Chapter 3

Emission Control and Alternate Fuels

Contents

TABLES

1. INTRODUCTION

In Chapter 2 you saw how controlling emissions is one of the four main concerns of engine-control strategies. Emission control is becoming a larger and larger factor in engine design. In this chapter, you will learn:

- How engine emissions form
- How engine controls operate to reduce emissions while meeting economy standards
- How engine emissions form smog according to climatic conditions
- How your cars and trucks on the road today will respond to coming changes in fuels—starting, fuel economy, driveability
- How your cars and trucks will be tested for emissions, particularly in the roughly 100 areas that are not attaining Clean Air standards as of 1993
- How alternate fuels affect the cars and trucks you're driving now, and how fuels will affect future vehicles

Green

"Green" is the worldwide term for an increasing concern for clean air and clean environment. Green will affect the cars and trucks you buy, beginning in the early '90s. Green is important enough that I will emphasize emissions and economy in this book, even in modifications for performance in Chapter 9. In Chapter 10, you'll understand how Inspection and Maintenance (I&M) for emissions depend on diagnostic systems of fuel injection/engine control for the troubleshooting.

I'll start with traditional emission control as it has defined electronic engine control and engine design.

2. EMISSION CONTROL

The development of today's fuel-injection and engine control systems links closely with the increasing demand for control of harmful exhaust emissions.

- Exhaust emission-control could not have been accomplished without fuel injection/engine control
- Fuel injection/engine control would not have been so successful and widely used without the challenges of meeting emission-control regulations

With changing legislation and tougher regulatory standards, engine-control systems have undergone significant changes. Emission standards have tightened, but modern engine control provides the driveability demanded by owners. Fuel-economy standards have tightened, generally requiring smaller engines, but fuel injection/engine control has added power.

2.1 Combustion By-products

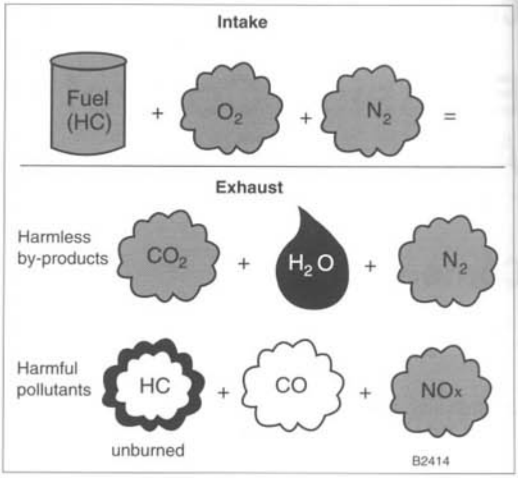


Fig. 2-1. The emission equation: Engine takes in fuel, oxygen, and nitrogen (top). Combustion produces harmless by-products: carbon dioxide, water, and nitrogen (middle); and harmful pollutants: unburned hydrocarbons, carbon monoxide, and oxides of nitrogen.

Combustion of the air-fuel mixture in the engine cylinders creates gaseous by-products that make up the exhaust. Some of these are relatively harmless, and some are known to be harmful. Traditionally three exhaust gasses have been controlled as the most harmful ones:

- Hydrocarbons (HC)
- Carbon monoxide (CO)
- Oxides of nitrogen (NO_x)

Emission of these three gasses is regulated by the Federal Clean Air Act of 1970. As revised in 1990, the regulations require reduced emissions beginning in 1994 and gradually tightening through the year 2000. Two new developments affect engine controls and the fuels you will be burning. 1) Better control of current regulated gasses is needed, as well as regulation of other polluting gasses, because of more vehicles being driven more miles. 2) Emissions depend on the motor-vehicle system—the powertrain/controls, and the fuel being burned. More on that later.

The exhaust gasses are normally colorless and invisible. Every television story concerning vehicle pollution shows pictures of smoking tailpipes, but I want to set you straight: A clear tailpipe is not the sure sign of a clean-burning engine; it may be pumping out invisible pollutants.

According to a recent report I reviewed, EPA studied 50 high-mileage gross polluters, all running closed-loop engine control. All failed the I&M test, some with ten times the allowable emissions. None of these gross-polluting vehicles showed blue smoke at the tailpipe.

Sometimes TV stories on pollution show pictures as in Fig. 2-2. They're not showing pollution, but steam.

Fig. 2-2. Tailpipe steam is visible when natural water vapor, H_2O, condenses in cold air. Pollution is normally not visible, and what's visible is not necessarily pollution.

Each engine family is certified under the Federal Test Procedure (FTP) to operate within the defined limits of HC, CO, and NO_x, as measured by the exhaust output during a controlled set of driving cycles.

Fig. 2-3. Every car and light truck engine is certified to meet EPA emissions standards, and from those measurements, standards for fuel economy. Drivers follow exact driving pattern. Dynamometer rolls load engine according to inertia weight and resistance to movement, including friction, tire rolling resistance, and aerodynamic drag.

Harmful Emissions—Controlled

Hydrocarbons (HC): Gasoline is a mixture of many compounds composed of hydrogen and carbon. In the combustion process, these elements combine with oxygen to form the by-products of water (H_2O) and carbon dioxide (CO_2). HC in the exhaust is unburned gasoline, the result of incomplete combustion.

Carbon Monoxide (CO): CO, a poisonous gas, is another result of incomplete combustion. When gasoline burns completely, the carbon exits the exhaust pipe as CO_2.

Oxides of Nitrogen (NO_x): NO_x refers to several kinds of nitrogen oxide which result from chemically combining nitrogen and oxygen during combustion. Nitrogen and oxygen are normal parts of air, but they exist in air as separate elements. As long as the combustion temperature stays below about 1300°C (2400°F), the nitrogen and oxygen do not combine. The nitrogen passes out the exhaust pipe just as it came in, separate and harmless. However, if combustion temperatures rise only slightly higher, the two elements combine chemically into various forms of of gasses that become NO_x, a key element of smog.

Harmless Emissions—Not Controlled

Carbon Dioxide (CO_2) (Greenhouse Effect): Until recently, carbon dioxide (CO_2) was considered a harmless emission. But now consider the "greenhouse" effect. Recent studies show that CO_2 is accumulating in the upper atmosphere, trapping global heat much as glass traps heat in a greenhouse.

Other greenhouse gasses include CFC (Freon—being phased out of air conditioners), NO_x, and CH_4 (methane, not Methanol). Most experts consider that global warming of only a few degrees would have disastrous worldwide results. The probable results are rises in global temperatures, successive heat waves, and iceberg melting, which could raise ocean levels to flood seaside properties worldwide.

The amount of CO_2 coming from our exhaust pipes is astonishing, even if invisible. See Fig. 2-4. The numbers work out like this:

- For 1 lb. of fuel = 3.2 lb. of CO_2
- For 1 gal. of fuel = 20 lb. of CO_2
- For 1 gal. of fuel = about 750 cu.ft. of CO_2, or twice the volume of a typical car

Any burning of fossil fuels such as oil, gasoline, and coal produces CO_2. Automobiles are a significant source. Unlike the other combustion by-products, we can't treat CO_2 to eliminate its effects. Reduction requires reducing the amount of fuel burned. That is the basis of the so-called "carbon tax."

What can we do in driving to reduce CO_2? Avoid unnecessary idling, for one thing. Turn off your engine when parked, even if it means less heating or air conditioning. Choose vehicles that burn less fuel with lighter, more efficient, smaller engines, because CO_2 increases with fuel burned. Impose your own restrictions on driving. Car pool, combine your trips, use public transit, walk.

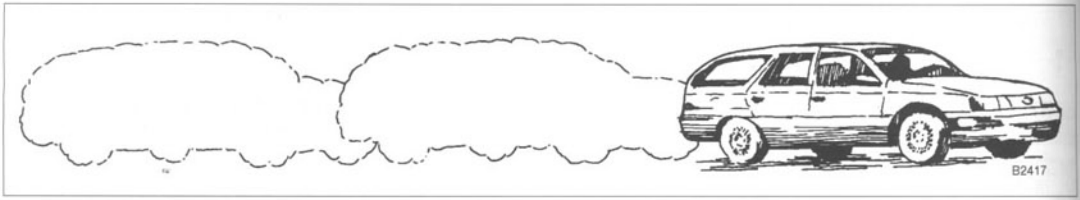


Fig. 2-4. For each gallon of gas burned, we leave behind a cloud of invisible CO_2 equal to twice the volume of a typical car.

Emission Limits

Why do government agencies keep tightening limits on cars and trucks? Haven't we done our share? Compared to pre-control, our 1980–90 cars emit 86% less HC, 92–96% less CO, and 76% less NO_x.

That's true, but we have more vehicles on the road, and we're driving more. Vehicle Miles Traveled (VMT) is increasing about 3% per year. Compounded, 3% a year is almost 35% more VMT in 10 years, double the VMT in the 33 years from the first emission control to the year 2000.

Tightening HC, CO and NO_x limits may be better for us than restrictions on driving, such as Mexico City, where "Each car must stay off the road one day a week." And, of course, we don't hear that much about controls imposed on other sources of pollution, such as refineries, powerplants, dry cleaners, bakeries (honest—gasses from the yeast rising in the dough!).

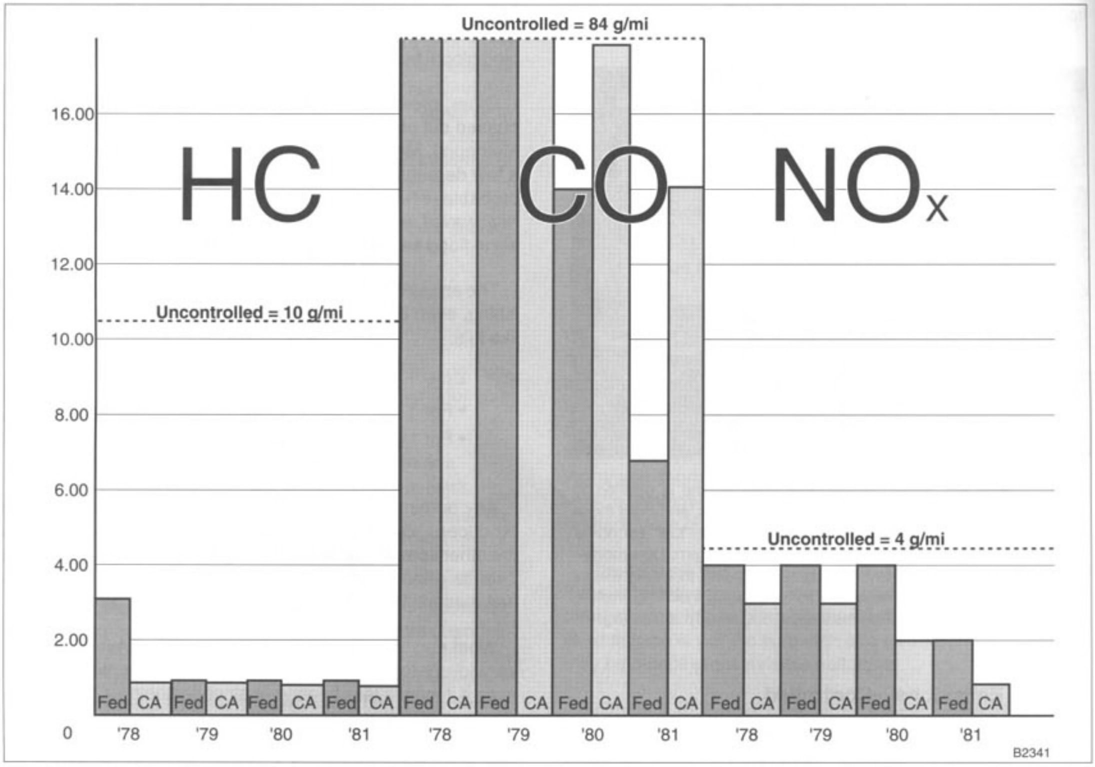
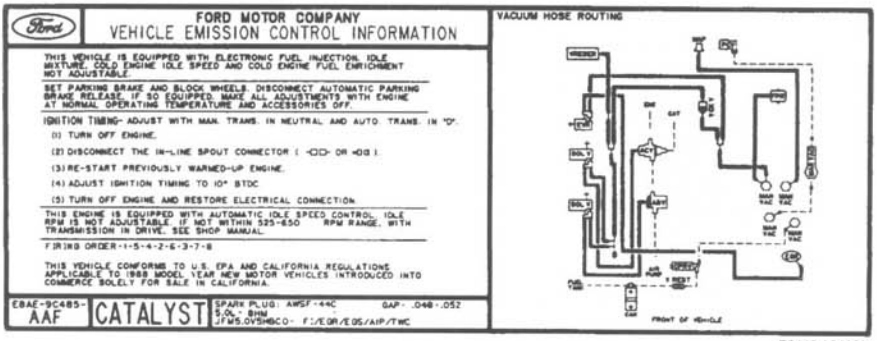


Fig. 2-5. Emission limits tightened from 1979–81, stayed level for rest of 1980s. Fuel injection became increasingly necessary to meet standards. Note '81 California CO limit was higher than Federal because California Air Resources Board (CARB) determined NO_x reductions were more important to smog control, and CO and NO_x are interrelated.



FORD MOTOR COMPANY
VEHICLE EMISSION CONTROL INFORMATION

THIS VEHICLE IS EQUIPPED WITH ELECTRONIC FUEL INJECTION. IDLE MIXTURE, COLD ENGINE IDLE SPEED AND COLD ENGINE FUEL ENRICHMENT NOT ADJUSTABLE.

SET PARKING BRAKE AND BLOCK WHEELS. DISCONNECT AUTOMATIC PARKING BRAKE RELEASE, IF SO EQUIPPED. MAKE ALL ADJUSTMENTS WITH ENGINE AT NORMAL OPERATING TEMPERATURE AND ACCESSORIES OFF.

IGNITION TIMING- ADJUST WITH MAN. TRANS. IN NEUTRAL AND AUTO. TRANS. IN "D".
(1) TURN OFF ENGINE.
(2) DISCONNECT THE IN-LINE SPOUT CONNECTOR (-◯◯- OR -◯◯).
(3) RE-START PREVIOUSLY WARMED-UP ENGINE.
(4) ADJUST IGNITION TIMING TO 10° BTDC
(5) TURN OFF ENGINE AND RESTORE ELECTRICAL CONNECTION.

THIS ENGINE IS EQUIPPED WITH AUTOMATIC IDLE SPEED CONTROL. IDLE RPM IS NOT ADJUSTABLE. IF NOT WITHIN 525-650 RPM RANGE, WITH TRANSMISSION IN DRIVE, SEE SHOP MANUAL.

FIRING ORDER-1-5-4-2-6-3-7-8

THIS VEHICLE CONFORMS TO U.S. EPA AND CALIFORNIA REGULATIONS APPLICABLE TO 1988 MODEL YEAR NEW MOTOR VEHICLES INTRODUCED INTO COMMERCE SOLELY FOR SALE IN CALIFORNIA.

E8AE-9C485-
AAF

CATALYST

SPARK PLUG: AWSF-44C GAP- .048-.052
5.0L- 8HM
JFM5.0V5HBCO- F:/EGR/EOS/AIP/TWC

B2418-A9426A

Fig. 2-6. Underhood labels identify the limit of the limits (50-state label shown). 49-state (Federal) vehicles cannot be registered new in California (registering less than 7,500 miles on the odometer).

Doing Better than the Limits

As emission limits tighten (**Table a**), governments encourage manufacturers to do better than the limits by allowing them pollution credits against future-year pollution excesses. The 1993 Ford Escort/Mercury Tracer sold in California meets the 1997 limits, four years ahead of schedule. HC is cut by over 50%, with a loss in fuel economy of one mpg. A larger catalytic converter is mounted closer to the engine, designed to heat up sooner. The oxygen sensor also heats up sooner, aided by an electric heater. The law also allows CAFE credits for beating CAFE, and for using alternate fuels.

"50-state cars," "49-state cars," "California cars," can there be different cars for different states? Yes. And why not a New Jersey car? The answers are simple, and yet they are not. In Southern California, the warm climate and the terrain, an open bowl facing the ocean breezes, turned out to be "ideal" to discover how vehicle engines contribute to smog. Californians operate about 1 out of 7 vehicles in the U.S., so you understand why the state began pollution control in 1966, before the rest of the U.S. followed in 1968. When the first Federal limits were legislated, California insisted on tighter limits for itself. Congress agreed, but decreed that any other state that wanted tighter limits for itself could only adopt California limits.

- 50-state car qualifies to Federal and CA limits
- 49-state car is OK to Federal limits, but not to CA. Some 49-state cars are identical to CA cars, but are labeled 49-state to qualify for the shorter Federal warranty requirements. A 49-state car may not be licensed in CA with less than 7,500 miles on the odometer
- A California car qualifies only in CA and may not be sold outside the state

It's bad enough that the world's car makers must build two quite different cars for the U.S., but to build 50 different sets of limits for one country, requiring 50 different engine controls! New York, Massachusetts and several other states (mainly North-Eastern) with their own serious smog problems are passing legislation requiring cars sold in their states to conform to California limits. So perhaps we're headed for something like "10-state" and "40-state" cars.

Table a. Changing Limits—Grams/Mile

	Through 1992		1993–1996	
	FED	CA	FED	CA
HC	0.41	0.39	0.25 NMHC	0.25 NMHC*
CO	3.4	7.0	3.4	3.4
NO_x	1.0	0.4–0.7	0.4	0.4–0.7

*Beginning 1994, California requires that NMOG be measured instead of NMHC. This has the effect of requiring fuel of less volatility. Each manufacturer must *average* 0.25 NMOG for its fleet, with no vehicle higher than 0.39 g/mi. Each year, these NMOG limits tighten, gradually reducing NMOG to 25% of the 1994 standards. Also, HC limits tighten beginning 1994. Manufacturers must certify these limits for the first 50,000 mi. of operation, and are allowed slightly greater HC and CO to 100,000 mi. After that, the owner is responsible for meeting the applicable limits.

As the new limits phase in, a greater percentage of cars are required to meet the limits each successive year (sooner in California). For example, as shown in **Table b**, by model year 1995, 100% of each maker's passenger cars and light duty trucks sold in California must meet the new limits, but in the other 49 states only 80% need to meet the limits.

Table b. Phase In of New Emission Limits

	1993	1994	1995	1996
California	40%	80%	100%	100%
Federal	–	40%	80%	100%

2.2 Smog Formation

Smog is a fact of life that has been affecting our cars and trucks since the late 1960s. Increasingly, it will affect our driving and indeed, what we can do to our vehicles. Its impact on our environment, our health, indeed our lives are so important that governments and industry are working together to reduce its effects and to improve the quality of our lives. Those of us who love cars and who love to drive are coming to recognize what we can do to be responsible motorists.

Fig. 2-7. The real costs of smog—health, vegetation, property—are recognized as greater than costs of reducing air pollution.

The word "Smog" came in with cars, right? Well, cars and trucks have made smog serious worldwide, but the word appears in the 1905 Oxford English language dictionary. Smoke from coal heating, plus fog in London—they called it "smog."

Today, Smog refers to a "soup" of many gasses, principally ground-level ozone, cooked in the sunlight from gasses emitted from motor vehicles. Besides smog, vehicle air pollution includes carbon monoxide (CO), and oxides of Nitrogen (NO_x) from industry, plus dust and particulate matter.

In high concentrations, ground-level ozone is hazardous to people and growing things, such as trees and plants. Ozone (O_3) is poisonous because it contains an extra atom as compared to good oxygen (O_2). You may hear also of upper-level ozone that protects the Earth from ultraviolet rays from the Sun. Formed by different processes, upper-level ozone is good; ground-level ozone is bad.

Effect of Climate

As air pollution has increased and spread to more cities, new measurements show that it varies with the seasons and the climate. The seasonal effects are so important that fuel blends sold in different areas of the country are tailored to the season. How the different fuels are handled by your engine-control system can affect starting, driveability, performance and economy.

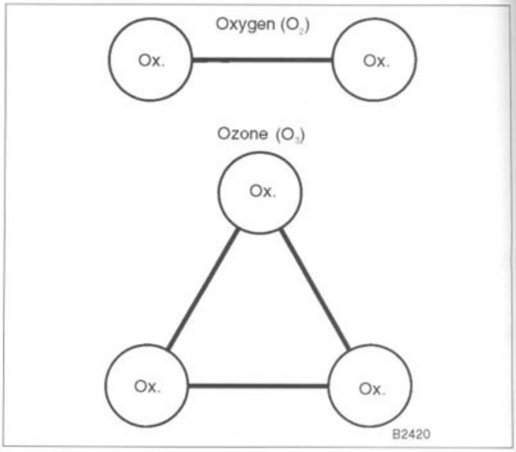


Fig. 2-8. Ozone is O_3, an extra atom of oxygen attached to an ordinary oxygen molecule, O_2. In summer, ozone is most important threat from smog. In longer, hotter, sunny hours, smog increases, resulting from more cooking of the "soup".

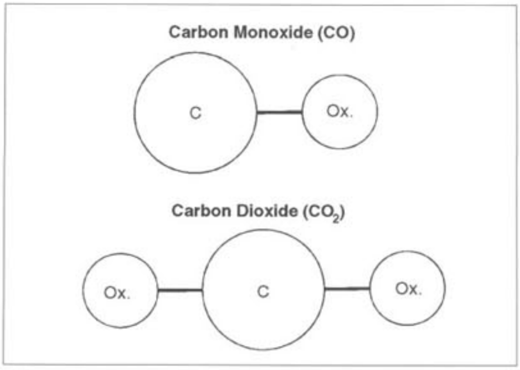


Fig. 2-9. Carbon Monoxide (CO) combines one atom of carbon with one atom of oxygen. In winter, (CO) is most important air pollution threat. CO increases because 1) more cold starts with more cold-start emissions, and 2) temperature inversions and weather concentrate pollutants in lower atmosphere.

Non-attainment Areas

Air quality worsens according to climate, number of vehicles, miles traveled, vehicle condition, and traffic idling. Based on summation of daily monitoring by EPA, most major cities reach or exceed dangerous levels of ozone and/or CO on at least several days a year. They fail to "attain" Federal air quality standards. **Table c** lists the worst offenders. You may notice different engine operation (driveability, cold-starting, fuel

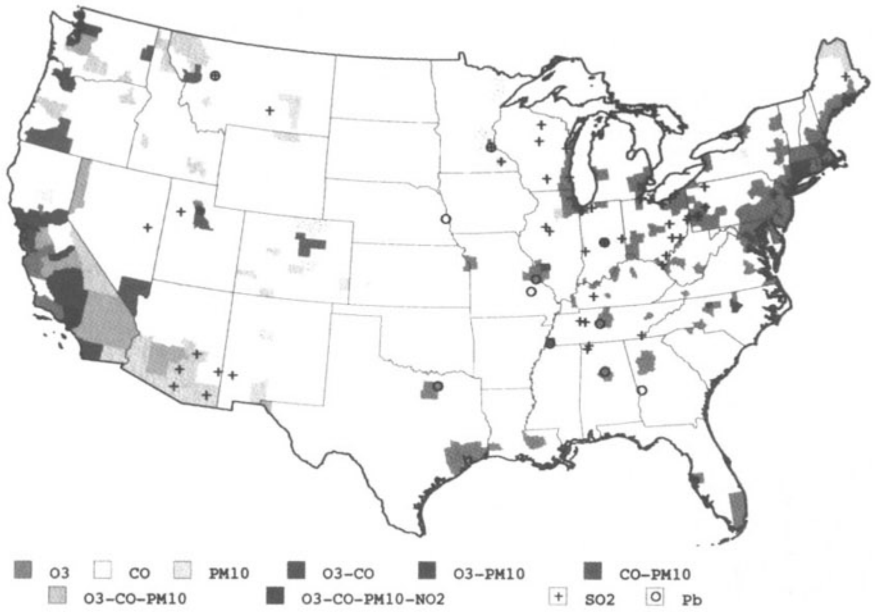


Fig. 2-10. EPA monitoring stations measure air quality to determine when areas do not meet air-quality standards. "PM-10" is dust and soot suspended in air.

economy) depending on your part of the country—depending on if you drive in a "non-attainment" area. In non-attainment areas, two things may change your vehicle operation:

- Fuel may be modified to reduce emissions
- More Inspection and Maintenance (I&M) may be required for licensing

Table c. Top Smog Cities

Ozone Metropolitan Areas	Ozone Days	CO Cities	CO Days
1. Los Angeles Anaheim/Riverside CA	137	1. Los Angeles CA	71
2. Bakersfield CA	44	2. Spokane WA	37
3. Fresno CA	24	3. Oshkosh WI	32
4. New York/New Jersey/Connecticut	17	4. Steubenville OH, Weirton WV	31
5. Sacramento CA	16	5. Las Vegas NV	26
6.Chicago IL/Indiana/Wisconsin	13	6. New York City	26
7. San Diego CA	12		

NOTE —
Five of the big 7 ozone areas are in sunny California. No wonder California has taken the lead in pollution controls. New York City & Chicago represent largest vehicle concentrations. San Diego claims (with good reason) that one-third of their ozone pollution is blown down the coast from Los Angeles. The complete list includes about 100—varying from year to year.

Other Gasses Emitted

We have improved our ability to measure low levels of the traditional exhaust gasses. Recent research shows that some other emitted may increase smog formation at ground level, while other emitted gasses may decrease smog formation. And some gasses in the stratosphere affect global warming, adding to our smog vocabulary:

Formaldehyde: A compound of hydrogen, carbon and oxygen, HCHO. Produced in trace quantities from combustion of alcohol-based fuels, it irritates eyes, nose and throat, for some people even at minimal levels. May increase cancer risk.

Methane: A particular form of hydrocarbon, CH_4, found in natural gas. Methane does not react to form smog. A Greenhouse gas, it contributes to global warming, along with CO_2.

NMHC: Non-Methane Hydrocarbon, a Federal (EPA) standard of measure. NMHC is measured instead of HC because methane is stable and does not react to form ground-level ozone.

NMOG: Non-Methane Organic Gas, a California standard *of measure beginning in 1993. These include hydrocarbons,* alcohols, aldehydes, ketones and ethers.

VOC: Volatile Organic Compounds, a broad category including the hydrocarbons, NMHC, and NMOG that vaporize at ambient temperatures (volatile), and are carbon-based (organic).

Also added to our vocabulary are Oxygenates—fuels or fuel additives containing oxygen that burn with less oxygen, forming less Carbon Monoxide (CO):

- Methanol, 50% oxygen by weight
- Ethanol, 35% oxygen by weight
- MTBE, 18% oxygen by weight—an additive
- ETBE, 16% oxygen by weight—an additive

Ozone-forming Potential

Reactivity Adjustment Factor (RAF) is a measure of the ozone-forming potential of any Volatile Organic Compound (VOC). *California (and states following CA limits) measures* the combined effect on smog of the vehicle and the fuel it burns. After the emitted gasses are measured, they are multiplied by the RAF. So, the cleaner the fuel the vehicle is designed to operate on, the less restrictive the emission controls.

The basis for the new approach to emission control is ozone-forming potential. As it turns out, this is affected by the ratio of Volatile Organic Compounds (VOC) to NO_x. The strategies to reduce smog may vary in different parts of the country, and in different seasons:

- With low VOC ratio (VOC less than 10 times NO_x), control VOC more than NO_x
- With high VOC ratio (VOC more than 20 times NO_x), control NO_x more than VOC.

Controlling NO_x means measuring emissions under load, unlike most emission testing in the early '90s. Emission testing under load affects how vehicles are "smog-checked."

Why Green?

Emission control can get pretty complicated and you may be asking, Why Green? Health impacts, for one thing. Ozone can cause burning sensations in your lungs and can aggravate asthma, making it harder to breathe. (Besides attacking humans, ozone attacks plants, plastics, rubber.) Other smog *pollutants irritate your eyes. CO can reduce oxygen flow to* your brain, impairing your motor coordination. CO interferes with your heart's delivery of oxygen to your body, aggravating chest pains, angina.

Acid pollution for another. The formation of nitric acid and sulfuric acid turns into acid rain. In Los Angeles, the fog can be as acidic as lemon juice—imagine that in your lungs. Trees die; the Greens party in Germany calls it "Waldsterben" or forest death. Lakes and streams become too acidic to support fish. Buildings are eaten away, especially marble.

Now that you know some of the combustion by-products and the importance of controlling them, I will discuss how electronic engine controls operate to reduce them.

2.3 Effects of Air-fuel Ratios on Pollutants

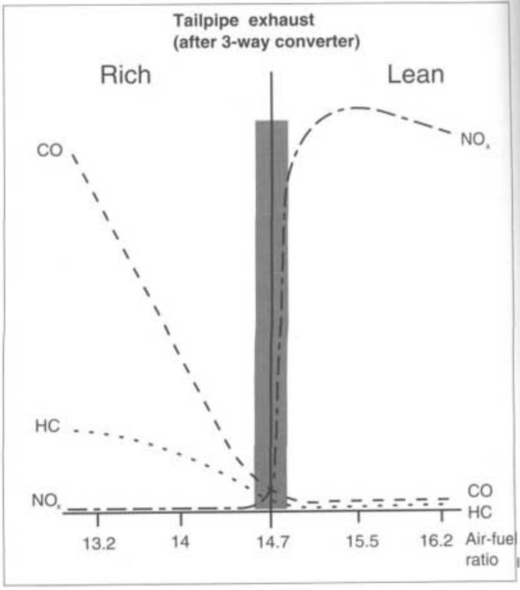


Fig. 2-11. Tailpipe exhaust after converter shows least emission of controlled gasses when air-fuel ratio changes back and forth in narrow range around ideal or stoichiometric 14.7.

Just as variations in the air-fuel ratio change power output and fuel consumption, they also change exhaust emissions. As I described, the air-fuel ratio is a key to complete combustion of the fuel. It also affects combustion temperature that, in turn, affects the formation of pollutants. What's more, the air-fuel ratio changes exhaust-gas oxygen levels, and that affects the operation of the catalytic converter.

- Too rich (too little air), then the fuel will not burn completely. The unburned fuel comes from the engine as higher HC and CO
- Too lean (too much air), then lean misfire increases HC (raw fuel), and elevated combustion temperature increases NO_x
- When the mixture is ideal, 14.7, the catalytic converter can treat the exhaust-gas mixture to deliver the least emissions from the tailpipe

When flying piston-engine aircraft, emissions are not as important as engine temperature affected by air-fuel ratio. I adjust for a rich air-fuel mixture during high-power climbs to keep the engine cool. (The effect in a car will reduce NO_x.) Then, during cruise, I lean the mixture for economy, knowing it will increase engine temperature. If the needle on the engine temperature gauge starts to rise above the green arc, I know I have leaned the mixture too much. If you install an exhaust gas temperature (EGT) gauge on your vehicle engine, you can make similar observations (though the mixture is not usually cockpit-adjustable).

2.4 Effects of Spark Timing on Pollutants

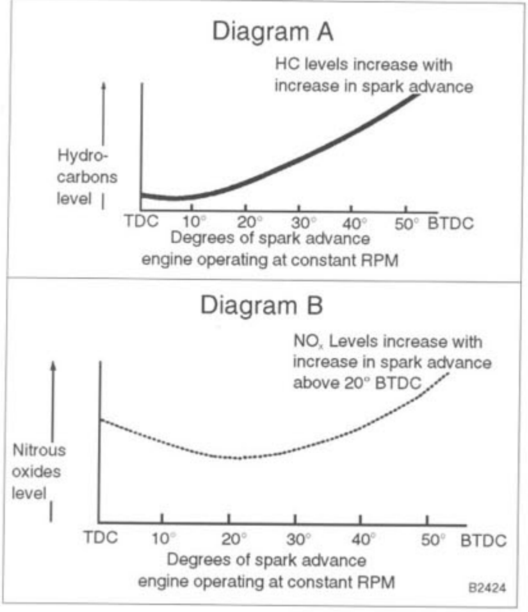


Fig. 2-12. Lowest HC (HydroCarbon) emissions result from spark timing near TDC. As timing is advanced, say to 50 degrees, HC emissions more than double. Emission of NO_x (Nitrogen Oxides) increases with spark advance above about 20 deg. BTDC.

2.5 Exhaust Gas Treatment

So far, we have been talking about the effects of air-fuel ratio and spark timing on engine-out exhaust.

Some Ford engines (generally the larger) use Exhaust Gas Recirculation (EGR) to reduce the formation of NO_x. Some engines, again the larger, use Air Injection (thermactor) to oxidize (burn) HC and CO in the manifolds and in the catalytic converter.

Exhaust Gas Recirculation (EGR)

Exhaust Gas Recirculation (EGR) is a technique for reducing the formation of oxides of nitrogen (NO_x). The EGR valve routes a small amount of exhaust gas (5 to 15%) into the intake manifold and back into the combustion chambers. This dilution of the air-fuel mixture lowers combustion temperature. You'll remember that excessive combustion temperature is the cause of NO_x formation.

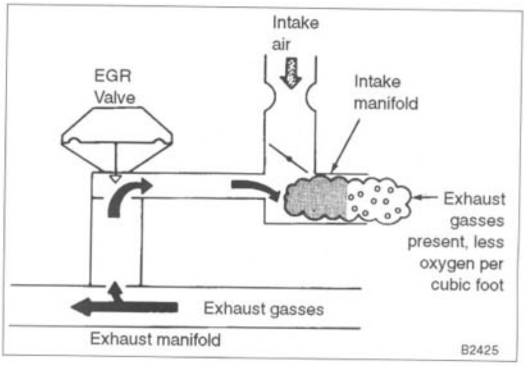


Fig. 2-13. Exhaust gas is admitted from the exhaust manifold into the intake manifold (operating at a lower pressure) through a control valve.

Air Injection

One of the early approaches to reduce emissions was air injection. An engine-driven air-injection pump, commonly referred to as a "smog pump," can deliver air into the exhaust manifold. Adding air during warm-up tends to burn HC and CO resulting from the rich starting mixtures, reducing emissions. Not incidentally, this increases underhood heat. Exhaust-manifold burning has the additional advantage of heating the Exhaust Gas Oxygen Sensor, and the catalytic converter, both of which must be hot to operate.

Pulse-Air is another way to add air to the engine exhaust. Pulse-Air allows air to be drawn from the air cleaner through a set of reed-valves. The natural pulsations in the exhaust pressure operate the reed-valve. It opens to allow air into the exhaust stream when the pressure is lower, and closes to prevent backflow when the pressure is higher.

With electronic engine control, air can be added to the oxidation converter part of the catalytic converter, described below. This can come from the Air Injection pump, or from the Pulse Air Valves to burn the HC and CO in the catalytic converter instead of in the exhaust manifold. Ford refers to air injection as Thermactor systems. In the '90s, few Ford engines

Fig. 2-14. Many larger Ford engines use smog pumps, engine-driven air pumps, to deliver oxygen (air) into exhaust system, either eat xhaust manifold or at catalytic converter.

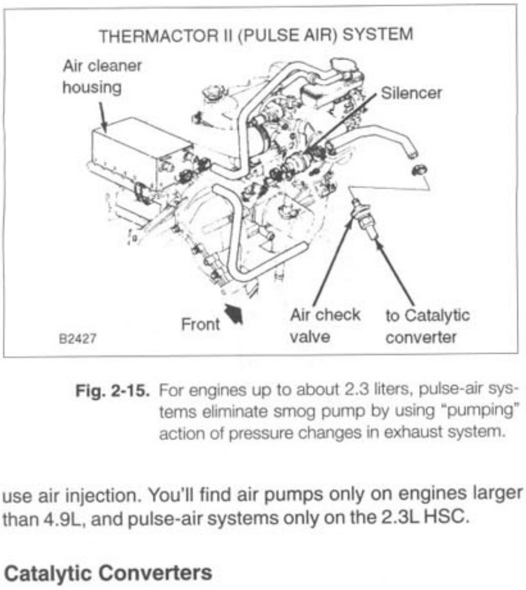


Fig. 2-15. For engines up to about 2.3 liters, pulse-air systems eliminate smog pump by using "pumping" action of pressure changes in exhaust system.

use air injection. You'll find air pumps only on engines larger than 4.9L, and pulse-air systems only on the 2.3L HSC.

Catalytic Converters

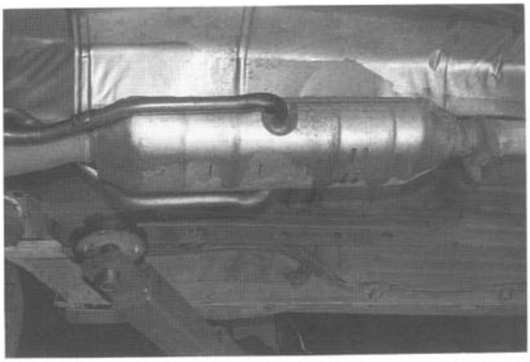


Fig. 2-16. Catalytic converter treatment of exhaust generates heat. Converter heat shield protects vehicle and anything combustible under the vehicle. Many Ford cars and trucks use two converters.

Catalytic converters form part of the exhaust system, located between the exhaust manifold and the tailpipe. The catalytic converter contains special materials, called catalysts. Catalysts promote additional chemical reactions with the pollutants in the exhaust gas and convert them into less harmful substances. The term "catalytic" means the conversions take place without affecting the catalyst itself, usually small amounts of rare metals such as platinum, pallaium, and rhodium.

Oxidation Catalysts (OC) make use of air supplied by an air pump or Pulse Air Valve. Oxygen in the air converts CO to CO_2 and converts HC to H_2O. In early years, Ford engine control used OC in combination with Three-Way catalysts (TWC).

Three-Way catalysts reduce NO_x as well as oxidize CO and HC. The combination of a Three-Way Catalyst and an oxidation catalyst in one housing—a dual-bed catalyst—produces a series of chemical reactions that reduce all three pollutants. A disadvantage of dual-bed catalysts is that they rely on a slightly rich air-fuel ratio that increases fuel consumption. In later years, you'll find only TWC, or two TWC on engines larger than 3.0L.

To work most efficiently, a converter must be hot enough to begin the conversion of exhaust gasses. Conversion further raises the temperature of the converter, increasing its efficiency. For this reason, it is placed in the exhaust system as near to the engine as possible. Most catalytic converters require heat shields to prevent combustion of something under the vehicle.

A series of misfires in a cylinder can deliver raw fuel into the converter, making it too hot. Too hot for too long can permanently damage the converter, so don't drive with a bad plug or wire.

Remember that, in complete combustion, $HC + O_2 + N_2 = CO_2 + H_2O + N_2$. Incomplete combustion produces CO instead of CO_2 and high temperature combustion, as from a lean mixture, combines $N_2 + O_2$ to form NO_x. See earlier Fig. 2-1.

In the three-way catalytic converter, we want to 1) add oxygen to oxidize the HC and CO to make H_2O and CO_2, and 2) take away oxygen to reduce NO_x, separate it into N and O_2.

You might think it's as simple as taking the oxygen away from the NO_x and giving it to the CO. Stated simply, that is what happens in some three-way catalytic converters.

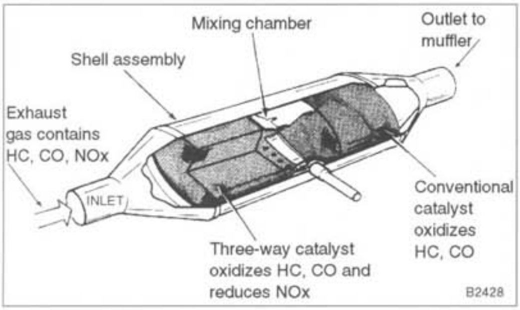


Fig. 2-17. Dual-bed catalytic converter combines three-way catalytic converter (TWC) with oxidation catalyst (OC).

The catalytic material in the converter helps these chemical reactions take place. For reduction (taking away oxygen from NO_x) to match oxidation (adding oxygen to CO and HC), the proportion of the gasses in the engine exhaust must be controlled very closely. That means the intake air-fuel ratio must always be in the narrow range near stoichiometric—an air-fuel ratio of 14.7 parts of air to one part of fuel. In some Ford three-way converters, air (oxygen) is pumped in after the reduction to further enhance oxidation.

> The story of emission control, three-way catalytic converters, carburetors, fuel injection and oxygen sensors is a fascinating story of worldwide development. I had the good fortune to be there at the beginning.
>
> In 1971, I was writing technical films for a corporation with a new development—one of the first catalytic converters. In the lab, they showed me good control by the converter, but only if the engine had precise control of air-fuel ratios. With 1971 carburetors, they couldn't even control air-fuel mixtures adequately on one car in the lab, let alone in quantity production.
>
> About the same time I was working with engineers in the Bendix Research Labs on another project. They showed me their system for electronic fuel injection that could provide the kind of precise control needed, using a feedback system (closed loop). By 1974 Bendix demonstrated the system to Cadillac. Cadillac adopted Bendix MPI without the feedback, apparently satisfied they could meet 1976 emission limits without it. They called the system EFI. It followed 9 years after the Bosch EFI introduced in 1967 by VW, and operated much the same.
>
> Under the cross-licensing agreement, in Europe Bosch pushed ahead, adapting the oxygen sensor to the L-Jetronic EFI system. In 1978, Volvo and Saab introduced Bosch feedback EFI systems to meet California emission limits. Also in 1978, Ford and other U.S. manufacturers introduced some electronically-controlled feedback carburetors to solve the same emission problems.

Earlier Fig. 2-11 illustrates the degree of emission control afforded by a three-way catalyst on an engine running very near the stoichiometric ratio. You can see that if the air-fuel mixture strays from 14.7:1, the proportion of exhaust gasses (HC, CO, & NO_x) exiting the converter changes. As the air-fuel ratio becomes leaner, hotter combustion temperature causes increased production of NO_x. A rich mixture will produce an excess of HC and CO.

With the air-fuel ratio maintained at 14.7:1, the converter can reduce the emission of all three pollutants to very low levels. Precise control, however, is very important to the successful operation of three-way converters. Any significant deviation from 14.7:1 upsets the balance of the chemical reactions in the converter and the level of one or more pollutants increases dramatically. Development of three-way catalytic converters has been accompanied by development of more sophisticated systems for the fine control of air-fuel ratio.

Canister Purge—Evaporative Fuel Vapor

Unburned hydrocarbons can pollute the atmosphere another way unless they are contained. Canisters under the hood contain fuel vapors forming over the liquid fuel in the tank. Yet the tank must not be sealed, otherwise, the fuel pump could not draw fuel for the engine.

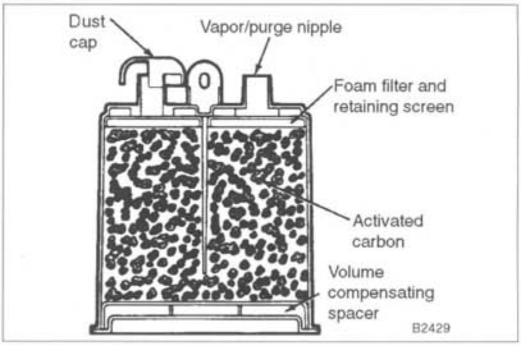


Fig. 2-18. Carbon canister stores fuel vapors from tank and engine. Canister is purged by drawing fuel vapor into engine, under control of the control module.

The canister is purged by drawing the fuel vapors into the engine but only under certain engine conditions, as discussed in Chapter 8. Purging must be controlled by a valve so the vapors do not disturb the proper air-fuel ratio.

The more you know something about emissions and the limits placed on them by legislation, the more you'll understand how fuel-injection and engine-management systems work.

Some Ford fuel-injected vehicles reduce the amount of emitted gasses by improved engine design. These engines are able to eliminate some types of emission control that interfere with driveability, including Exhaust Gas Recirculation (EGR) and air pumps.

Table d. 1992–'93 Engines Meeting Limits Without Some Emission Control Systems

Model	EGR	Secondary Air
Festiva 1.3L	No	No
Capri 1.6L	No	No
Escort/Tracer 1.8L	No	No
Escort/Tracer 1.9L	Yes	No
Probe 2.0L	Yes	No
Probe 2.2L	Yes	No
Mustang 2.3L OHC	Yes	No
Probe 2.5L V6	Yes	No
Probe 3.0L Taurus SHO 3.0\3.2L	No, (Y CA) Y (3.2L)	No
Taurus/Sable 3.0L	Yes	No
T'Bird 3.8L SC	Yes	No
T'Bird/Cougar/ 3.8L Continental/ Taurus/Sable-Police	Yes	No
Crown Victoria/ Grand Marquis 4.6L Mark VIII 4.6L-4V	Yes	No
Ranger 2.3L OHC Truck	No except M/T	No
Ranger 2.9L Truck	No	No
Aerostar 3.0L Van	No	No
Ranger/Explorer/ Aerostar 4.0L	No	No

2.6 Conflicting Demands on Engine Control

I've described engine needs for a combustible mixture of air and fuel, and how variations in mixture influence performance. And I've described engine needs for variable spark timing. While power is always a requirement, modern engine control systems face additional demands:

- Fuel economy, due to legislation and increasing concern over cost and availability of gasoline
- Exhaust emissions, due to environmental concerns and resulting legislation
- Driveability, due to drivers' demands for quick starting and smooth, trouble-free performance under any operating conditions

> In designing an engine and its control system, two regulation factors must have priority: emissions and economy. Unless it meets standards for both emissions and economy, the vehicle is not street-legal to sell in the U.S. That may seem tough, but think about this—Indy cars racing at 220 miles per hour must also consider fuel economy. Each car is limited to 278 gallons of pure methanol, total fuel for the race. If they don't get 1.8 miles per gallon, they don't cross the finish line. For comparison, that's equivalent to over 3 miles per gallon on gasoline (higher gasoline energy content). Indy drivers don't worry about emissions, but they adjust the electronic controls from the cockpit to enrich the mixture to increase power when necessary, and to lean the mixture for economy if necessary to finish. You better believe those drivers watch fuel economy as it trades off with performance.

Each of these factors places different demands on the engine-control system, and the design engineer must consider tradeoffs. Adjusting the system for maximum power also means increasing fuel consumption. Minimizing fuel consumption means sacrificing power and driveability. Choosing either maximum power or minimum fuel consumption may mean increased exhaust emissions. The modern fuel delivery system must be able to maintain strict control of air-fuel ratio to achieve the best compromises and meet these conflicting demands in the most acceptable way. This means slight sacrifices of power and fuel economy in exchange for optimum emission control.

Fuel injection can maintain the air-fuel ratio within closer tolerances than carburetor systems. For the manufacturer, fuel-injection means better emission control and better fuel economy, both important in meeting increasingly stringent government regulation. For the owner, fuel-injection means achieving fuel economy and emission control while preserving driveability and maximum power.

Fuel Economy—CAFE

CAFE (pronounced "cafay") stands for Corporate Average Fuel Economy. Each corporation must meet rated fuel economy averaged for all domestic or import cars or trucks produced in a model year, or pay a stiff fine.

Ford and each other manufacturer must meet the CAFE standards for its domestic fleet, and separately for its import fleet. For purposes of the law, the economy figure is the rated test miles per gallon, calculated 55% CITY rating, and 45% HIGHWAY rating. As most people know, the ratings are made under controlled conditions for comparison of all vehicles, and to conform to legislated limits. The ratings do not represent what mileage you will "get."

While some customers of the 1990s rate power and reliability higher on the list than economy, other customers choose their vehicles for economy as they face rising oil prices and increased taxation. Ford must consider both customer de-

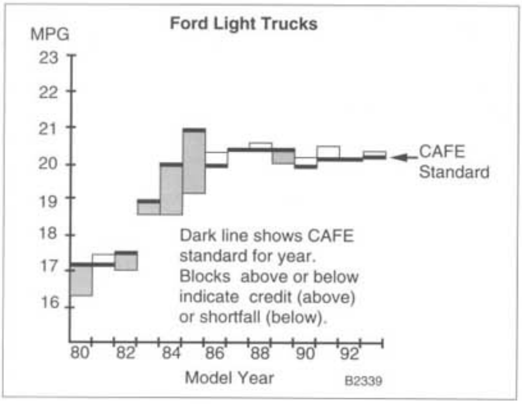


Fig. 2-19. Light truck fuel economy (CAFE) standards.

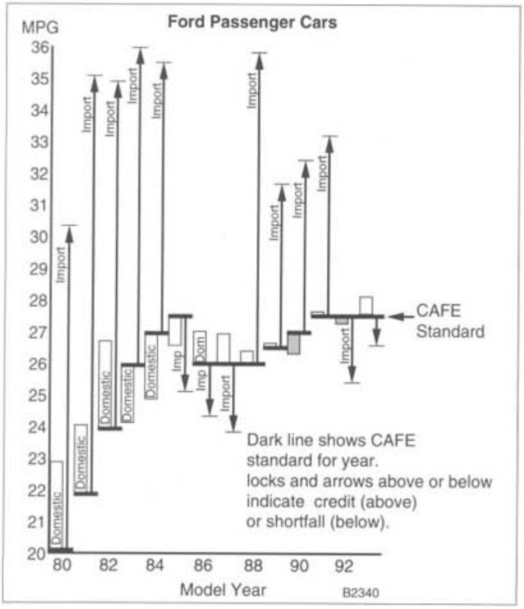


Fig. 2-20. Domestic passenger car fuel economy (CAFE) standards are averaged separately from imports.

mands, and CAFE standards. Higher standards are legislated in the interests of reducing emissions and global warming, and in reducing the U.S. dependence on imported oil.

The industry trend in composite (55/45) rated miles per gallon (mpg) turned upward beginning in 1975, as catalytic converters replaced engine de-tuning as a means of emission control. Government legislation established average mpg standards to apply to the total passenger car fleet and to the truck fleet each manufacturer delivers each year. Imports are averaged separately. Further, the car target mpg standard raised each year, starting at 18 mpg in 1978, and rising to 27.5 mpg in 1985. After a brief cut back in 1986 to 26 mpg, federal standards were again raised to 27.5.

Originally, trucks were exempt from legislation limiting emissions and fuel consumption. But, beginning in 1980, light truck standards were established. This is in part recognition of the increasing use of light trucks, including vans, such as Mercury Villager and Ford Aerostar, as passenger cars.

Credits are allowed to offset CAFE shortfalls, carried forward or backward for 3 years. Notice how 1992 model year import MPG drops when large cars (Crown Victoria and Grand Marquis) are rated as imports instead of domestics.

3. ALTERNATE FUELS

Gasoline, refined from petroleum, is one of the most concentrated forms of energy. Yet its worldwide use contributes to air pollution and greenhouse gases, and increases U.S. import of what could become a scarce resource.

I've discussed how emission control requires changes in engine hardware. But it's important to consider the engine/fuel combination. Beginning 1995–96, in all states, fuels are changing to help reduce auto pollution. I'll start with the ways new gasoline fuels affect your regular Ford emissions.

To encourage the development and sale of alcohol-based fuels, EPA modifies the fuel economy rating, counting only the gasoline burned, according to design intent. Thus, an M-85 vehicle, rated at 15 mpg, is designed to burn 15% (15/100) gasoline. It scores the same as a 100 mpg car. That does good things for the manufacturer's CAFE.

Beginning in 1993 in California, Ford and others began selling Flexible Fuel Vehicles. Based on driving such a vehicle, I can report that the system is "transparent"—you don't notice any difference, except the need to fill up more often. You may notice the instrument-panel readout from the fuel sensor. Mine read "83", or 83% methanol, M-83. Actually, it was telling me that a little gasoline, M-0, was mixed with mostly M-85. Of course, that changes as a result of fill-ups.

How do alternate fuels affect engines you're now driving, and how do alternate fuels affect future Ford powerplants?

3.1 Dedication and the Future

Any consideration of alternate fuels looks at the cars and trucks on the road, and at the fuel distribution network. You

Changing engine hardware affects new cars and trucks being built and sold, but it takes up to 20 years to turn over 95% of the fleet

Changing fuel affects almost all vehicles on the road immediately

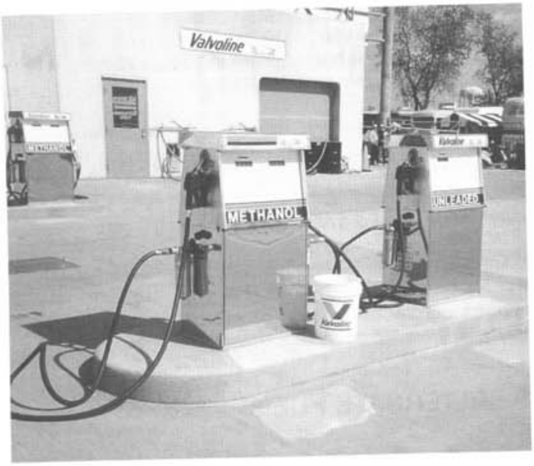


Fig. 3-1. Indy race cars are fueled by Methanol to help increase power, but they can't burn pump gasoline—they are "dedicated" vehicles.

can expect to see three classes of vehicles, 1) Existing, 2) Dedicated, and 3) Transition. Ford fuel injection/engine control systems are involved in all three:

1. Existing vehicles, the 170 million on the road today (and most of those being built in the near future) must operate on what can be distributed widely. Any change to the fuel must satisfy existing engines and fuel systems.
2. Dedicated vehicles operate only on a specific alternate fuel. The advantage is a no-compromise design that takes advantage of the strengths of the alternate fuel. For example, the anti-knock rating of pure methanol allows higher compression ratios and more power. The disadvantage is fewer filling stations.
3. Transition vehicles, also known as Flexible Fuel Vehicles (FFV), operate on alternate fuels, and also on existing fuels, including any mix. Advantage—fill up anywhere, but lose the benefits of high compression because the engine and its control system must still operate with gasoline. Transition vehicles emit less CO and reduce dependence on foreign oil. They also help to establish the distribution network for alternate fuels. But, because of the necessary compromises, transition vehicles can cost more and satisfy less.

3.2 Fuels You May Be Burning—Existing Vehicles

In general, the objectives of providing cleaner gasolines are:

- Reduce smog-forming emissions by reducing aromatic HC
- Reduce cancer-causing benzene
- Maintain catalytic converter efficiency by reducing sulfur

In addition to the familiar Regular (87 Octane), and Premium (91 Octane), you can now burn Mid-Grade (89 Octane), depending on instructions in your Owners Manual. Some aromatics, such as Toluene, increase octane, but refineries juggle other compositions to maintain the normal ratings. Octane ratings are not considered part of emission control.

> **NOTE —**
> If you're considering adding lead to your fuel, be aware that, since 1996, it is illegal to burn leaded fuel in any vehicle on U.S. public roads. Manganese additives, such as MMT, have been illegal in California since 1977.

Beyond Octane ratings, you have little or no choice in the pump gas you burn. Rather, your fuel depends on your part of the country—the smog problems as measured, daily, by:

- Non-attainment of Ozone standards
- Non-attainment of CO standards

The solutions to Ozone are different from solutions to CO, and if you have both Ozone and CO, that's different again.

Those measurements are affected by (not necessarily in this order):

- Local weather, temperature inversions--warm air above cool air
- Prevailing winds and terrain
- Pollution "transported" by prevailing winds from upwind sources
- Concentration of vehicles and traffic congestion

One at a time, I'll look at what you'll be burning in the foreseeable future, depending on where you're driving:

1. Conventional gasoline
2. Winter oxygenated gasoline
3. Reformulated gasoline, Federal RFG, Phase I
4. Reformulated gasoline, Federal RFG, Phase II
5. California RFG, Phase II

In some parts of the country, there's controversy about these new fuels, but tests by several industry groups and by several government agencies agree on a number of things when comparing new fuels to previous fuels:

- No engine changes required, such as tune up
- No meaningful difference in performance or acceleration
- No effect on vehicle warranties
- Some slight loss in mileage

Conventional Gasoline

Conventional gasoline is sold in parts of most states (not California) where air quality is satisfactory, with few "non-attainment" days, and in most of the nation's "open-space" ar-

As of 1997, if you drive coast-to-coast, or even cross-country, you might be burning several different kinds of gasoline. All of these are different from the fuels of the early 1990s, including what was then called "Reformulated Gas." And some fuels you burn in 1997 will probably change by the year 1998, and again by 2000. In most parts of the country, summer fuels differ from winter fuels. During spring changeover, summer fuels may cause longer crank times on a real cold day. Why? Lower vapor pressures, but fuel-injected engines are less affected than carbureted.

eas, but not most of the nation's cars. The differences from most previous gasolines:

- Lower vapor pressure (volatility) to reduce HC emissions
- Additives (detergents) to reduce engine deposits
- Fuel economy losses expected: about 1% in the summer, with usual winter weather losses

Winter Oxygenated Gasoline

Winter oxygenated gasoline is used where CO measures too high. It is used in most states (not California), and is required where air-quality measurements show significant CO non-attainment days. It is generally sold during four to five "high CO" months (such as October through May), with the exception of being sold year 'round in the Minneapolis/St. Paul area. The differences from most previous oxygenated gasolines:

- Added oxygenates, usually MTBE (Methyl Tertiary Butyl Ether); also Ethanol (grain alcohol). SInce Oxygenates reduce energy in the fuel, MTBE has 2.8% less energy. Ethanol has 3.4% less energy
- Increased vapor pressure to assist Open Loop operation: cold starts, warm-up, W.O.T. acceleration (winter vapor pressures more than summer, but less than previous winter vapor pressures)
- Fuel economy losses of 2 to 3%, plus usual winter losses of 5 to 15%, but remember that famous line: "your mileage may vary."

Reformulated Federal Gasoline, Phase I RFG

Phase I RFG will be sold year 'round until the year 2000 in parts of most states (not California). It is required where air-quality measurements show significant Ozone non-attainment days. The differences from most previous gasolines:

- Reduced toxic chemicals—some cancer-causing—including Benzene, a cancer-causing aromatic, and other aromatics
- Reduced sulfur; sulfur-dioxide with moisture makes sulfuric acid that damages lung tissues and also vehicle smog-control equipment
- Oxygenates used all year (required by federal law), principally important during Open-Loop operation such as cold start/warm-up; mostly MTBE, and some Ethanol
- Reduced Summer Vapor Pressure to reduce VOC in refueling, in tailpipe emissions and EVAP system losses; compare to 9.0 psi previous:
  - 7.1 psi Southern states (VOC control region 1)
  - 8.0 psi Northern states (VOC control region 2)
- Increased deposit-control additives to reduce deposits on injectors and valves
- Expect economy losses of 2 to 3%, plus the usual winter-weather losses of 5 to 15%
- Emission reductions:
  - CO about 11%
  - VOC (NMHC), tailpipe and EVAP, about 9%
  - NOx about 4%
- Expect increased prices at the pump, based on increased refinery costs of 2 to 5 cents/gallon

Reformulated Gasoline, Federal RFG, Phase II

Phase II RFG will be sold year 'round beginning in 2000 in parts of most states (not California). Compared to 1990 gasoline, further limitations of polluting elements of gasoline will reduce:

- VOC by 27% in Southern states, and 29% in Northern states
- Toxics by 21%
- NOx by 6.8%

California Reformulated Gas (RFG), Phase 2

You've already seen that California has significantly more vehicle pollution than other states. Its fuels are different, and are required for sale in the entire state and only in California. The differences from other gasolines (limits by volume):

- Reduced toxic chemicals—some cancer-causing
  - Benzene, a cancer-causing aromatic (1.2%)
  - Other aromatics (30%)
  - Olefins (10%) to reduce the reactivity of EVAP losses, and reduce NOx
- Reduced sulfur (80%); sulfur-dioxide makes sulfuric acid that damages lung tissues and also catalytic converters
- Oxygenates added all year (1.8–2.7% in winter; 0–2.7% in summer); mostly MTBE, with some Ethanol. This has limited effectiveness in reducing tailpipe or evaporative VOC, except in Open-Loop, but is federal requirement
- Reduced Summer Vapor Pressure—limit 7.0 psi—to reduce VOC in refueling, in tailpipe emissions and EVAP system losses, compare to previous California limit of 7.8 psi
- Increased deposit-control additives to reduce deposits on injectors and valves

- Expect economy losses of 1% compared to previous California winter gas, plus usual winter losses of 5-15% (oxygenates have less energy than gasoline)
- Some cold starting problems on exceptionally cold Spring days, due to early distribution of Summer fuel; less likely with these 1988+ fuel-injected engines than with carbureted engines
- Emission reductions:
  - CO, greater than 11%
  - VOC (NMHC), tailpipe and EVAP, greater than 17%
  - NOx, greater than 11%
  - Sulfur dioxide, greater than 80%
  - Total toxic emissions, greater than 44% (potency weighted)
- Increased prices at the pump, based on increased refinery costs of 5 to 15 cents/gallon

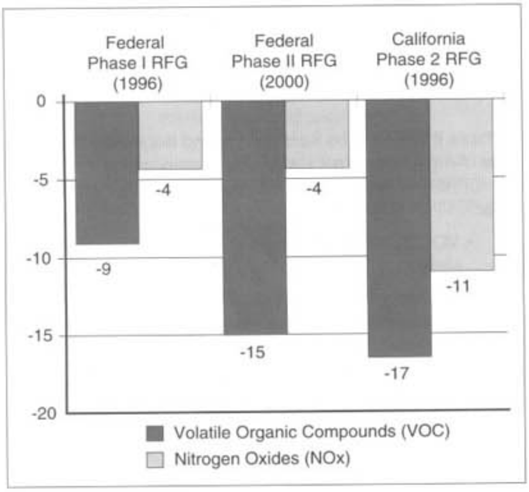


Fig. 3-2. Comparing Smog-forming emissions of new fuels, reference 1994 California conventional gasoline.

What's the bottom line? Ford approves their use. Automakers have participated in tests of the new fuels. Fuel Recommendations in your Owners Manual refer to fuels sold then, and this is now. These fuels did not exist when most of those manuals were written.

- With high mileages, greater than 100,000, you can expect deterioration of some flexible fuel lines—about 3%. That is no different from deterioration factors with old fuels.
- Fuels do vary from one refinery to the next, even as they meet the new specifications. If you have trouble, change brands or change stations

3.3 Advanced Technologies for Dedicated Vehicles

Some proposed fuels demonstrate greater advantages when the engines and their control systems can be designed for their exclusive use. Dedicated vehicles do not operate on existing supplies such as gasoline-based fuels.

Methanol—M-85

Pure methanol (M-100) is an attractive fuel for several reasons:

- It burns more cleanly
- Its high pump-octane rating, 110, improves engine power and economy
- It is cheap, widely available, and reduces our dependency on foreign oil. However, pure methanol presents problems, including cold-start vaporization

M-85 is the most promising fuel, a blend of 85% methanol and 15% gasoline. The gasoline in the M-85 helps solve the cold-starting problem of M-100. Dedicated vehicles using M-85 need special high-flow injectors, including a cold-start injector, similar to most Bosch systems. M-85 also needs modifications to the fuel system to solve the corrosion problem. Because of the low relative energy, M-85 fuel tanks must be about twice the normal size, or you have to stop and fill up twice as often. And methanol is toxic, poisonous to swallow, dangerous on your skin.

M-85 is quite different from an M-5 gasoline blend. In dedicated vehicles, the 102 pump-octane rating of the M-85 blend allows use of high compression ratios and advanced spark timing without knocking. M-85's increased cooling effect increases the density of intake air, improving power slightly. An engine dedicated to M-85 can deliver more power and economy than if it were designed to run on gasoline. Because methane is non-reactive in the atmosphere, its ozone-forming potential is much smaller than gasoline. But the formation of formaldehyde may be a serious pollution threat.

Special oil is needed to counteract more severe wear in the cylinder walls and to neutralize the formation of special acids. Additives are needed to prevent the forming of emulsions—methanol is not soluble in oil as gasoline is.

M-85 reduces the fire hazard in collisions. (Gasoline ignited in 180,000 vehicles in 1986, and caused about 760 deaths.) Methanol vaporizes less and is less likely to burn. Methanol fire releases a small fraction of heat compared to a gasoline fire. EPA estimates methanol could save 95 lives out of 100 compared to a gasoline fire. However, using water on an M-85 fire could cause separation of the gasoline from the alcohol, a floating gasoline flame and an invisible methanol flame.

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Natural Gas (NG) Vehicles

Natural Gas (NG) is an excellent motor fuel. It has an octane rating of 130 and costs about half as much as gasoline. NG-dedicated vehicles need no gasoline fuel-injection system, and much simpler control for spark and bypass air-idle. NG burns cleanly, less HC and CO, but burns hotter in the cylinders, so NO_x may need more control. It is safer than gasoline (no vehicle fires on record).

The fuel is stored as a compressed gas under pressure of about 3,000 psi (21,000 kPa). NG enters the engine as a gas, prolonging the life of the plugs and the lubricating oil, "500,000-mile engine life" is predicted. And the U.S. supply is plentiful. This is the same fuel that we burn in our houses for cooking, home heating, water heating and clothes-drying.

If it's that good, why are we still burning gasoline? One simple answer is: There are few NG vehicles because there are few NG filling stations because there are few NG vehicles because there are few NG filling stations. . . . The stimulus for increasing use of NG will come from government agencies responsible for reducing smog in critical areas, beginning with California. Already, you're seeing early usage in fleets operating shorter runs in urban areas, and utilizing central fueling facilities. NG offers much promise for cleaner air, and energy independence. With the wide distribution of low-pressure natural gas to businesses for heating, the major requirement is for a compressor to fill vehicle tanks.

Fig. 3-3. Experimental NG fuel pumps provide fill-ups, but must supply fuel through special fittings under pressure as high as 3,000 psi (21,000 kPa).

Fig. 3-4. NG first usage is more likely on trucks because NG tanks are bulky.

The driver of a vehicle dedicated to alternate fuel operation can feel mighty lonely as he watches his fuel supply dwindle, passing service stations selling only gasoline. I remember the feeling, driving one of the early passenger-car diesels.

3.4 Transition Vehicles—FFV (Flexible Fuel Vehicles)

M-85 to Gasoline

Until we have a nationwide supply of M-85, most alternate-fuel engines must operate on both gasoline and the alternate fuel. They must have regular compression ratios suitable for gasoline and cannot take full advantage of the properties of M-85.

Considering the scarcity of M-85 stations, the engine must operate on any mixture between M-85 and gasoline, depending on whether gasoline or M-85 is added to the fuel mixture already in the tank. The EEC system includes a Flexible Fuel (FF) sensor in the fuel line that signals the control module about the fuel mixture, causing changes in injected fuel pulse-times, and spark timing.

The FF sensor calculates the percentage of methanol in the system by sensing electrical properties and temperature of the fuel. The sensor signals the control module to adjust the air-fuel ratio and the spark timing. Final mixture adjustments are modified according to exhaust-gas signals from the oxygen sensor.

Flexible-fuel systems require special tanks, lines, pumps, sender, and filter. Injectors are special, also exhaust-gas oxygen sensor, catalytic converter, and the control module.

On 1993 models, additional fuel is delivered to assist cold starting below 15°C (60°F) because methanol does not vaporize as well as gasoline. The control module determines the delivery of fuel based on temperature. The Flexible Fuel Cold-start Adapter is a 10-inch spray bar that mounts in the intake manifold plenum chamber.

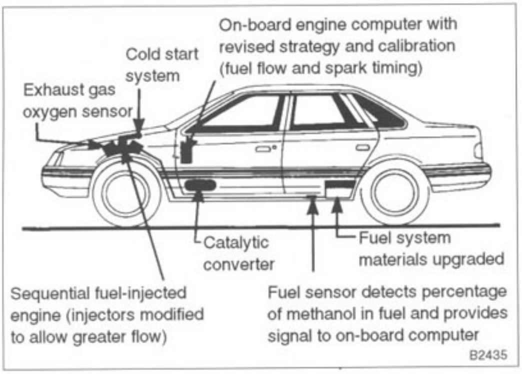

Fig. 3-5. M-85 Flexible-Fuel Ford automatically selects fuel metering and spark timing to match fuel delivered to engine.

Natural Gas (NG) Dual Fuel Vehicle

Ford is experimenting with answers to NG problems. When I examined a Ford Taurus converted to burn NG, I could see that the bulky storage tanks occupied most of the trunk. The engineer demonstrating the car told me:

- The tanks in the NG demonstration Ford will carry it about the same distance as the gasoline in the normal tank
- The fill-up sources for compressed gas are rare. NG must be compressed to about 3,000 psi, using the natural gas that is delivered at about 0.4 psi into homes and businesses

In most cases conversion is not recommended. Ford is delivering some factory-modified light trucks to utilities. Filler fittings are being standardized. Quick-fill is possible in about the same time as liquid fuel at your service station. Overnight fill-up is also available, using a local compressor.

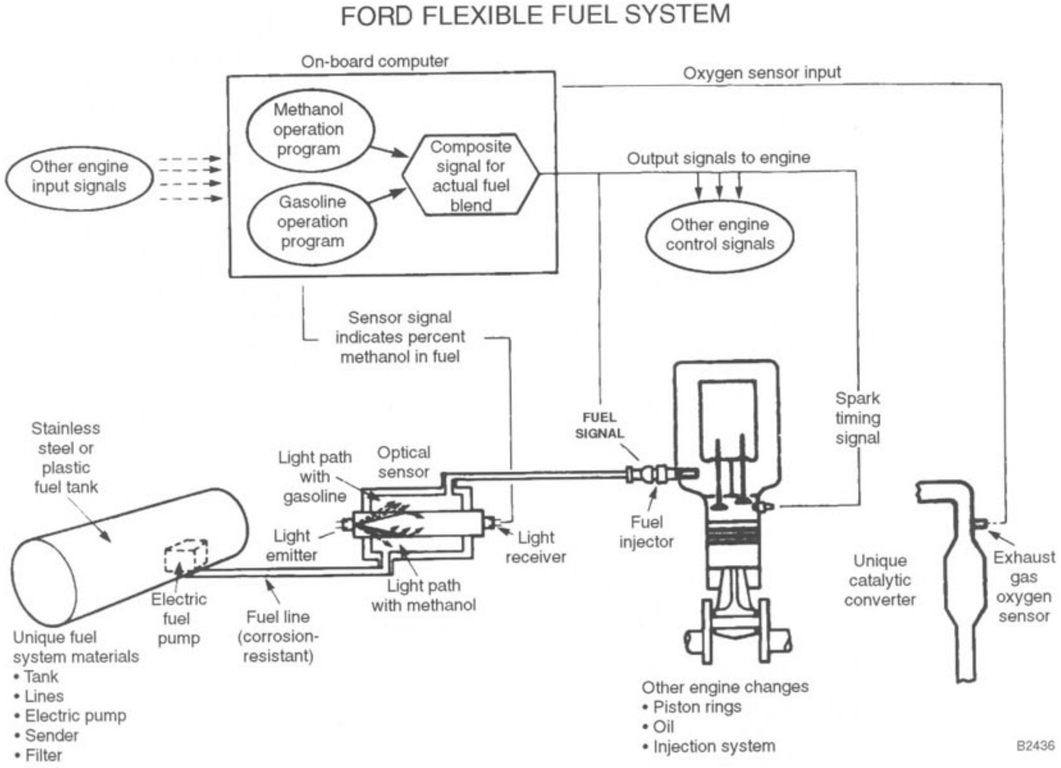

Fig. 3-6. M-85 flexible fuel sensor signals changes in fuel optical properties for different mixtures between M-85 and pure gasoline (M-0).

Fig. 3-7. Ford Taurus converted to dual fuel, capable of operating on NG (Natural Gas) without fuel injection, or gasoline.

For the average driver, there are few fill-up stations. The engine must operate dual-fuel. That means it must retain its compression ratio and spark timing for gasoline so it cannot take advantage of the high-octane of NG.

Fleet owners will be the first filling stations for private owners, again probably trucks and utility vehicles at first. And as more vehicles are converted to NG, you'll see private filling stations. With those, more dedicated NG vehicles can be manufactured, generally at much less cost than vehicles operating dual fuel. Such engines will still use electronic engine control, but will need no fuel injection, reducing cost still further.

Summary/Conclusion

How does it all add up? The new fuels are helping to clean the air and to reduce our dependence on imported oil. Within the limits described above, they are satisfactory for use in current vehicles designed to run on gasoline. If you notice any difference from pure gasoline, the engine may knock less because of the higher octane of the blends, and the gas mileage may be reduced slightly because of the lower energy content of the blends.

According to a recent study by the California Energy Commission, comparative costs in the year 2000 show a slight increase in cost for M-85 FFV, and a significant saving for M-85, Dedicated and NG, FFV. For dedicated NG, expect even more savings, plus better range and 0-60 times. To encourage use of cleaner fuels, these may be skewed by government tax advantages. See **Table e**.

Table e. Relative Cost/Performance of Driving 100,000 Miles

Fuel	Cost per 100,000 mi. (compared to gasoline)	Range: miles per 15 gal.	0–60 times, in sec.	Refuel time, min.
Gasoline	$5,000 (100%)	510	12	2
Methanol (M-85) Flexible	$5,200 (104%)	300	11	2
Methanol (M-85) Dedicated	$4,460 (90%)	350	10	2
NG FFV	$3,000 (60%)	125	12	5
Electricity	$2,100 (42%)	100	20	360

For ecology reasons, you may be buying one of Ford's Flexible Fuel Vehicles as the vehicles become more available, and as M-85 fuel pumps become more convenient. As M-85 fuel availability improves, you may be driving vehicles with M-85 dedicated engines, with much higher compression ratios, and advanced fuel-injection systems. The engine will operate much more fuel efficiently, compensating in part for the lower energy in each gallon of M-85. It will also decrease HC emissions by another 50%. But if you're committed to M-85, your friendly gasoline pump is not for your vehicle. Even if the engine runs on gasoline, the engine knock could be destructive.

If you're driving an NG Ford, it may be a dual-fuel type so you can fill with gasoline if the NG tank is empty. The engine can be switched over to operate on the EEC fuel-injection system. If the truck is a dedicated NG, end of story—no fuel injection; EEC for spark control. All you've got are low emissions, great starting in cold weather, high octane compression ratios, the cleanest engines inside, and short range.

The alternate-fuels story begins in California. California currently registers 1 out of 7 vehicles in the U.S., and drives them more VMT than the rest of the country. If you live there, and especially in smoggy Southern California, I can promise you one thing, you will be among the first to enjoy the benefits, and to experience the challenges of alternate fuels. The California bellwether often points to what's ahead in the other 49 states. Stay tuned because the fuel picture is changing even as I write.