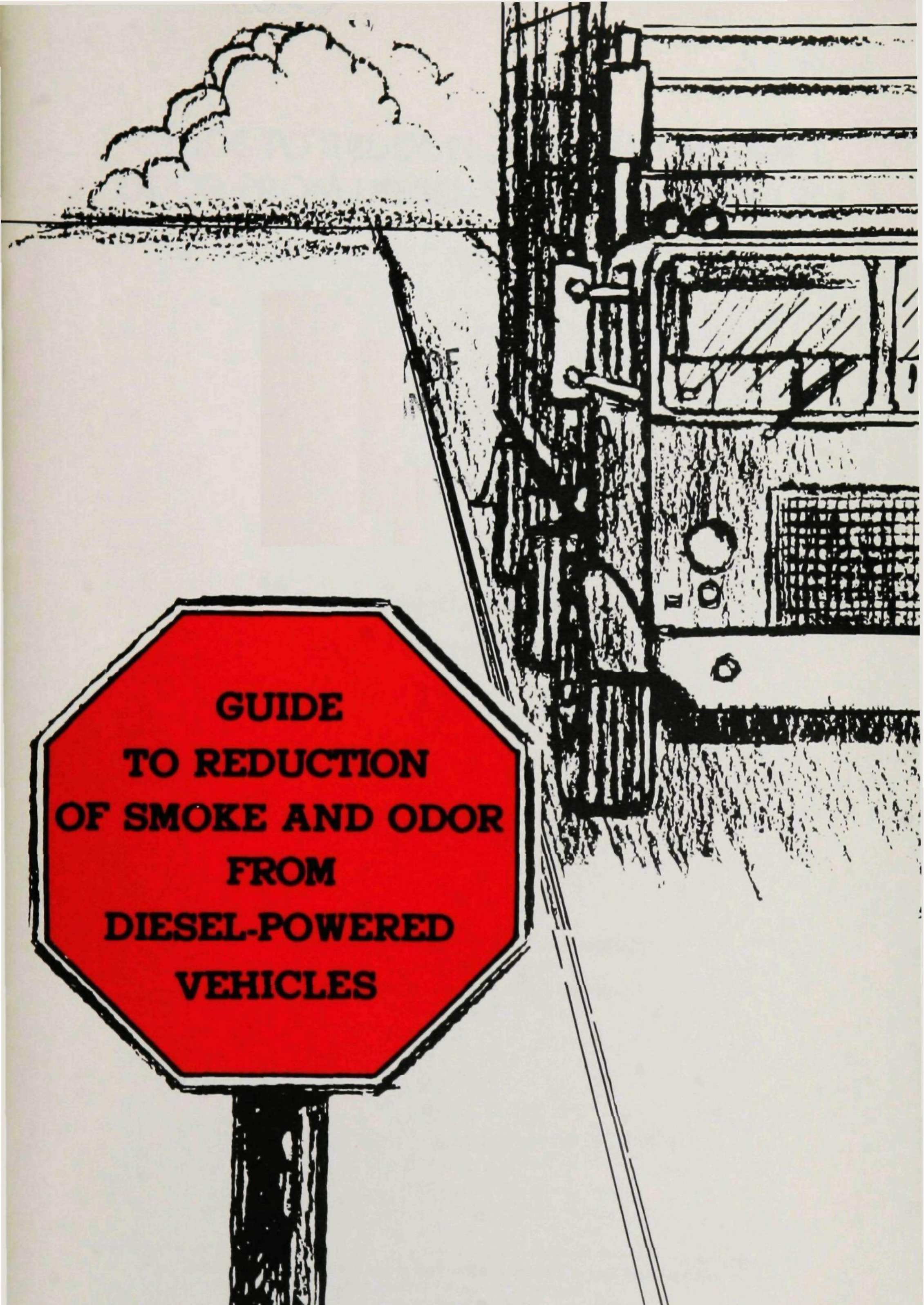

U. S. ENVIRONMENTAL PROTECTION AGENCY

GUIDE TO REDUCTION OF SMOKE AND ODOR FROM DIESEL-POWERED VEHICLES

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and
Office of Air Programs

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GUIDE TO REDUCTION OF SMOKE AND ODOR FROM DIESEL-POWERED VEHICLES

INTRODUCTION

In our air pollution-conscious country, the public is aware of all pollution from motor vehicles especially that which they can see or smell. Less than 1 percent of vehicles registered in this country are diesel-powered and less than 5 percent of the fuel consumed by highway vehicles is used by diesel-powered vehicles. Still, millions of Americans each year have some contact with diesel vehicles. Because such a large number of peopie are exposed to the smell and smoke of diesel exhausts, adverse reactions or complaints have reached significant proportions.

State and local governments at all levels continue to establish and enforce regulations limiting smoke from motor vehicles, particularly the diesel. These regulations indicate that this country will not tolerate excessive smoke from diesel-powered vehicles.

As of January 1970, engine manufacturers must certify that all new diesel engines installed in highway vehicles of more than 6,000 pounds gross vehicle weight meet Federal smoke standards as given in the *Federal Register* of June 4, 1968. Although no Federal standard for controlling diesel odors exists now, such standards will probably be set up once suitable ways of measuring odors are available. One state has established a standard for diesel odors that is based on the subjective reactions of a panel of ten people who are exposed to the exhaust fumes near the point of discharge. The method will have to be improved before odor regulations based on it can be enforced.

The purpose of this *Guide* is to help reduce the amount of smoke and odor produced by diesel-powered vehicles. This reduction can only be accomplished by a team approach in which everybody on the team is important. From the selection of the power package and fuel through maintenance and driver performance, each person must do his part if smoke and odor emissions are to be reduced.

The following pages contain practical information and recommendations that can help in this task. These guidelines are the result of a detailed study of technical literature and reports dealing with diesel smoke and odor and of interviews with engine and vehicle manufacturers, fuel and additive suppliers, fleet operators, and enforcement agencies. This *Guide* discusses the general characteristics of diesels, ways to reduce smoke, and ways to reduce odor, each in separate sections.

GENERAL CHARACTERISTICS OF DIESEL ENGINES

Regardless of design, all diesel engines operate on the compression-ignition principle in which air is compressed and liquid fuel is injected under high pressure. The high-temperature mixture ignites spontaneously, resulting in power output from the engine. Both two-stroke (one power stroke per cylinder for each engine revolution) and four-stroke (one power stroke per cylinder for every two revolutions) are used. Diesel engines are either naturally aspirated or turbocharged. In the first, air is taken in from the atmosphere without external assistance. In turbocharged engines, exhaust energy is used to power a turbine air compressor that increases the amount of air inducted per engine stroke. In naturally aspirated engines, the amount of air taken in depends on engine speed because there is no throttle in the air inlet system in the diesel as there is in the gasoline engine.

The amount of fuel injected determines the power output. During idle, very little fuel is needed, but at high speeds (high power output), of course, more fuel is needed. A convenient way to think of the diesel is in terms of the air-fuel ratio:

$$\text{air-fuel ratio} = \frac{\text{weight of air available for combustion}}{\text{weight of fuel available for combustion}}$$

An air-fuel ratio of about 100:1 is present during idle, but at high power output, the ratio is closer to 20:1. When the air-fuel ratio is 15:1, the chemically correct amounts of air and fuel are present for complete combustion. Since the ratios in diesel engines are greater than this, the diesel operates *air*-rich. Generally speaking, if the fuel supplied to the cylinders for combustion were kept constant, an increase in air would result in decreased smoke production. If the air supplied to the cylinders for combustion were kept constant, an increase in fuel would produce an increase in smoke. In many diesel engines, then, the amount of smoke produced is directly related to the air-fuel ratio.

Sources of air pollution are either stationary (industrial or domestic) or mobile (automotive). Mobile sources such as cars, trucks, and buses produce about half of all the pollutants emitted into the atmosphere. In terms of the actual tons of air pollutants produced by mobile sources, the diesel output is relatively minor, but the smoke and odor from diesels are much greater than from other types of surface transportation.

Figure 1 gives a general comparison of the various pollutants produced by gasoline- and diesel-powered vehicles. The diesel emits less carbon monoxide (CO) and hydrocarbons (HC) than the gasoline engine. The nitrogen oxides (NO_X) emitted are about the same for the two types of vehicles. Smoke and odor emissions, however, are much greater from the diesel than from the gasoline engine. Some diesels may produce smoke when operated with an air-fuel ratio less than 25:1. Odor production from diesels, however, does not seem to be directly related to the air-fuel ratio.

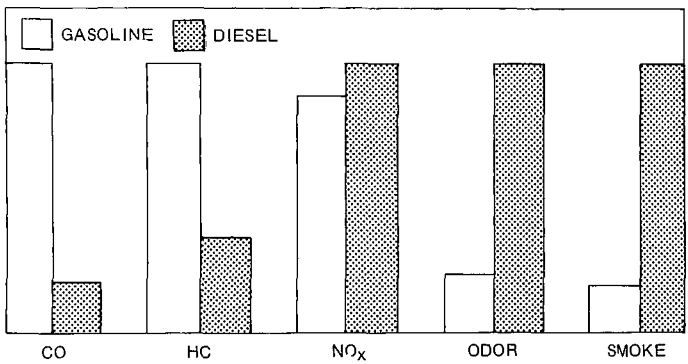


Figure 1. Relative levels of pollutants emitted by gasoline- and diesel-powered vehicles.

TYPES AND CAUSES OF SMOKE

Smoke is usually the result of incomplete combustion. The three types of smoke and their composition are:

1. *Dark, black,* or *hot* smoke, which consists of unburned carbon particles (soot) and is usually associated with operating speeds, loads, and temperatures.
2. *Blue* smoke, which contains unburned engine oil that reaches the combustion chamber because of worn piston rings, cylinder liners, and/or valve guides. Some partially burned fuel may also be present in this type of smoke.
3. *White* or *cold* smoke, which is made up of droplets of unburned liquid fuel and is usually associated with the startup or idle of some engines.

Black smoke, the most common type of exhaust smoke, is the main concern of this *Guide.* Black smoke is always a result of incomplete combustion. White (cold) smoke can be reduced by reducing idle time, especially after initial startup, and by using fuel that has the right ignition properties for the climate or prevailing temperature. Cold smoke can also be reduced by parking the vehicle indoors or by using engine-block heaters. Blue smoke can usually be eliminated by engine maintenance or overhaul.

TYPES AND CAUSES OF ODOR

The chemical compounds in the exhaust that cause odor have not yet been identified. Diesel odors are even hard to describe. In fact, observers have to be trained for the job of judging kinds and amounts of odors because no instruments now available can measure odor. Just as the methods of judging and describing odors are far from satisfactory, the exact cause of odors are not well known. It is known, however, that the design of a vehicle can change the intensity of an odor and thus the detection of that odor by the public.

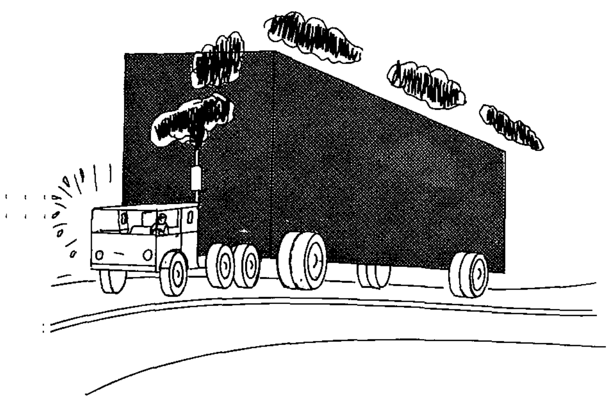
GUIDELINES FOR REDUCING SMOKE

The guidelines that follow are presented under the headings of engine size and application, derating, maintenance, driver effects, fuel, and control methods, and are given to help the purchaser, mechanic, and driver of diesel-powered vehicles reduce smoke emissions as much as possible.

EFFECTS OF ENGINE SIZE AND USE ON SMOKE

The choice of what diesel engine to use in a truck or bus is often more art than science, even though engine manufacturers provide excellent guides for choosing engines for specific applications. Unfortunately, the manufacturer's recommendations are sometimes used just as rough guidelines, especially when vehicles are bought through competitive bidding. In order to save $100 to $500 on a vehicle costing $20,000 to $30,000, a buyer sometimes chooses a slightly smaller engine than the one needed to do the job. A buyer should always remember that:

Diesel-powered vehicles generally need and use all the power available. Gasoline-powered passenger cars, on the other hand, generally use only a fraction of the power available.



Too small an engine often has no power margin for the requirements of higher route speeds and greater loads, or for the results of deteriorations in engine performance. In order to get more power out of an engine when he needs it, a driver often overfuels. But since overfueling causes more exhaust smoke, an operator should never adjust the fuel delivery beyond the specifications given by the manufacturer. As commonly believed, power and smoke are usually related. As shown in Figure 2, however, a small increase in power,

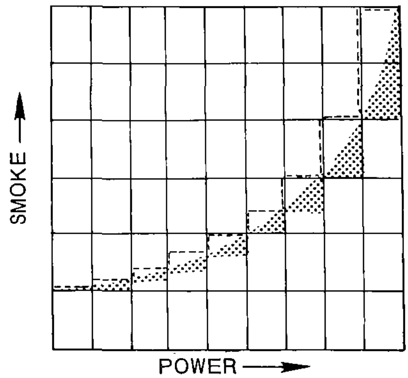


Figure 2. Smoke versus power output of typical naturally aspirated engines.

especially at the upper range, produces a larger increase in smoke.

Depending on the smoke characteristics of an engine, an increase in power or the amount of overload can not only produce too much smoke but can possibly damage the engine. If the engine is marginal in size or is too small, it will often be fully loaded, with the net effect that more smoke is produced.

The elevation at which a vehicle must operate is an important consideration in choosing an engine, especially from the standpoint of smoke production. Some types of engines are fairly insensitive to altitude but others produce much more smoke at higher altitudes. Figure 3 shows the general effect of

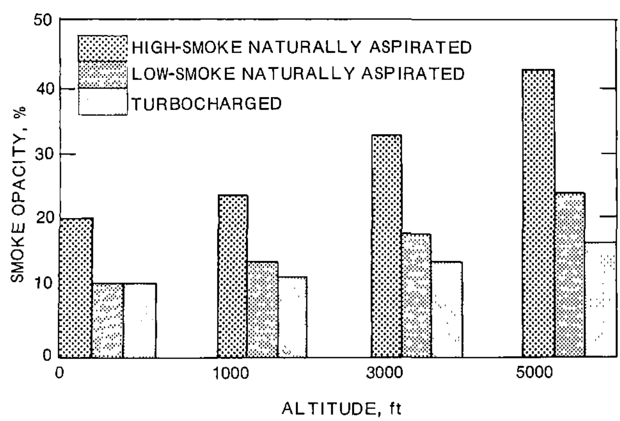


Figure 3. General effect of altitude on hot smoke pro duction by diesel engines.

altitude on smoke production by naturally aspirated and turbocharged engines. As the figure indicates, a naturally aspirated engine that produces very little smoke at sea level may produce only a little more smoke at 5,000 feet. Another type of engine that produces smoke of about 20 percent opacity at or near sea level may produce smoke of 40 percent opacity at 5,000 feet. The turbocharged engine is generally considered to be less sensitive to altitude than many naturally aspirated engines.

Naturally aspirated and turbocharged engines with known low-smoke characteristics are the best diesel engines for operation at higher altitudes. If a vehicle is consistently operated at a high altitude and is used in extensive stop-and-go service, a low-smoke, naturally aspirated engine, adjusted for the altitude, should be used. Such an engine will probably produce less smoke overall than a turbocharged engine, which has a greater smoke tendency during initial acceleration. On the other hand, if a vehicle is to be used for cruise-type operations, a turbocharged engine should be used because it will produce less smoke at the same altitude than the naturally aspirated engine.

ENGINE DERATING CAN HELP REDUCE SMOKE

Engine derating is one of the most widely used methods for cutting down the production of visible smoke. Derating, which is the reduction of the available power or rating of an engine, is usually done by reducing the amount of fuel injected per stroke throughout the operating speed range of the engine. Engine derating generally involves injector replacement, fuel pump calibration, reduction of fuel delivery pressure, governor setting, or a combination of these. If done in the field, this type of servicing should be accomplished at an authorized service center.

Because of design characteristics, some engines produce more smoke with an increase in engine speed, especially at the higher end of the speed range. The reverse is true for other engines. Engine derating ordinarily reduces smoke output over the whole operating speed range, especially for engines with moderate- to high-smoke tendencies (Figure 4). For some types of engines, a reduction in the maximum recommended or rated speed will result in less smoke, largely because these engines produce more smoke when they are operated near the upper end of their speed range. Derating by reducing the maximum recommended speed simply gets rid of the smoke that would otherwise be produced at higher engine speeds. Derating by this method does not change the power available in the rest of the operating speed range.

Fleet operators have found that it is a good practice to buy vehicles with derated engines because they realize better fuel economy and extended engine life, with less maintenance. The slight increase in initial cost is more than compensated for on a strict economic basis. Adding a turbocharger to certain engines

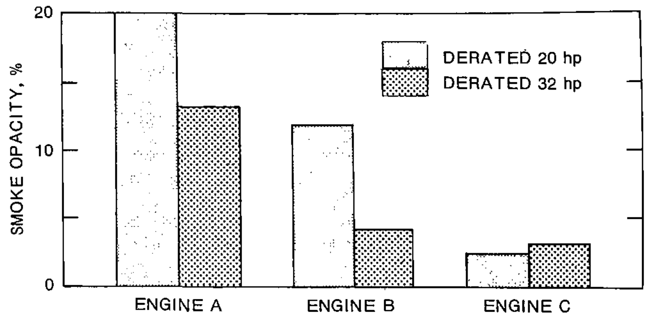
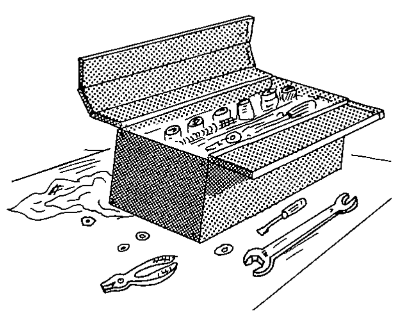


Figure 4. Effect of engine derating on exhaust smoke from three moderate- to high-smoke engines.

makes it possible to get the same power from those engines but with improved fuel economy and less smoke. When turbochargers are added solely to increase power output, however, smoke is not reduced.

FUEL SYSTEM MAINTENANCE AFFECTS SMOKE



One of the advantages of the automotive diesel engine is its ability to operate at higher horsepower levels for long periods of time with little or no attention. Maintenance for the diesel usually involves the fuel injection or air induction systems (covered in the next section). The condition of the fuel injection system has a definite effect on engine smoke output. The fuel injection system is probably abused and misused more than any other part of a diesel engine. The fuel system includes the tank, delivery and return lines, primary and secondary fuel filters, transfer and injection pumps, and injectors. The injection system on engines with the "unit type" injector includes a mechanical assembly to actuate the injector. An injector often operates satisfactorily for well over 100,000 miles.

Injectors atomize liquid fuel by forcing it under high pressure through small holes at a certain time in the cycle. Whatever happens during operation to change the spray characteristics, or the start, duration, or end of injection may affect engine performance and the amount of visible smoke produced. Sticky or worn injectors that do not seal tightly, have lost their preload due to wear, or otherwise do not permit clean injection with a full spray pattern can increase smoke, odor, lubricating oil contamination, and engine wear. Carbon deposits on the injector may also distort the spray pattern and cause more smoke.

In order to minimize odor and smoke, some maintenance departments have a rigorous program for periodic injector replacement and repair. Bench test equipment is used to balance the flow and match injector delivery rates, spray patterns, and penetration. Bench test equipment is also used to check flow and to calibrate injection pumps on a periodic basis. The net effect is to make sure that fuel is injected into each cylinder in a similar way. The additional cost of maintenance has paid dividends in longer engine life, lower fuel consumption, and reduced smoke and odor.

Some unit injection systems have a number of wear points in the mechanism that actuates the injector. These systems operate from the camshaft of the engine, and, as wear develops, the start of injection takes place later than desired. The fuel is not delivered into the combustion chamber at the optimum time for good combustion. Late injection generally results in dense smoke. For some engines, this problem is most pronounced at high engine speeds, but for others, it is worse at lower engine speeds. Cleaning or replacing the injectors is only part of the maintenance necessary to the injection system; the manufacturer's installation adjustment specifications should also be strictly followed.

In cases where injection timing becomes faulty more quickly than the injector itself, timing and adjustments should be checked more often, or the timing should be advanced slightly to compensate for wear. Caution should be used in advancing the timing, however, because of the resulting tendency to increase peak pressure in the engine and reduce engine life.

INDUCTION AND EXHAUST SYSTEM MAINTENANCE AFFECTS SMOKE

Injectors are often blamed for poor performance and excessive smoke when it is really the induction and exhaust systems of the engine that need attention. Maintaining these parts of the engine is generally straight-forward and is easier than maintaining the injector system. Since the air-fuel ratio substantially affects the amount of smoke produced by a diesel engine, air induction and exhaust systems influence smoke production. The general effects of intake and exhaust restrictions on smoke and power are shown in Figures 5a and 5b. Some engines, especially naturally aspirated engines, are

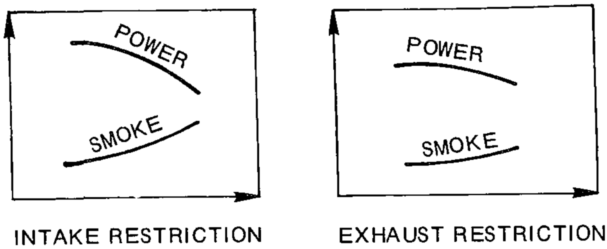


Figure 5. General effect of intake and exhaust restriction on smoke and power.

quite sensitive to both intake and exhaust system clogging or restriction. Not only does the restriction of the air intake system affect the smoke output of the engine, but it can mean an economic loss resulting from the loss of power. A restriction of either the intake or outlet tends to increase exhaust temperatures and makes scavenging of the combustion chamber less efficient. Vehicle and engine manufacturers must work together in the design and installation of the engine to make sure that intake and exhaust systems do not limit engine performance.

If the air cleaner is too small or is partially clogged, the engine simply can not take in enough air. In turn, decreased air intake lowers the air-fuel ratio, increases exhaust temperatures and smoke, and reduces power.

The induction system may include a turbocharger, which uses energy in the exhaust gases to force air into the engine. When the exhaust gases do not contain enough energy, such as during acceleration from idle, the turbocharger may not provide a full air charge.

Valving in the intake and exhaust systems also plays an important part in the ability of an engine to breathe and, therefore, in the smoke it produces. If valve underheads become loaded with deposits, the internal restriction that results could eventually require the rebuilding of cylinder heads. Worn valve guides and bushings, and piston rings and liners can result in excessive oil consumption, which can produce blue smoke as well as black. If blue smoke persists under cruise conditions, a major overhaul may be needed.

The service manuals supplied by engine manufacturers give a good deal of information on how to control smoke through maintenance practices. This information ranges from troubleshooting hints for determining the cause of smoke to detailed specifications and tolerances on working parts. These manuals should be used for establishing preventive maintenance programs, training diesel mechanics, and assisting in day-to-day repairs.

EFFECT OF DRIVER TECHNIQUES ON SMOKE

Interviews with drivers, driver supervisors, and fleet operators have shown the need to clear up a common misunderstanding about the relationship between smoke and power:

Power is not proportional to smoke!

This is probably the most misunderstood fact about a diesel. It is important to note again that a slight increase in available power could result in a much greater increase in visible smoke, for when an engine cannot take in more air to support combustion efficiently, the small increase in horsepower is at a high cost in both fuel consumption and smoke production (Figure 6).

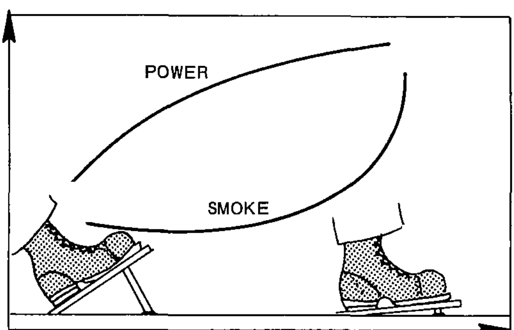
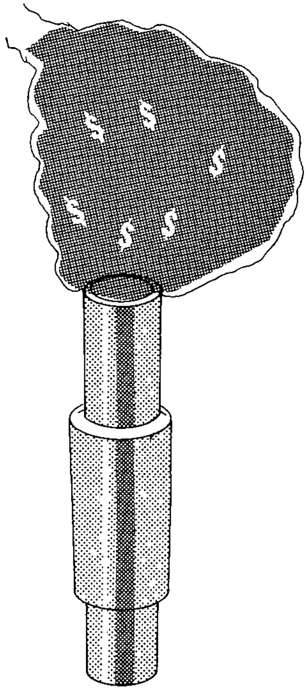


Figure 6. Smoke and power as affected by accelerator position.

Instead of making road adjustments that increase the amount of smoke produced, a driver should report any complaints he has about bad performance or losses in power to the maintenance and driver supervisors, and should keep at it until the causes are found and fixed. Chassis dynamometers, which are often used by service garages, can be used to check out losses in power by measuring the power available at the rear wheels. Overfueling the engine by making certain adjustments – such as road adjustments and changes in the fuel pumps, delivery pressure, or injector backpressure – just puts off that much longer proper maintenance or the use of the right-sized engine for the job. In the meantime, of course, overfueling results in more smoke. The fleet operator who sees smoke coming from his diesels should realize that more than smoke is going up the stacks because smoke can mean poor performance, shorter life, added maintenance, bad public relations, and smoke citations – in short, money.

Most drivers have been warned that they should "keep the engine speed up" to reduce smoke. Underspeeding the engine at full load, called "lugging," may produce more smoke and can cause



mechanical stress and eventual damage. The driver should make it a habit to drive within the manufacturer's recommended speed range.

Driving habits can have a great deal of influence on the amount of smoke produced, depending on when and how long maximum power is required. In most cases, of course, this is fixed by the route the driver has to travel. If the driver will accelerate gradually, when possible, he can reduce the duration and amount of smoke production. On truck-tractors with vertical stacks, some fleets have installed a special mirror that shows the tip of the exhaust pipe and helps the driver minimize smoke by "feathering" the accelerator pedal during acceleration and cruise conditions. When the driver of a loaded vehicle is negotiating a hill or trying to hold a minimum route speed and keep traffic flow orderly, he has no choice except to operate the vehicle at its maximum power condition. For nonturbocharged engines, this may be the maximum smoke condition as well.

EFFECT OF TYPES OF FUEL ON SMOKE

Diesel fuel is usually available as two types: Number 1, which is a light or kerosene-like fuel, and Number 2, which is a heavier fraction. Number 1 fuel is sometimes used by diesels involved in stop-and-go, medium-duty operations in cities. Number 2, because it costs less and has a higher heat content, is used almost entirely for line-haul trucking and for other uses that require continuous, high-power output. The main thing to remember in selecting diesel fuel is that the fuel should conform to the specifications around which the engine was designed.

The most important properties of fuels are volatility, gravity, viscosity, ignition quality (cetane rating), and hydrocarbon composition. Volatility, or distillation range, is a measure of the vaporization characteristics of a fuel. Generally speaking, less smoke will be produced, without any fuel rate adjustment, if a low-boiling-range, low-gravity Number 1 diesel fuel is used in place of the heavier, higher-boiling-range Number 2 fuel. The use of the lighter fuel results in a loss in power, though, and is actually a type of derating. Fuel Number 1 has less weight per volume than Number 2. Since fuel is injected by volume, less weight is injected per stroke—and fewer Btu's—so that less smoke and power are produced. If a fuel has too high a specific gravity or too high a maximum boiling point, it may cause excessive carbon deposits and exhaust smoke.

Viscosity is an important property because it influences the flow and lubricating characteristics of fuels. Viscosity is critical in the fuel delivery system, especially in the injectors, where it affects the pattern of the fuel spray. If the fuel used has lower viscosity than that recommended, the fuel may leak past the plunger during the downstroke of some unit injectors. This leakage results in reduced fuel delivery, less power, and less smoke. Viscosity affects the size of fuel droplets and volatility affects the rate of evaporation of the droplets. Together, viscosity and volatility can affect combustion efficiency and, therefore, the exhaust smoke produced. The importance of ignition quality, or cetane rating, depends on the design of the engine.

It goes without saying that the fuel should be free of foreign matter such as water, dirt, or other particles, and that its quality should be uniform and dependable. Although quality fuels are available from all major producers, contamination may occur in storage, where moisture and corrosion can build up in fuel lines and tanks. To protect the finely machined components of the fuel injection system, there are usually at least two filter elements located in the fuel supply system. A primary filter is usually located near the fuel tank, followed by a secondary filter. Some types of injectors have a screen in the body of the injector for final filtration. In addition to routine cleaning or replacement of the fuel filters, routine cleaning or draining of the fuel tanks is recommended. The suction pipes through which the fuel is drawn from the vehicle tank should clear the bottom of the tank so that water and sediment are not picked up. Dispensing and storage tanks must be included in a successful fuel cleanliness program.

There are a large number of diesel fuel additives on the market that are intended for fuel storage stability, engine cleanup, and/or combustion improvement. Additives have to be selected with care, however, since they could possibly become pollutants themselves. Fuel storage stabilizers are usually combustible enough that there is little chance they will conttibute to pollution. In fact, if fuel stabilizers help reduce engine malfunctions by keeping the quality of fuel consistent, then they indirectly reduce air pollution.

Some additives are excellent dispersants and will suspend the water and sediment in the fuel that sometimes tend to clog primary filters. All tanks and supply lines must be thoroughly cleaned before such additives are used. Other additives have been shown to extend injection life, so that maintenance costs and the malfunctions that cause smoke problems are reduced.

Additives that are rated as combustion improvers frequently contain metals, and there is growing concern that even though they reduce smoke, they may produce metal-containing combustion products that are toxic. Such fuel additives should not be used if they release into the atmosphere any noxious or toxic materials that are not ordinarily emitted by the engine.

EFFECT OF CONTROL DEVICES ON SMOKE

A number of devices and techniques have been proposed for the reduction of smoke emissions. Turbocharging, discussed previously, is helpful, especially during cruise-type conditions. During accelerations, rack limiters or aneroid controls can help maintain the air-fuel ratio so that the engine performs well and smoke is controlled. Turbocharging kits have been added by some operators to existing engines. The kit permits the uprating of engine power, but this is not usually done when the goal is to reduce smoke as much as possible.

Dual fuel or fumigation systems using liquefied petroleum gas (LPG) have found limited application in diesel trucks. These systems meter a small amount of LPG into the intake manifold to start precombustion reactions that help the fuel burn better. Though the use of LPG reduces smoke somewhat, the need for a dual fuel supply limits the popularity of this system. Then too, the warranty may be voided because overfueling can occur with the LPG fumigation system.

A number of methods have been tried for changing the appearance of the smoke plume. Some operators have tried discharging the smoke downward, near the drive wheels, to spread it out, only to find that the smoke looked worse. In many cases, the downward-directed exhaust smoke was not only more noticeable but obscured the visibility of other motorists. Sometimes, depending on design, the smoke entered the vehicle cab and bothered the driver. Some operators of stop-and-go-type vehicles that are properly maintained have found that an exhaust stack aimed toward the ground or parallel to it, and near the ground, is better than a vertical stack for keeping soot near the road level.

Other methods for changing the appearance of the exhaust plume that have been tried include adding fresh air to the exhaust pipe to dilute the smoke, or using a number of small pipes to break up the single plume. Pipes of different sizes, shapes, and arrangements for inducting dilution air have also been tried. None of these has been satisfactory and, more often than not, they made the smoke more noticeable. Dilution is not really a control measure and is not recommended because it does not reduce the amount of particles given off by the exhaust, just the concentration.

Improved component matching and the wider usage of automatic transmissions are potential methods for reducing odor and smoke. The heavy-duty automatic transmission is expected to improve driveability, route speed, and maintenance, and it may reduce odor and smoke considerably by preventing the engine from being overloaded throughout its speed range.

Passing the exhaust through afterburners or catalytic mufflers has been considered, but these devices are not technically promising for smoke control because they need very high temperatures to oxidize the carbon particles in the exhaust. The electrostatic precipitation of carbon particles has been tried with diesel exhaust, but is not practical because the carbon particles quickly coat the inside and short-circuit the system. Mechanical filters and separators have also been suggested for removing smoke from the exhaust stream but these methods usually increase exhaust backpressure beyond allowable limits, or they are just too inefficient and involve too much cleaning and repair.

Federal smoke requirements for 1970 diesel engines have been met, however, without external devices or equipment such as those mentioned. The test procedure includes a 1,000-hour run to show that the engine will continue to meet the smoke limits over a long time. Actually, the need for external devices for controlling smoke from engines qualified under the 1970 Federal smoke standards should not be necessary if engine use is in line with manufacturer's recommendations. The critical requirements for reducing smoke are: (1) the use of an engine large enough to do the job, (2) the use of the appropriate fuel for the engine selected, and (3) an emphasis on the maintenance necessary to keep the engine running properly.

GUIDELINES FOR REDUCING ODOR

Guidelines for reducing diesel odor are much harder to formulate than those for smoke because less is known about the causes of and factors influencing diesel odor. The guidelines are given under the same headings used in the smoke section, but they are much briefer because of the level of current knowledge.

EFFECTS OF ENGINE SIZE AND USE ON ODOR

The selection of a diesel engine that produces a minimum of odor involves the entire vehicle design and goes beyond engine type or size. Broadly speaking, incomplete combustion brought about by the wrong air-fuel ratio, inadequate fuel injection, inadequate time for the burning process, insufficient temperature to promote complete combustion, incorrect fuel, incorrect speed, etc., are all factors that may influence the odor produced by engines.

Experience indicates that engines operated in highway-type uses in vehicles equipped with vertical stacks put out odors that are less noticeable than those from diesel-powered vehicles equipped with horizontal exhaust pipes. An engine will usually produce less odor when operated under highway-type conditions than in city-type, stop-and-go service. Although not all the reasons for this are understood, engine temperature and engine speed may have some influence. Engine size—that is, displacement and power output—does not influence exhaust odor as much as it affects smoke. At low or high idle (zero power output), however, some engines produce a noticeable odor but no visible smoke. Odor levels from four-stroke turbocharged engines are not generally different from those from naturally aspirated four-stroke engines.

The position of the exhaust pipe, however, has a gross effect on odor. The quantity or quality of the odors given off is not reduced, but the gases are dispersed and are usually less noticeable to the public. For this reason, less perceptible odors result from vertical stacks than from low-to-the-ground, or horizontal, exhausts.

CAN ENGINE DERATING HELP REDUCE ODOR?

Field and laboratory experience indicates that there is little advantage in derating an engine for the sole purpose of reducing odor. The effect of a moderate amount of derating in a well-maintained, properly adjusted engine is usually difficult to see. Speed and power variations within the operating range of the engine seem to have only a slight effect on odor.

FUEL SYSTEM MAINTENANCE AFFECTS ODOR

Engine maintenance can have an effect on odor. Depending on the type of engine, fuel injection characteristics can have as much effect on odor as they do on smoke. In most cases, improving combustion reduces both smoke and odor.

Most manufacturers of automotive diesel engines have active programs aimed at reducing exhaust smoke, odor, and other emissions and periodically they put out improved products that can be incorporated into older engines. As an example, the crown-type S fuel injector used in older Detroit Diesel 71-E series engines can be replaced with needle-type N injectors, a change that reduces smoke and odor. Recently, an improved version of the N-type injector was put into production and is currently furnished in new engines. Almost the same reduction in odor from older engines can be obtained by replacing, at a nominal cost, the S-type injector used in many of the existing engines with the new N-type injector. The reduction in odor possible with this change is shown in Figure 7.

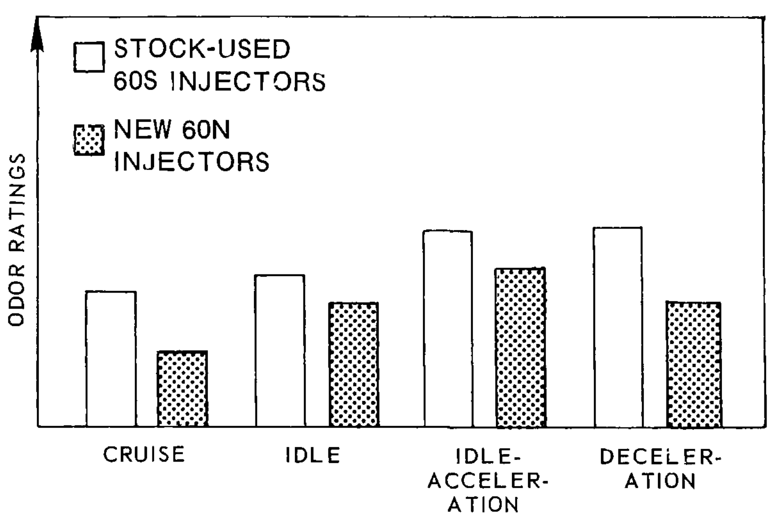


Figure 7. Effect of injector type on odor.

An injector with deteriorated spray pattern and cutoff may cause significant levels of odor. For example, if fuel is injected into the combustion chamber after the normal cutoff point, it may be only partially burned. During deceleration of certain engines, a fairly pungent odor occurs if the injectors are badly worn and do not positively cut off the fuel. The effect of late injection on odor production has yet to be investigated; however, it is not expected to be significant. Diesels often produce higher odor levels in the winter than in the summer, or in cold climates relative to warm climates. In addition overcooling may increase odor. High-temperature thermostats, thermostatically controlled radiator shutters, or variable-speed, thermostatically controlled fans, if properly maintained, are all devices that will keep engine temperatures at an optimum level.

INDUCTION AND EXHAUST SYSTEM MAINTENANCE AFFECTS ODOR

The induction system has a significant effect on odor in some uses and in some engine types. A seriously restricted air intake may result in exhaust products with highly objectionable odors.

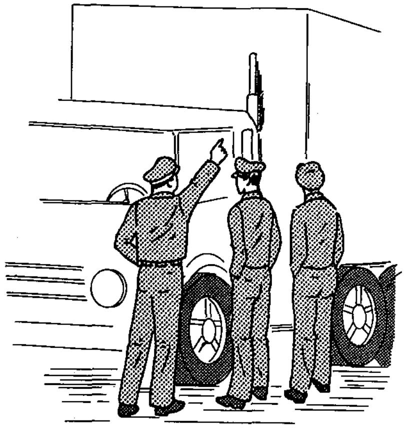
Many fleet maintenance departments have internal maintenance procedures, preventive maintenance schedules, and service policies that are based on manufacturers' recommendations and service manuals as well as on their own direct experience. The result is an individualized approach, tailored closely to the fleet application and need. Service bulletins concerning parts and procedural changes are published by the manufacturer and should be incorporated into the fleet maintenance procedures. In addition, detailed procedural instructions to the mechanic are usually effective in keeping odor as low as possible through proper engine maintenance. If smoke and odor control are not presently emphasized, a continuing program of information, education, and training that advocates a clean, clear exhaust is recommended. When it is carefully used, an incentive program or some other recognition can show management's concern about exhaust emissions and can result in better odor and smoke control.

EFFECT OF DRIVER TECHNIQUE ON ODOR

Just as he can influence the amount of smoke from his vehicle, the driver is able to reduce odor under certain conditions. Road adjustments of the engine fueling system made to increase power also increase the smoke output and can increase odor as as well. A double reason exists, then, for *not* making such adjustments. Furthermore, keeping the engine speed within the manufacturer's recommended operating speed range helps minimize odor and smoke. It is also important to keep the engine temperature up, particularly during cold weather.

Another way in which the driver and *only the driver* can reduce odor is to minimize idle time and light-load operation. Unburned fuel and products of combustion from some engines condense in the exhaust, particularly during warmup or shortly after engine startup, and a more intense odor may result. A good rule is to start the engine and get it under load as soon as practical. Idling the engine generally does not do much to warm up the engine; it only loads the combustion chamber with unburned fuel, which may dilute the lubricating oil. Local delivery operations are particularly bad in this respect because this type of operation usually includes a great deal of idle time, either at the end of the run or at delivery points. Actually, the engine should be shut off instead of being allowed to idle for long periods. Some localities have regulations that restrict the period of engine idle.

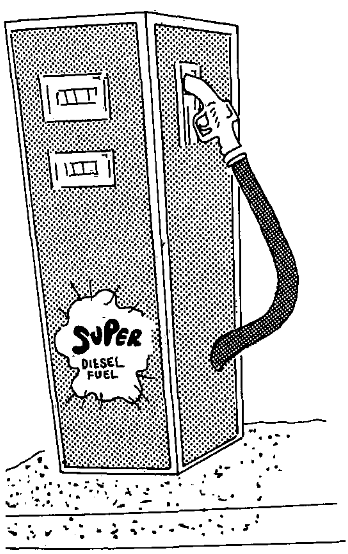
Any program for reducing vehicle odor and smoke should include driver training and education. Drivers should be encouraged to follow the recommended driving procedures described in handbooks published by most vehicle manufacturers. Management can improve the appearance of a fleet and reduce complaints or citations by encouraging drivers attitudes and habits that result in less smoke and odor. A driver should be constantly and habitually aware of the part he can play in reducing odor and smoke. Management has successfully increased driver awareness by asking drivers on the road to watch other trucks in their fleet for excessive smoke. If drivers cooperate and maintenance crews are alert during operation near depots, they can be an unbeatable team. Management must take the initiative in obtaining the cooperation of both



operation and maintenance. Scheduling should not be so critical, or replacement units so few and overworked, that a "smoker" or a malodorous vehicle cannot be brought in for a check after being reported.

EFFECTS OF TYPES OF FUEL ON ODOR

In general, engines are optimized by the manufacturer to operate with either Number 1 or Number 2 fuel. An engine optimized for Number 1 fuel may produce a more intense odor when it is operated on a Number 2 fuel. For example, a heavier, burnt-smoky, and sometimes more acrid odor has been reported from a municipal bus optimized for Number 1 but operating on Number 2 fuel. The usual kerosene-type fuel odor was less noticeable, however. Studies of fuels with widely different properties and impurities have not pinpointed specific cause and effect relationships.



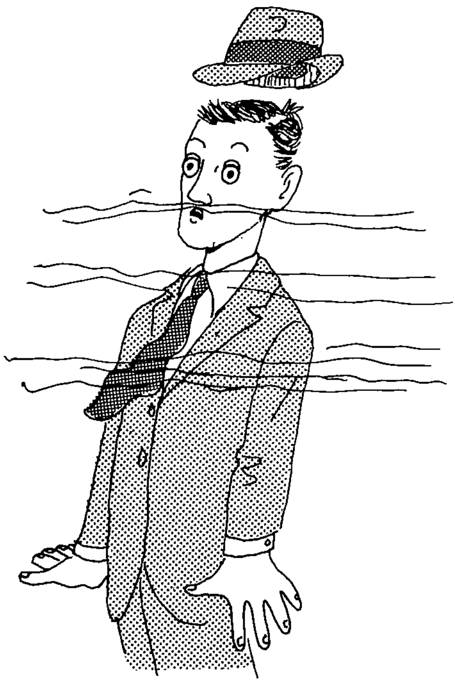
The additives used for controlling odor are either maskants or counteractants. A maskant has an odor that covers up the original odor; a counteractant reacts to form a new odor or to destroy the odor originally present. Some operators have found that the use of odor additives, mainly maskants, has helped reduce complaints. Laboratory tests have not shown that additives reduce the intensity of an odor; however, they do change the quality of the odor so that it sometimes becomes more acceptable. No unusual engine difficulties or maintenance problems have been reported when the maskant-type additives have been used. They do have certain disadvantages, though, including their cost, the fact that they may have or produce an odor that is more unpleasant to some people than the original odor, and the fact that they may create more toxic material in the exhaust. For these reasons, their use is not recommended.

Most diesel manufacturers have specific fuel recommendations for satisfactory engine operation. In addition, marketers of diesel fuel can help match the fuel specification to the particular engine and job application. The advice of both the engine manufacturer and the refiner should be obtained when fuel specifications are being determined, especially for abnormal climatic conditions or unusual duty cycles. Some engine manufacturers specifically warn against the use of fuel additives other than those they have approved; in some cases, the engine warranty may be jeopardized if additives are used.

EFFECT OF CONTROL DEVICES ON ODOR

Measures for controlling diesel odor include catalytic mufflers and many of the methods proposed for smoke reduction. Catalytic mufflers of the precious-metal type have been effective in reducing odor. Because of the dependence of reaction rates on exhaust temperature, the universal application of even the best catalytic muffler is not practical. In some engine uses, such as stop-and-go city deliveries, catalytic mufflers are only partially helpful in reducing odor. They are more effective with the high exhaust temperatures and nearly constant exhaust flow that are typical of a stationary engine or line-haul vehicle. Most fleet operators have thought that the initial cost of equipment and installation (as much as $500 on some vehicles) and the costs of operating and maintaining them do not justify the use of catalytic mufflers except when extended operation in confined, unventilated areas is required. Even then, exhaust odors and irritants may be reduced less than 50 percent. Some designs require the periodic or even continuous burnoff of contaminants to renew the surface of the catalyst and maintain performance. This requires additional equipment and operating expenses; furthermore, in some applications, the regeneration process could present a safety problem. Further research and development are required to determine the full potential of catalytic mufflers as well as to make them usable on a large variety of motor vehicles.

As mentioned earlier, the position and the direction of vehicle exhaust stacks can have an important effect on the odor noticed by



the pedestrian or motorist. More than just diluting the exhaust fumes, such stacks can direct odorous gases away from the observer. This does not reduce the total amount of odor given off, of course, but the nuisance effect can be reduced. Three to ten times the atmospheric dispersion can be achieved by using a vertically directed stack ending 12 feet above the road instead of a horizontal pipe 1 foot off the road. To reduce the noticeability of odor, straight vertical stacks ending as high as practical above the road are recommended.

Some operators have found that in certain stop-and-go operations, the use of throttle-opening delays or dash pots to control the rate of acceleration has reduced odor and smoke emissions. Fuel injector design seems to have an important bearing on odor and can potentially reduce both smoke and odor futher. New, improved fuel injectors, for example, were found to reduce odor and smoke by about one-third in several low-compression two-stroke engines, and the cost per injector is nominal.

The use of other control devices such as afterburners and wet scrubbers has been suggested. Direct flame incineration, though successful in controlling odor in some stationary applications, has not been applied to mobile engines. Variations in exhaust flow and the differences in engines and uses are seen as disadvantages, along with probable cost and safety factors. Wet scrubbers are even less practical because of the weight and space needed to handle large quantities of high-temperature exhaust without developing excessive backpressure.

SUMMARY OF RECOMMENDATIONS

The purpose of this *Guide* is to help minimize odor and smoke from diesel-powered vehicles. A team effort by everyone involved in the purchase, operation, maintenance, application,and driving of diesel-powered vehicles is needed to achieve the goal of minimum odor and smoke. The suggestions offered are summarized below:

1. Since the *air-fuel ratio* has a greater effect on smoke emissions from diesel engines than other factors, anything that tends to reduce this ratio, such as excess fuel or insufficient air, will lead to more smoke and should, therefore, be avoided.
2. Engine derating, the method usually employed to reduce smoke, is recommended and should be considered good procurement policy.
3. Vehicle and engine maintenance programs must include a continuing campaign against faulty fuel injectors, restricted air cleaners, and incorrect adjustment of injectors.
4. Turbocharging can be used to minimize visible smoke during operation at high elevations. New engines can be procured with this feature, and kits may be obtained from some manufacturers to modify existing naturally aspirated engines.
5. Odor and smoke from certain buses and trucks powered by two-cycle engines can be reduced by the use of improved needle-type unit injectors in place of the original crown-type injectors. Use of the needle injector in the older E-series engine may reduce odor and smoke to the level emitted from the newer N-series engine. This recommended conversion can be accomplished at a nominal cost per injector.
6. Drivers should develop those driving habits that are known to minimize odor and smoke emissions. Drivers should, for instance, avoid excessive engine idle and underspeeding (lugging). In addition, they should use a rear-view mirror aimed at the exhaust outlet so that they are aware of excessive smoke emissions. An active and continuing driver education program should be instituted to encourage drivers to operate their vehicles in a manner that produces the least possible amounts of smoke and odor.

7. The location and direction of the vehicle exhaust stack or pipe can make a significant difference in the noticeable and potentially objectionable aspects of smoke and odor. To reduce the noticeability of odor, the use of a straight vertical stack terminating as high above the ground as possible should be considered. In some stop-and-go applications in public areas, the use of a horizontal, low-to-the-ground exhaust has been found necessary to reduce fallout of soot.
8. The fuel selected should conform to the specifications recommended by the manufacturer of the engine.
9. Fuel additives for the reduction of diesel odor and smoke should not be used if they cause the emission into the ambient air of any noxious or toxic matter that is not ordinarily emitted by the engine.