty diesels were updated beginning in 1991 through to 1994; they were also updated in 1998, 2002, 2007, and 2010. This series of updates led to dramatic drops in emissions, with particulate emissions dropping 90% from 2004 to 2007 and both NO_X and particulate dropping 90% from 2007 to 2010 **FIGURE 7-22**. For example, engine manufacturer diagnostics (EMD) apply to all MY2007 and newer heavy-duty engines used in vehicles over 14,000-lb gross vehicle weight rating (GVWR). Also starting in MY2007, crankcase emission controls were required. On turbocharged engines, the crankcase could be vented to the atmosphere, but the weight of crankcase emissions was totaled with exhaust emissions. However, crankcase controls are more practical for heavy-duty diesels because deterioration of crankcase emissions with engine wear was added to the exhaust deterioration factors. Emission standards for 2010, EPA 10, heavy-duty diesels were:

- Particulate matter: 0.01 g/bhp-hr
- Oxides of nitrogen: 0.20 g/bhp-hr
- Non–Methane Hydrocarbon (NMHC): 0.14 g/bhp-hr

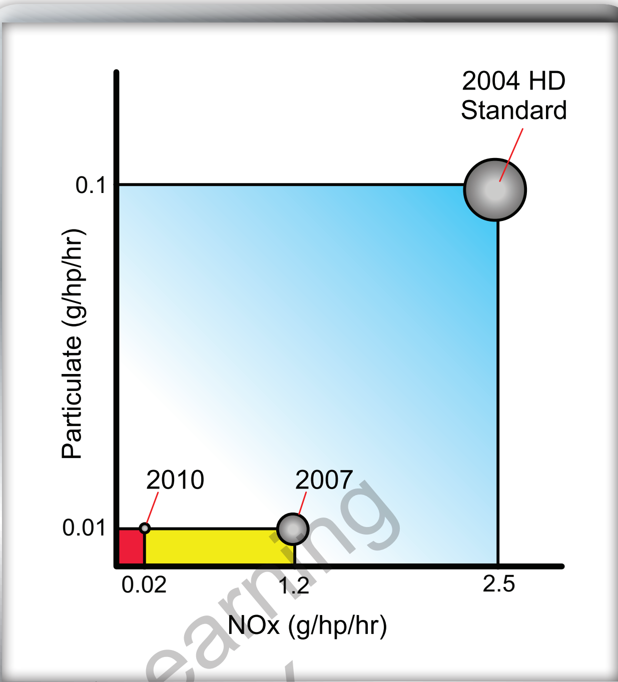

FIGURE 7-22 Heavy-duty diesel emissions standards changed dramatically between 2004 and 2010 leading to dramatic drops in emissions.

Heavy-duty on-board diagnostics (HD-OBD) are part of the newest emission legislation and use a more sophisticated set of emission standards that were introduced in 2010. A phase-in period from one engine family from a manufacturer to all engine families was required by 2013. HD-OBD standards are developed continuously by the Society of Automotive Engineers (SAE) and adopted on a yearly basis by the EPA as a legislated standard. The HD-OBD system is designed to detect potential conditions which could lead to excessive emissions **FIGURE 7-23**.

FIGURE 7-23 A display from an engine manufacturer's diagnostic software used to assist engine diagnostics and repair.

Off-Road Standards

Standards for off-road equipment are different than those for on-highway equipment **FIGURE 7-24**. These standards are referred to as **Tier 1, 2, 3, and 4 emission standards** and are harmonized worldwide with European standards. Tier 1, established in 1994 and phased in between 1996 and 2000, represents the earliest phase in increasingly stricter emission limits, with Tier 4 being the final, cleanest, standard of the four phases. These standards are based on horsepower ratings, with larger horsepower engines taking longer to implement emissions standards. Off-road diesels have emission standards applied depending on the power and year the engine is produced. Emission standards lag on-highway engines but approach the same levels by the 2015–2020 phase-in period. Tier 1 standards remained in effect until the Tier 2 and/or Tier 3 standards took effect. Tier 2 and Tier 3 standards were established in 1998 to be phased-in for various horsepower ratings between 2001 and 2008. An interim Tier 4 standards phase-in began in 2011, and a final standard began being implemented in 2013. Emission standards for off-road equipment lag on-highway engines but will eventually approach the same levels **FIGURE 7-25**.

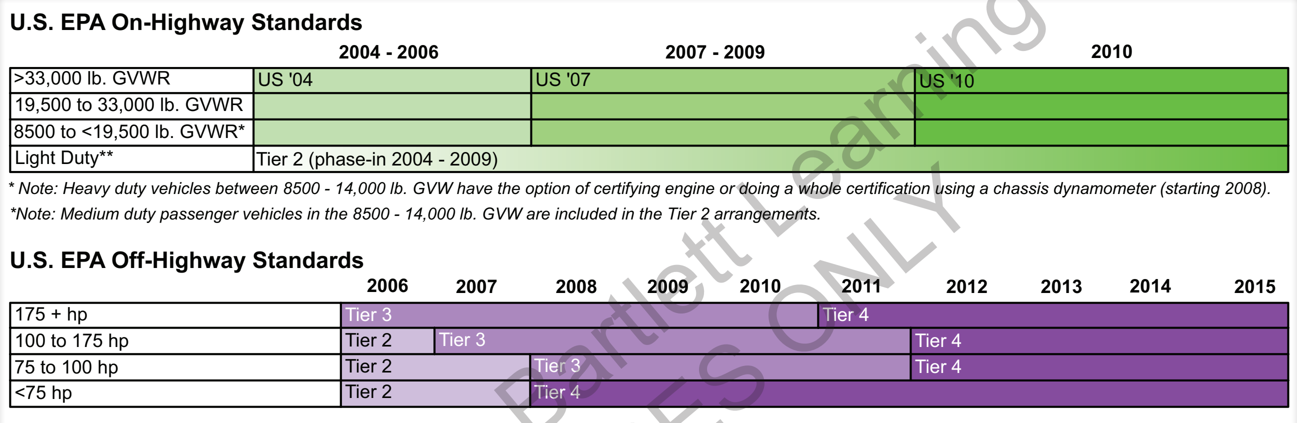

FIGURE 7-24 Tier standards for off-highway and on-highway engines.

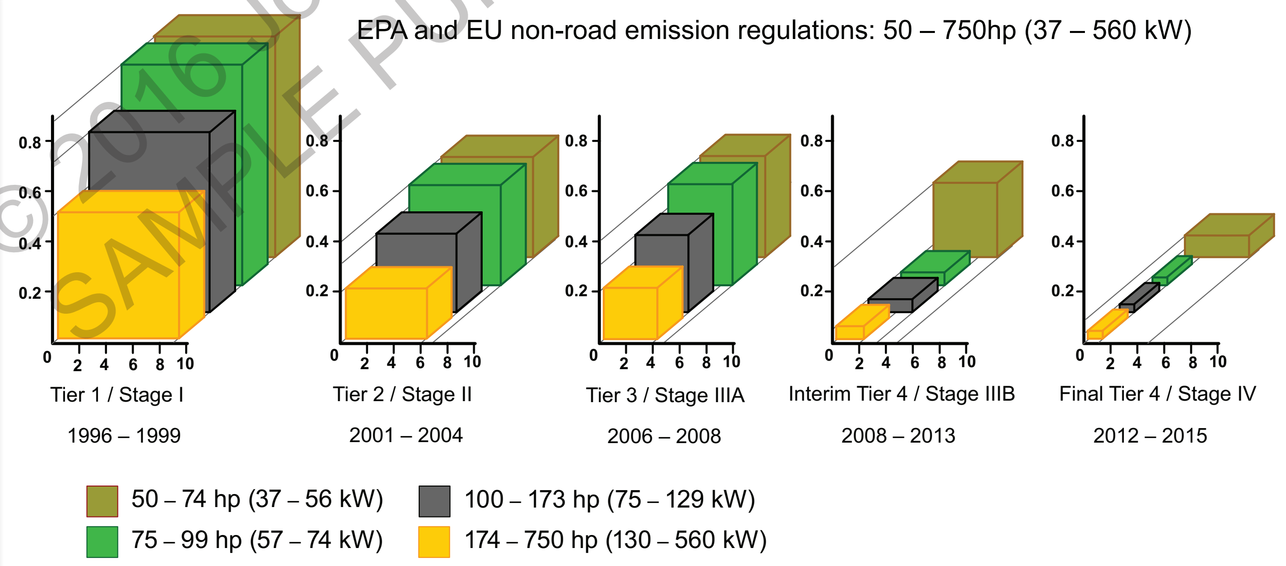

FIGURE 7-25 Emission standards for off-road diesels lag on highway standards but reduce exhaust emissions to almost insignificant levels like on-highway vehicles. Standards are based on power output and year of manufacture.

Testing Emissions

EURO and EPA emission standards measure emission outputs recorded when a dynamometer is placed on either an engine or chassis FIGURE 7-26. Chassis dynamometers measure emissions based on distance travelled by the complete vehicle. Before a vehicle or engine can be certified for use on or off highway, the test protocol, which is a precise schedule of varying speed and load conditions, must be completed to determine whether the vehicle or engine emissions remain below the maximum limits through the test cycle. The mass of emissions produced by the engine or vehicle is collected and measured during the driving cycle.

Opacity Testing

Opacity testing is the common measurement for evaluating smoke density from diesel engines. This is based on the principle of light extinction by exhaust smoke. A beam of light of a particular wavelength is passed through a sample of smoke FIGURE 7-27. Opacity, the measure of smoke density, is based on the percentage of light blocked. The darker the smoke, the higher the percentage of opacity. A measure of 75% opacity means 75% of the light is blocked, while 25% is transmitted. The procedure used by law enforcement agencies to measure smoke emissions is based on the SAE J1667 Snap Acceleration Test. This is a non-moving vehicle test which can be conducted along the roadside, in a truck stop, at a vehicle repair facility, or at inspection maintenance test facilities. The Snap Acceleration Test is intended to be used on heavy-duty trucks and buses powered by

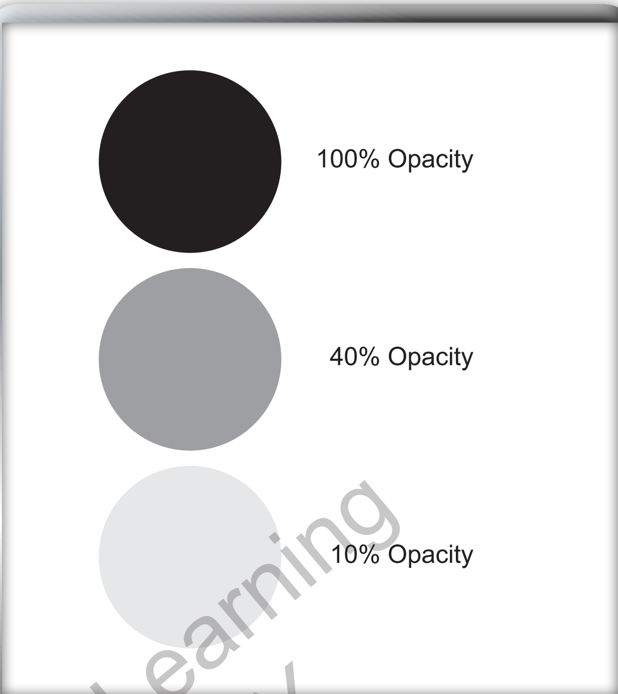

FIGURE 7-27 Diesel emissions are measured by law enforcement agencies using a variety of opacity tests. Opacity is a measure of smoke density.

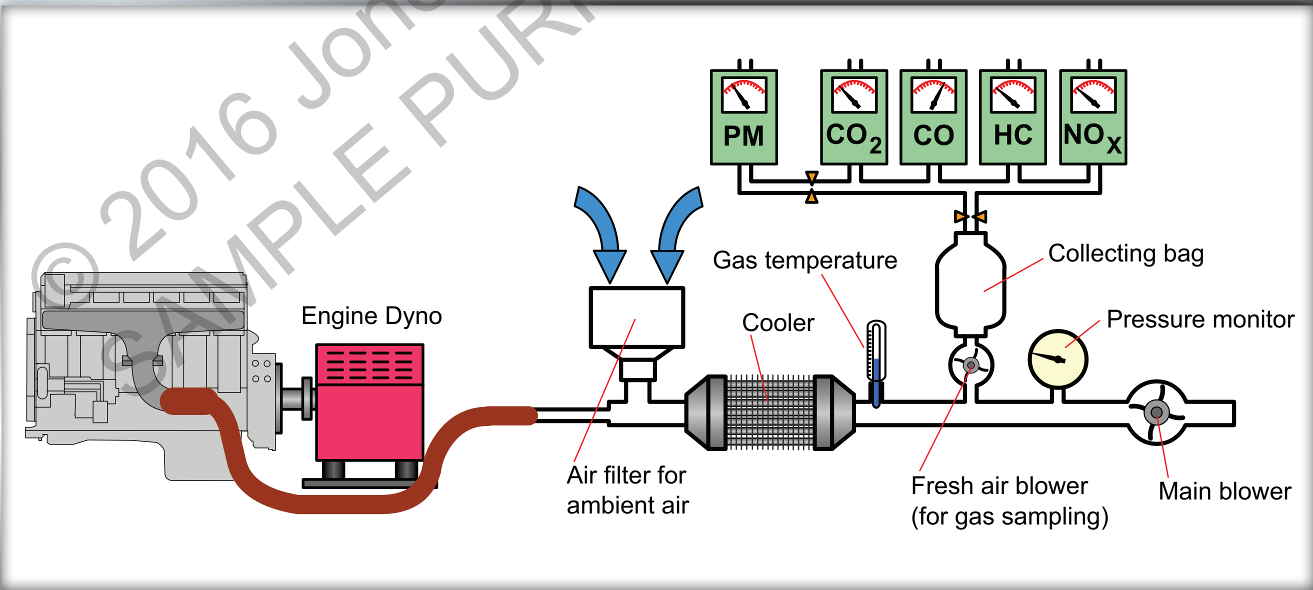

FIGURE 7-26 Heavy-duty diesel emissions are measured on a dynamometer in a test cell.

diesel engines. The procedure is intended to provide an indication of the state of maintenance and/or tampering of the engine and fuel system relative to the factors that affect exhaust smoke.

Emission Control and Monitoring Systems

Emissions standards require that manufacturers monitor and control diesel engine emissions. While certain monitoring systems are required for diesel engines, manufacturers are relatively free to determine how they will control emissions to meet standards, as long as they do meet the standards. They design systems and processes that will effectively and cost-efficiently meet the standards. This section will detail several common emission monitoring and control systems.

Diesel Engine Emission Controls

Diesel emissions can be controlled in a variety of ways. Common emissions controls will be discussed in detail in other chapters in this volume. Some examples of engine technology required to meet the 2007–2010 Engine Manufacturers Diagnostics or EPA-07 standards include:

- Common rail injection with injection rate shaping
- Unit injection with injection rate shaping capabilities
- Low- and high-pressure cooled exhaust gas recirculation (EGR)
- Variable geometry turbochargers (VGT's)
- Charge air cooling (CAC)
- Two-way oxidation converters (DOCs)
- Diesel particulate filters (PTOx Particulate Trap Oxidizing Converter)
- Selective catalyst reduction (SCR)
- NO_x traps and NO_x adsorbers
- Exhaust gas sensors—wide range oxygen and NO_x

Diesel Engine Emission Monitors

Major engine systems which influence the production of emissions are monitored by the EMD or HD-OBD systems. These monitors are essentially diagnostic strategies used to determine if an emission system is functioning correctly. As detailed earlier, EMD, a pre HD-OBD emission monitoring system, and HD-OBD are used on heavy-duty diesels.

Engine Manufacturer Diagnostics

EMD systems are required in all MY2007 and newer heavy-duty engines used in vehicles over 14,000-lb GVWR. EMD systems check the functioning of the fuel delivery system, exhaust gas recirculation system, particulate filter, and emissions-related circuit continuity and rationality for the engine control module (ECM) inputs and outputs. To detect emission system malfunctions, the diagnostic manager, a piece of software installed in the ECM, checks to detect any condition which could potentially cause emissions to exceed maximum threshold limits. Major **emission monitors** in EMD systems are listed in TABLE 7-3.

A diagnostic data link connector located below the dash and to the left of the steering column has six or nine pins and is used to access SAE fault codes from

TABLE 7-3: Engine Manufacturer Diagnostics

Engine System	System Analysis
Fuel system	• Fuel pressure • Fuel-injection quantity • Multiple fuel-injection event performance • Fuel-injection timing • Exhaust gas sensor monitoring (NO_X and O_2 only)
Misfire monitoring	• Must detect misfire occurring continuously in one or more cylinders during idle.
EGR system	• EGR flow rate • EGR response rate • EGR cooling system • Mass air flow rate
Boost-pressure control systems	• Under- and over-boost malfunctions • Wastegate operation • Slow turbocharger response • Charge air cooler efficiency
Glow plugs	• On-time • Glow plugs enabled • Intake heater operation
Diesel exhaust aftertreatment systems (Monitor requires potential faults to be detected before emissions exceed standards for any of the following systems)	• Oxidation catalyst • Lean NO_X catalyst • SCR catalyst • NO_X trap • PM trap

on-highway trucks and buses. The fastest and most modern communication protocol between service tools and vehicle networks is J-1939. Data is transmitted in both directions between the vehicle and service tool using a nine-pin data link connector.

Heavy-Duty On-Board Diagnostics

HD-OBD emissions standards for heavy-duty diesel-fueled engines began in 2010. HD-OBD has many specific standards governing everything from the style, type, and location of electrical and diagnostic connections, to communication standards, emissions thresholds, fault code structure and emission monitoring strategies. The **malfunction indicator lamp (MIL)** joined other lamps on the instrument panels of heavy-duty vehicles to meet HD-OBD requirements FIGURE 7-28. Whenever an emission-related fault exceeds a threshold level, the MIL is required to switch on to alert the driver of a potential fault FIGURE 7-29. More about HD-OBD system operation is found in other chapters in this volume. HD-OBD monitors include the features listed in TABLE 7-4.

Comprehensive Component Monitoring (CCM)

The CCM is part of the HD-OBD system. Its function is to monitor electrical circuits operating powertrain components that:

- Can cause a measurable emissions increase during any reasonable driving conditions
- Are used for other OBD monitors
- Are required to monitor input components for circuit and rationality faults
- Are required to monitor output components for functional faults

The CCM is not tied to emission thresholds. Any electrical problem related to emission systems will cause the MIL to illuminate.

FIGURE 7-28 The MIL, a requirement under HD-OBD, switches on to alert the driver of a potential fault.

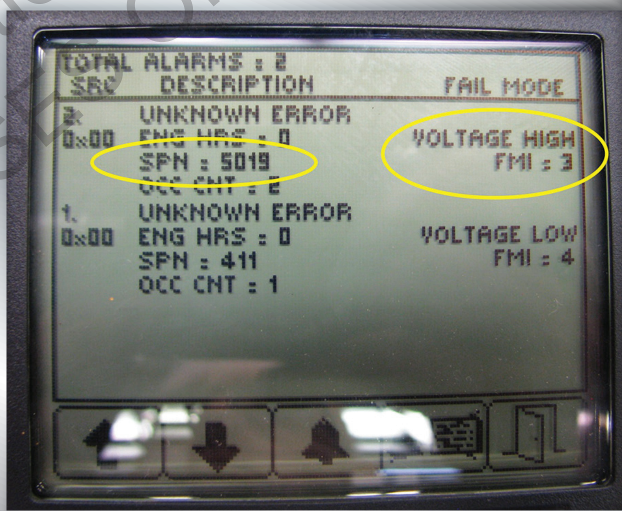

FIGURE 7-29 On-board diagnostic systems provide a wealth of information to technicians, which is used to diagnose emission-related faults.

TABLE 7-4: On-Board Diagnostics (OBD)

Engine System	System Analysis
NMHC	
Catalyst conversion monitors	• Diesel oxidation catalyst • Diesel oxidation catalyst efficiency monitor • DPF regeneration assistance monitor • Diesel oxidation catalyst SCR assistance monitor
NO_X converting catalyst monitoring	• Selective catalyst reduction catalyst • Efficiency monitor • Selective catalyst reduction feedback • Control monitors • Selective catalyst reduction tank level
Misfire monitor	• Similar in function to EMD but does not set the MIL
Fuel system monitor	• Fuel rail pressure sensor circuit • Fuel rail pressure sensor range • Injector code missing or invalid • Fuel system injection pressure control • Fuel rail pressure monitors • Injection timing • Injection quantity • Zero fuel calibration • Feedback controls
Exhaust gas sensor monitor	• Air-fuel ratio sensors: tailpipe NO_X • O_2 sensor control module
EGR system monitor	• EGR rate system monitor • EGR cooler/EGR cooler bypass monitor • EGR system slow response • EGR closed-loop control limits monitor • Mass airflow closed-loop control limits monitor
Boost-pressure control system monitor	• Intrusive turbo position and response monitoring • Intrusive wastegate monitoring • Functional overboost monitoring • Functional underboost monitoring • Threshold underboost monitoring • Charge air cooler monitoring
Particulate filter monitor	• DPF filter efficiency and missing substrate monitors • DPF frequent regeneration monitor • DPF incomplete regeneration monitor • DPF feedback control monitors • DPF restriction monitor
Crankcase ventilation pressure	• Crankcase pressure is monitored but faults do not set the MIL.
Cold start and warm-up monitoring	
Glow plug resistance monitor	• Glow plugs enabled • Glow plug resistance • Intake heater operation
Comprehensive component monitor (CCM)	• All circuit monitoring for components supporting other monitors and powertrain control operation are the same as EMD.

Wrap-up

Ready for Review

- Emissions legislation requiring reduction of vehicle emissions drives most changes in engine technology.
- Emissions from modern diesel engines are so low that only test instruments with the highest sensitivity can measure their exhaust emissions.
- Diesel engines produce lower emissions per ton of weight carried than gasoline engines.
- Noxious emissions from diesels comprise 0.2–0.3% of untreated exhaust compared to as much as 3% from spark-ignition, gasoline-fueled engines.
- Diesel-powered vehicles travel farther carrying heavier loads while using less fuel than spark-ignition engines.
- If motor vehicles produced no NO_X emissions, photochemical smog would not exist.
- Diesel engines produce more NO_X and particulate emissions than spark-ignition engines, but they produce lower levels of hydrocarbons and carbon monoxide emissions.
- Most diesel exhaust particulate emissions is composed of black carbon or soot.
- NO_X formation is a major emission problem plaguing diesel engines due to their higher compression ratios, cylinder pressures, and temperatures.
- Diesel fuel does not produce significant evaporative emissions, and diesel fuel systems are not regulated for evaporative emissions.
- Crankcase emissions are classified as particulates because they contain oil droplets.

- Excess air, higher combustion temperatures, and pressure in diesel engines means lower amounts of hydrocarbons and carbon monoxide emissions are produced.
- Diesel fuel properties and the short time fuel has to mix with air and burn contribute to higher amounts of particulate formed in engine cylinders.
- Hard-to-burn fuel molecules called aromatic molecules produce the distinctive odor of diesel exhaust.
- Reducing sulfur content in fuel reduces particulate formation.
- Finer atomization of fuel reduces particulate formation.
- Carbon dioxide emissions constitute a greenhouse gas (GHG) and as such are regulated indirectly through fuel economy standards.
- The Environmental Protection Agency (EPA) and the EURO 1–6 set the emission standards for most of the world.
- The use of ultra-low-sulfur diesel fuel has enabled the use of exhaust aftertreatment systems such as Selective Catalyst Reduction (SR) systems and particulate filters.
- Emission decals indicating compliance with emission standards are required by all on- and off-road diesel engines.
- Heavy-duty diesels have a durability requirement to remain emission compliant and not exceed certification limits for 10 years or 435,000 miles (700,065 km).
- EPA and EURO (EEA) emission standards are harmonized for off-road diesel engines.
- Exhaust opacity is a measurement of exhaust smoke density. Higher opacity means the smoke is darker.
- On-board diagnostic system monitor the engine operation to detect the presence of any fault which could potentially cause increased emissions.
- The malfunction indicator lamp (MIL) illuminates whenever an emission-related fault is detected by the on-board diagnostic system.

Vocabulary Builder

blow-by The leakage of air past the piston rings into the crankcase.

carbon dioxide (CO_2) A harmless, colorless, odorless gas which is a by-product of combustion. It is also classified as a greenhouse gas (GHG).

carbon monoxide (CO) A regulated poisonous gas emission which is odorless, colorless, and tasteless. It is a by-product of incomplete combustion.

crevice volume The area above the top compression ring between the piston crown and the cylinder wall.

diesel particulate filter (DPF) A device installed in the exhaust system to filter out black carbon soot and other particulate from the exhaust stream.

emission monitor A diagnostic strategy used by the engine control module to evaluate whether emission-related systems are functioning correctly.

engine manufacturer diagnostics (EMD) A pre HD-OBD standard for an on-board diagnostic system used to detect emission related faults.

greenhouse gas (GHG) A gas classified as contributing to global warming because it traps heat in the atmosphere.

heavy-duty on-board diagnostics (HD-OBD) The most recent EPA standard for detecting emission-related faults in heavy-duty vehicles.

hydrocarbon (HC) A molecule, often a fuel, composed of hydrogen and carbon atoms.

malfunction indicator lamp (MIL) A dash-mounted warning light used to alert the driver when an emission-related fault is detected by the on-board diagnostic system.

opacity A measure of the percentage of light blocked by exhaust smoke which is used to evaluate exhaust gas density.

oxides of nitrogen (NO_X) A category of noxious emissions made up of oxygen and nitrogen.

ozone A noxious gas molecule composed of three oxygen molecules.

particulate matter (PM) A category of noxious emissions composed of a combination of very small solid or liquid particles.

photochemical smog A type of air pollution that gives the atmosphere a hazy, reddish-brown color.

selective catalyst reduction (SCR) An exhaust aftertreatment system designed to break down NO_X gases in the exhaust system into harmless substances.

Tier 1, 2, 3, and 4 emission standards Consecutive phases of increasingly cleaner off-road emission standards.

volatile organic compound (VOC) Any carbon-containing molecule that is highly reactive.

Review Questions

1. Categories of noxious emissions are referred to as regulated emissions because they:
   - **a.** are greenhouse gases.
   - **b.** fail an Ames test.
   - **c.** are regulated by a legislative standard.
   - **d.** each have an emission monitor to detect the production of a noxious gas.
2. Ultra-low-sulfur fuel has been used since 2007 because:
   - **a.** it produces fewer emissions.
   - **b.** high-sulfur diesel is more costly and difficult to produce.
   - **c.** it provides increased power and improves fuel economy.
   - **d.** it enables the use of diesel catalyst in the exhaust system.
3. The highest NO_X levels are produced during which of the following conditions?
   - **a.** High combustion temperatures, low compression ratios
   - **b.** Low combustion temperatures, high compression ratios
   - **c.** High combustion temperatures, high compression ratios
   - **d.** Low combustion temperatures, low compression ratios
4. In which of the following categories of emissions do crankcase emissions belong?
   - **a.** Hydrocarbons
   - **b.** NO_X
   - **c.** Particulates
   - **d.** Carbon monoxide
5. Ultrafine particulate is the most hazardous emission because it:
   - **a.** makes up the greatest mass of all particulate categories.
   - **b.** quickly settles and falls to ground level.
   - **c.** penetrates lung tissue very deeply.
   - **d.** is a visibility hazard.
6. The useful life requirement for a heavy-duty diesel is:
   - **a.** 110,000 miles (177,000 km) 10 years.
   - **b.** 185,000 miles (297,728 km) or 10 years.
   - **c.** 435,000 miles (700,065 km) or 10 years.
   - **d.** 100,000 miles (160,000 km) or 5 years.
7. The 2007 emission-monitoring system responsible for detecting potential faults which could cause heavy-duty diesel emissions to rise above maximum legislated levels is known as:
   - **a.** engine manufacturer diagnostics (EMD).
   - **b.** heavy-duty on-board diagnostics (HD-OBD).
   - **c.** comprehensive component monitor (CCM).
   - **d.** engine control module (ECM).
8. Diesel engines do not use evaporative emissions controls because:
   - **a.** fuel tanks are sealed and not vented to the atmosphere.
   - **b.** vapors from diesel fuel are not toxic.
   - **c.** diesel fuel has low volatility and exerts very low vapor pressure.
   - **d.** there are fewer diesel-powered vehicles on the road and emissions are of little consequence.

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SAMPLE CHAPTER
DIESEL ENGINE EMISSIONS

Fundamentals of
Medium-Heavy Duty Diesel Engines

Gus Wright

Based on the *2014 National Automotive Technicians Education Foundation (NATEF) Medium/Heavy Truck Tasks Lists* and *ASE Certification Test Series* for truck and bus specialists, ***Fundamentals of Medium-Heavy Duty Diesel Engines*** is designed to address these and other international training standards. The text offers comprehensive coverage of every NATEF task with clarity and precision in a concise format that ensures student comprehension and encourages critical thinking.

Fundamentals of Medium-Heavy Duty Diesel Engines describes safe and effective diagnostic, repair, and maintenance procedures for today's medium and heavy vehicle diesel engines, including the most current, relevant, and practical coverage of:

- HD-OBD emission diagnostics
- Common rail injection systems
- Exhaust after treatment systems, including diesel particulate filters, selective catalyst reduction (SCR), and lean NOx traps (LNT)
- Variable geometry and series turbocharging
- Exhaust gas recirculation
- Engine braking
- Major engine OEM-specific coverage of fuel, air induction, and diagnostic systems
- Electronic signal processing and sensor technology

ADDITIONAL FEATURES INCLUDE:

- Up-to-date NATEF coverage
- Support of ASE certification test preparation for diesel engine, medium-heavy truck, and bus test series
- A clear, accessible writing style
- Reinforcement of concepts learned
- Application to real-world practice
- A wealth of photographs, illustrations, and step-by-step explanations with visual summaries

ALSO AVAILABLE
The ***CDX Medium/Heavy Truck, 2014 NATEF Edition*** online learning system features:

- Complete coverage of the *2014 National Automotive Technicians Education Foundation (NATEF) Medium/Heavy Truck Tasks Lists*
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