Aftermarket Vehicle Conversions

Overview

The Energy Policy Act of 1992 (42 U.S.C. 13212 (a) and (b)) specifies minimum purchase requirements for alternative fuel vehicles in the Federal fleet. The schedule for acquiring light-duty alternative fuel vehicles follows:

- FY 1993 5,000 vehicles
- FY 1994 7,500 vehicles
- FY 1995 10,000 vehicles
- FY 1996 25 percent of Federal fleet acquisitions
- FY 1997 33 percent of Federal fleet acquisitions
- FY 1998 50 percent of Federal fleet acquisitions
- FY 1999 and after 75 percent of Federal fleet acquisitions

The Federal government normally acquires about 50,000 vehicles each year.

Although alternative fuel vehicles have been under development for more than a decade, their availability from the automobile manufacturers was not sufficient in calendar year 1992 to allow the various Federal agencies to meet the requirements of the Act. The decision was made to use aftermarket conversions to fill the gap until a sufficient number of original equipment models could be made available at a reasonable cost. Aftermarket conversions involve equipment additions after the vehicle is sold, to allow vehicles originally designed for one fuel to operate on another. There are many U.S. companies that convert light-duty gasoline vehicles to allow them to operate on compressed natural gas or liquefied petroleum gas.

In February 1992, the National Renewable Energy Laboratory initiated a competitive procurement for aftermarket conversion of vehicles in the Federal fleet. Such conversions enable the vehicles to operate on an alternative fuel. The procurement was initiated to develop subcontracts with several alternative fuel vehicle conversion companies across the nation, with the goal of converting about 1,000 Federal government vehicles. The U.S. Department of Energy provided the funding for these conversions. As of August 1995, about half of the targeted conversions were completed, with the remainder either on order or in the planning stages.

The conversion effort has succeeded in helping the Federal government meet the requirements of the Act during a period of limited model availability. Activities will be phased down during 1996, however, because original equipment availability has significantly improved.

Table 4. Expansion of Alternative Fuel Vehicle Availability between 1992 and 1996

1992 Model Year Vehicles

Manufacturer	Model	Body Style	Fuel
Chrysler-Dodge	Ram van/wagon	Full-size van	CNG
GM-Chevrolet	C1500/C2500	Full-size pickup	CNG
GM-Chevrolet	Lumina	Mid-size sedan	Ethanol
Ford	F700	Medium-duty truck	LPG

1996 Model Year Vehicles

Manufacturer	Model	Body Style	Fuel
Chrysler-Dodge	Ram van/wagon	Full-size van	CNG
Chrysler-Dodge	Ram pickup	Full-size pickup	CNG
Chrysler-Dodge/ Plymouth	Caravan/Voyager	Minivan	CNG
Ford	Contour	Compact sedan	CNG/Bi-fuel
Ford	Taurus	Mid-size sedan	Methanol
Ford	Taurus	Mid-size sedan	Ethanol
Ford	Crown Victoria	Full-size sedan	CNG
Ford	F150/F250	Full-size pickup	CNG
Ford	Econoline	Full-size van	CNG
Ford	F150/F250	Full-size pickup	LPG/Bi-fuel
Ford	F700	Medium-duty truck	LPG

Table 4 compares the availability of alternative fuel vehicles from the original equipment manufacturers at the start of the Federal light-duty program in 1992, with their corresponding availability in 1996, and illustrates the expanded product availability during this time frame.

Program Description

At this time, light-duty vehicles are commonly converted to operate on one of two alternative fuels: compressed natural gas or liquefied petroleum gas (propane). Aftermarket conversions inherently represent a compromise of vehicle technology, so a key program objective is to obtain the highest-quality conversions available. Consequently, when selecting subcontractors to perform the work, experience, capabilities, and demonstrated ability to meet the high performance criteria were weighted more heavily than price. With regard to actual equipment, only higher-quality, "closed-loop, feedback" conversion kits were used, because these are known to provide the best emissions performance. Best industry practices were required during installation of the kits. For instance, all compressed natural gas conversions were installed according to the National Fire Protection Association's Specification 52. This specification includes detailed instructions for installing the fuel system and tank. Similarly, liquefied petroleum gas conversions were installed according to the National Fire Protection Association's Specification 58.

Vehicles converted to operate on compressed natural gas have a minimum specified driving range of 70 miles. In most cases, however, the range is substantially more. In contrast, vehicles converted to operate on liquefied petroleum gas have a minimum specified driving range of 170 miles.

Each aftermarket vehicle conversion is protected by a warranty that covers all installed conversion system parts and associated labor for three years or 36,000 miles, whichever comes first. Conversion subcontractors are also responsible to repair or replace any engine, fuel system, electrical, or electronic system components damaged by the installed conversion equipment during this period. As required by the provisions of the Act, subcontractors are required to sign individual warranty agreements with Chrysler, Ford, and General Motors.

The first light-duty vehicle conversions were completed during the summer of 1994. Conversion activities are continuing through the date of this writing.

Table 5 shows the total number of conversions currently completed, planned, or on order, by Federal agencies as of August, 1995.

Figure 42 shows the distribution of conversions, by state, that are completed, planned, or on order.

Figure 43 shows the distribution of conversions, by vehicle type, that are completed, planned, or on order.

Figure 43 illustrates that more than 90 percent of all conversions are taking place on pickups and vans. This is a good sign because the original equipment manufacturers are concentrating on producing these same types of vehicles.

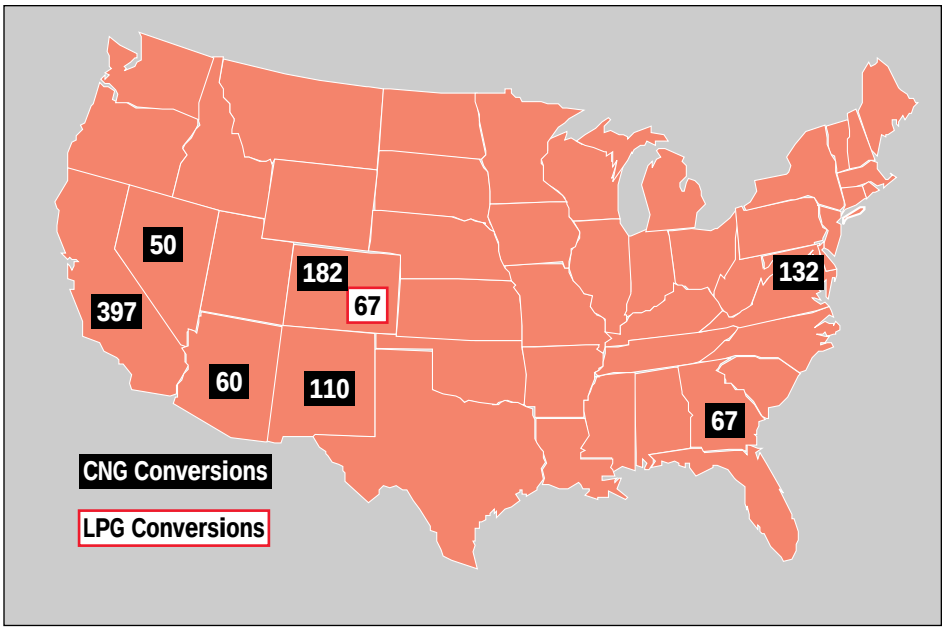
Most light-duty vehicle conversions (more than 92 percent) are bi-fuel conversions, which means that the vehicle may operate on either gasoline or the designated alternative fuel. The remainder are "dedicated" conversions, which means that the vehicles may operate only on the designated alternative fuel.

The cost of a light-duty vehicle conversion depends on the alternative fuel of interest, the level of conversion technology used, and the size

Table 5. Conversions by Federal Agency

Agency	CNG	LPG	Total Vehicles
Air Force	414	0	414
Marines	220	0	220
General Services Administration	160	40	200
Navy	97	0	97
National Institutes of Health	67	0	67
Forest Service	32	24	56
Other Federal Agencies	8	3	11
Totals	998	67	1065

Figure 42. States in which aftermarket conversions included in the program are located



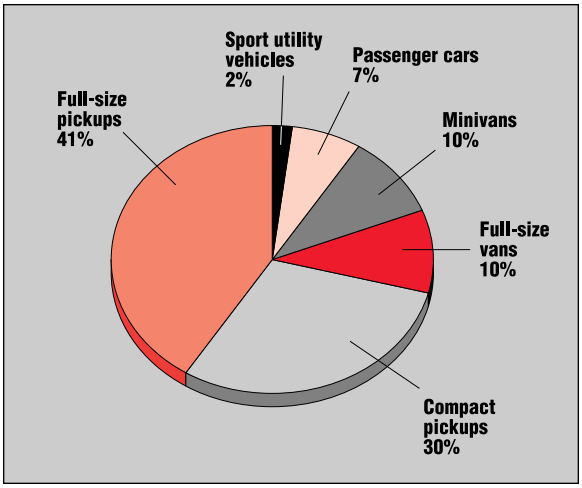


Figure 43. Vehicle conversions by vehicle type (1,065 total)

or quantity of the fuel tanks. The average total cost for each compressed natural gas conversion in the program is about $4,500. The average total cost for each liquefied petroleum gas conversion, on the other hand, is about $2,700. The overall cost of each conversion, especially in the case of compressed natural gas, depends heavily on the number and size of the fuel tanks. The fuel tanks specified for each conversion, in turn, depend on the vehicle type and desired range. For some vehicles, more than one tank is installed.

Where possible, every effort was made to target vehicles located in cities designated by the U.S. Department of Energy as "Clean Cities." Converted vehicles will be operating in six of the 45 communities designated as Clean Cities (as of April 1, 1996): Atlanta; Denver; Las Vegas; Washington, D.C.; Albuquerque; and Colorado Springs.

Emissions Results

During the 1995 fiscal year, the program began testing emissions on a limited number of these aftermarket conversion vehicles. A very large test matrix of vehicles and conversion kits would need to be tested to fully answer the question of how various conversion kits perform on a large cross-section of vehicle types, given the expected variability in individual vehicle performance and emission test results. As an initial step, emissions testing was begun in 1995 on a limited number of vehicles included in the Federal aftermarket conversion program. Sixteen vehicles, including eight new vehicle models, and two different conversion kits (one each for compressed natural gas and liquefied petroleum gas) were included in this effort. A list of the number and type of vehicles is shown in Table 6.

As stated earlier, the conversion program was designed to use only high-quality conversion systems. GFI Control Systems kits were installed in the vehicles converted to operate on compressed natural gas. Impco ADP Systems were installed in the vehicles converted to operate on liquefied petroleum gas. These modern conversion kits use electronic controls to continually adjust the air/fuel ratio based on a signal from the exhaust gas oxygen sensor. These closed-loop, feedback control conversion kits represent the state of the art of equipment available in 1995, and they constitute a minimum technological requirement for the conversion program because they are generally expected to be cleaner and more reliable than the older nonfeedback kits.

In addition to having closed-loop feedback control, the GFI kits can be electronically calibrated to a specific engine model for improved emissions performance. Consequently, an attempt has been made to test emissions on only those compressed natural gas vehicles in the conversions program for which an engine calibration exists. Furthermore, all vehicles included in the Federal conversion program were required to conform

to the U.S. Environmental Protection Agency's emissions requirements for conversions (see sidebar on page 75). Other criteria used to select vehicles for emissions testing include low mileage before conversion, and similarity to original equipment alternative fuel vehicle models available from the manufacturers.

To establish an emissions baseline, each vehicle was tested on California Phase 2 reformulated gasoline before conversion. The conversion kit was installed shortly after (within 1,000 miles of) the baseline test, and subsequent emissions tests were performed first on reformulated gasoline and then on the alternative fuel (compressed natural gas or liquefied petroleum gas). The compressed natural gas used for emissions testing was specially blended from tightly controlled constituent gases, and the liquefied petroleum gas was produced to conform with the industry-accepted specification (known as HD5) for transportation propane fuel. All emissions tests conformed to the Environmental Protection Agency's Federal Test Procedures (see sidebar on test procedures on page 21) using the Urban Dynamometer Driving Schedule. In addition, standard one-hour diurnal heat-build and hot-soak evaporative test procedures were included. Plans are to test the vehicles once each year to establish emissions durability over time and accumulated mileage.

Although the first-round emissions results from the vehicles in the Federal aftermarket conversion program are somewhat mixed, the following general observations can be made. The results are summarized in Table 7.

Table 6. Converted Vehicles Emissions Tested in 1995

Compressed Natural Gas (kit make and model: GFI)

Manufacturer	Model	Quantity
Plymouth	Acclaim	2
Ford	Taurus	2
Chevrolet	Astro (minivan)	1
Dodge	(minivan)	2
General Motors	Safari (minivan)	2
Dodge	B250 full-size passenger van	2
General Motors	C1500 pickup	2
Total CNG		13

Liquefied Petroleum Gas (kit make and model: Impco ADP)

Manufacturer	Model	Quantity
Ford	F150 pickup	2
Ford	Taurus	1
Total LPG		3

In general, installing compressed natural gas conversion kits did not adversely affect the reformulated gasoline emissions profile. In other words, for most vehicles and most constituents, the difference was negligible between the emissions recorded for reformulated gasoline before and after conversion (less than 10 percent). For the liquefied petroleum gasoline conversions tested, two of three showed relatively large increases in emissions when tested

Table 4. Emission Test Results from Aftermarket Conversions

Washington DC Conversion Vehicles

Vehicle Model	Model Year	Before Conversion (RFG)			After Conversion (RFG)			After Conversion (CNG)		
		NO_X	CO	NMHC	NO_X	CO	NMHC	NO_X	CO	NMHC
Acclaim	1992	0.23	4.13	0.15	NC	◒	◒	●	○	○
Acclaim	1992	0.46	3.52	0.11	NC	◓	NC	●	◒	◒
Astro	1992	1.01	2.42	0.48	◒	NC	NC	◒	●	◒
Caravan	1992	0.75	1.30	0.23	◒	●	◓	●	●	◒
Caravan	1992	0.53	1.96	0.24	◒	◒	NC	●	●	◒
Safari	1993	1.14	4.92	0.46	NC	◒	NC	◒	NC	○
Safari	1993	1.20	6.19	0.54	NC	◒	◒	◒	◒	○
Taurus	1994	0.22	1.08	0.09	◓	NC	◒	●	●	NC
Taurus	1994	0.17	0.98	0.08	NC	◓	◓	●	●	NC

Denver CNG Conversion Vehicles

Vehicle Model	Model Year	Before Conversion (RFG)			After Conversion (RFG)			After Conversion (CNG)		
		NO_X	CO	NMHC	NO_X	CO	NMHC	NO_X	CO	NMHC
B250	1994	2.31	8.66	0.84	NC	NC	NC	◒	◓	○
B250	1994	0.65	2.75	0.16	◒	NC	NC	◒	●	○
C1500	1994	0.49	2.88	0.17	NC	◒	NC	◒	●	○
C1500	1994	0.61	3.98	0.18	NC	NC	NC	◒	●	○

Denver LPG Conversion Vehicles

Vehicle Model	Model Year	Before Conversion (RFG)			After Conversion (RFG)			After Conversion (LPG)		
		NO_X	CO	NMHC	NO_X	CO	NMHC	NO_X	CO	NMHC
F150 Pkup	1994	1.20	0.66	0.09	◒	●	●	NC	○	●
F150 Pkup	1994	0.88	0.80	0.08	NC	●	●	NC	○	●
Taurus	1994	0.25	0.80	0.09	NC	◓	NC	●	○	◓

○ Large emissions decrease (>50%)

◒ Moderate emissions decrease (10%–50%)

◓ Moderate emissions increase (10%–50%)

● Large emissions increase (>50%)

NC = No change (i.e., less than 10%)

on reformulated gasoline after conversion. This indicates that either the kit or the installation had a negative impact on gasoline emissions performance. This is an area of concern for conversion systems, but at this point the test sample size is too small to make general conclusions. Additional testing, designed to further investigate this problem, is planned in 1996.

It should be noted that the liquefied petroleum gas conversion kit is of a substantially different design than the compressed natural gas kit. It is therefore impossible in this program to make any comparisons between compressed natural gas and liquefied petroleum gas fuel, even if both tests were done on the same make and model of vehicle.

The emissions comparison between reformulated gasoline and the alternative fuel in these conversions is not promising. Six of the nine vehicles converted in Maryland recorded substantial increases in oxides of nitrogen when tested on compressed natural gas, and five of nine recorded substantial increases in carbon monoxide when tested on compressed natural gas, relative to the corresponding levels obtained in the tests on reformulated gasoline. Seven of the nine Maryland vehicles achieved a decrease in non-methane hydrocarbon emissions when tested on compressed natural gas, relative to the values obtained in tests on reformulated gasoline.

In the case of the vehicles converted and tested in Denver, all those converted to compressed natural gas exhibited a small decrease in oxides of nitrogen, a substantial decrease in non-methane hydrocarbon emissions, and a substantial increase in carbon monoxide emissions when tested on compressed natural gas relative to the corresponding values obtained in tests on reformulated gasoline.

Two of the three liquefied petroleum gas conversions in Denver showed no change in oxides of nitrogen, and all three showed a substantial decrease in carbon monoxide, and a substantial increase in non-methane hydrocarbon emissions when tested on liquefied petroleum gas relative

Emissions Standards for Aftermarket Conversions

In 1974, the U.S. Environmental Protection Agency issued Mobile Source Enforcement Memorandum No. 1A, which states the agency's interim policy with regard to enforcing the "tampering" prohibition of the Clean Air Act. The primary objective of this memorandum was to ensure unimpaired emission control of motor vehicles throughout their useful lives. This memorandum, in effect, states that aftermarket conversion of vehicles to an alternative fuel will not be considered "tampering" if the installer has a "reasonable basis" for knowing that such modifications will not adversely affect emissions performance. As a result of increased aftermarket conversion activity, an additional fact sheet was issued by the Environmental Protection Agency on March 4, 1993, stating that a "reasonable basis" may include certificaton of the conversion kit by the California Air Resources Board, the Colorado Department of Health (for high-altitude areas), or by performing other Federally-recognized test procedures. All vehicles included in the Federal conversion program were required to conform to these criteria.

In 1994, the Environmental Protection Agency established new certification standards for aftermarket conversions. In order for a conversion to count as a "clean fuel vehicle" and be eligible for the Environmental Protection Agency's fleet program, or for a state to claim emissions benefits, the converter must certify the converted vehicle to these new standards. Vehicles can still be converted under Memorandum 1A, but they cannot then be used for claiming emissions benefits. The Energy Policy Act does not require that a conversion meet these new certification standards to be counted as an alternative fuel vehicle.

to the corresponding values obtained in tests on reformulated gasoline.

The results from this study cannot be considered comprehensive or conclusive because of the limited number and types of vehicles tested, especially for liquefied petroleum gas. However, a trend has been established for vehicles converted to compressed natural gas. Typically, they exhibit an emissions benefit in terms of non-methane hydrocarbons, but they tend to realize substantial increases in either oxides of nitrogen or carbon monoxide. Substantial decreases in non-methane hydrocarbons are to be expected for compressed natural gas vehicles, because the total hydrocarbons in the exhaust are composed of at least 90 percent to 95 percent methane. Too few liquefied petroleum gas conversions have been tested to establish a trend, but the initial testing has highlighted two areas of concern. The first is the emissions performance on gasoline after conversion, and the second is the increase in non-methane hydrocarbons when tested on liquefied petroleum gas after conversion.

These early emissions results for aftermarket conversions, when contrasted with the considerable emissions improvements obtained with dedicated compressed natural gas vehicles from the original equipment manufacturers (see the discussions on light-duty vehicle emissions, pages 20–28), highlight the need to consider both the fuel and the vehicle technology when evaluating options for reducing air pollution. Although using dedicated compressed natural gas vehicles from the original equipment manufacturers, for example, yields substantial emissions benefits, it cannot be assumed that all fuel system technologies will achieve this end. The aftermarket conversion vehicles that have been emissions tested so far will continue to be monitored, and the need for additional testing or the inclusion of additional vehicles will be evaluated.

Summary

Aftermarket conversions can play an important role in the transition to more widespread use of alternative fuel vehicles. However, the disappointing emissions performance of these relatively advanced closed-loop feedback kits to date raises the question of their overall contribution to reducing emissions. In addition, many less advanced and less expensive kits exist, and the technical literature confirms that they generally exhibit worse emissions performance.

Nonetheless, conversions currently dominate the alternative fuel market. Even with increasing model availability from original equipment manufacturers, many conversion strategies involve significant price advantages, which may eventually delay expansion of the original equipment manufacturer market.