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Fuel Systems And Emission Controls

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Fuel Systems and Emission Controls, Fourth Edition

Classroom Manual and Shop Manual

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Introduction to Fuel Systems and Emission Controls

Fuel Systems and Emission Controls is part of the Chek-Chart Automotive Series. The package for each course has two volumes, a *Classroom Manual* and a *Shop Manual.*

Other titles in this series include:

- *Automatic Transmissions and Transaxles*
- *Automotive Brake Systems*
- *Automotive Heating, Ventilation, and Air Conditioning*
- *Automotive Steering, Suspension, and Wheel Alignment*
- *Automotive Engine Repair and Rebuilding*
- *Engine Performance, Diagnosis, and Tune-Up*
- *Automotive Electrical and Electronic Systems.*

Each book is written to help the instructor teach students to become competent and knowledgeable professional automotive technicians. The two-manual texts are the core of a learning system that leads a student from basic theories to actual hands-on experience.

The entire series is job-oriented, designed for students who intend to work in the automotive service profession. Knowledge gained from these books and the instructors enables the student to get and keep a job in the automotive repair industry. Learning the material and techniques in these volumes is a giant leap toward a satisfying, rewarding career.

The books are divided into a *Classroom Manual* and *Shop Manual* for an improved presentation of the descriptive information and study lessons, along with representative testing, repair, and overhaul procedures. The manuals are to be used together: The descriptive material in the *Classroom Manual* reinforces the application material in the *Shop Manual.*

Each book is divided into several parts and each of these parts is complete by itself. Within each part are several related chapters. Instructors enjoy the complete, readable, and well-thought-out presentation of the chapters. Students benefit from the many learning aids included, as well as from the thoroughness of the presentation.

The series was researched and written by the editorial staff of Chek-Chart. Chek-Chart has been providing vehicle specification, training, and repair information to the professional automotive service field since 1929. Chek-Chart maintains a complete, up-to-date automotive data bank, which was used extensively to prepare this textbook series.

Because of the comprehensive material, the hundreds of high-quality illustrations, and the inclusion of the latest automotive technology, instructors and students alike find that these books maintain their value over the years. Many master technicians form the core of their professional library with Chek-Chart publications.

How To Use This Book

Why Are There Two Manuals?

Unless you are familiar with the other books in this series, *Fuel Systems and Emission Controls* is unlike any other textbook you have used before. It is actually two books, the *Classroom Manual* and the *Shop Manual*. They have different purposes and should be used together.

The *Classroom Manual* teaches what a technician needs to know about fuel system and emission control theory, systems, and components. The *Classroom Manual* is valuable in class and at home, both for study and for reference. The text and illustrations are used for years to refresh the memory—not only about the basics of fuel systems and emission controls but also about related topics in automotive history, physics, and technology.

The *Shop Manual* teaches test procedures, troubleshooting techniques, and how to repair the systems and components introduced in the *Classroom Manual*. The *Shop Manual* provides the practical, hands-on information required for working on fuel systems and emission controls. Use the two manuals together to understand fully how the systems work and how to make repairs when something is not working.

What Is In These Manuals?

These key features of the *Classroom Manual* make it easier to learn and to remember the material:

- Each chapter is divided into self-contained sections for easier understanding and review. This organization clearly shows which parts make up which systems, and how various parts or systems that perform the same task differ or are the same.
- Most parts and processes are fully illustrated with drawings or photographs. Important topics appear in several different ways, to make sure other aspects of them are seen.
- Important words in the text are printed in **boldface type** and are defined on the same page and in a glossary at the end of the manual. Use these words to build the vocabulary needed to understand the text.
- Review questions are included for each chapter. Use them to test your knowledge.
- Every chapter has a brief summary at the end to help review for exams.
- Every so often, sidebars—short blocks of "nice to know" information—are included in addition to the main text.

The *Shop Manual* has detailed instructions on test, service, and overhaul procedures for modern electrical and electronic systems and their components. These are easy to understand and often include step-by-step explanations of the procedure. The *Shop Manual* contains:

- Helpful information on the use and maintenance of shop tools and test equipment
- Safety precautions
- Clear illustrations and diagrams to help locate trouble spots while learning to read service literature
- Test procedures and troubleshooting hints that help you work better and faster
- Repair tips used by professionals, presented clearly and accurately
- A sample test at the back of the manual that is similar to those given for Automotive Service Excellence (ASE) certification; use this test to help study and prepare when ready to be certified as an electrical and electronics expert.

Where Should I Begin?

If you already know something about fuel systems and emission controls and know how to repair them, this book is a helpful review. If you are just starting in automotive repair, then the book provides a solid foundation on which to develop professional-level skills.

Your instructor has designed a course to take advantage of what you already know and what facilities and equipment are available. You may be asked to read certain chapters of these manuals out of order. That is fine. The important thing is to really understand each subject before moving on to the next.

Study the vocabulary words in boldface type and use the review questions to help understand the material. When reading the *Classroom Manual*, be sure to refer to the *Shop Manual* to relate the descriptive text to the service procedures. When working on actual vehicle systems and components, look to the *Classroom Manual* to keep the basic information fresh in your mind. Working on such a complicated piece of equipment as a modern automobile is not easy. Use the information in the *Classroom Manual*, the procedures in the *Shop Manual*, and the knowledge of your instructor to guide you.

The *Shop Manual* is a good book for work, not just a good workbook. Keep it at hand while actually working on a vehicle. It folds flat on the workbench and under the chassis, and is designed to withstand quite a bit of rough handling.

When performing actual test and repair procedures, a complete and accurate source of manufacturer specifications and procedures is needed for the specific vehicle. Most automotive repair shops have either the annual service manuals from the vehicle manufacturer, which list these specifications, or an independent guide, such as the Chek-Chart *Car Care Guide*. This unique book, with ten-year coverage, is updated each year to provide service instructions, capacities, and troubleshooting tips needed to work on specific vehicles.

Contents

On the Covers:
Front — SystemOne™ ASM emissions inspection system from Environmental Systems Products, Inc.
Rear — General Motors Multec fuel injector

PART ONE

Fuel System and Emission Control Fundamentals

1

Introduction to Fuel Systems and Emission Controls

The combustion process in automotive engines produces harmful by-products that are discharged from the engine and become air pollutants. Emission control systems are necessary to minimize the formation and discharge of these pollutants.

When emission control requirements were first introduced, manufacturers and car owners were able to comply by installing add-on or "hang-on" devices that were not an integral part of engine and vehicle design. As regulations became more strict, manufacturers had to include emission controls in basic engine design.

The first emission control regulation was adopted in California in 1961. Today, almost three decades later, emission control regulations are still being tightened and new control systems developed. Sophisticated computer-controlled systems appear on most cars, and emission control requirements are important considerations in the design and operation of all parts of the fuel system. The ignition system, which provides the spark for combustion, plays an equally important role in emission control.

How did these great changes in automotive emission controls come about? What exactly is air pollution, and how does the automobile contribute to it? This chapter examines air pollution and automotive emissions, including the legislation controlling emissions and the ways in which manufacturers have met the regulations.

AIR POLLUTION—A PERSPECTIVE

We can define air pollution as the introduction of contamination into the atmosphere in an amount large enough to injure human, animal, or plant life. There are many types and causes of air pollution, but they all fall into two general groups: natural and man-made. Natural pollution is caused by such things as the organic plant life cycle, forest fires, volcanic eruptions, and dust storms. Although pollution from such sources is often beyond our control, we can control man-made pollution from industrial plants and automobiles.

Most urban and large industrial areas around the world suffer periodic air pollution. During the late 1940s, a unique form of air pollution was identified in the Los Angeles area. When certain pollutants are exposed to sunlight, irritating chemical compounds form called **photochemical smog**. As this phenomenon increased both in intensity and frequency, it posed more of a problem. California took the lead in combating it by becoming the first state to place controls on motor vehicle emissions, figure 1-1. As smog gradually began to appear in other parts of the country, the federal government moved into the area of regulation.

Figure 1-1. During the 1960s, high levels of airborne pollutants in the Los Angeles basin prompted the state of California to enact emission control regulations.

To understand why, we must look at the automobile-produced elements that form air pollution and smog.

MAJOR POLLUTANTS

An internal combustion engine emits three major gaseous pollutants into the air: **hydrocarbons (HC)**, **carbon monoxide (CO)**, and **oxides of nitrogen (NO_X)**, figure 1-2. In addition, an automobile engine gives off many small liquid or solid particles, such as lead, carbon, sulfur, and other **particulate matter (PM10)**, which contribute to pollution. By themselves, all these emissions are not smog, but simply air pollutants.

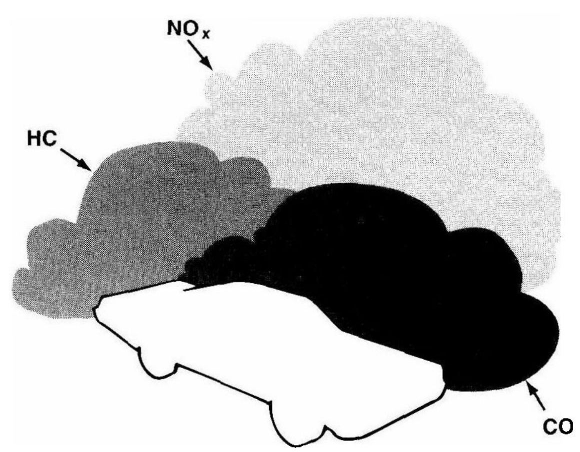

Figure 1-2. Hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NO_X) are the three major automotive pollutants.

Hydrocarbons

Gasoline is a HC compound. Unburned HCs given off by an automobile are mostly unburned fuel. Over 200 different varieties of HC pollutants come from automotive sources. While most come from the fuel system and the engine exhaust, others are oil and gasoline fumes from the crankcase. Even a car's tires, paint,

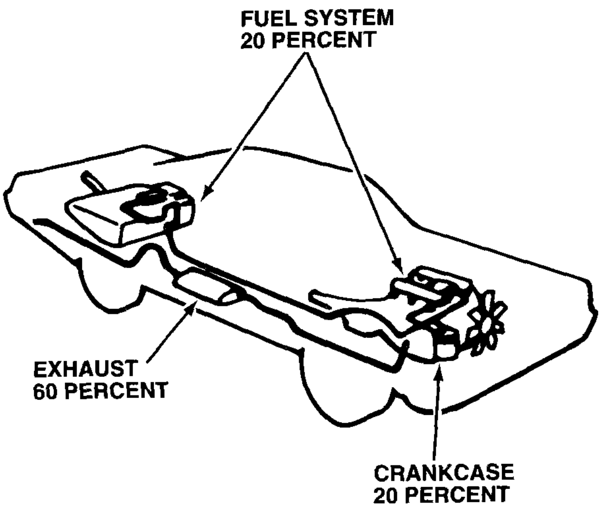

Figure 1-3. Sources of hydrocarbon emissions.

and upholstery emit tiny amounts of HCs. Figure 1-3 shows the three major sources of HC emissions from an automobile:

- Fuel system evaporation—20 percent
- Crankcase vapors—20 percent
- Engine exhaust—60 percent.

HCs are the only major automotive air pollutant that comes from sources other than engine exhaust. HC's molecules of all types are changed into other compounds by combustion. If an automobile engine burned gasoline completely, there would be no HCs in the exhaust, only water and carbon dioxide (CO_2). But when the vaporized and compressed air-fuel mixture is ignited, combustion occurs so rapidly that gasoline near the sides of the combustion chamber may not get burned. This unburned fuel then passes out with the exhaust gases. The problem is worse with engines that misfire or are not properly tuned.

Carbon Monoxide

Although not part of photochemical smog, CO is also found in automobile exhaust in large amounts. A deadly poison, CO is both odorless and colorless. CO is absorbed by the red corpuscles in the body, displacing the oxygen (O_2). In a small quantity, it causes headaches, vision difficulties, and delayed reaction times. In larger quantities, it causes vomiting, coma, and death.

Because it is a product of incomplete combustion, the amount of CO produced depends on the way in which HCs burn. When the air-fuel mixture burns, its HCs combine with O_2. If the air-fuel mixture contains too much fuel, there is not enough O_2 to complete this process, so CO forms. Using an air-fuel mixture with less fuel makes combustion more complete. The leaner mixture increases the ratio of O_2, which reduces the formation of CO by producing CO_2 instead.

CO_2, although not considered a pollutant affecting public health, does contribute to global warming. Currently, scientists are studying the relationship between CO_2 levels and global warming.

Oxides of Nitrogen

Air is made up of about 78 percent nitrogen, 21 percent O_2, and one percent other gases. When the combustion chamber temperature reaches 2,500EF (1370EC) or greater, the nitrogen and O_2 in the air-fuel mixture combine to form large quantities of NO_X. NO_X also is formed at lower temperatures, but in far smaller amounts. One component of NO_X, nitrogen dioxide, is extremely toxic to humans. In addition, NOX combines with other elements in the air to form nitric acid, a contributor to acid rain. In the presence of sunlight, NO_X and HCs combine to form **ozone**, a powerful oxidizer, and primary component of smog. Ozone makes breathing difficult, causes headaches, lowers your immunity to diseases, and injures many types of vegetation.

Photochemical Smog: A combination of pollutants that forms harmful chemical compounds when acted upon by sunlight.

Hydrocarbon (HC): A chemical compound made up of hydrogen and carbon. A major pollutant given off by an internal combustion engine. Gasoline is a hydrocarbon compound.

Carbon Monoxide (CO): An odorless, colorless, tasteless poisonous gas. A major pollutant given off by an internal combustion engine.

Oxides of Nitrogen (NO_X): Chemical compounds of nitrogen given off by an internal combustion engine. They combine with hydrocarbons to produce ozone, a primary component of smog.

Particulate Matter (PM10): Microscopic particles of materials such as lead and carbon, that are given off by an internal combustion engine as pollution.

Ozone: A gas with a penetrating odor, and a primary component of smog. Ground-level ozone forms when HCs and NO_X, in certain proportions, react in the presence of sunlight. Ozone irritates the eyes, damages the lungs, and aggravates respiratory problems.

Lowering the engine's combustion temperature reduces NO_X formation. However, it also makes the air-fuel mixture burn less efficiently, creating large amounts of HC and CO. To combat this problem, manufacturers use various emission control systems which we will study in later chapters.

Particulate Matter

Particulate matter (PM10) consists of microscopic-ten microns (0.000039 in.) or smaller-solid particles, such as dust, soot, and smoke, that remain in the atmosphere for a long time. PM10 is a prime cause of secondary pollution. For example, particulates such as lead and carbon tend to collect in the atmosphere. Large amounts of these substances can penetrate deep into our lungs, causing lung disease.

Particulates produced by automobiles are a small percentage of the total particulates in the atmosphere. Most come from fixed sources, such as factories. Although automobiles do produce particulates, the amount has decreased considerably in the past few decades because the fuel industry has eliminated additives such as lead from gasoline and changed other characteristics of the fuel. As a result, the amount and types of additives used in gasoline are carefully controlled.

Sulfur Oxides

Sulfur in gasoline and other fossil fuels (coal and oil) enters the atmosphere in the form of **sulfur oxides (SO_X)**. As SO_X breaks down, they combine with water in the air to form corrosive sulfuric acid, which is a secondary pollutant. Starting in the 1980s, there has been a lot of publicity about this type of pollution —commonly referred to as "acid rain"—especially in the northeastern United States and Canada.

POLLUTION AND THE AUTOMOBILE

A single car actually gives off only microscopic amounts of pollutants, but there are millions of automobiles in use in the United States. Multiply each car's contribution toward air pollution by the number of cars, then you have the potential for a staggering amount of pollution. Without emission controls, automobiles would create almost as much air pollution as all other sources combined.

Great progress has been made in reducing automobile air pollution since 1966. HC emissions from the engine crankcase and fuel system have been almost totally eliminated. The other 60 percent of HC emissions—from the exhaust—has been lowered considerably. From 1970-93, the HC and CO emissions of a typical car each decreased about 85 percent, figure 1-4. Figure 1-5 shows how dramatically the emissions of a typical car have fallen in the decades since regulations began.

However, some of these gains are offset by an equally dramatic increase in the number of cars on the road and the number of miles people drive their cars. The United States Environmental Protection Agency (EPA) estimates that vehicle travel has doubled since 1970, due in great part to urban sprawl. So, although each car pollutes less, there are many more cars contributing to pollution.

SMOG-CLIMATIC REACTION WITH AIR POLLUTANTS

Smog and air pollution are not the same thing: Smog is a form of air pollution, but air pollution is not necessarily smog. Although all three major pollutants are by-products of combustion, each is created in a different way. HCs come mostly from unburned fuel, CO from air-fuel mixtures that contain too much fuel, and NO_X from high combustion chamber temperatures. HC and NO_X are the two principal materials that combine in the atmosphere in sunlight to form smog, or ozone.

The Photochemical Reaction

Although scientists can create smog in laboratory experiments, they do not completely understand what it is. They do know, however, that three things must be present for smog to form in the atmosphere:

- Sunlight
- Relatively still air
- A high concentration of HC and NO_X.

When these three elements coexist, the sunlight causes a chemical reaction between the HC and NO_X and creates smog.

Temperature Inversion

Normally, air temperature decreases at higher altitudes. Warm air near the ground rises and becomes cooler by contact with the cooler air above it. When nature follows this normal pattern, smog and other pollutants are carried away. But some areas experience a natural weather pattern called a **temperature inversion**. When this occurs, a layer of warm air prevents the upward movement of cooler air near the ground. This inversion acts as a "lid" over the stagnant air. Because the air cannot rise, smog and pollution collect.

When the inversion layer is several thousand feet high, the smog can rise enough for reasonable visibility.

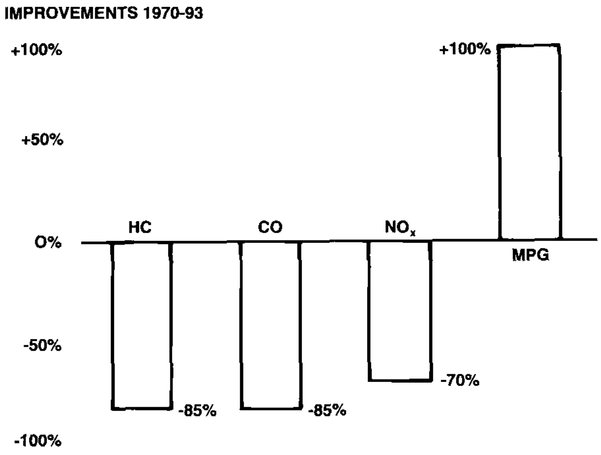

Figure 1-4. Since 1970, the average car's pollution has fallen, and its fuel-efficiency has increased greatly. (Information courtesy of the U.S. EPA)

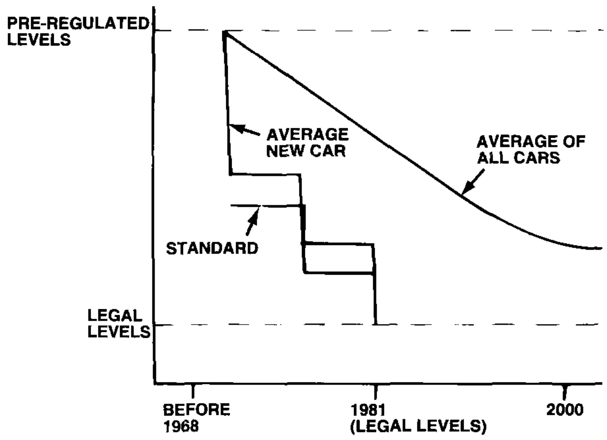

Figure 1-5. Clean air legislation has lead to dramatic decreases in the amount of pollution cars create. (Information courtesy of the U.S. EPA)

But when the inversion layer is within 1,000 feet (300 meters) of the ground, it traps the smog. This reduces visibility, making the distant landscape impossible to see, figure 1-6, and causing people to experience eye irritation, headaches, and difficulty in breathing. Temperature inversion was first noted in the Los Angeles area, which provides a classic example of this phenomenon. Surrounding mountains in that area form a natural basin in which temperature inversion is present to some extent for more than 300 days a year.

AIR POLLUTION LEGISLATION AND REGULATORY AGENCIES

Once the problem of air pollution was recognized, it became the subject of intense research and investigation. By the early 1950s, scientists believed that smog in Los Angeles was caused by the photochemical process. California, as we noted earlier, became the first state to enact legislation designed to limit automotive emissions. Standards established by California one year often became U.S. federal standards the next year.

Regulatory Agencies

The United States EPA is the federal agency responsible for enforcing the Clean Air and Air Quality Acts passed by Congress. It was formed as part of the Department of Health, Education, and Welfare. The California Air Resources Board (CARB) has authority roughly parallel to that of the EPA, but extends only to vehicles sold in or brought into California, figure 1-7. Canadian vehicle emission standards are established by the national Ministry of Transport.

Emission Control Legislation

Beginning with the 1961 new cars, California required control over crankcase emissions. This became standard for the rest of the United States with new 1963 cars. That year, domestic manufacturers voluntarily equipped their new models with a blowby device that virtually eliminated crankcase emissions on all cars.

California followed by requiring that 1966 and later new cars sold within its boundaries have exhaust emission controls. The use of exhaust emission control systems was extended nationwide during the 1967-68 model years.

The first federal air pollution research program began in 1955. In 1963, Congress passed the Clean Air Act, providing the states with money to develop air pollution control programs. This law was amended in 1965 to give the federal government authority to set emission standards for new cars, and was amended again in 1977-78. Under this law, emission standards were first applied nationwide to 1968 models.

In addition to the Clean Air Act, the federal government took a new approach to air pollution in 1967 with the Air Quality Act. This act and its major amendments of 1970, 1974, and 1977, instituted

Sulfur Oxides (SO_X): Sulfur given off by processing and burning gasoline and other fossil fuels. As it decomposes, sulfur dioxide combines with water to form sulfuric acid, or "acid rain.

Temperature Inversion: A weather pattern in which a layer, or lid, of warm air keeps a layer of cooler air trapped beneath it.

Figure 1-6. Smog engulfs the Los Angeles Civic Center in the 1960s. When the base of the temperature inversion is only 1,500 feet (457 meters) above the ground, the inversion layer—a layer of warm air above a layer of cool air—prevents the natural dispersion of air contaminants into the upper atmosphere.

changes designed to turn piecemeal programs into a unified attack on pollution of all kinds. Canada attacked its own smog problem with vehicle emission requirements established by the Ministry of Transport which took effect with 1971 models.

The 1990 Clean Air Act

In 1990, the U.S. Congress amended and updated the Clean Air Act for the first time in 13 years. Besides making tailpipe standards more stringent and expanding vehicle Inspection and Maintenance (I/M) Programs, the 1990 law focused on fuel itself, in addition to vehicle technology. Some key aspects of the 1990 Clean Air Act include

- Tighter tailpipe standards
- CO control
- Ozone control
- Reformulated gasoline
- Other controls.

Figure 1-8 shows a timetable for implementing certain provisions of the 1990 Clean Air Act.

Tighter tailpipe standards

Tailpipe standards for 1990-93 were 0.41 gram per mile (g/m) HC, 3.4 g/m CO, and 1.0 g/m NO_X. The 1990 Clean Air Act requires phasing in lower-limited standards for HC and NO_X between 1994-96-0.25 g/m of nonmethane HC and 0.4 g/m NO_X. The law also requires the EPA to study whether even stricter standards are necessary, feasible, and economical. If the EPA determines by 1999 to lower the standards, they will be halved beginning in the 2004 model year.

Carbon monoxide control

The EPA places primary blame for CO pollution on mobile sources (including cars and trucks, as well as other vehicles, such as bulldozers and construction equipment) in 39 U.S. cities.

CALIFORNIA PASSENGER CAR NEW VEHICLE STANDARDS

YEAR	HC	CO	NO_x
1966-69	275 ppm	1.5%	-
1970	2.2 g/m	23 g/m	-
1971	2.2 g/m	23 g/m	4.0 g/m
1972	3.2 g/m	39 g/m	3.2 g/m
1974	3.2 g/m	39 g/m	3.0 g/m
1975-76	0.9 g/m	9 g/m	2.0 g/m
1977-79	0.41 g/m	9 g/m	1.5 g/m
1980	0.41 g/m	9 g/m	1.0 g/m
1981-92	0.41 g/m	7 g/m	0.7 g/m

Figure 1-7. This chart of California exhaust emission limits for new cars shows how standards became more stringent in the wake of the Clean Air Act. California standards are stricter than federal standards. (Information courtesy of the California Air Resources Board)

CO emissions from cars are particularly high during cold weather, when vehicles operate less efficiently. While previous CO standards applied only at 75°F (24°C), the 1990 Clean Air Act establishes an additional CO standard of 10 g/m at 20°F (-7°C). If CO levels are still excessive in six or more cities by 1997, the standard will be tightened to 3.4 g/m, to be met beginning with the 2002 model year.

The 1990 law also requires a higher O_2 content in the gasoline sold during the winter in the 39 CO-saturated cities, a requirement that took effect in 1992. O_2 leans the air-fuel mixture, reducing CO emissions, lowering fuel economy, and increasing CO_2 emissions.

Ozone control

Ozone—the combination of HC and NO_X, the primary component of smog—is the most widespread air quality problem in the United States. The U.S. EPA rates the following areas as having a "severe" ozone problem:

- New York City and Long Island in New York State, and north New Jersey
- Baltimore, Maryland
- Muskegon, Michigan
- Chicago, Illinois;
- Gary, Indiana
- Lake County and Milwaukee, Wisconsin
- Houston, Galveston, and Brazoria, Texas
- San Diego, Southeast desert, and Ventura County, California.

Los Angeles, California, receives its very own ozone rating: "extreme." Approximately 15 other cities and urban areas across the United States are rated as having "serious" ozone levels, and about 30 more have "moderate" ozone problems.

Gasoline vapors are a major source of HC in ozone, so the 1990 Clean Air Act calls for reducing evaporative emissions by such means as improved engine and fuel system vapor traps and wider use of systems to capture vapors during refueling in smoggy cities. In addition, the Clean Air Act places a cap on fuel volatility—reducing its tendency to evaporate.

Reformulated gasoline (RFG)

The 1990 Clean Air Act established standards for the content of gasoline sold in the nine worst ozone areas. This "cleaner" gasoline must meet or exceed a certain minimum O_2 content, and it must not exceed a certain maximum level of benzene. Also, the gasoline must reduce toxic and smog-forming emissions 15 percent

■ How New Cars Are Emission-Certified

Whether you can buy a particular new car each year—and where you can buy it—depend on the manufacturer's success in the emission certification process. The U.S. Environmental Protection Agency (U.S. EPA) performs a constant-volume sampling test for each car, called the Federal Test Procedure (FTP), or the Federal Vehicle Certification Standard Procedure. Some vehicles are also tested by the California Air Resources Board.

As each new model year approaches, manufacturers build prototype, or emission-data, cars for U.S. EPA use. The manufacturers are responsible for conducting a 50,000-mile (80,000-kilometer) durability test of their emission control systems. Before the U.S. EPA test, the manufacturers drive the test cars for 4,000 miles (6,500 kilometers) to stabilize the emission systems.

The manufacturer preconditions the car before the U.S. EPA test, then it stands for 12 hours at an air temperature of 73°F (22°C) to simulate a cold start. The actual test is done on a chassis dynamometer, using a driving cycle that represents urban driving conditions. The car's exhaust is mixed with air to a constant volume and analyzed for harmful pollutants.

The entire test requires about 41 minutes. The first 23 minutes are a cold-start driving test. The next 10 minutes are a waiting, or hot-soak period. The final eight minutes are a hot-start test, representing a short trip in which the car is stopped and started several times while hot. If the emissions test results for all data cars are equal to or lower than the HC, CO, and NO_X standards, the EPA grants certification for the engine "family," and the manufacturer can sell the car to the public.

This certification process explains why some engines disappeared in the wake of clean-air legislation—they were too "dirty" and could not be "cleaned up." It also explains why some powertrain combinations may not be available in California—which has different requirements—when they can be purchased in other states.