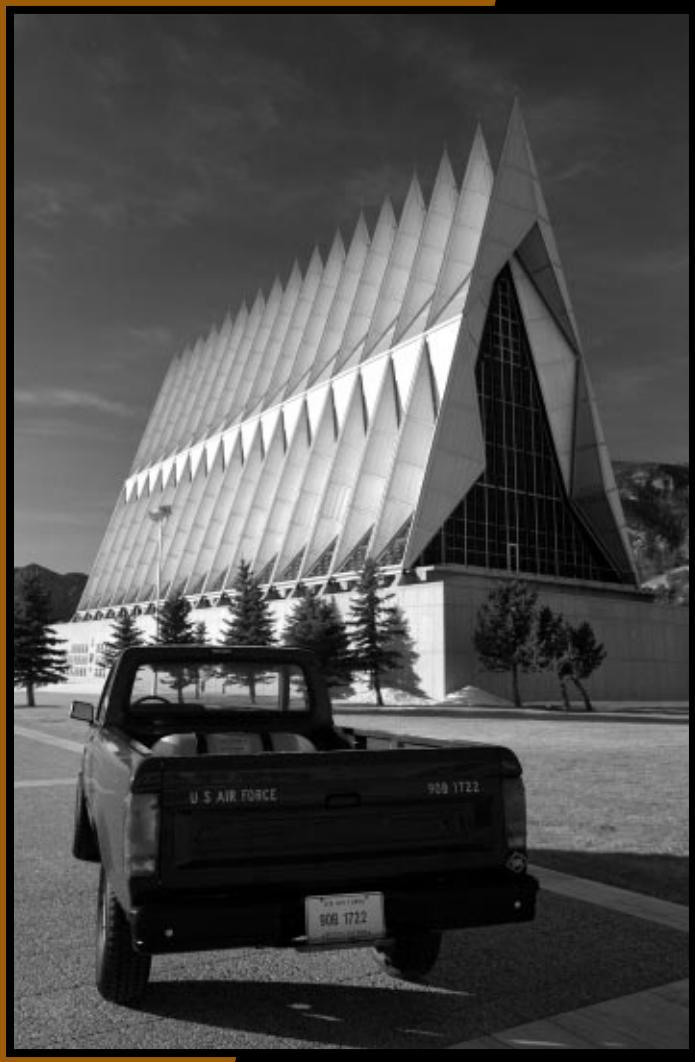
Compressed Natural Gas and Liquefied Petroleum Gas Conversions: The National Renewable Energy Laboratory's Experience



Compressed Natural Gas and Liquefied Petroleum Gas Conversions: The National Renewable Energy Laboratory's Experience

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Executive Summary

The National Renewable Energy Laboratory (NREL) contracted with conversion companies in six states to convert approximately 900 light-duty Federal fleet vehicles to operate on compressed natural gas (CNG) or liquefied petroleum gas (LPG). The contracts were initiated in order to help the Federal government meet the vehicle acquisition requirements of the Energy Policy Act of 1992 (EPACT) during a period of limited original equipment manufacturer (OEM) model availability.

In order to obtain the best possible conversions, companies were selected based primarily on their experience and capabilities instead of price. With regards to equipment, only higher quality "closed-loop feedback" kits were allowed, and kits were required to be installed according to National Fire Protection Association (NFPA) standards. Furthermore, all conversions were required to comply with Environmental Protection Agency requirements for vehicle conversions. Fuel tanks were sized to achieve a driving range exceeding 70 miles for CNG and 170 miles for LPG. Installers were required to provide a 3-year/36,000-mile warranty on the converted vehicles. The average price of the conversions in the program was $4,500 for CNG and $2,800 for LPG. The first vehicles from each company were inspected for conformance to contract requirements prior to delivery of the vehicles.

Fleet managers at each Federal site selected the vehicles they wanted converted and whether they were to be bi-fuel or dedicated conversions. Approximately 90% of all conversions were performed on compact or full-size vans and pickups, and 90% of the conversions were to bi-fuel operation. With a positive response from the fleet managers, this program helped the Federal government meet the vehicle acquisition requirements of EPACT for fiscal years 1993 and 1994, despite limited OEM model availability. The conversions also helped to establish the infrastructure needed to support further growth in the use of alternative fuel vehicles.

As a part of its larger mission to objectively evaluate the performance of all alternative fuel vehicles, NREL selected 16 of the conversions for emissions testing. Thirteen CNG bi-fuel conversions and three LPG bi-fuel conversions were emissions-tested using Federal Test Procedures and California Phase 2 reformulated gasoline as a baseline fuel. Emissions levels of all three studied exhaust emissions (non-methane hydrocarbons [NMHC], carbon monoxide [CO], and oxides of nitrogen [NO_x]) were either improved or unchanged on only 2 vehicles out of the 16 when running on the alternative fuel. CNG conversions generally showed a significant reduction in NMHC emissions, but an increase in either CO, NO_x, or both. The three LPG conversions tested showed increased emissions on gasoline after conversion, in addition to showing mixed results on LPG. The increased emissions on gasoline after conversion are likely a result of the kit design or installation rather than the

What is a Conversion?

In an aftermarket conversion, equipment is added to a vehicle that was originally designed for one fuel to allow it to operate on an alternative fuel. Converting gasoline vehicles to CNG or LPG operation is common. Converting diesel vehicles is less common. Typically the conversion company adds a fuel tank or tanks, fuel lines, a pressure regulator to reduce the pressure of the fuel to usable levels, and a mixer or carburetor to mix the CNG or LPG with the incoming air. In addition, most modern conversions have an electronic control system to control the fuel/air ratio to the precise levels required by today's vehicles. A switch and related hardware are also installed to switch from one fuel to the other. All existing emissions-related equipment must be left on the vehicle because they are required for proper emissions control, and are required to be left undisturbed by Federal emissions regulations.

fuel. No comparison between CNG and LPG was possible because the conversion kits used for CNG and LPG were dramatically different in design and operating principles.

These emissions results contrast with those from an OEM-manufactured CNG model also tested by NREL, where substantial across-the-board emissions benefits were realized, and demonstrate that the technology level is as important as the fuel in obtaining low emissions.

In conclusion, the program has been successful in helping the Federal government meet the vehicle acquisition requirements of EPACT, establishing infrastructure, increasing the displacement of imported oil, and evaluating the emissions performance of converted vehicles. With the relatively widespread availability of OEM vehicles in the 1996 model year, the program is now being phased out.

Overview

The Energy Policy Act of 1992 (EPACT) specifies minimum purchase requirements for alternative fuel vehicles (AFVs) in the Federal fleet. The schedule for the acquisition of light-duty AFVs 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. However, with downsizing and reductions in appropriations, the annual acquisition is expected to decrease to approximately 35,000 vehicles.

Although AFVs 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 fiscal year 1993 requirements of EPACT. Aftermarket conversions, which involve equipment additions after the vehicle is sold, were used to fill the gap until a sufficient number of original equipment manufacturer (OEM) models were made available at a reasonable cost. Aftermarket conversions allow vehicles originally designed for one fuel to operate on another. Many U.S. companies convert light-duty gasoline vehicles to allow them to operate on compressed natural gas (CNG), or liquefied petroleum gas (LPG), sometimes called "propane."

In February 1993, the National Renewable Energy Laboratory (NREL) initiated a competitive procurement for the aftermarket conversion of Federal fleet vehicles. The objective was to develop multi-year subcontracts with several conversion companies across the nation to allow conversion of existing vehicles from several Federal agencies. The U.S. Department of Energy (DOE) provided the funding for these conversions. As of March 1996, about 90% of the 900 targeted conversions were complete. The rest were on order.

Table 1. Expansion of Alternative Fuel Vehicle Availability between 1992 and 1996

1992 Model Year Vehicles

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

1996 Model Year Vehicles

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

The conversion effort succeeded in helping the Federal government meet the requirements of EPACT for fiscal years 1993 and 1994 despite limited AFV model availability. Activities will be phased down during 1996, however, because OEM AFV availability has significantly increased since 1992.

Table 1 compares the availability of alternative fuel vehicles from the OEMs 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.

Emissions Standards for Aftermarket Conversions

In 1974, the U.S. Ennvironmental Protection Agency (EPA) 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 EPA on March 4, 1993, stating that a "reasonable basis" may include certification of the conversion kit by the California Air Resources Board, or 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, EPA established new certification standards for aftermarket conversions. ("Standards for Emissions From Natural Gas-Fueled, and Liquefied Petroleum Gas-Fueled Motor Vehicles and Motor Vehicle Engines, and Certification Procedures for Aftermarket Conversions," *Federal Register*, September 1994). In order for a conversion to count as a "clean fuel vehicle" and be eligible for EPA'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 No. 1A, but they cannot then be used for claiming emissions benefits.

Program Description

Subcontractor Selection

Because vehicles converted to operate on CNG or LPG were originally designed and optimized to run on gasoline, they inherently represent a compromise of vehicle technology. Therefore, a key program objective was to obtain the highest quality conversions available. For this reason, experience, capabilities, and demonstrated ability to meet the high performance criteria were weighted more heavily than price when the subcontractors were selected.

Kit Selection

With regard to carburetion equipment, only higher quality, "closed-loop feedback" conversion kits were allowed, because these are known to provide the best emissions performance. Closed-loop feedback systems continuously monitor the exhaust gas composition and use this to control the fuel/air mixture precisely. (The automobile companies design virtually all current gasoline light-duty vehicles with closed-loop feedback systems). All conversions were also required to meet the EPA's emissions requirements for vehicle conversions (see sidebar this page.) The conversion companies in the program chose GFI Control Systems kits and IMPCO Technologies kits for the CNG conversions, and IMPCO Technologies ADP kits for the LPG conversions.

Tank Configuration

Program requirements called for all CNG conversions to have a minimum driving range of 70-75 miles. In most cases, however, the fuel tanks were sized to provide a greater range. In contrast, vehicles converted to operate on LPG were required to have a minimum driving range of 170 miles.

Standard tank sizes and placement were agreed to with each conversion company. In addition, optional tank sizes and placement were negotiated with the contractor. In many cases, the Federal agency ordering the vehicle would require a different tank or location than the standard configuration because of its particular needs.

Figure 1 shows a typical CNG fuel tank installation in a pickup.

All of the CNG tanks installed in the program are NGV2-certified tanks. Some conversion companies chose aluminum wrapped tanks, while others selected a steel wrapped design. In a few cases, full composite tanks were installed. CNG conversion companies were asked to recommend which tank installations should have a shield. Recommendations varied from installing no shields to installing shields on certain classes of vehicles, such as in pickups with the tank in the bed. In most cases, tank shields were also made optional, so that a Federal agency that wanted shields installed could order them separately. This was often the case with pickup trucks with a tank in the bed, where the agency planned to carry tools or other heavy objects in the back.

Warren Gretz, NREL/PIX 03807

Figure 1. Typical installation of a CNG tank in a pickup

Installation Procedures

Best industry practices were required during installation of the kits. For instance, all CNG conversions are installed according to the National Fire Protection Association's Standard 52. This specification includes detailed instructions for the installation of the fuel system and tank. Similarly, LPG conversions are installed according to the National Fire Protection Association's Standard 58.

Subcontractors were instructed not to deliver any completed conversions until NREL had inspected the first three vehicles. Vehicles were inspected for conformance to the Statement of Work with respect to components and installation procedures, as well as being test driven. Only after successfully passing inspection was the subcontractor allowed to deliver vehicles. During these inspections only minor infractions were noted, which were corrected immediately. We believe that these inspections played a key role in the quality of the conversions delivered.

Warranty and Training

Each conversion in the Federal program is protected by a warranty that covers all installed conversion system parts and associated labor for 3 years or 36,000 miles, whichever comes first. Conversion subcontractors are also responsible for repair or replacement of any engine, fuel system, electrical, or electronic system components damaged by the

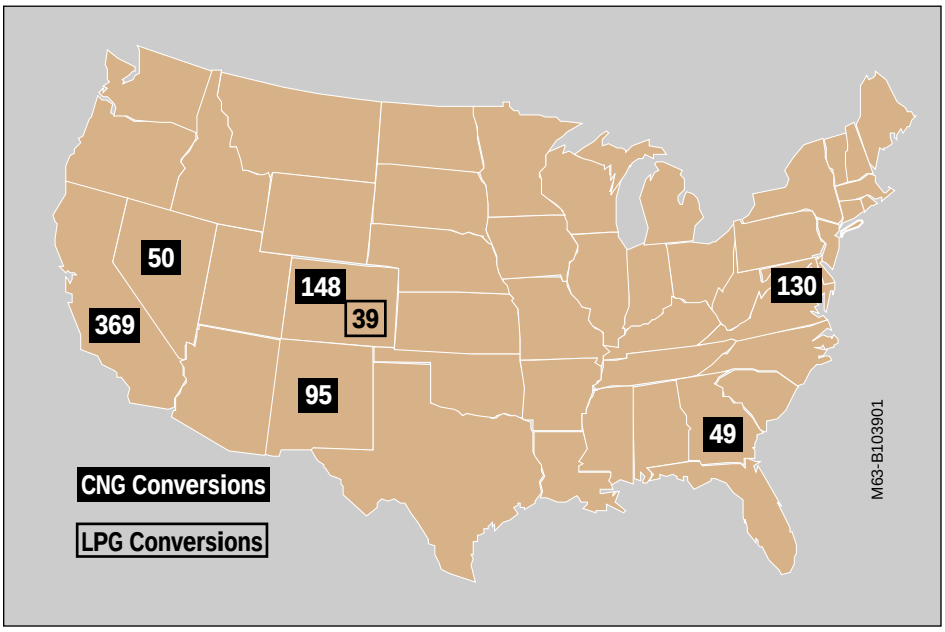
Table 2. Conversions by Federal Agency

Agency	CNG	LPG	Total Vehicles
Air Force	368	0	368
Marines	219	0	219
Navy	97	0	97
National Institutes of Health	66	0	66
Forest Service	2	24	26
Other Federal Agencies	89	15	104
Totals	841	39	880

installed conversion equipment during this period. As required by the provisions of EPACT, subcontractors were required to sign individual warranty agreements with Chrysler, Ford, and General Motors.

Subcontractors were also required to provide training to drivers at the Federal agencies, as well as to provide limited mechanic training for personnel servicing the vehicles.

Figure 2. Geographic distribution of conversions



Program Results

General

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

Table 2 lists the total number of conversions in this program completed or on order by Federal agencies. Figure 2 shows the distribution of conversions, by state, that are either completed or on order. Figure 3 shows the distribution of conversions, by vehicle type, that are either completed or on order. This figure illustrates that, based on fleet requests from managers, more than 90% of all conversions are taking place on pickups and vans. This is a positive sign because the OEMs are concentrating on producing these same types of vehicles.

Almost all of the light-duty vehicle conversions in this program (more than 90%) are “bi-fuel” conversions, which means that the vehicle may operate on either gasoline or the designated alternative fuel. The rest are “dedicated” conversions, which means that the vehicles may operate only on the designated alternative fuel. This shows that, given the choice, fleet managers in this program had a clear preference for bi-fuel vehicles. The automakers currently produce both dedicated and bi-fuel vehicle models.

Vehicle Cost

The cost of a light-duty vehicle conversion depends on the choice of

alternative fuel, the level of conversion technology used, and the size and quantity of the fuel tank(s). The average total cost for each CNG conversion in the program is about $4,500. The average total cost for each LPG conversion is about $2,800. The overall cost of each conversion, especially in the case of CNG, 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.

Infrastructure Issues

One objective of the program was to help "kick-start" the AFV market while the OEMs were developing a wider array of alternative fuel models. In several cases, the vehicles in this program provided sufficient fuel usage for an agency, in cooperation with other potential users, to justify the construction of a CNG station. In these cases, the use of bi-fuel was important as it allowed for greater fueling flexibility during construction of the new station.

Where possible, every effort was taken to target vehicles located in cities that DOE has designated as "Clean Cities." The objective of the clean cities initiative is to build a concentration of alternative fuel activity in the selected cities to make it easier for the fuel infrastructure to develop. Converted vehicles will be operating in 9 of the 45 designated Clean Cities: Atlanta; Denver; Las Vegas; Washington, D.C.; Albuquerque; Colorado Springs; Long Beach; Los Angeles; and the Southern California Association of Governments (SCAG).

Vehicle Performance

As part of NREL's on-going alternative fuel vehicle evaluation program, drivers of these and other alternative fuel vehicles are being contacted to solicit their input on how the vehicles are performing. At press time, the first driver survey of converted vehicles had not been completed. These data will be available in the future and will be issued in separate reports covering all the alternative fuel vehicles in the survey.

In addition to vehicle performance, NREL is evaluating the emissions performance of all types of alternative fuel vehicles. As part of this effort, a portion of the conversions in this program were emissions-tested for comparison to their emissions levels before conversion, and for comparison to the OEM alternative fuel vehicles that had already been tested in NREL's program. These results are discussed below.

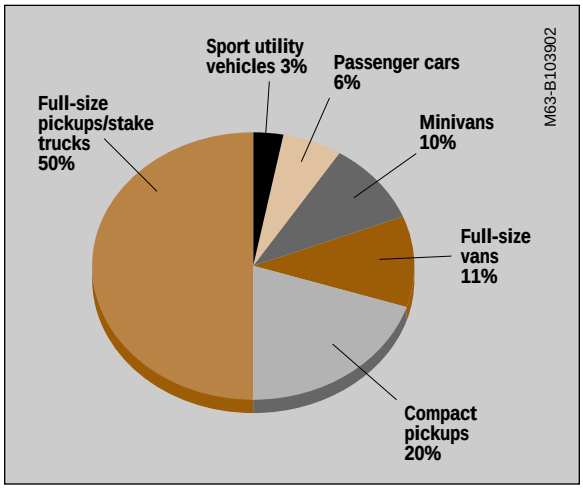


Figure 3. Vehicle conversions by vehicle type (880 total)

Emissions Testing

During 1995, emissions testing began 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

Table 3. Converted Vehicles Emissions Tested in 1995

Compressed Natural Gas (kit make and model: GFI)

Manufacturer	Model Year	Model	Emissions Standard	Quantity
Plymouth	1992	Acclaim	Tier 0	2
Chevrolet	1992	Astro (minivan)	Tier 0	1
Dodge	1992	Caravan (minivan)	Tier 0	2
General Motors	1993	Safari (minivan)	Tier 0	2
Ford	1994	Taurus	Tier 1	2
Dodge	1994	B250 van	Tier 0	2
General Motors	1994	C1500 pickup	Tier 0	2
Total CNG				13

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

Manufacturer	Model Year	Model	Emissions Standard	Quantity
Ford	1994	F150 pickup	Tier 0	2
Ford	1994	Taurus	Tier 1	1
Total LPG				3

and emissions test results. As a first step in answering this question, 16 bi-fuel vehicles (13 CNG and 3 LPG) were selected for emissions testing. The CNG conversions chosen for testing were converted by companies in either the Washington, D.C., or Denver area because NREL has contracts with emissions testing facilities in those areas. The LPG conversions were done in Denver. A list of the number and type of vehicles is shown in Table 3. All were relatively new models (1992 or newer). Three of the vehicles (the 1994 model Tauruses) were certified to EPA's most recent (and tighter) "Tier 1" emissions standards. This is important because by 1996 all new light-duty vehicles are required to meet Tier 1 standards.

All the CNG vehicles tested in the emissions program used GFI kits. Some of the vehicles used GFI II kits, which are a later version of the GFI kit. All the LPG conversions used IMPCO ADP kits. Both of these kits have closed-loop feedback control. In addition, the GFI kits can be electronically calibrated to a specific engine model for improved emissions and performance. In most cases, an engine-specific calibration is not needed for the engine to run, only for it to deliver optimum emissions and performance. Consequently, an attempt has been made to test emissions on only those CNG vehicles in the conversion program for which an engine calibration exists. (Note, however, that relatively few engine calibrations exist, compared to the number of engine models in the market. Converting only those vehicles for which an engine calibration exists would dramatically limit the types and quantities of vehicles that can be converted). The table in the Appendix shows which vehicles had engine calibrations designed specifically for that engine. In order to test vehicles that were in good condition, only vehicles with relatively low mileage were selected for the emissions testing part of the program. These vehicles will be re-tested as the mileage on them increases to evaluate the deterioration in emissions that normally comes with mileage.

To establish an emissions baseline, each vehicle was tested on California Phase 2 reformulated gasoline (RFG) prior to conversion. RFG was chosen as the baseline fuel for our entire emissions testing program, including testing of OEM alternative fuel models, because it represents the state of the art for low emissions performance gasoline. This reduces the likelihood that the AFVs will show marked improvement over the gasoline baseline. However, for alternative fuels to compete effectively with gasoline, they must compete with the most advanced gasolines. The conversion kit was installed shortly after (in most cases within 2000 miles of) the baseline test, and subsequent emissions tests were performed first on RFG and then on the alternative fuel (CNG or LPG). The CNG used for emissions testing was specially blended from tightly controlled constituent gases, and the LPG was produced to conform with the industry-accepted specification (known as HD5) for transportation propane fuel. All emissions tests conformed to EPA's Federal Test Procedures utilizing the Urban Dynamometer Driving Schedule.

The test results are summarized in Table 4 (next page), and detailed results are given in the Appendix. Although the first round of emissions results from the vehicles in the conversion program are somewhat mixed, a few general observations can be made.

Emissions Results

In general, the installation of GFI CNG conversion kits did not affect the gasoline emissions profile. In other words, for most vehicles and most constituents, the difference between the emissions recorded for RFG before and after conversion was negligible (less than 10%). For the IMPCO Technologies ADP LPG conversion kits tested, two out of three showed relatively large increases in emissions when tested on RFG 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 LPG test sample size is too small to make general conclusions.

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

The emissions comparison between RFG and the alternative fuel (both CNG and LPG) for these conversions is not impressive. Six of the nine CNG vehicles converted in Washington, D.C., recorded large increases in NO_x when tested on CNG, and five out of nine recorded large increases in CO when tested on CNG, relative to the corresponding levels obtained in the tests on RFG. Seven of the nine Washington, D.C., vehicles achieved a decrease in NMHC emissions when tested on CNG, relative to the values obtained in tests on RFG.

In the case of the CNG conversions in Denver, all of the vehicles exhibited a moderate decrease in NO_x, a

Table 4. Emission Test Results from Aftermarket Conversions (gm/mile without deterioration factors applied)

Washington, D.C. CNG Conversion Vehicles — *Kit make: GFI*

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 — *Kit make: GFI*

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 — *Kit make and model: IMPCO ADP*

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%)

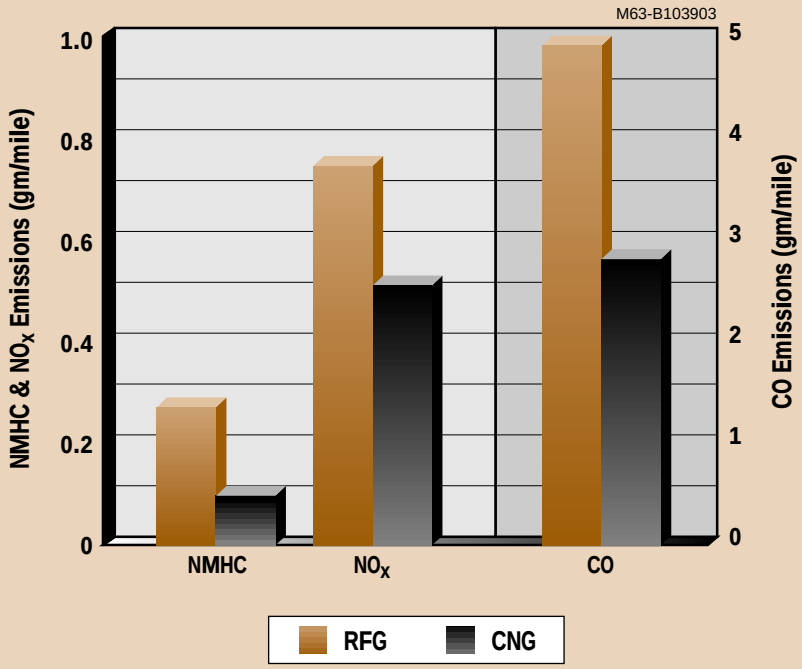


Figure 4. OEM Dodge Ram B250 Van average emissions results

OEM Emissions Results

Emissions performance of OEM alternative fuel vehicles is also being evaluated by NREL. To date, one model, a Dodge Ram Van with a 5.2L V8 dedicated CNG engine, has been evaluated. Fifty-two randomly selected CNG vans were tested and compared with forty-seven standard gasoline vans. Fuels and procedures used were the same as used for the conversion testing. The results showed consistent emissions reductions of all emissions studied. On average, NMHC emissions were reduced by 64%, CO by 43%, and NO_x by 31%, compared to gasoline controls (see Figure 4). Similar tests are planned for other OEM vehicles, including the Dodge dedicated CNG Caravan, which was certified to even lower emissions levels.

large decrease in NMHC emissions, and a moderate-to-large increase in CO emissions when tested on CNG relative to the corresponding values obtained in tests on RFG.

The LPG conversions in Denver showed mixed results. All three vehicles showed a large decrease in CO emissions. On the other hand, all three showed a moderate-to-large increase in NMHC emissions, and one showed a large increase in NO_x.

The results from this study cannot be considered comprehensive or conclusive because of the limited number and types of vehicles tested, especially for LPG. However, a general trend has been established for the CNG conversions. In most cases, they exhibit an emissions benefit in terms of NMHC, but, on the other hand, they tend to realize substantial increases in either NO_x, CO, or both. Substantial decreases in NMHC are to be expected for CNG vehicles, because the total hydrocarbons in the exhaust are composed of at least 90% to 95% methane. It should be noted that in the case of the single CNG model that was certified to Tier 1 emissions standards, a NMHC emissions benefit was not observed on CNG.

Too few LPG 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 NMHC when tested on LPG after conversion.

These early emissions results for aftermarket conversions, when contrasted with the considerable emissions improvements obtained with a dedicated CNG vehicle from an OEM (see sidebar), highlight the need to consider both the fuel and the vehicle technology when evaluating options for reducing air pollution. Although using a dedicated CNG vehicle from an OEM, for example, yielded substantial emissions benefits, it cannot be assumed that all fuel system technologies will achieve this end.

There is another troubling issue. Two of the 16 vehicles that were emissions-tested had much higher than expected emissions after conversion, and in one case lack of power, because of problems with the kit and/or installation. The results are shown in the Appendix (see vehicle numbers MD015COV and WY303CRV). In both cases, the vehicle was returned to the conversion company and the kit was repaired, after which the vehicle was retested. The results presented above are based on the lower values after repairs were performed. It is unclear whether these vehicles would have been returned to the conversion company for repair had they not been part of the emissions test program. In other words, drivers may not have complained about the vehicles because they may not have noticed a problem, or may have assumed that any performance degradation is typical of the alternative fuel. If this was the case, the emissions levels produced by the vehicles would have been higher—in one case dramatically higher—than shown in Table 4.

As mentioned in the sidebar on page 4 (Emissions Standards for Aftermarket Conversions), EPA issued new standards for the certification of conversions in September 1994. Fleets considering conversions should require that their converter provide proof that the vehicles being converted are certified according to these new standards.

Other studies have been performed where a conversion was optimized for a particular engine and vehicle and yielded impressive emissions results. This was not the purpose of this study, and it does not contradict these findings. This study was aimed at evaluating the emissions performance of a typical high-quality conversion, similar to what other government agencies may purchase to meet EPACT or other requirements.

Finally, it is important to note that emissions testing, and the resultant effect on the environment, is a complex and evolving science. Other factors beyond the three emissions constituents studied in this program are important. Ozone-forming potential, or the propensity to form smog, is a factor calculated from the ability of all the exhaust constituents (more than 300 of them) to react in the atmosphere to form smog. In addition, large benefits are often associated with alternative fuels in the reduction of toxic emissions such as benzene and 1,3-butadiene versus gasoline. More extensive testing is needed to calculate these effects. Finally, gaseous fuels are generally believed to perform better relative to gasoline under higher load and colder operating temperatures than

experienced during the test (the tests in this program are performed at room temperature). This is because gaseous fuels do not need fuel enrichment under these conditions like gasoline does.

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.

Conclusions

Aftermarket conversions can play an important role in the transition to the more widespread use of alternative fuel vehicles. In this program, they have been successful in helping the Federal government meet the vehicle acquisition requirements of EPACT, establishing infrastructure, and increasing the displacement of imported oil.

The disappointing emissions performance to date of these closed-loop feedback kits, however, raises the question of their overall emissions contribution to the environment. This is especially important when considering converting the latest model year vehicles, which have been certified to the lower (Tier 1) emissions standards. In addition, some existing kits are less advanced and less expensive than the ones tested, and the literature shows that these generally have worse emissions performance[1].

With the relatively widespread availability of OEM vehicles in the 1996 model year, this program is now being phased out.

For more information on CNG and LPG conversions, call the National Alternative Fuels Hotline at 1-800-423-1DOE and ask for our booklet titled "Facts about CNG and Propane Conversions," or visit our site on the World Wide Web at http://www.afdc.doe.gov

[1] *British Columbia Vehicle Emissions Inspection and Maintenance Program Experience of Alternative Fuel Vehicle Conversions, Stephen Stewart, David Gourley and Sam Loo, Province of British Columbia Ministry of Transportation and Highways, Motor Vehicle Branch.*

Appendix

Appendix: Emissions Test Data from Aftermarket Conversions

Washington, D.C. - CNG Conversions

Vehicle Number	Vehicle Make	Vehicle Model	Model Year	Conversion Kit Make & Model	Unique Engine Calibration?	EPA Cert Level	Test Date	Before/After Conversion	Test Odom	Test Fuel	Exhaust Emissions(g/mi)				
											NO_x	CO	NMHC	HC	CO_2
MD009CAV	Dodge	Acclaim	1992	GFI	no	Tier 0	02/08/95	Before	15347	RFG	0.238	4.12	0.147	0.166	359.4
MD009CAV	Dodge	Acclaim	1992	GFI	no	Tier 0	02/14/95	* Before (retest)	15365	RFG	0.215	4.14	0.154	0.175	372.8
MD009CAV	Dodge	Acclaim	1992	GFI	no	Tier 0	03/21/95	After	15589	RFG	0.215	3.33	0.106	0.121	347.3
MD009CAV	Dodge	Acclaim	1992	GFI	no	Tier 0	03/22/95	After	15615	CNG	0.743	1.58	0.064	0.411	269.3
MD010CAV	Dodge	Acclaim	1992	GFI	no	Tier 0	01/19/95	Before	44815	RFG	0.465	3.52	0.106	0.125	415.7
MD010CAV	Dodge	Acclaim	1992	GFI	no	Tier 0	03/17/95	After	46481	RFG	0.463	4.17	0.102	0.120	412.4
MD010CAV	Dodge	Acclaim	1992	GFI	no	Tier 0	03/21/95	After	46525	CNG	1.018	2.49	0.062	0.400	332.2
MD015COV	Chevrolet	Astro van	1992	GFI II	yes	Tier 0	05/18/95	Before	9125	RFG	1.007	2.42	0.482	0.540	496.3
MD015COV	Chevrolet	Astro van	1992	GFI II	yes	Tier 0	07/06/95	After	9418	RFG	0.852	2.32	0.460	0.509	504.7
MD015COV	Chevrolet	Astro van	1992	GFI II	yes	Tier 0	07/07/95	After	9444	CNG	0.439	9.47	0.666	3.115	399.2
MD015COV	Chevrolet	Astro van	1992	GFI II	yes	Tier 0	07/21/95	** After (recalib)	9718	RFG	0.869	2.38	0.468	0.516	502.7
MD015COV	Chevrolet	Astro van	1992	GFI II	yes	Tier 0	07/24/95	** After (recalib)	9744	CNG	0.788	4.42	0.374	1.966	394.1
MD007CMV	Dodge	Caravan	1992	GFI	no	Tier 0	01/26/95	Before	22293	RFG	0.750	1.30	0.228	0.257	465.9
MD007CMV	Dodge	Caravan	1992	GFI	no	Tier 0	02/24/95	After	22636	RFG	0.464	2.36	0.292	0.326	473.8
MD007CMV	Dodge	Caravan	1992	GFI	no	Tier 0	03/06/95	After	22676	CNG	1.469	3.82	0.154	0.856	379.4
MD008CMV	Dodge	Caravan	1992	GFI	no	Tier 0	03/03/95	Before	20885	RFG	0.531	1.96	0.239	0.263	463.0
MD008CMV	Dodge	Caravan	1992	GFI	no	Tier 0	03/23/95	After	21097	RFG	0.375	1.57	0.227	0.249	466.2
MD008CMV	Dodge	Caravan	1992	GFI	no	Tier 0	03/24/95	After	21123	CNG	1.584	3.24	0.121	0.767	370.0
MD013CWV	GMC	Safari	1993	GFI II	yes	Tier 0	04/07/95	Before	15296	RFG	1.144	4.92	0.464	0.526	499.9
MD013CWV	GMC	Safari	1993	GFI II	yes	Tier 0	09/12/95	After	19002	RFG	1.231	4.38	0.457	0.512	500.1
MD013CWV	GMC	Safari	1993	GFI II	yes	Tier 0	09/13/95	After	19028	CNG	0.888	4.71	0.122	1.390	400.3
MD014CWV	GMC	Safari	1993	GFI II	yes	Tier 0	03/24/95	Before	11001	RFG	1.201	6.19	0.538	0.608	506.8
MD014CWV	GMC	Safari	1993	GFI II	yes	Tier 0	05/30/95	After	11491	RFG	1.208	4.71	0.475	0.533	509.6
MD014CWV	GMC	Safari	1993	GFI II	yes	Tier 0	05/31/95	After	11518	CNG	0.765	5.16	0.255	1.437	413.6
MD011CTV	Ford	Taurus	1994	GFI	yes	Tier 1	01/24/95	Before	5641	RFG	0.223	1.08	0.091	0.102	461.6
MD011CTV	GMC	Taurus	1994	GFI	yes	Tier 1	03/16/95	After	6968	RFG	0.293	1.06	0.077	0.089	465.2
MD011CTV	GMC	Taurus	1994	GFI	yes	Tier 1	03/17/95	After	6993	CNG	0.711	1.78	0.090	0.587	374.9
MD012CTV	GMC	Taurus	1994	GFI	yes	Tier 1	02/02/95	Before	7791	RFG	0.168	0.98	0.082	0.092	459.6
MD012CTV	GMC	Taurus	1994	GFI	yes	Tier 1	05/05/95	After	12006	RFG	0.175	1.35	0.093	0.106	486.6
MD012CTV	GMC	Taurus	1994	GFI	yes	Tier 1	05/08/95	After	12030	CNG	0.864	1.54	0.081	0.577	395.0

* vehicle was retested to verify higher than expected emissions (values calculated in Table 4 are based on the average of the two tests)

** vehicle was retested after "re-calibration" by conversion company due to emissions and performance problems (results before "re-calibration" were not included in Table 4 summary calculations)

Appendix: Emissions Test Data from Aftermarket Conversions

Denver, CO - CNG Conversions

Vehicle Number	Vehicle Make	Vehicle Model	Model Year	Conversion Kit Make & Model	Unique Engine Calibration?	EPA Cert Level	Test Date	Before/After Conversion	Test Odom	Test Fuel	Exhaust Emissions(g/mi)				
											NO_x	CO	NMHC	HC	CO_2
WY302CRV	Dodge	B250 van	1994	GFI II	yes	Tier 0	06/02/95	Before	9475	RFG	2.528	8.29	0.819	0.911	581.0
WY302CRV	Dodge	B250 van	1994	GFI II	yes	Tier 0	06/14/95	* Before (retest)	9533	RF	2.098	9.20	0.853	0.949	574.4
WY302CRV	Dodge	B250 van	1994	GFI II	yes	Tier 0	07/12/95	After	9598	RFG	2.543	9.26	0.841	0.939	590.2
WY302CRV	Dodge	B250 van	1994	GFI II	yes	Tier 0	07/13/95	After	9617	CNG	1.607	13.02	0.142	1.355	456.6
WY303CRV	Dodge	B250 van	1994	GFI II	yes	Tier 0	06/01/95	Before	14488	RFG	0.646	2.75	0.162	0.207	572.9
WY303CRV	Dodge	B250 van	1994	GFI II	yes	Tier 0	06/23/95	After	14635	RFG	0.318	72.92	1.696	1.915	515.8
WY303CRV	Dodge	B250 van	1994	GFI II	yes	Tier 0	07/06/95	*** After (repair)	14691	RFG	0.479	2.78	0.150	0.190	572.5
WY303CRV	Dodge	B250 van	1994	GFI II	yes	Tier 0	07/11/95	After	14716	CNG	0.334	6.58	0.052	0.789	450.9
WY304CGV	GMC	C1500 pickup	1994	GFI II	yes	Tier 0	06/27/95	Before	3659	RFG	0.489	2.88	0.174	0.206	468.9
WY304CGV	GMC	C1500 pickup	1994	GFI II	yes	Tier 0	07/18/95	After	3715	RFG	0.464	2.26	0.158	0.190	480.5
WY304CGV	GMC	C1500 pickup	1994	GFI II	yes	Tier 0	07/19/95	After	3734	CNG	0.433	6.63	0.058	0.918	380.1
WY305CGV	GMC	C1500 pickup	1994	GFI II	yes	Tier 0	05/23/95	Before	6674	RFG	0.615	3.98	0.181	0.218	475.6
WY305CGV	GMC	C1500 pickup	1994	GFI II	yes	Tier 0	06/06/95	After	6745	RFG	0.606	3.94	0.180	0.219	486.5
WY305CGV	GMC	C1500 pickup	1994	GFI II	yes	Tier 0	06/07/95	After	6764	CNG	0.428	6.62	0.041	0.774	384.1

* vehicle was retested to verify higher than expected emissions (values calculated in Table 4 are based on the average of the two tests)
*** vehicle was retested after repair by conversion company due to extremely high CO results (results before the repair were not included in Table 4 summary calculations)

Denver, CO - LNG Conversions

Vehicle Number	Vehicle Make	Vehicle Model	Model Year	Conversion Kit Make & Model	Unique Engine Calibration?	EPA Cert Level	Test Date	Before/After Conversion	Test Odom	Test Fuel	Exhaust Emissions(g/mi)				
											NO_x	CO	NMHC	HC	CO_2
DV002PFV	Ford	F150 pickup	1994	IMPCO ADP	NA	Tier 0	02/17/95	Before	4633	RFG	1.199	0.66	0.094	0.208	644.4
DV002PFV	Ford	F150 pickup	1994	IMPCO ADP	NA	Tier 0	03/15/95	After	4773	RFG	1.022	1.04	0.142	0.384	654.8
DV002PFV	Ford	F150 pickup	1994	IMPCO ADP	NA	Tier 0	03/16/95	After	4792	LPG	1.252	0.31	0.390	0.460	550.2
DV003PFV	Ford	F150 pickup	1994	IMPCO ADP	NA	Tier 0	01/10/95	Before	7878	RFG	0.876	0.80	0.076	0.152	671.3
DV003PFV	Ford	F150 pickup	1994	IMPCO ADP	NA	Tier 0	05/24/95	After	11744	RFG	0.95	1.26	0.161	0.257	690.9
DV003PFV	Ford	F150 pickup	1994	IMPCO ADP	NA	Tier 0	05/25/95	After	11763	LPG	0.855	0.31	0.387	0.474	576.2
DV004PTV	Ford	Taurus	1994	IMPCO ADP	NA	Tier 1	01/11/95	Before	8768	RFG	0.250	0.80	0.093	0.104	394.3
DV004PTV	Ford	Taurus	1994	IMPCO ADP	NA	Tier 1	03/20/95	After	9122	RFG	0.269	1.09	0.085	0.096	401.7
DV004PTV	Ford	Taurus	1994	IMPCO ADP	NA	Tier 1	03/23/95	After	9140	LPG	1.944	0.30	0.133	0.165	365.5

NA - not applicable to IMPCO conversion kits

Produced for the U.S. Department of Energy

1000 Independence Avenue, SW
Washington, DC 20585

by the National Renewable Energy Laboratory,
A DOE national laboratory

NREL/SP-425-20514
DE96000538
April 1996