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Alternative Fuels Utilization and the Automotive Emission Certification Process

Prepared for

U. S. Department of Energy

Assistant Secretary for
Conservation and Solar Applications
Office of Transportation Programs
Washington, D. C. 20545

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for

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Assistant Secretary for
Conservation and Solar Applications
Office of Transportation Programs
Washington, D. C. 20545
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FOREWORD

This report was written to provide a basic understanding of the automotive emissions certification process and its impact on alternative fuels utilization in highway vehicles.

The vehicle certification process is perceived as one of the major environmental and regulatory hurdles that alternatives to petroleum transportation fuels will face on their way to commercialization. This process is probably one of the least understood national requirements on "big business" by lay people. Thus, misunderstanding leads to confusion when viewing auto industry public statements regarding alternative fuels and other substantial future changes. This report will focus on certification process understanding for lay persons.

One reason for the automotive industry's concerned view about designing and building vehicles that operate on alternative fuels (such as alcohol, alcohol/gasoline blends, and substitutes from coal and shale) is that according to regulatory interpretation of Federal law, today's vehicles must be designed to operate on fuels that are "substantially similar" to those used in certifying 1975 and later model year vehicles. Since some (or maybe even all) of the emerging alternative fuels do not fit the definition of "substantially similar," it is important to understand the vehicle certification process to more fully appreciate industry's position in this matter. Thus, this report aims to broaden that understanding by all who are affected by the process.

The process addressed by this report is quite complicated. Simplification of discussion is attempted through concentration on "light duty" vehicles, those under 8,500 lbs. gross vehicle weight; e.g., cars, most pick-up trucks, and vans. It must be recognized that there are significant differences between the certification of light and heavy duty vehicles. The overall processes are similar.

This report is based in part on the background of T.J. Timbario of Mueller Associates, who was associated with five

model-year certification programs for a major U.S. automobile manufacturer. Thus, the report attempts to convey a perspective based chiefly on that experience. As a result, there are few references.

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I. SUMMARY

Other than within the automobile industry and in the Environmental Protection Agency, there is little appreciation of the impact that current vehicle emissions certification processes could have on the introduction of alternative fuels. In fact, the vehicle certification process is potentially one of the largest environmental and regulatory hurdles that alternatives to petroleum transportation fuels will face on their way to commercialization.

It must be borne in mind that the Clean Air Act of 1977 is the law of the land and that other than in relatively minor particulars where some discretion is accorded the EPA Administrator in enforcing it, it binds the automobile industry and the EPA. In recognition of the profound influence on vehicle emissions exerted by the chemistry of the fuel, the Clean Air Act provides for standardized test fuels as well as standardized vehicle test procedures. Currently, the former requirement is filled by Indolene, a closely controlled gasoline for emissions testing of spark ignition engine vehicles and by a similarly standardized diesel test fuel for diesel engine vehicles.

Section 211(f) of the Clean Air Act requires that commercially offered fuels and fuel additives be "substantially similar" to those used in certifying model year 1975 and later vehicles. Certain of the more promising alternative fuel candidates cannot meet this criterion. This is not to say that with appropriate adjustments and calibrations engines and vehicles could not meet existing emissions standards using these fuels. However, in a given state of adjustment, the engines and vehicles of today and the near-to mid-term future probably will not be capable of complying with Clean Air Act provisions using either the alternative fuel or a petroleum fuel interchangeably. This

is a key factor, since petroleum motor fuels and alternative fuels will certainly coexist in the marketplace, at least in the early years of alternative fuel availability.

To date, waivers of Section 211(f) have been granted by the EPA on a case-by-case basis for several oxygenated fuel additives. In all cases but one it was possible to show that these would not aggravate vehicle emissions nor contribute to emissions control component failure. Continued marketing of the one fuel (Gasohol) which was not clearly absolved was permitted on the basis of its very small share of the total highway vehicle fuel market. Obviously, the Clean Air Act cannot admit of such interpretation for future alternative fuels or fuel additives which are, and must be, capable of displacing significant amounts of petroleum.

The automotive emissions certification process comprises several major phases, each of considerable magnitude and complexity:

- o Certification Application Submission
- o 50,000 Mile Durability Vehicle Testing
- o 4,000 Mile Emission Data Vehicle Testing
- o Running Change Evaluation
- o Selective Enforcement Audit

The costs and vehicle quantities involved in the vehicle test and evaluation phases range in the order of 50 or more vehicles at about \$100,000 per vehicle for 50,000 mile durability testing, to 200-300 or more vehicles at about \$40,000 per vehicle for 4,000 mile emission data vehicle testing. A failure at any point in the process wipes out the entire investment of time, money and effort in achieving Clean Air Act compliance for the affected engine family and dictates a repeat of the process if such vehicles are to be produced and sold.

Given the provisions of the law and the technical facts of the matter, the distinct possibility exists that at some time in the relatively near future, automotive manufacturers may be

faced with the legal necessity of certifying their vehicles on two or more fuels. Assuming the technological obstacles of designing, building and servicing engine and emission control systems sufficiently sophisticated to permit Clean Air Act compliance on two or more chemically disparate fuels can be overcome, the costs and logistics of performing the expanded certification testing will still be an imposing burden.

The intent of this report is to provide a basic understanding of the emissions certification process and its impact on alternatives fuels utilization in highway vehicles.

II. INTRODUCTION

In the U.S., there is widespread realization that sooner or later, substitutes must be found for petroleum-derived fuels. In transportation, especially in highway transportation, petroleum now provides virtually all transportation fuel; primarily as gasoline and distillates such as diesel fuel.

There are obstacles to the introduction of any alternative fuel. Until petroleum products become substantially more expensive, simple economics will remain one of the largest. However, there are impediments in existing law to the introduction of alternatives such as alcohols, alcohol-gasoline blends and synthetic fuels made from coal and oil shale. These barriers have received little attention. Their scope will probably not be fully appreciated until a major effort is undertaken, using one or more of the likely alternative fuels, to meet the vehicle emissions standards with which cars and trucks now must routinely comply using traditional petroleum-based fuels.

The EPA recently announced its proposed interpretation of Section 211(f) (1) of the Clean Air Act which it is charged with enforcing, and which deals with fuels and fuel additives.^{[1]*} Under Section 211(f) no fuel or fuel additive (which designations would appear to include, for example, alcohol used in a blend with gasoline or by itself as a "neat" fuel) may be introduced into trade after March 31, 1977 unless it is "substantially similar" to fuels or fuel additives used in certifying 1975 and subsequent model year vehicles.^[2] EPA's interpretation is based on three technical criteria. Waivers of Section 211(f) will be granted for fuels that satisfy the first and for fuel additives that satisfy any of the three. The criteria are as follows:

1. The fuel or fuel additive (exclusive of any carrier oils or solvents present to ensure an additive's compatibility

*Numbers in brackets denote references which appear at the end of this report.

with a base fuel) contains either carbon and hydrogen only or carbon, hydrogen and oxygen only and is sold as or in an unleaded fuel with final chemical and physical properties typical of those of the unleaded fuel used in certifying 1975 and later vehicles, or;

2. The fuel additive contains carbon, hydrogen and nitrogen or carbon, hydrogen, oxygen and nitrogen and its concentration in the finished fuel is not more than 0.25 weight percent, or;

3. The fuel additive has a molecular structure and chemical composition identical to a fuel additive used in certifying 1975 or later vehicles and its concentration in unleaded gasoline (by weight) has not been increased by more than 50 percent.

The effect of these regulations would seem effectively to be the exclusion of the most promising of available alternatives unless the requirements of Section 211(f) are specifically waived. For the present, at least, waivers have been granted for methyl tertiary butyl ether (MTBE), tertiary butyl alcohol (TBA) and an oxygen-bearing fuel additive produced by a major refiner. These waivers are for the materials used as gasoline additives but not as bulk fuels in and of themselves.^[3] A waiver requested for Gasohol (10% ethyl alcohol - 90% unleaded gasoline) was not explicitly granted nor refused pending the development of further data and in view of the fact that it represented only a minuscule fraction of U.S. gasoline consumption. The EPA allowed the continued marketing of Gasohol.^[4]

In bringing an alternative fuel to market, the would-be supplier is charged with the responsibility of proving that it does not create a greater air quality hazard than exists with current fuels, nor contribute to the failure of any emissions-related component of the vehicle. At least one specific group of alternative fuel candidates, the oxygenated hydrocarbons (alcohols, ethers, etc.), are different enough chemically from the more common petroleum hydrocarbons that current engines cannot accommodate fuels from either group interchangeably while in

a single state of tune and adjustment. Even in the case of an alternative such as ethanol, used in a mild (10%) blend with gasoline, the difference in fuel chemistry between the blend and straight gasoline is significant. Although both might yield acceptable vehicle operation, and either might permit the vehicle to comply with the applicable emissions standards, the Clean Air Act interpretation precludes the sale of a blend (and thus its use as a petroleum extender) until cars which will use it are shown to be capable of being certified with it.

These considerations bring home the powerful influence that emission control standards for cars and trucks will have on the future introduction of alternative fuels. They point out the necessity of understanding something of the vehicular emissions certification process and what it currently means to vehicle manufacturers, buyers and the Federal government authorities who administer the program. The effects of this program and the legal requirements it places on cars and trucks will be no less important for alternative fuels.

Based on the EPA criteria as specified in Section 211(f)(1) of the Clean Air Act, it would appear that any fuel not "substantially similar" to one used in certifying 1975 and later model year vehicles could not be burned in vehicles until emission conformity is demonstrated. If it is reasonable to assume that the implementation of alternative fuels will proceed in an evolutionary fashion over a period of years, then at some point during that evolutionary process conventional and alternative fuels will coexist, for a while at least. Under these conditions, it appears that dual automotive emission certification programs might be required. This is of great concern to the auto industry because it would complicate an already strenuous and expensive process.

Any new fuel requiring a significantly different range of air-fuel ratios for optimal combustion (whether or not it also necessitated changes in engine components or fuel and emission

control system design) would require that the EPA consider whether the present certification fuel (Indolene, a standardized gasoline for emission test purposes) provided a satisfactory representation of the new fuel. If it did not, a new, additional certification fuel would have to be defined. If the two certification fuels, Indolene and the new fuel, were appreciably different in their air-fuel ratio requirements, then the optimal engine calibrations for the two would also be significantly different. Were the engine and vehicle optimized for one fuel and even if certification were achieved with that fuel, it is very unlikely that the vehicle could also qualify for a Certificate of Compliance on the other test fuel.

Thus, to qualify on both fuels, vehicle design standards would have to be much more stringent and more costly to achieve than is now the case. If certification were required on both fuels, the effort and expense now associated with this exercise would be doubled, as would the attendant risk of disqualification.

The intent of this report is to present an overview of what is involved in emission certification in the hope that the impact of any potential requirement for dual certification (as a means to an end) will be better understood.

III. BACKGROUND

Since 1968, American automobile owners have been at least vaguely aware that under the hoods of their cars are assemblages of devices intended to reduce pollution. Frequently, these same devices were identified in the public mind as the reasons that automobiles perhaps didn't idle as smoothly as in previous years, stalled repeatedly after the first start-up of the day or delivered poor fuel economy. Today, ten or more years since the problems of vehicular exhaust emissions and urban air pollution first entered the general awareness, most of us have come to terms with the gadgetry under the hoods of our cars and recognize that the efforts of auto manufacturers and government officials have been motivated by concern for the health and welfare of the public.

A few of us may have noticed that urban air quality has improved in the past several years and many of us have noticed that our cars' fuel economy and performance have improved substantially since the earlier days of emission controls.

Few of us, however could name the specific chemical pollutants that vehicles produce or how they produce them. Most of us know that it is the Environmental Protection Agency (EPA) which is responsible for determining whether vehicles meet the particular emissions regulations for the year of their manufacture. The current petroleum supply and cost situation has produced an acute awareness of the EPA's automobile fuel economy ratings, but few people realize that these estimates are developed in conjunction with the annual vehicle emission certification effort. The certification process is undertaken at the EPA's Ann Arbor, Michigan, Motor Vehicle Emissions Laboratory (MVEL). It may involve 200 to 400 vehicles or more from each major manufacturer and require many months to complete. The result, when all goes well, is that a given model car or truck, with a given

drivetrain is certified to meet Federal emissions regulations and to do so for 50,000 miles with specified maintenance. The vehicle "package" thus becomes legal for sale in the U.S. that model year.

To appreciate the magnitude and complexity of the task that faces the automobile industry and the EPA each year, a task which grows larger and more difficult annually, it is helpful to understand something about the origin and evolution of the exhaust emissions standards and the nature of the certification process.

The familiar spark ignition engine and the diesel engine, which power virtually 100% of our cars and trucks, both produce the power to drive a vehicle by burning petroleum fuels with air. By and large, they do this quite efficiently. Over the EPA driving cycle, more than 98 percent of the exhaust gas they produce is composed of non-pollutants: water vapor (H_2O), carbon dioxide (CO_2) and the unchanged nitrogen (N_2) from the combustion air. Figure 1 illustrates the "inputs and outputs" of an internal combustion engine vehicle. Only about 1.5% or less of the exhaust is considered polluting. That part of the exhaust comprises mostly carbon monoxide (CO), unburned hydrocarbons (HC) and oxides of nitrogen (NO_x). Small amounts of other organic pollutants are also generated, including such compounds as aldehydes, but these are usually grouped with the unburned hydrocarbons. A closer look at these pollutants and the ways in which they arise is helpful to our examination of the vehicle emissions certification process.

Gasoline and diesel fuel are complex mixtures of hydrocarbon (HC) compounds of widely varying molecular weights and structures but which contain only hydrogen (H) and carbon (C). Inevitably, some fuel will pass through the engine without becoming hot enough in the presence of sufficient oxygen (O_2) to burn completely. This amount of fuel is generally very small compared to the total fuel demand of healthy engine, but some unburned fuel or hydrocarbons will always be present in the exhaust. Exhaust hydrocarbons (and similar compounds which may not be true hydrocarbons in the chemical sense) can also be formed by partial combustion. In this case, fuel molecules are oxidized

FIGURE 1, THE EXHAUST PRODUCTS AND POLLUTANT EMISSIONS OF A TYPICAL MOTOR VEHICLE

to intermediate products, chemically between the unburned (raw) fuel and the products of total combustion. Fuel molecules may also combine in multiple ways with hot residual exhaust gases.

The normal evaporation of fuel from fuel tanks and carburetors also accounts for some HC emissions. Since 1971 these evaporative gasoline losses have been controlled very effectively by the familiar activated charcoal canisters tucked away in engine compartments. Fuel evaporative emissions are now so effectively controlled that volatilized hydrocarbons from automobile paint and vinyl interiors have become a significant part of the remaining HC emissions. Evaporative emission control systems can save considerable gasoline rather than causing a vehicle to consume more. Exhaust (tailpipe) hydrocarbon emissions are much more difficult to control but steady progress has been made.

During the high-pressure combustion process in an engine's cylinders, some small amount of largely unburned or partially-burned fuel will escape past the piston rings into the engine crankcase. These gases, called "blowby," contain water vapor and acids which will condense, contaminating and diluting the oil and in some cases, attacking certain metals in the engine. Since the early 1960's, blowby has been controlled by recycling it back into the engine to be burned. Before that time, blowby gases were emitted directly to the atmosphere through vents from the engines called road draft tubes. Blowby recycle is now accomplished by the PCV or positive crankcase ventilation system. Like evaporative emission controls, the PCV system can save considerable gasoline and in no way reduces a vehicle's fuel economy.

Carbon monoxide (CO) is probably the best known automotive pollutant. Most people know it is the carbon monoxide in a vehicle's exhaust that is most immediately toxic and the reason a car shouldn't be left running in an unventilated garage. Carbon

monoxide is the result of incomplete combustion. When a hydrocarbon fuel is burned completely, all its carbon is converted to carbon dioxide (CO_2). However, CO is an intermediate product in this reaction. In combustion which occurs with insufficient oxygen to burn all of the carbon to CO_2 , the intermediate CO survives and becomes an air pollutant. Typically, CO is the most plentiful pollutant that cars produce, by weight.

Oxides of nitrogen (NO_x) is a general term which, like HC, generically refers to a number of compounds. All are made up of nitrogen and oxygen, both of which are found in air. High temperatures are needed to make nitrogen, which is normally quite inert, combine with oxygen. The necessary temperatures are easily reached (and exceeded) in most fuel burning systems. Once formed, nitrogen oxides are quite stable compounds and tend not to decompose back to O_2 and N_2 . In the presence of sunlight, nitrogen oxides interact with hydrocarbons in the air to form a number of chemical compounds referred to as oxidants. The complex series of HC- NO_x reactions which creates oxidants gives rise to what we know as smog.

Other pollutants also appear in the exhaust of modern automobiles, but they are much less prevalent. Sulfur (S), for example, is present in all petroleum products to some degree. When the fuels are burned, the sulfur is oxidized to compounds that are referred to collectively as oxides of sulfur (SO_x). Compared to other sources of SO_x such as fossil fuel power plants, the automobile's contribution is negligible. Particulate emissions, as their name implies, are solid particles such as dusts and smokes. Particulate emissions from gasoline-engine vehicles are usually lead salts which slough off exhaust system parts when a vehicle is accelerated strongly. As leaded gasoline is phased out, particulate emissions from gasoline-fueled vehicles will decline to virtually nothing. Only if they are in poor mechanical shape (oil burning) or grossly maladjusted (much excess fuel) do gasoline engines emit smoke. Diesel engines, on the other hand, can emit significant (and often visible) amounts of particulate and smoke even when well-tuned and mechanically sound. These

emissions are not regulated as of the writing of this report. Until the diesel engine's higher efficiency and excellent fuel economy became so attractive to automobile buyers, there were too few diesels on the road to pose a serious problem. Emission standards for particulates have been proposed (dating back to 1971) and will probably be enacted for diesel engine vehicles in the near future.

The Federal government began its involvement in the air pollution area in 1955 by empowering the Department of Health, Education and Welfare to provide research and technical assistance to problems relating to air pollution. This was further implemented by the Clean Air Act of 1963 which was designed to stimulate state and local air pollution control activity. An amendment to the Clean Air Act in 1965 specifically authorized the writing of national standards for emissions from all new motor vehicles sold in the United States. The result has been the requirement of exhaust emission control devices on automobiles nationwide beginning with the 1968 models.^[5]

In passing the Clean Air Act of 1970 and the various amendments to it, Congress continued the attack on air pollution in the U.S., convinced of the singularly large contribution that the private automobile was making to that problem. Table 1 shows the original estimates of air pollutant sources and their relative magnitudes that were prepared by the U.S. Department of Health, Education and Welfare.^[5] These estimates of the magnitude of pollutant emissions and the growing knowledge of their health effects were the basis for the continued efforts that Congress pursued. Standards were to be established by the EPA, which would also be responsible for testing prototype vehicles each model year to assure that vehicles sold subsequently would meet the applicable standards. Increasingly stringent standards were to be phased in over a period of five years, until by 1975 (it was hoped) passenger cars would emit 90% less HC and CO than 1970 model year cars and 90% less NO_x than 1971 model year cars.

TABLE 1, THE NEED FOR AUTOMOTIVE EMISSION CONTROL: 1966-68 DEPT.

OF HEW ESTIMATE OF TOTAL U.S. EMISSIONS
(MILLIONS OF TONS PER YEAR) [5]

	CO	HC	SO _x	NO _x	PARTICULATES
Transportation					
Motor Vehicles	59.2	15.6	1.0	7.2	1.0
Other Forms	4.6	1.0	-	1.0	-
Stationary Electric Power Generation Sources	0.9	0.7	15.0	10.0	4.0
Refuse Disposal	7.8	0.4	1.0	0.6	1.0
Industry	9.7	4.6	9.0	0.2	6.0
Miscellaneous*	16.9	8.5	-	1.7	-
TOTAL	100.0	32.0	26.0	20.7	12.0
% From Motor Vehicles	59.2%	48.2%	3.9%	34.8%	8.5%

*Includes emissions from forest and other fires, industrial solvent evaporation and gasoline marketing.

Initially, both in California and nationwide, exhaust emissions were measured on a concentration basis, as parts per million by volume (ppm) or mole percent. The vehicle was placed on a chassis dynamometer and operated over a prescribed driving cycle. The driving cycle used in California to certify 1966 and newer vehicles and by the Federal government to certify 1968-71 vehicles has commonly been referred to as the California Cycle.^[5]

Because air pollution depends upon both the concentration of pollutant emitted and the volume, the 1970 and 1971 Federal standards were based upon a calculated mass emission rather than just concentration. The California driving cycle was used but average vehicle emission concentrations were multiplied by a total cycle calculated exhaust volume which varied with vehicle weight according to a predetermined formula. This pseudo-mass emission assessment was an interim step toward a true mass emission measurement. A true mass emission measurement procedure was developed for use in certifying 1972 and newer cars. The procedure, discussed in more detail in Chapter IV, employed variable dilution sampling, often termed Constant Volume Sampling (CVS), and included a new driving cycle. For 1972-74 vehicles, a single gas sampling bag was employed and the cycle has been termed CVS-1. For certification of 1975 and later vehicles three sample bags are employed to better assess the proportion of warmed-up to cold engine emissions. This version has been termed CVS-3. Table 2 provides a summary of Federally-required emission standards for automobiles as they were originally planned.^[5]

Over the years, the technical difficulty and economic impact of achieving these standards were not fully appreciated. As a result, there have been several postponements in the phase-in of more stringent exhaust emission standards. The ultimate goal established for the U.S. in 1970, 0.4 gram per mile of NO_x, has been modified to 1.0 gram per mile and slated to go into effect in 1981, with the more difficult 0.4 gram per mile target designated a "research goal" for the time being. California,

TABLE 2, HISTORICAL DEVELOPMENT OF FEDERAL AUTOMOTIVE EMISSION STANDARDS^[5]

YEAR	HC	CO	NO _x	PARTIC- ULATES	FEDERAL REGISTER REFERENCE
"California" Cycle					
1968	275 ^a	1.5% ^b	-	-	Vol. 21, No. 61, Pt. II, Mar. 30, 1966.
1970	2.2 ^c	23 ^c	-	-	Vol. 33, No. 108, Pt. II, June 4, 1968.
1971	2.2 ^c	23 ^c	4.0 ^{c, d}	-	
FTP CVS-1 Cycle					
1971	4.6 ^c	47 ^c	4.0 ^c 3.0 ^c	-	Vol. 35, No. 219, Pt. II, Nov. 10, 1970
1972	3.4 ^c	39 ^c			
1973-74	3.4 ^c	39 ^c			
FTP CVS-3 Cycle					
1975	0.41 ^c	3.4 ^c	3.0 ^c	0.1 ^{c, e}	Vol. 36, No. 128, Pt. II, July 2, 1971
1976	0.41 ^c	3.4 ^c	0.4 ^c	0.1 ^{c, e}	

a: parts per million

b: mole percent

c: grams per mile

d: California requirement only

e: proposed

however, plans to enforce the original 0.4 gram per mile NO_x regulation beginning in 1982. Table 3 shows the standards as they have been enforced from 1976 and as they are planned for the early 1980's.

It should be noted that there are numerous ways in which these standards may yet be modified, postponed or waived depending on the engineering problems and economic penalties that are encountered and any revamped estimates of public health effects which may become available.

TABLE 3, PASSENGER CAR AND LIGHT TRUCK EMISSION STANDARDS AS
SPECIFIED BY THE CLEAN AIR AMENDMENTS OF 1977, 1976-1985
(GRAMS PER MILE) [5]

YEAR	Passenger Cars						Light Trucks					
	Federal			California ^a			Federal			California		
	HC	CO	NO _x	HC	CO	NO _x	HC	CO	NO _x	HC	CO	NO _x
1976	1.5	15.0	3.1	0.9	9.0	2.0	2.0	20.0	3.1	0.9	17.0	2.0
1977	1.5	15.0	2.0	0.41	9.0	1.5	2.0	20.0	3.1	0.9	17.0	2.0
1978	1.5	15.0	2.0	0.41	9.0	1.5	2.0	20.0	3.1	0.9	17.0	2.0
1979	1.5	15.0	2.0	0.41	9.0	1.5	1.7	18.0	2.3	0.41 0.50	9.0	1.5 ^b 2.0 ^c
1980	0.41	7.0	2.0	0.41	7.0	1.0 ^d	1.7	18.0	2.3	0.41 0.50	9.0	1.5 ^b 2.0 ^c
1981	0.41	3.4 ^e	1.0 ^f	0.41	3.4	1.0 ^d	1.7	18.0	2.3	0.41 0.50	9.0	1.0 ^b 1.5 ^c
1982	0.41	3.4 ^e	1.0 ^f	0.41	3.4	0.4 ^g	^h					
1983	0.41	3.4	1.0 ^f	0.41	3.4	0.4 ^g						
1984	0.41	3.4	1.0 ^f	0.41	3.4	0.4 ^g						
1985	0.41	3.4	1.0	0.41	3.4	0.4 ^g						

^aThe Federal standards are applied to diesel engines.

^bFor vehicles of 4,000 lb. inertia-weight or less.

^cFor vehicles of 4,000 lb. inertia-weight or more.

^dAlternatively, vehicle can be certified to 1.5 grams/mile for 100,000 miles instead of 50,000.

^eA waiver of the standard of up to 7 grams/mile is possible.

^fA waiver of the standard up to 1.5 grams/mile is possible.

^gAlternatively, vehicle can be certified at 1.0 gram/mile for 100,000 miles instead of 50,000

^hLight truck emission standards have not been promulgated beyond 1981.

Source: Material developed from briefings with the Environmental Protection Agency, Assistant Administrator for Air and Waste Management, Deputy Administrator for Mobile Source Air Pollution Control, Sept. 1978.

IV. EMISSIONS CERTIFICATION TEST PROCEDURES

The automobile emissions standards are expressed in terms of the amount, in grams, of each regulated pollutant that a car may lawfully emit over each mile it is driven. It is easy to see that a formal, recognized test procedure is necessary if accurate and meaningful measurements are to be made, since the manner in which a vehicle is operated has a strong bearing not only on how much fuel it burns but also on the amount and proportions of the emissions it produces.

For the purposes of the EPA's Federal automobile emissions certification, the need for a standard, well-defined test procedure is filled by the Federal Test Procedure (FTP), a vehicle "driving" schedule executed on a chassis dynamometer. ^[7] This device permits the stationary vehicle to be operated as though it were on the open road. The vehicle's driving wheels turn rolls which are loaded by a braking device to simulate rolling and aerodynamic resistance and by heavy flywheels which simulate the vehicle's inertia in accelerations and decelerations. The FTP has been changed several times since it was established in 1968 because emissions measuring technology has improved a number of times and efforts have been made to make the FTP more representative of "real life" automobile operation.

The current FTP is described in Figure 2 and has evolved from an early test called the California Cycle that was developed from actual in-traffic driving data collected in Los Angeles. The Federal Test Procedure is the equivalent of an 11.1 mile drive and takes about 50 minutes. The maximum speed is about 55 miles per hour. The average speed is a little over 21 miles per hour. After the test vehicle "cold soaks" for at least 12 hours at about 75°F in the test environment (simulating overnight parking), it is started from a cold engine condition and operated according to the cycle for 1372 seconds, or about 7.5 miles. The engine is then shut off and the vehicle is required to "hot soak" for 10 minutes, after which the engine is restarted and the car driven for the remaining 505 seconds (a repeat of the first 505 seconds)

FIGURE 2, FEDERAL TEST PROCEDURE URBAN DYNAMOMETER DRIVING SCHEDULE

which corresponds to 3.6 miles of driving. Since the engine is started from a cold condition, the first 505 seconds of operation is called the "cold transient portion," and reflects engine warm-up to a stabilized temperature. The remainder of the driving cycle prior to the 10-minute hot soak is termed the "stabilized portion."

While the test vehicle is being operated through the driving cycle, exhaust samples are collected by a system called a Constant Volume Sampler (CVS). Figure 3 is a simplified schematic diagram of the sampling system.^[7] The CVS system is designed to measure the true mass of emissions. A large positive displacement pump draws a constant total volume flow of dilution air plus all the exhaust gas through the system. The vehicle exhaust is mixed with filtered room air before the mixture is drawn through the pump. Before entering the pump, the exhaust gas-air mixture is controlled to within $\pm 10^{\circ}\text{F}$ of a reference temperature by a heat exchanger. A fraction of the diluted exhaust stream is drawn off and allowed to fill initially empty plastic bags. After the first 505 seconds of vehicle operation, the diluted exhaust flow is switched from the "cold transient" bag to the "stabilized" bag. A third or "hot transient" exhaust sample from the final 505 seconds is collected using the same bag that held the cold transient sample, the latter being pumped to emissions analyzers before collection of the third diluted sample is begun. Concurrently, with each exhaust sample, a sample of the ambient air is taken to permit correcting the exhaust emissions samples for pollutants that entered with the dilution air.

The total volume of diluted exhaust that passes through the CVS during the test cycle is measured. The concentration of each emission constituent is measured from the bag samples. These bag concentration values are equivalent to the average concentrations of the same constituents in the CVS flow stream during the test cycle.

Since the average concentration of each constituent, the density of each given constituent and the total diluted exhaust volume are known, the total mass of each constituent emitted

FIGURE 3, CONSTANT VOLUME SAMPLING TEST SYSTEM

during the test cycle can be calculated. Dividing the mass emissions by the total vehicle test miles traveled gives the output of each pollutant in terms of grams per mile.

Another chassis dynamometer driving schedule is used for the purpose of developing the somewhat controversial highway fuel economy figure for each vehicle package. Appropriately called the Highway Fuel Economy Test (HFET), it simulates a trip of about 10 miles without intermediate stops at an average speed of a little over 48 miles per hour. The bulk of it is at highway speeds of over 50 mph. It is not currently used for emissions measurement but there has been consideration of using the test this way particularly for NO_x , to aid in identifying automobiles which perform cleanly over the stop-and-go FTP but emit significantly more NO_x when driven at steadier, higher speeds.

A separate test is used for evaporative hydrocarbon emissions testing. Called the SHED (Sealed Housing for Evaporative Determinations) procedure, the test is designed to measure a vehicle's emissions when it is parked after a warm-up drive. It is conducted separately from any of the simulated road drive testing, but is an integral and mandatory part of the overall Federal Test Procedure.

V. THE EMISSION CERTIFICATION PROCESS AND ACHIEVEMENT OF COMPLIANCE

No brief description of the auto emissions standards and the tests used to determine compliance with them can convey the sheer size of the task of preparing for Certification. It confronts a major, full-line auto manufacturer each year. Typically, the vehicles the manufacturer will seek EPA permission to begin testing are the ones he hopes to be selling a year or more later.

Because the road to certification is fraught with obstacles and pitfalls that can effectively return a manufacturer to the starting point at any time right up to (and including) the final EPA test, considerable "lead time" is required to assure that the emissions certificate will be earned in time to start production of cars.

The vehicles which each manufacturer delivers to the EPA laboratory for certification testing are usually evaluated twice by the manufacturer over the FTP. Between these two tests, each vehicle accumulates 4,000 miles of operation according to an EPA-prescribed and approved driving schedule which can be adapted to test track laps or conducted on programmed chassis dynamometers controlled by pre-recorded magnetic tapes. However, it is not sufficient that the vehicle simply meet the Federal Standards each of the first two times it is tested by the manufacturer and in the one "official" certification test performed at the EPA laboratory. Automobile manufacturers must certify that the cars they offer for sale would meet the Federal Standards if tested over the FTP at any time in their first 50,000 miles of customer service. In most cases, a vehicle's emissions do not remain constant over its lifetime. Even if it is carefully maintained, a car will often show deterioration of its control over one or more of the regulated emissions as it accumulates mileage. This is not always the case; some cars control their pollutant output very consistently and others even show some improvement over time. In general, however, emission control can be expected to deteriorate somewhat as a vehicle

ages in day-to-day use. As a result, in order to assure emission compliance at 50,000 miles, a 4,000 mile certification test vehicle and all production vehicles of the same general powertrain configuration must be designed so as to better the standards by a safe margin. The procedure used to assure that this is the case is one of the largest and most expensive facets of the overall certification process and happens largely "behind the scenes". It will be reviewed in the discussion of the certification process which follows.

Since the certification process is the backbone of EPA's program of controlling mobile source emissions, and due to the necessity of ensuring acceptable air quality, it is expected to continue for at least the next several years in a form much like that in which it exists today.

In the approximately ten years that automotive emission controls and certification have been required, the process has grown in complexity to the point where the EPA must yearly handle and process reams of paperwork (relating to automotive manufacturers' applications), and concurrently test and "oversee" many hundreds of vehicles. A simplified flow chart of the certification process that must be followed prior to new model introduction is presented in Figure 4. While this was developed for light duty vehicles, it is analogous to that for heavy duty vehicles of over 8,500 lbs. gross vehicle weight, except that heavy duty testing (for both gasoline and diesel engines) is conducted using test engines on an engine dynamometer. There are other differences between light duty (vehicle/track/chassis dynamometer) certification and heavy duty (engine/engine dynamometer) certification too numerous to specify in detail here. Examples are:

- o Accumulation of operating time for heavy duty vehicles (HDV) vs. accumulation of mileage for light duty vehicles (LDV).
- o Highly transient (speed and engine temperature) chassis dynamometer emission testing (LDV) vs. stabilized speed/load at selected points (according to the test schedule)

FIGURE 4, THE CERTIFICATION PROCESS

that cover the range from deceleration to wide-open-throttle (HDV). (This may change soon, as a chassis dynamometer-type test has been proposed for HDV certification.)

- o Calculation of emissions on a grams/brake horsepower-hour basis for HDVs vs. grams/mile basis for LDVs.
- o Lack of evaporative emission testing on heavy duty engine applications.
- o Different test cycles for gasoline and diesel heavy duty engines vs. the same test cycle for gasoline and diesel light duty vehicles.

As mentioned, Figure 4 describes the certification process almost simplistically; each block could, in itself, easily be developed into a flow chart of complex proportions. While it appears that the automobile manufacturer may have the more complicated portion of the procedure due to the sheer number of action blocks, there is still an enormous amount of activity that the EPA must perform within each of its action blocks.

The responsibilities of the manufacturer(s) and the EPA are set out in their approximate sequential relationship. The overwhelming majority of physical testing is done by the vehicle manufacturers at their own facilities, but key, schedule-controlling decisions rest with EPA personnel and their judgment of whether both the intent and letter of the Clean Air Act have been fulfilled.

A brief synopsis of the process is presented below. Additional details form the remainder of this chapter.

- o Certification Application Submission involves the manufacturers' submissions of Part I applications, which illustrate in some detail the characteristics of each engine family intended to be certified. Factual vehicle data as well as sketches of engine and emission component configuration are included. Curves of carburetor air and fuel flow, distributor spark advance, and other emission component characteristics are also

included. Part I submissions are reviewed by the EPA staff for conformity, adequacy, accuracy, etc., and the manufacturer is notified that he may proceed with durability fleet data gathering if his application is approved. The EPA specifies engine family classification criteria in order to separate vehicle and engine/emission system component characteristics in a way that sets limits on the deviation of such characteristics. For example, engine displacement differences of say, 10% or less might be considered as within the same engine family, while differences of more than 10% would be considered as constituting different engine families. Similar logic is applied to other major engine/emission system components in order to establish the unique differences among engine families.

The maintenance requirements for vehicles of each engine family are one of many pieces of documentation the manufacturer submits to the EPA. These consist essentially of the product service literature which the manufacturer will make available to the working mechanics in his dealers' service departments and to other private service centers.

After the EPA indicates which vehicle packages it wishes the manufacturer to subject to durability testing, the manufacturer builds his fleet of durability vehicles.

- o Durability Vehicle Testing comprises the first hardware-oriented phase of the certification process. This is the portion of the process that establishes vehicle/engine emission control deterioration as a function of mileage (or hours, in the case of heavy duty engine certification). In the case of light duty vehicles for example, the durability vehicle for each selected

engine family begins its durability data generation with a "zero" mile emission test (intended to be representative of a vehicle leaving the assembly line) and is tested at 4,000 miles, 10,000 miles, and at every 5,000 miles of durability thereafter throughout the 50,000 mile course. Maintenance must be performed in accordance with the prior EPA-approved maintenance procedures established by the manufacturer. At the end of this period, all of the emission data are plotted and a best-fit straight line is generated.

From these graphs, a "deterioration factor" (DF) is obtained for each engine family. The DFs determine the emission levels that each 4,000 mile Data Fleet vehicle must meet.

- o Emission Data Vehicle Testing and Evaluation comprises the second test phase of the certification process and serves as the last step in achieving a certificate of conformity prior to model year introduction. This phase involves the EPA selection of manufacturers' intended product line offerings by engine family. Up to six vehicles per engine family can be chosen by EPA for 4,000-mile testing. These vehicles are representative of actual production line models and are required to accumulate 4,000 miles (125 hours in the case of heavy duty engine certification) before they are emission tested for conformity. Only when all of the EPA-selected vehicles within an engine family are certified can the manufacturer begin production of that engine family product line after submission of the applicable Part II emission data results and appropriate parts lists.

- o Running Changes involve the additional certification of manufacturers' product line offerings after the initial 4,000 mile data fleet is certified. Processing and handling of running changes is not as straightforward as that of initial 4,000 mile data fleet submissions. A great deal of judgment is used in the evaluation of running change requests. Some requests may not require test substantiation, others may require only "back-to-back" testing (two tests, one without and one with the modifications), and still others may require building a completely new vehicle for 4,000-mile testing.

The first phase, 50,000 miles of durability testing per vehicle, (or 1,500 hours of engine testing, in the case of heavy duty truck engines), establishes the emission level deterioration factors for each major engine family. Deterioration factors are derived from emission test data generated at 4,000 miles, 10,000 miles and every 5,000 miles thereafter. For these data, a measure of the vehicle's emission deterioration with mileage is determined and used to "adjust" the emission standards which subsequent 4,000-mile data fleet vehicles must meet to compensate for this deterioration. Durability test vehicles are often built with experimental versions of engine and emission control hardware intended for production models. These vehicles are driven according to a prescribed driving cycle to determine if all of the system components will last reliably for at least 50,000 miles when maintained according to the manufacturers' recommended and EPA-approved maintenance schedules. By the time it is complete, this program may cost over \$100,000 per vehicle and involve 50 or more vehicles for each full-line auto manufacturer. It consumes about a year of full-time testing and endless laps on a test track and/or thousands of hours of automatically controlled chassis dynamometer operation as each vehicle accumulates 50,000 miles.

While accumulating 50,000 miles of simulated use, a durability fleet vehicle is strictly limited to the scheduled and diagnostic maintenance procedures the manufacturer has told the EPA he will recommend to his customers and service people. The Clean Air Act requires the manufacturer to warrant all emissions-related components of the vehicle (which is almost everything) to be reliable for 50,000 miles when maintained to manufacturer's specifications. It requires him to replace under this warranty any component that fails before this time and in spite of correct service.

If a durability vehicle fails even one of its every-5,000-mile FTP tests, the vehicle is deemed to have failed the entire program in that configuration. The manufacturer is now faced with a knotty dilemma. If he can demonstrate to EPA officials that the failure is an isolated, one-of-a-kind event and does not likely predict many similar failures and increased emissions among cars and trucks sold to the public, he will be allowed to repair or replace the failure-causing component, re-test the vehicle to show that its FTP emissions have been returned to "normal," and continue the vehicle's mileage accumulation. If the EPA considers the failure to be the type that is likely to plague many private auto owners and make their vehicles emit increased pollutants, the durability vehicle in question must be withdrawn from the program. The manufacturer now must start over virtually from "square one," preparing a new durability vehicle that incorporates an improved or redesigned component or something that will probably solve the problems of the original, ill-fated durability vehicle. By then he may have lost only a week or so, or he might be months behind schedule. The introduction of the models represented by the failed durability vehicle will be delayed accordingly, which has a real dollar cost in the competitive automobile sales world.

An even more agonizing situation for the manufacturer is to see a trend of worsening emissions in a durability vehicle which will surely cause it to fail one of its FTP tests before 50,000 miles has been reached. Many such gradual deteriorations give no indication even to experienced test drivers that anything is amiss. The EPA's criterion regarding this sort of failure is that if an average automobile owner would not be aware of it and sufficiently concerned about the symptoms he could detect to take his vehicle back for service, then the manufacturer may not perform unscheduled maintenance. With no complaint from a test driver about the vehicle's performance or driveability, the vehicle can either be allowed to slide inexorably into an emissions violation before 50,000 miles (or at least finish with an undesirably high Deterioration Factor) or it can be pulled out of durability testing and work begun on a new emission systems configuration.

With these sorts of obstacles to overcome in an atmosphere of crucial deadlines and never enough time, it is easy to see why the annual Certification procedure at a major auto company is a time of seven-day workweeks and twenty-four-hour-a-day availability for the engineers, technicians and decision makers who must shepherd a whole fleet of cars and trucks toward the all-important emissions certificate.

Successful completion of durability testing, whether on schedule or delayed, marks the point (as shown in Figure 4) at which the EPA reviews the manufacturers' data, determines Deterioration Factors for the various engine families and authorizes the beginning of work on the vehicles which will be tested for final certification. This phase consists of test cars representative of the actual production versions and requires that each vehicle within each engine family be certified after 4,000 miles to the emission levels determined by the durability fleet. In many cases, these 4,000 mile test vehicles must meet emission

levels substantially lower than the published standards to allow for emission deterioration. Testing may involve 200 to 300 vehicles (or more) per manufacturer depending on the manufacturer's proposed model offerings. The average cost of this testing is about \$40,000 per vehicle.

The process of certifying representations of vehicles intended for production begins with the manufacturers' submissions (actually resubmissions) of Part I information that describes each vehicle model (within each engine family) intended for production. From this submission, EPA selects up to six vehicles per engine family for 4,000-mile certification. It is important to note that production versions of these certification vehicles cannot be manufactured and sold until each 4,000-mile Data Fleet vehicle within the engine family is certified. Non-certification of one Data Fleet vehicle in the engine family denies certification to the entire family.

Four-thousand-mile Data Fleet vehicles are usually tested once by the manufacturer when newly built, and again when the requisite 4,000 miles are achieved. Assuming everything proves out as planned, the EPA is notified and when time and space are available in the Ann Arbor laboratory, the vehicle is sent to the MVEL for the all-or-nothing Certification FTP. Again, if all goes well, things remain "simple" as shown in Figure 4. A failure at this point wipes out the entire investment of time, money and effort in achieving Clean Air Act compliance for that engine family. If the manufacturer is faced with the loss of only a few hundred sales of the nonconforming model, he may elect not to offer it that year rather than go back to the beginning of the process and start over. If the failed model is an expected high-volume seller, there may be far too much at stake to consider the write-off and the manufacturer will have little choice but to begin again.

Another phase of the certification process involves changes (called Running Changes) which manufacturers may wish to make to certified vehicle packages after these have entered into production. Such changes are inevitable and there are a number of legitimate reasons why they may in fact be necessary and desirable. The EPA must first be convinced that a proposed change to an already-certified model will not alter its ability to comply with the standards. If the manufacturer can show sufficient evidence that established compliance will not be upset, his running change will be allowed.

In today's climate, a running change might well be motivated by the manufacturer's discovery of improvements (related to emission component revisions) that yield better fuel economy with no significant change in emissions. In some cases, running changes may be requested for the purpose of polishing the performance or driveability of vehicles which, under the pressures of time, were not optimized for other factors such as overall driveability.

Something to remember regarding the very large number of Federal Test Procedure evaluations that a given vehicle prototype may undergo in the course of its certification is that each must be complete--including a SHED evaporative emissions evaluation. Due to the requirement of a 12-hour "cold soak" before each FTP test, only one test cycle can be done per day unless 24-hour-a-day operation is accepted.

Once a manufacturer's vehicle is certified for production, the last phase of certification process is entered. (This phase is not described in Figure 4.) It is called Selective Enforcement Audit or SEA. It is basically assembly line testing of vehicles destined for the market. Implicitly, it places stringent requirements on auto manufacturers for precise control over their manufacturing processes and product uniformity. Audits are usually conducted by EPA personnel based on the size of the manufacturer's production facilities and product line. Priority

is given to testing vehicles whose durability fleet and certification prototypes have shown a tendency to more rapid emissions deterioration or which have passed their tests by narrow margins. When an audit is conducted, two percent of that assembly plant's auto production is subjected to full-scale FTP emissions testing with the requirement that at least 90% of the individual cars meet the same, deterioration-adjusted emissions standards as the 4,000 mile certification cars. Testing is conducted at the builder's factory at his expense and is overseen by EPA personnel.

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