LPG/PROPANE

Fuel Description

Liquefied petroleum gas (LPG) is any mixture of several hydrocarbon compounds that are gases at normal room temperatures and pressures but can be liquefied under moderate pressure at atmospheric temperatures. These gases can include: paraffins occurring between ethane (a gas) and pentane (a liquid)[45] and monolefins occurring between ethene and pentene. The paraffins include propane, iso-butane, and butane. The monolefins include propylene, isobutene, 1-butene, and 2-butene. Propane is the predominant component in most LPG mixtures in the U.S. and many times LPG is referred to generically as "propane."

LPG is obtained several ways. Most of the paraffins found in LPG are recovered during natural gas processing and from the removal of light hydrocarbons from crude oil. These paraffins are by-products of gas production and crude oil refining. Most of the olefins found in LPG are by-products of the catalytic cracking units used by refiners to produce lighter hydrocarbons from heavier crude stocks.[46]

LPG is distributed throughout the U.S. primarily by pipelines and tank trucks. In New York State, a major pipeline that originates in Texas carries LPG eastward across the State, ending at a large terminal in Selkirk, approximately 10 miles south of Albany. At terminals like the one in Selkirk, the LPG is loaded onto tank trucks for distribution to users.

LPG is stored onboard vehicles as a pressurized liquid. Storage pressure will depend on the storage temperature and the fuel composition but is generally less than 250 psi at normal ambient temperatures. LPG storage tanks are required to reserve 20% of their total volume as vapor space to allow for expansion. The required vapor space and the lower energy content of LPGs (on a volume basis when compared to gasoline) require the use of larger tanks than conventional fuels to achieve equivalent driving range. For example, propane has only about 70% of the energy per gallon that gasoline does. Consequently, the volume of propane required to equal the energy in gasoline is about 40% larger. This is illustrated in Figure 2.52. In addition, LPG fuel tanks are usually cylindrical (a shape well suited for pressure vessels) and are therefore more difficult to package within a vehicle than an equivalent sized, conformable, gasoline fuel tank.

---

[45] Compressed Gas Association, Handbook of Compressed Gases, Second Edition, Van Nostrand Reinhold Company, 135 West 50th Street, New York, NY 10020, Copyright 1981.

[46] Owen, K. and T. Coley, Automotive Fuels Reference Book, Second Edition, SAE International, 400 Commonwealth Drive, Warrendale, PA 15096, Copyright 1995.

LPG storage pressure, while moderate, is much higher than for gasoline (which is slightly above atmospheric) and requires the use of stronger, heavier tanks. A propane vehicle fuel storage tank storing the equivalent of 10 gallons of gasoline would weigh approximately 130 lb (73 lb for the tank and 57 lb for the fuel). This compares to a gasoline system weighing approximately 85 lb (22 lb for the tank and 63 lb for the fuel). This is illustrated in Figure 2.53 on a gasoline gallon equivalent basis.

Figure 2.52 Volume to Store Equal Amounts of Energy, Propane Compared to Gasoline (Fuel Only, No Hardware)

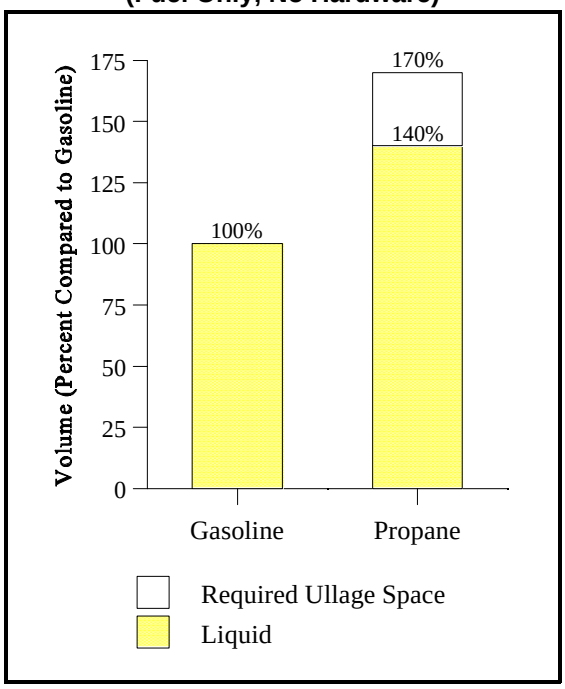
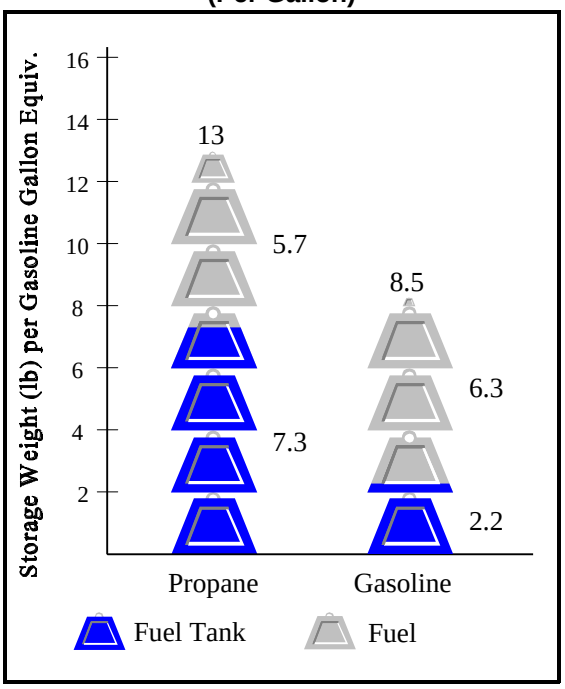


Figure 2.53 Comparison of Propane and Gasoline Fuel System Storage Weights (Per Gallon)



Fuel Properties

LPG has many properties that make it useful as a vehicle fuel. While fuel storage volumes and weights are higher than those required for gasoline, they are lower than for CNG and comparable to M85 and E85.

While many of the gases that make up LPG have high octane ratings, several do not. The blending motor octane values (research octanes are typically higher) along with other properties of interest for different components of LPG are given in Table 2.22.[47] Fuels for use in LPG vehicles are usually required to meet an industry standard called HD-5 (ASTM D1835). This standard limits the amount of propylene and other low-octane components in the fuel. (Table 2.23 shows the HD-5 fuel requirements.) The octane rating of propane,

[47] Owen, K. and T. Coley, Automotive Fuels Reference Book, Second Edition, SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

or LPG meeting the HD-5 standard, is high enough to allow an increase in compression ratio in the engines of dedicated propane vehicles, which should improve overall efficiency relative to gasoline.

Table 2.22 Properties of Compounds Found in Typical LPG Mixtures Compared to Gasoline

	Propane	n-Butane	iso-Butane	Propylene	Butene	Gasoline
Vapor Density Relative to Air[1]	1.55	2.07	2.06	1.47	1.93	~4.0
Boiling Point (ºF)[2]	-44	31	11	-54	21	80-437
Vapor Pressure at 100ºF (psia)[2]	189	52	72	226	63	~8
Motor Octane Number[2]	97	90	98	85	80	80-90
Energy Density (Btu/gal)[2]	82,500	94,100	90,300	83,900	96,100	109,000-119,000

[1] Compressed Gas Association, Handbook of Compressed Gases, Second Edition, Van Nostrand Reinhold Company, 135 West 50th Street, New York, NY 10020, Copyright 1981.
[2] Obert, E.F., Internal Combustion Engines and Air Pollution, Third Edition, Intext Educational Publishers, New York, Copyright 1973.

Table 2.23 HD-5 Requirements

Property	Specification
Propane (volume %)	90 minimum
Propylene (volume %)	5 maximum
Butane and heavier (volume %)	2.5 maximum
Vapor Pressure at 100ºF	208 psi
Sulfur (ppm mass)	120 maximum

Emissions Reactivity

By itself, propane is estimated to have only 56% of the reactivity of hydrocarbons from typical gasoline. However, when propane is burned in an engine, some hydrocarbons other than propane are produced that are more reactive than propane. The ozone-forming potential of the hydrocarbon exhaust emissions for propane vehicles has been found to be 63% less than equivalent vehicles operating on reformulated gasoline.[48] In addition, dedicated propane vehicles have fuel systems that are not vented, eliminating evaporative emissions. Overall, the ozone-forming potential of propane vehicles should be between one-quarter and one-half that of their gasoline counterparts.

Greenhouse Gases

The principal greenhouse gas emitted by gasoline and propane vehicles during operation is CO_2. The lower carbon content and higher hydrogen content of propane compared to gasoline means that vehicles operating on propane will emit less CO_2 than similar vehicles operating on gasoline (assuming the same fuel efficiency). Assuming equal vehicle efficiencies the propane vehicles will emit 12% less CO_2 than gasoline vehicles. When fuel production and other greenhouse gases are included, propane vehicles are estimated to have 10 to 20% lower overall estimated greenhouse gas impact than gasoline vehicles.[49,50]

Vehicle Technology

Vehicle fuel systems for LPG vehicles are similar in design to those used for CNG vehicles. Current LPG fuel system designs, like those in CNG vehicles, meter gaseous fuel. Liquid fuel is drawn from the tank and sent to a single unit that lowers its pressure and vaporizes it simultaneously. Engine coolant is used to heat the vaporizer to help prevent freeze-ups. This low pressure gaseous fuel is supplied to a fuel mixer (in principle similar to a gasoline carburetor). Currently, the more sophisticated computer-controlled fuel injection systems available for CNG have not been adapted to use LPG. Figure 2.54 is a schematic of a typical LPG vehicle fuel system. Aside from the fuel system, other components of a LPG engine are similar to those

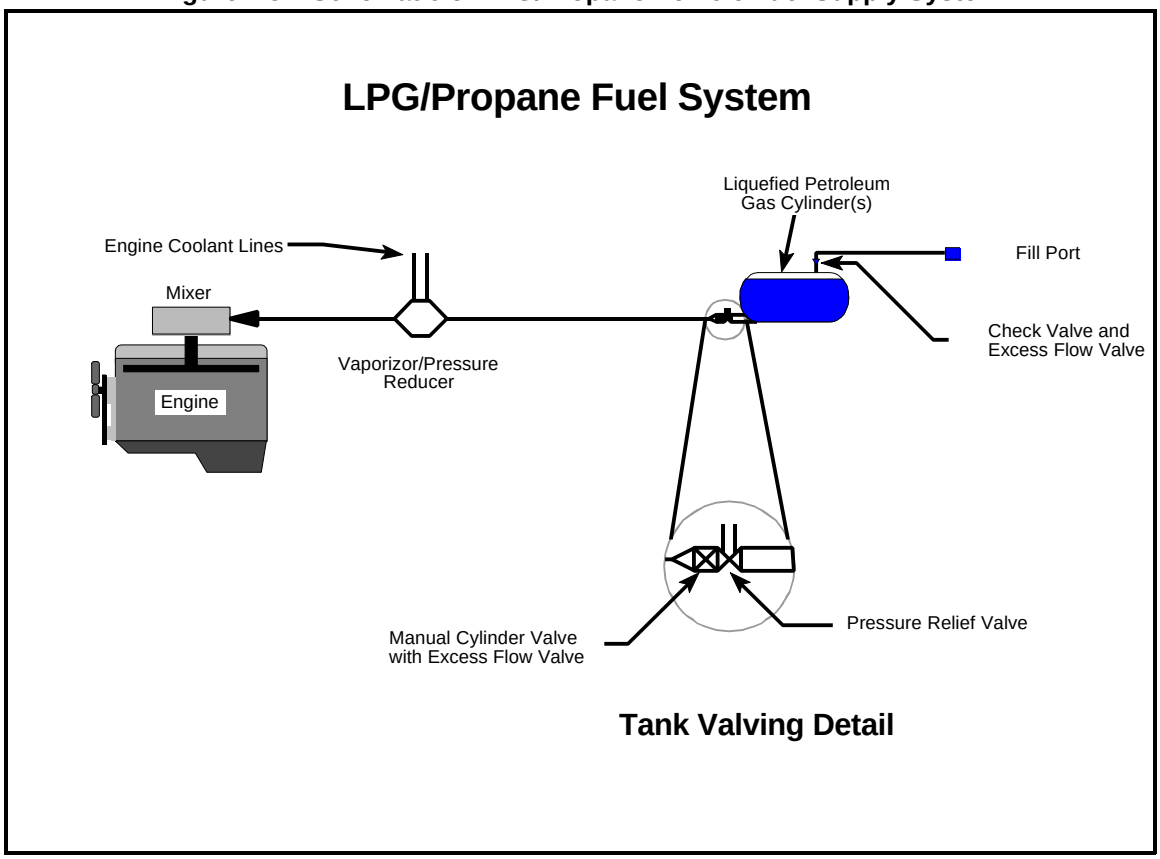
---

[48] Whitney, K.A. and B.K. Bailey, "Determination of Combustion Products from Alternative Fuels - Part I: LPG and CNG Combustion Products," SAE Paper No. 941903, SAE International, 400 Commonwealth Drive, Warrendale, Pennsylvania 15096-0001.

[49] Senthil, V., "Alternatives to Traditional Transportation Fuels - 1994 - Volume 2: Greenhouse Gas Emissions," U.S. Department of Energy, Energy Information Administration, Report No. DOE/EIA-0585(94)/2, August 1996.

[50] Wang, M.Q., "Development and Use of the GREET Model to Estimate Fuel-Cycle Energy Use and Emissions of Various Transportation Technologies and Fuels," Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439, March 1996.

Figure 2.54 Schematic of LPG/Propane Vehicle Fuel Supply System



used in gasoline vehicles. LPG vehicle fuel systems are sealed and generally do not emit any evaporative emissions.

LPG fuel systems are equipped with several safety-related valves as shown in Figure 2.54. These valves include:

- Safety Relief Valve: This valve is designed to release vapor from a tank that has been over-filled or overheated. The valve is designed to release fuel until the pressure inside the tank is reduced to a safe level.
- Manual Cylinder Valve: This valve isolates the fuel in the cylinder from the rest of the fuel system (except for the safety relief valves). The valves have an internal excess flow valve designed to close at high fuel flow rates. The valves also incorporate a check valve to prevent the backflow of fuel into the cylinder.

- Fill Check Valve With Excess Flow Valve: The check valve is a spring loaded type, designed to close whenever flow from the fill port has stopped or reversed. The excess flow valve is designed to prevent release of fuel if the fill line is sheared off from the cylinder.

The New York State Office of Parks, Recreation and Historic Preservation (NYSOPR) fleet demonstration project of the AFV-FDP featured five light-duty propane trucks: a 1985 Dodge pickup (shown in Figure 2.55), two 1992 Ford F-series pickups (Figure 2.56), and two 1991 Chevrolet S-10 Blazer sport-utility vehicles (Figure 2.57). All five were converted to dedicated propane operation. Data were also collected from three comparable gasoline control vehicles.

All of the vehicles operating on propane used an IMPCO, Inc. gaseous fuel system consisting of a mixer and other items shown in Figure 2.54. Air-fuel mixtures for all of the vehicles were set during installation. The S-10 and F-150 vehicles had an engine management system (EMS) fuel pilot air-fuel ratio controller. The EMS receives a signal from the oxygen sensor(s), relates it to fuel mixture ratios, and transmits a control signal to the fuel control valve, which modulates bleed air to the mixer. In this way the air-fuel ratio is continuously adjusted. With this arrangement the fuel system will theoretically (within its limits of operation) adjust operations for small errors in initial setup and for drift due to mechanical wear and other factors, which helps to maximize the efficiency of three-way catalyst emission control systems.

The 1985 Dodge Pickup utilized the same basic IMPCO fuel system without the closed-loop fuel control processor since this model year predates the use of an oxygen sensor in the OEM fuel system/exhaust manifold. Hence, it operated in open-loop configuration. Further, the Dodge was not equipped with a catalytic converter. Table 2.24 summarizes the engine and fuel systems used on these vehicles. All five propane conversions were done by Propane Equipment Corporation. The incremental conversion cost including fuel tanks and installation is estimated to be between $2,000 and $2,200.

The engines in the conversion vehicles were not fully optimized for propane operation. All used standard OEM gasoline ignition timing and no mechanical changes were made to the engines. Propane enters the engine as a gas (unlike gasoline that enters the engine predominately as a liquid) which displaces air that would otherwise enter the engine and be available to support combustion. Because less air is available for combustion, power output when using propane is typically degraded 5% to 10% relative to operation using gasoline. A remedy for this power loss is an advance in spark timing or increase in compression ratio, possible because of the high octane value of propane. However, advancing spark timing may have adverse NO_x emission consequences.

Figure 2.55 NYSOPR Dodge Ram 350 with Propane Tank Visible

Figure 2.56 NYSOPR Propane Ford F-150

Figure 2.57 NYSOPR Propane Chevrolet S-10 Blazer

Table 2.24 NYSOPR Propane and Gasoline Vehicles

Vehicle Description	Fuel	Useable Tank Capacity, gal	Engine	Fuel System
#92-4512 1992 Ford F-150 Pickup	Gasoline	18.2	4.9L-I6	OEM: Sequential Electronic Fuel Injection
#92-4413 1992 Ford F-150 Pickup	Propane	26.2	4.9L-I6	IMPCO: Gaseous Fuel Carburetor with Closed-loop Feedback Control
#92-4409 1992 Ford F-150 Pickup	Propane	26.2	4.9L-I6	IMPCO: Gaseous Fuel Carburetor with Closed-loop Feedback Control
#91-3648 1991 Chevrolet S-10 Blazer	Gasoline	20.0	4.3L-V6	OEM: Throttle Body Fuel Injection
#91-3570 1991 Chevrolet S-10 Blazer	Propane	14.0	4.3L-V6	IMPCO: Gaseous Fuel Carburetor with Closed-loop Feedback Control
#91-3569 1991 Chevrolet S-10 Blazer	Propane	14.0	4.3L-V6	IMPCO: Gaseous Fuel Carburetor with Closed-loop Feedback Control
#85-4528 1985 Dodge Ram 350	Gasoline	20.0	5.2L-V8	4-Barrel Carburetor
#85-4529 1985 Dodge Ram 350	Propane	18.2	5.2L-V8	IMPCO: Gaseous Fuel Carburetor **without** Closed-loop Feedback Control

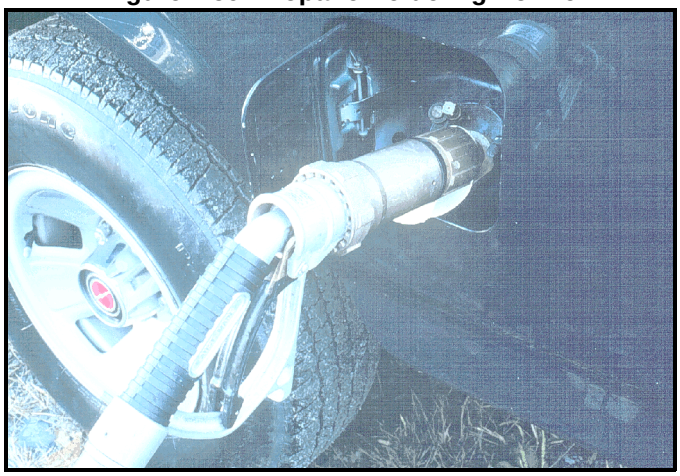
Refueling Infrastructure

Propane refueling facilities are similar in many ways to gasoline refueling facilities. The main difference is that the fuel is stored as a pressurized liquid. During refueling, the fuel is pumped, as gasoline would be, from the storage tank into the vehicle fuel tank. Two refueling facilities were installed to support the AFV-FDP propane vehicles operated by NYSOPR at James Baird and Mills-Norrie State Parks (both parks are near Poughkeepsie, Dutchess County). These facilities (see Figure 2.58) are skid-mounted and self-contained, requiring only a flat area to place the skid and electrical hook-up for operation. The facilities consist of 1,000-gallon aboveground storage tanks, electrically powered dispensing pumps, and mechanical volume metering.

Figure 2.58 NYSOPR Propane Vehicle Being Refueled

The facilities used in support of the AFV-FDP were not designed as public stations. If the stations had been designed for public use, they would more closely resemble current gasoline refueling facilities. The main difference is that the propane refueling nozzle must be physically locked onto the vehicle. This is usually accomplished using a lock ring (with either a screw or camlock design) and is needed to prevent the release of pressurized fuel. The refueling connection is a dry-break

Figure 2.59 Propane Refueling Nozzle



design; i.e., the refueling connectors (station nozzle and vehicle receptacle) are designed not to allow any fuel to be released or transferred unless they are locked together. Figure 2.59 shows the refueling nozzle from the James Baird State Park refueling facility attached to a vehicle during refueling. In addition, most propane vehicles currently have a bleed or spitter valve. During refueling the valve is opened, which releases vapor from the vehicle tank making room for liquid propane entering the tank. The bleed valve is attached to the tank so that once the tank is filled with 80% liquid the valve will begin to vent liquid fuel, letting the operator know that refueling is complete. This system is used to supplement the automatic stop-fill system.

The refueling facilities installed to support the AFV-FDP vehicles did not need to be as sophisticated as public stations. Dispensing fuel requires the operator to turn on the pump and manually open the main fuel shut-off and bleed valves. After refueling the vehicle bleed valve is closed, the pump switched off, and the main fuel shut-off valve is closed. Drivers and mechanics were trained in refueling facility operation at the beginning of the project and again after approximately one year of operation. The training highlighted the differences between gasoline and propane, the common safety precautions that need to be followed when refueling propane vehicles, and the procedure for operating the propane refueling facility. Refueling facility purchase and installation costs are quite similar to those for gasoline. In many cases the cost can be lower since secondary containment is not needed.

Operations and Maintenance

The vehicles were based and refueled at the James Baird State Park and also refueled at the Mills-Norrie State Park. The Dodge pickups (propane and control) were outfitted with a dump bed and used primarily on park grounds hauling dirt, brush, and mulch. During the winter the Ram 350 was outfitted with a plow blade for snow removal. Both uses involved lots of low-speed operation. The Fords and Blazers were used both on park grounds and between parks. Operation between parks involved moderate to high-speed sustained highway driving.

Throughout this project, four of the five propane vehicles remained on the road and steadily accumulated mileage. Figure 2.60 illustrates the cumulative mileage accumulation for the project vehicles. The propane vehicles averaged 543 miles/month, which is slightly higher than the three gasoline control vehicles that averaged 464 miles/month. In 1994 the Dodge truck, which only saw occasional use, was retired due to the age of the chassis.

Figure 2.61 details the cumulative amount of propane and gasoline used: 5,450 volumetric gallons of propane and 2,476 gallons of gasoline (used by control vehicles only) were consumed by project vehicles over the data collection period.

Figure 2.60 NYSOPR Vehicle Mileage Accumulation

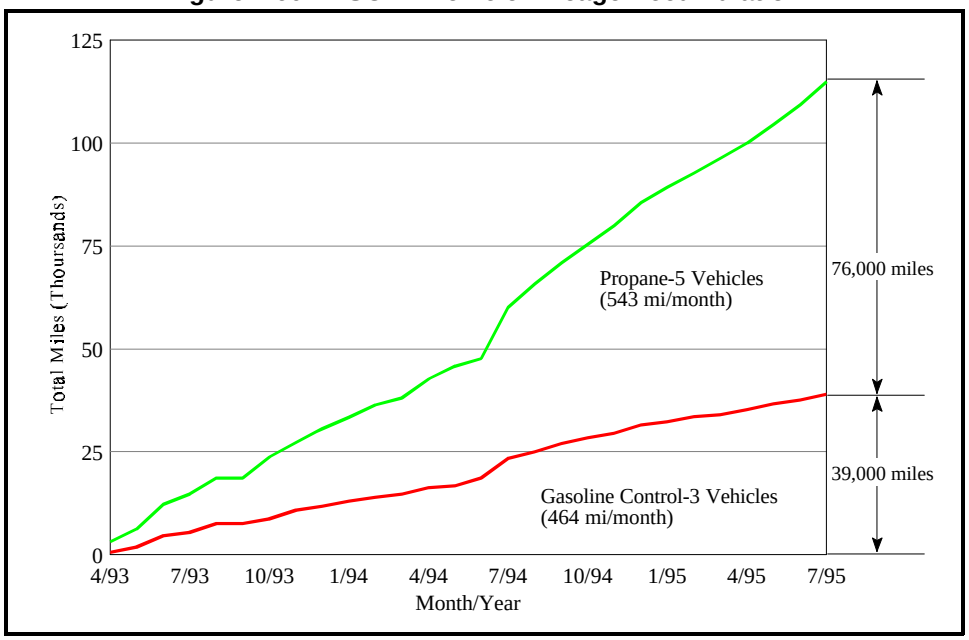


Figure 2.61 NYSOPR Vehicle Fuel Consumption

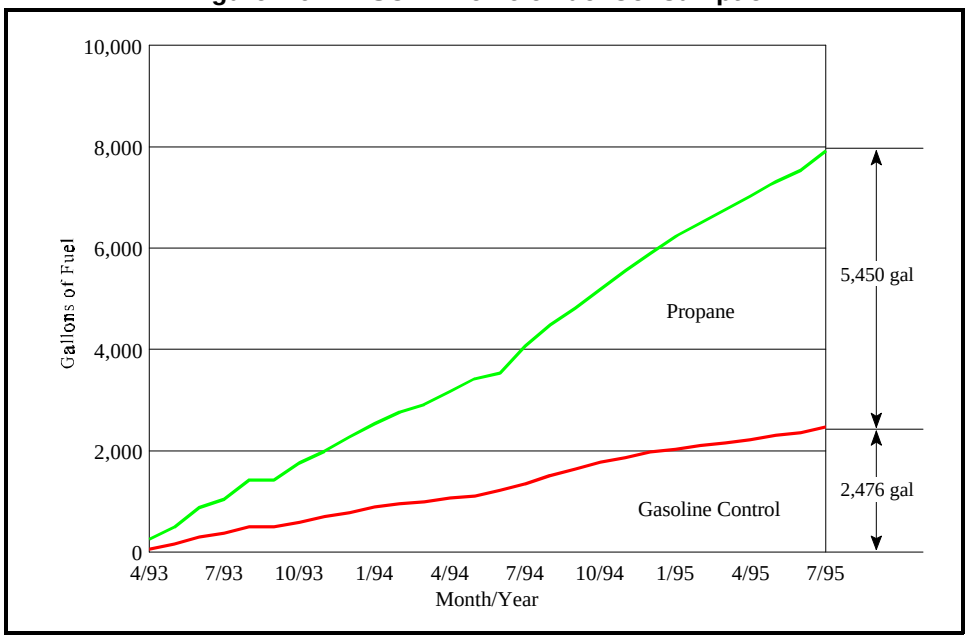


Table 2.25 Fuel Economies Calculated from Emission Test Results

Vehicle	HFET		City Cycle	
	Propane[1]	Gasoline	Propane[1]	Gasoline
1992 Ford F-150 Pickup Control Vehicle	NA[2]	24.3	NA	16.1
1992 Ford F-150 Pickup	24.1	23.9[3]	15.8	15.4[3]
1992 Ford F-150 Pickup	24.4	23.9[3]	15.4	15.6[3]
1991 Chevrolet S-10 Blazer Control Vehicle	NA	31.5	NA	19.7
1991 Chevrolet S-10 Blazer	29.1	29.7[3]	19.7	20.0[3]
1991 Chevrolet S-10 Blazer	28.6	28.0[3]	18.5	18.1[3]
1985 Dodge Ram 350 Control Vehicle	NA	12.3	NA	10.5
1985 Dodge Ram 350	NT	NT	10.0	9.9[3]

[1] Propane fuel efficiency reported in miles per gasoline equivalent gallon
[2] NA indicates that data item is not applicable, while NT indicates that data item was not tested.
[3] Pre-conversion fuel efficiency

Fuel Economy. Laboratory fuel economies were calculated based on dynamometer emission testing of the eight project vehicles. Emissions tests were provided by Texaco Research & Development and conducted annually from 1993 through 1995 by Compliance Research Labs in Linden, New Jersey. Vehicles were tested according to the Federal Test Procedure following both the Urban Dynamometer Driving Schedule (City Cycle) and the Highway Fuel Economy Test (HFET) cycles. The fuel economy results of these tests are shown in Table 2.25. Laboratory testing showed similar fuel efficiencies between the propane and gasoline vehicles (measured on a gasoline equivalent basis).

Reliability and Durability. Maintenance data were collected at the James Baird State Park vehicle maintenance facility and warranty data were also supplied by the vehicle conversion firm. Examination of these data reveal that throughout this project only two incidents occurred that required maintenance to the propane vehicles, other than typical scheduled preventive maintenance.

The first incident occurred during emission testing of one of the Chevrolet S-10 Blazers. The vehicle was running poorly and investigation revealed that a threaded orifice, used to control how quickly the mixture adjusted to signals from the oxygen sensor, was missing. The missing orifice was subsequently replaced and the vehicle readjusted for smooth running. None of the other vehicles had this problem.

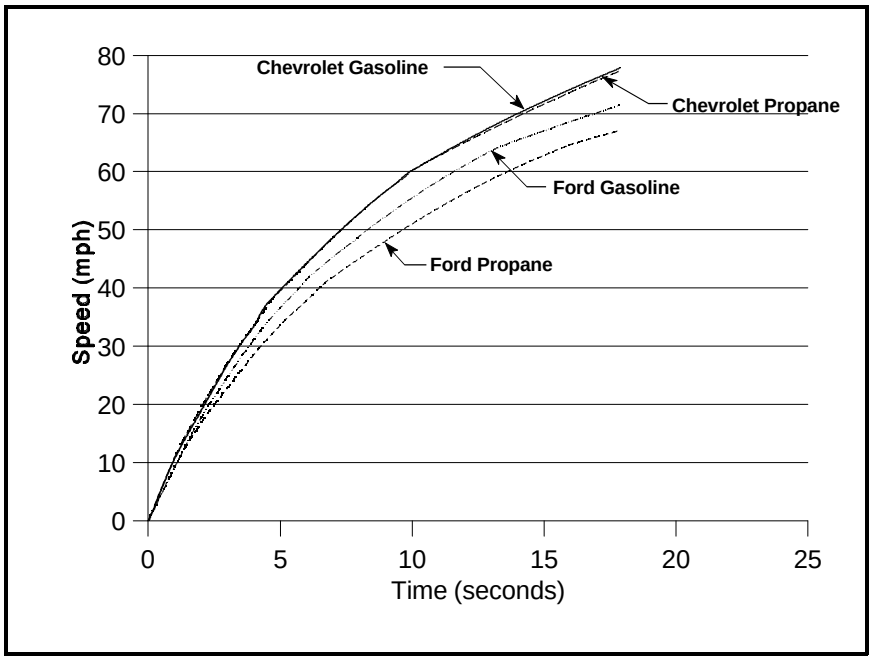
The other unscheduled maintenance item involved the contamination of the fuel systems from high boiling point hydrocarbons present in the fuel. Contamination was found on several of the vehicles. Contamination of the hoses and vaporizers/regulators resulted in difficult cold starting, which became evident in the winter of 1994/1995. The effects of the contamination were gradual and took more than a year of operation before becoming apparent. To remedy this situation, regulators were cleaned and the hoses replaced. Investigation into the cause of the contamination pointed to two probable causes: leaching of plasticizer from the hoses, and/or possible contamination during the production, transport, and storage of the fuel. Analysis of the propane showed that it contained a small amount of higher boiling point hydrocarbons, likely picked up during pipeline transport. These heavy hydrocarbons will not vaporize with the propane and accumulate in the vaporizer. Over time, even with low concentrations of higher boiling point hydrocarbons in the fuel they will accumulate and eventually clog passageways in the vaporizer. Preventive cleaning of the hoses and vaporizer is advised prior to winter operation to forestall future starting or drivability problems.

Acceleration. The Chevrolets and Fords were tested for acceleration performance by conducting quarter mile, wide-open-throttle acceleration runs from a standing start. Figure 2.62 details the velocity versus time relationship for these vehicles. The Chevrolet 0-60 mph acceleration was virtually identical for both the propane and gasoline vehicles (10.0 seconds and 9.9 seconds, respectively). The gasoline control Ford pickup was approximately 2 seconds faster at 0-60 mph than the propane version (11.6 seconds and 13.6 seconds, respectively).

Since the engines in the propane vehicles in this project were not fully optimized for propane, it was expected that the propane vehicles would have somewhat slower acceleration. Use of propane in an engine not specifically designed for it may result in loss of power of 5% to 10%. This power loss is primarily related to the displacement of intake air by the fuel vapor. Reduction in power can be partially compensated either by increasing the compression ratio or advancing the spark timing, exploiting propane's higher octane value, but neither option was attempted on the project vehicles. It is speculated that the propane fuel systems installed on the Fords may be more restrictive to airflow than that of the Chevrolets and, therefore, exacerbate the power loss from air displacement.

The equivalent performance between the gasoline and propane Chevrolets was somewhat unexpected. Since these vehicles were tested in an "as-is" state and, therefore, represent a random state of tune, it is unclear whether the propane Blazer conversion actually produces performance equivalent to the stock gasoline Blazer or whether the stock gasoline Blazer in this test was somewhat out of tune and operating at reduced acceleration performance.

Figure 2.62 Velocity versus Time Graph of Standing Start Acceleration Tests



Emissions. Each vehicle (propane test and gasoline control) was dynamometer emission tested annually (1993, 1994, 1995). In addition, before converting the vehicles to propane they were emissions tested on gasoline. The tests were performed in accordance with the Federal Test Procedure (FTP). Results included emissions of CO, NO_x, and total hydrocarbons (HC) expressed as grams per mile.

Figure 2.63 details the CO emissions for the propane vehicles and the control vehicles as measured over the FTP. Figures 2.64 and 2.65 use the same format to illustrate NO_x and HC emissions. The 1985 Dodge RAM 350 is a heavy-duty vehicle and its emissions certification is based on engine not vehicle measurements. Also, it is the only propane vehicle tested that did not have an exhaust catalyst. It was certified not to exceed 37.1 g/bhp-hr CO, 10.6 g/bhp-hr NO_x , and 1.9 g/bhp-hr HC standards based on the heavy-duty engine transient test procedure. Therefore, results from the FTP on the Dodge, while providing an indication of emissions performance relative to other vehicles, are not comparable to the standards used to certify this vehicle.

Examination of the CO emissions from the propane vehicles shows that all but one of the light-duty (under 8,500 lb GVW) vehicle tests were within the EPA standards. For the light-duty vehicles, propane did not have any adverse effect, nor did it cause any significant improvement in CO emissions. For the non-catalyst equipped vehicle propane did offer a modest improvement in CO emissions.

Figure 2.63 Carbon Monoxide Emission Test Results for NYSOPR Propane and Gasoline Vehicles

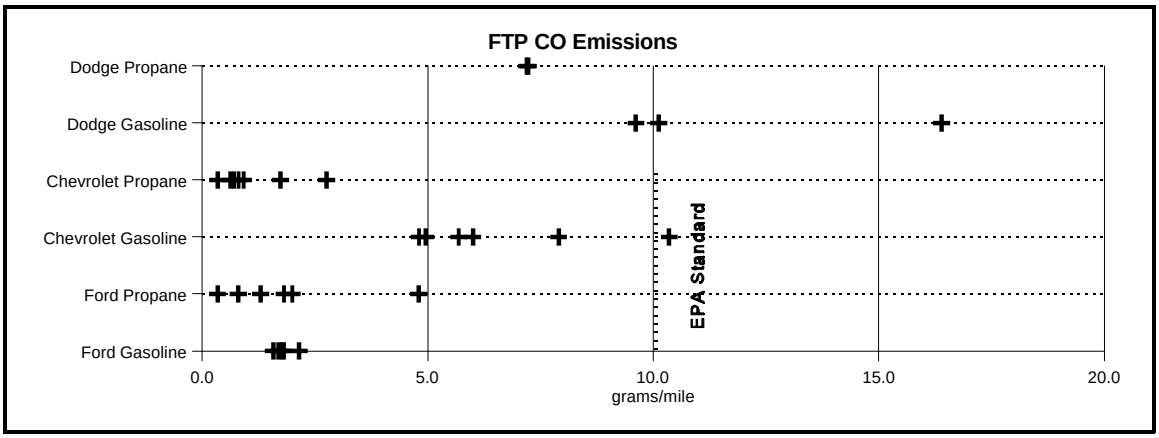


Figure 2.64 Oxides of Nitrogen Emission Test Results for NYSOPR Propane and Gasoline Vehicles

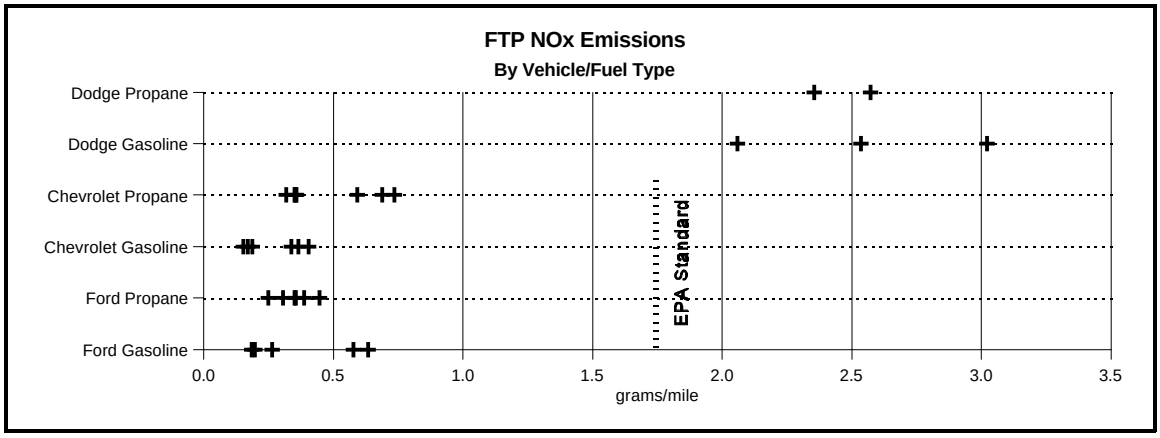
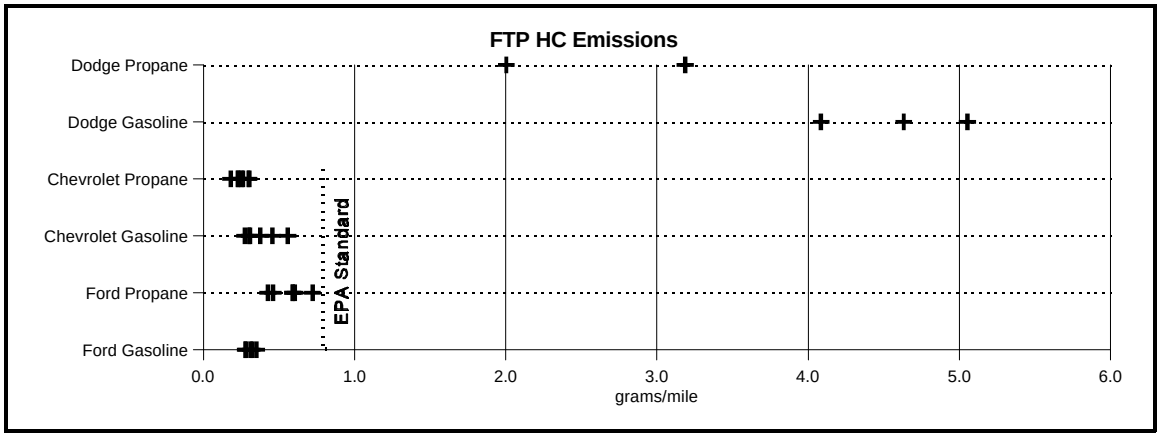


Figure 2.65 Hydrocarbon Emission Test Results for NYSOPR Propane and Gasoline Vehicles



Examination of the NO_x emissions from the propane vehicles shows that all of the light-duty vehicle tests were within the EPA standards. Propane did not have any adverse effect, nor did it cause any significant improvement in NO_X emissions for any of the vehicles tested.

Examination of the HC emissions from the propane vehicles shows that all of the light-duty vehicle tests were within the EPA standards. For the light-duty vehicles propane did not have any adverse effect, nor did it cause any significant improvement in HC emissions. For the non-catalyst equipped vehicle propane did offer a modest improvement in HC emissions. Because the reactivity of the HC emissions from propane vehicles is generally lower than that of vehicles operating on gasoline,[51] even without significant reductions in HC emissions the potential ozone produced from these emissions should be significantly lowered.

Fuel Costs. The price of propane delivered on site is highly dependent on volume. In New York State, small volumes (1,000 gallons per year) may cost as much as $0.95 per propane gallon before taxes ($1.31 per gasoline-gallon equivalent). In larger volumes, the price could drop to below $0.60 per propane gallon. Federal tax on propane is $0.183 per gallon, and the New York State tax and local taxes total $0.155 per gallon, for a total of $0.338 per gallon. (See Appendix L for a more complete discussion of alternative-fuel taxes in New York State.) Adding taxes makes the price of propane $0.94 to $1.29 per gallon ($1.32 to $1.81 per gasoline-gallon equivalent). If propane were dispensed in high volume at commercial stations, additional costs would be incurred to pay for the station operating costs. However, the wholesale price of propane would probably decline under such a scenario, with the net result being a propane price around $1 per gallon ($1.40 per gasoline-gallon equivalent), which should be competitive with gasoline.

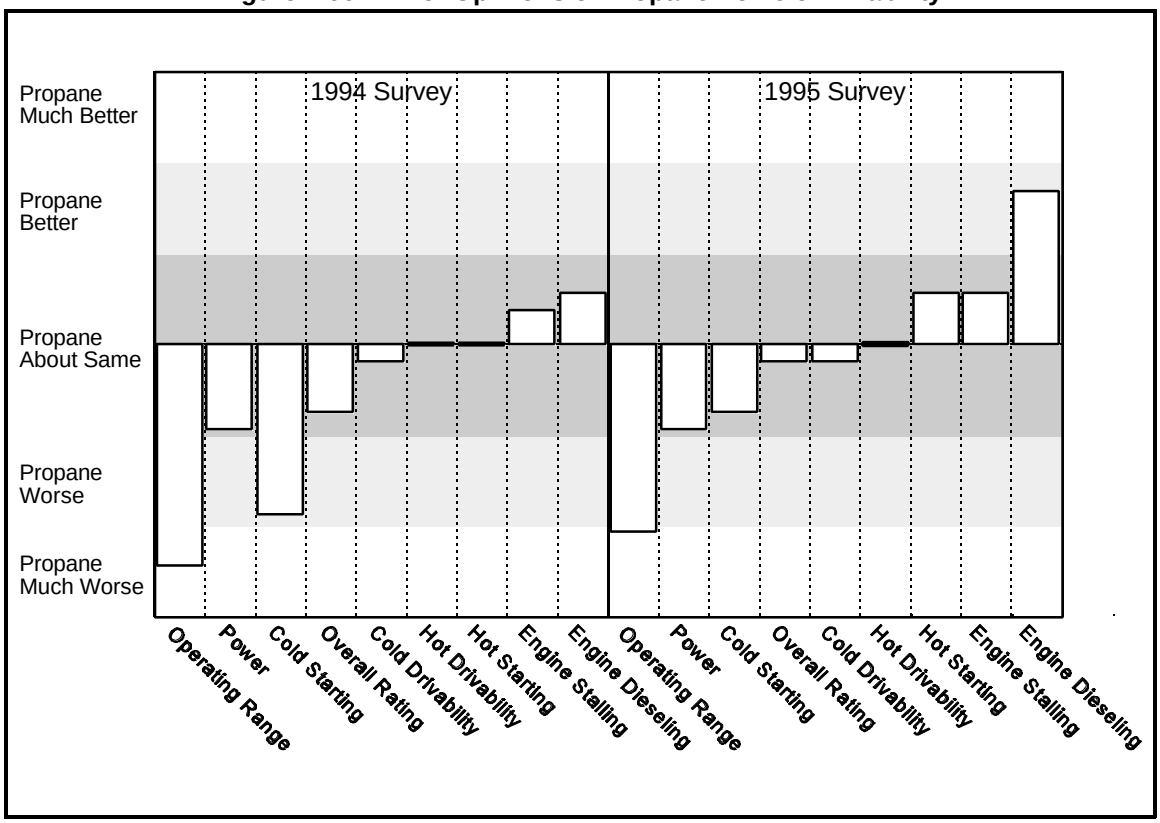
Propane varies in price seasonally due to its demand as a heating fuel in rural areas. A large transportation demand for propane would be more constant year-round and could help to dampen seasonal price changes, but the increased demand also might cause average propane prices to rise.

Driver Surveys. The AFV-FDP included two surveys of NYSOPR drivers to evaluate vehicle drivability and determine attitudes about the refueling facility. These averaged results indicate relative improvement or degradation of vehicle and refueling station performance when compared to conventional fuel counterparts. The results of the driver surveys are presented in Figure 2.66, showing driver ratings for the vehicles, and Figure 2.67 showing driver ratings of the refueling facilities.

---

[51] Whitney, K.A. and B.K. Bailey, "Determination of Combustion Products from Alternative Fuels - Part I: LPG and CNG Combustion Products," SAE Paper No. 941903, SAE International, 400 Commonwealth Drive, Warrendale, PA 15096, 1994.

Figure 2.66 Driver Opinions of Propane Vehicle Drivability

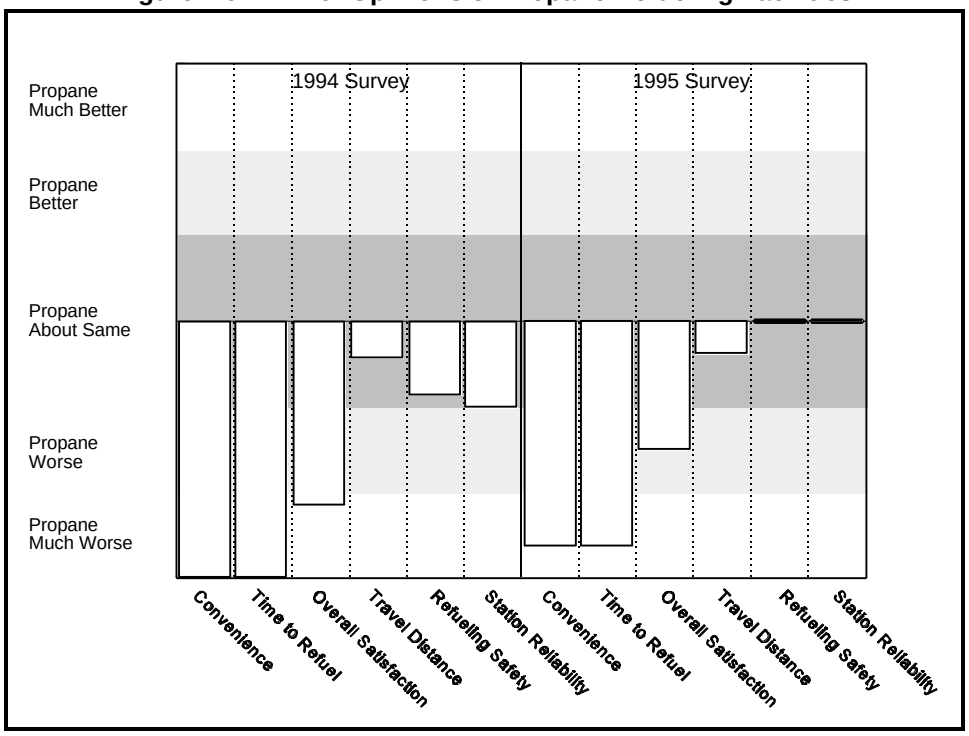


Vehicle operating range was the most negative aspect of propane vehicle use cited by drivers, followed by power and ease of cold starting. Some of the drivers' concern about operating range is due to lack of public refueling stations and inaccurate and unreliable fuel gauges. These concerns were similar to those expressed by users in California.[52]

In the first survey drivers expressed concern over the safety of the refueling system. The original system's method of preventing fuel flow before attaching the refueling nozzle to the vehicle could easily be defeated. In addition, the original refueling procedure required the operation of numerous valves. Since some operators did not frequently refuel the vehicles they reported much of the initial training was forgotten and they were unsure of themselves during the refueling process.

[52] Murphy, M.J., "Safety and Occupational Hygiene Results - CleanFleet Alternative Fuels Project," SAE Paper No. 950397, SAE International, 400 Commonwealth Drive, Warrendale, PA 15096, 1995

Figure 2.67 Driver Opinions of Propane Refueling Facilities



Based on these concerns modifications were made to the refueling system (replacement of the refueling nozzle with a true dry-break system and consolidation of several valves) to make refueling faster and more convenient. Based on these system improvements, the results of the 1995 survey show improvement in all categories of propane refueling system operation over the 1994 survey.

Safety. During the NYSOPR demonstration, there were no safety-related incidents in operating or repairing the propane vehicles. There were safety concerns initially with the refueling system due to the possibility that propane could be released when the nozzle was not connected to the vehicle. These concerns were allayed by installing a refueling nozzle more convenient to use and by simplifying the sequence for turning on the propane system to allow refueling.

Facility Modifications

Since the properties of propane differ from those of conventional fuels, servicing and storing propane vehicles in a facility designed for conventional fuel vehicles may require facility modifications. These modifications would be required to take the fuel property differences into account in order to maintain or improve facility safety. Current national code organizations including the National Fire Protection Association (NFPA),

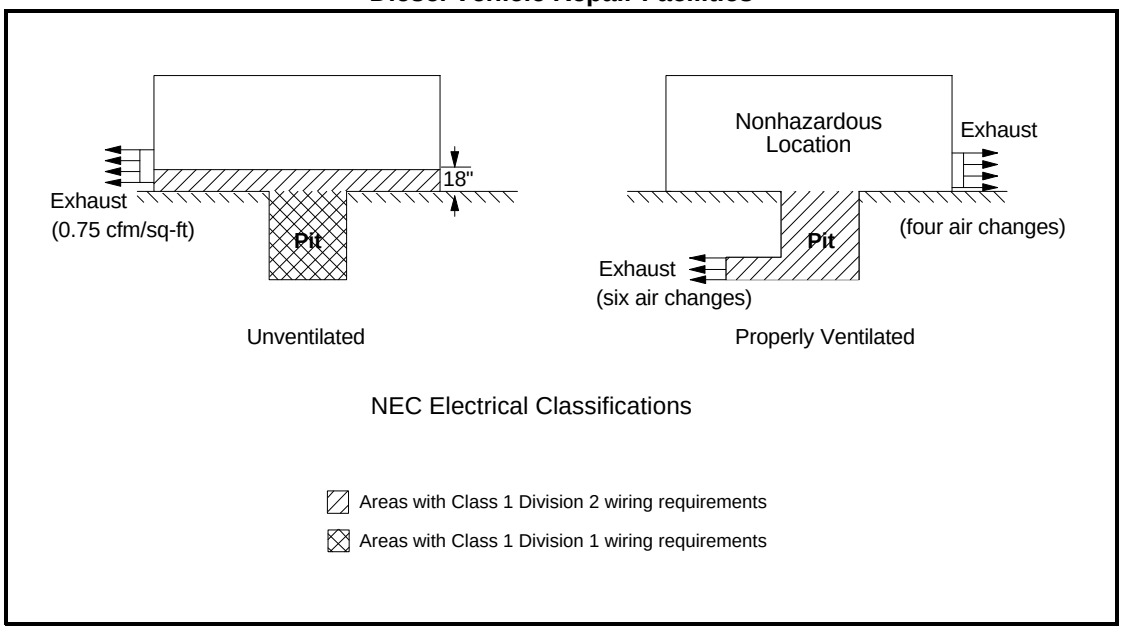
National Electric Code (NEC), and the Building Officials and Code Administrators (BOCA), have issued general guidelines for facilities servicing propane vehicles. These guidelines were used with existing conventional fuel building codes to identify possible electrical and mechanical modifications to the NYSOPR repair facility where propane vehicles were serviced. Safety code requirements are designed to keep fuel vapors outside their flammability limits and isolated from ignition sources using the properties of fuels and their vapors to help determine locations where upgraded electrical and ventilation systems are needed.

Both propane and gasoline vapors are heavier than air, filling depressions and low lying areas. Current garage design standards increase safety for both fuels by minimizing areas near the floor where vapors can accumulate, and by removing sources of ignition from low lying areas. Although propane is stored as a liquid, it exists as a vapor at atmospheric pressures. At 70°F approximately 35% of a large spill will vaporize immediately; smaller spills or slower release rates will experience even higher initial rates of vaporization. The quantity of flammable mixture present due to propane releases will be greater than for a similar sized gasoline fuel release because the propane will vaporize more quickly than the gasoline. So even though the vapors associated with both a gasoline and propane fuel release will travel to the lowest points in a facility (e.g., repair pits, drainage systems, floor depressions), propane will generate a greater volume of vapors than gasoline and may require increased ventilation.

Both the NFPA and the NEC provide ventilation and electrical requirements for garages where gasoline and diesel vehicles are repaired. These NFPA and NEC requirements are illustrated in Figure 2.68. Areas below grade used for repairing vehicles must have forced-ventilation systems capable of continuously removing at least 0.75 cubic feet of air per minute for each square foot (cfm/sq-ft) of floor space. This ventilation requirement helps prevent accumulation of heavier-than-air fuel vapors, which could accumulate in below-grade areas. Suspended unit heaters must be located at least eight feet above the floor. In addition, other heaters with glowing elements must be located at least 18 inches above the floor. All electrical equipment installed less than 18 inches above the ground must comply with NEC's Class I Division 2 wiring requirements to limit the probability of ignition occurring in hazardous environments. All electrical equipment installed in unventilated pits must comply with NEC's Class I Division 1 wiring requirements.

Based on existing codes and the properties of LPG, the requirements for conventional fuels should be sufficient for facilities repairing LPG vehicles. However, because of the nature of LPG (gases pressurized to form liquids) additional ventilation requirements may be desirable.

Figure 2.68 NEC and NFPA Mechanical and Electrical Requirements for Gasoline and Diesel Vehicle Repair Facilities



The current repair facility at James Baird State Park is heated by overhead infrared tubes. These tubes are installed more than 8 feet above the floor and do not present an ignition danger with a heavier-than-air fuel vapor. Since the garage was designed to repair conventional vehicles, the electric system has been designed so that all wiring closer than 18 inches to the floor meets Class 1 Division 2 requirements and should not need modification.

Adjacent to the vehicle repair area is a small engine repair area. Chain saws, lawn equipment, and other small engines are repaired here. The testing and operation of this equipment presets an ignition hazard. If engines are operated or tested closer than 18 inches to the floor the ignition source would be located in an area where released propane vapor could accumulate. This hazard was controlled by changes in work procedures so that either small engines are not started whenever a propane vehicle is in the repair facility or repairs and engine testing are always performed on a work table (more than 18 inches above the floor).

During the demonstration none of the vehicles were involved in any fuel-related accidents or incidents. All propane vehicles were converted using methods and components that met all applicable government and industry safety standards.

A safety evaluation of the maintenance facility was conducted to assess its suitability for storing and maintaining propane vehicles. Based on the characteristics of propane relative to conventional fuels, applicable national codes and research material, and the fuel system equipment on the vehicles, the following specific recommendations were made:

- Train workers in the properties of propane, the design and operation of propane vehicle and refueling systems, and the proper maintenance procedures for propane vehicles.
- Make changes to the ventilation system and remove potential ignition sources (found in the buildings infrastructure and created during certain repair procedures) to prevent ignition of released propane.
- Consider installation of a combustible gas detection system to provide warning of propane fuel accumulations.

Examination of the recommendations and evaluation of the safety risks, relative to the small number of propane vehicles in the fleet and the cost of ventilation and gas detection systems, resulted in the decision to modify vehicle storage and maintenance procedures rather than modification of the site. Training on propane fuel properties, refueling procedures, and storage and maintenance safety procedures was conducted early in the project by the New York Propane Gas Association.

Other Demonstrations

Several other government-sponsored propane vehicle evaluation reports have recently been published, including reports by the Federal Government (through NREL - the National Renewable Energy Laboratory)[53] and the States of California[54] and Texas.[55] These have been reviewed and compared to the findings of the AFV-FDP.

The California and NREL fleets had gasoline vehicles converted to propane using IMPCO fuel systems. The Texas fleets used any one of a number of different conversion systems. Unfortunately, the Texas reports did not match the results with the kit used, so they cannot be used for direct comparison with the AFV-FDP. The

---

[53] Whalen, P., et al., "Alternative Fuel Light Duty Vehicles — Summary of Results from the National Renewable Energy Laboratory's Vehicle Evaluation Data Collection Efforts," National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, Colorado 80401-3393, May 1996.

[54] Sverdrup, G.M., et al., "The CleanFleet Alternative Fuels Demonstration Project," SAE Paper No. 912665, SAE International, 400 Commonwealth Drive, Warrendale, PA 15096, 1991.

[55] Matthews, R.D., et al., "The Texas Project: Part 1-Emissions and Fuel Economy of Aftermarket CNG and LPG Conversions of Light-Duty Vehicles," SAE Paper No. 962098, SAE International, 400 Commonwealth Drive, Warrendale, Pennsylvania 15096-0001.

Table 2.26 Percent Change in FTP Emissions, Propane Compared to Gasoline (Note: Average Propane g/mile Shown in Parenthesis)

Vehicle Type	Hydrocarbons			Carbon Monoxide			Oxides of Nitrogen		
	AFV-FDP	Calif.	NREL	AFV-FDP	Calif.	NREL	AFV-FDP	Calif.	NREL
Ford Taurus			+65% (.17)			-68% (0.3)			+650% (1.9)
Ford F150/ E150 Van	+83% (0.57)	+67% (0.55)	+86% (0.47)	+2% (1.8)	-2% (2.3)	-67% (0.31)	-7% (0.56)	+7% (0.82)	+4% (1.1)
Chevrolet Van		+68% (0.71)			-41% (5.3)			-67% (1.0)	
Chevrolet S10 Blazer	-31% (0.25)			-81% (1.1)			+66% (0.78)		
Dodge Ram	-43% (2.6)			-40% (7.2)			-3% (4.0)		

NREL tests included Ford Taurus sedans and Ford F-150 pickups. The California program included Chevrolet and Ford vans. All of the vehicles were FTP emission tested. The California program used control vehicles for comparison while the published NREL data shows results for before and after conversion tests. These results are compared to the AFV-FDP results in Table 2.26.

Generally CO emissions decreased with propane or remained the same, HC emissions increased (except for the S10 and the Dodge Ram), and NO_x showed mixed results. The non-catalyst Dodge showed decreases in all three measured emission levels when operating on propane.

The only vehicle that is comparable across all three demonstration programs was the Ford F-150 pickup/E-150 Van tests. All have the same 4.9-liter, inline, six-cylinder engine and use IMPCO propane fuel systems. These vehicles demonstrated similar results for HC and NO_x. For CO, the NREL vehicle showed a significant decrease while the other two demonstrations showed no real change. In addition, the NREL F-150 showed significantly lower CO emission levels than were achieved with either of the other demonstration programs (regardless of fuel used). The reason for this discrepancy is unknown. The NREL F-150 results are based on a single vehicle compared to the three vehicles in the AFV-FDP and the six vehicles in the California program.

Drivers of the vehicles included in the California demonstration were surveyed on their attitudes on using propane. One third of the respondents expressed concerns related to vehicle safety. The major safety concern (cited by 27% of those that had safety concerns) was lack of acceleration, stalling, and reliability of the vehicles. There were also anecdotal comments on starting difficulties, especially first thing in the morning. Of the seven respondents, five had run out of fuel while operating the vehicles. This was blamed on lower

operating range coupled with unreliable fuel gauges. Refueling also raised concerns. Drivers did not like releasing fuel with the spitter valve. The refueling procedure was also more complex and problems arose when unfamiliar drivers were required to use the vehicles.

Lessons Learned

Use of the propane vehicles over the two years of the demonstration showed that they can be used in place of gasoline vehicles in some applications. Some areas were also discovered where improvements would be needed before larger acceptance of propane vehicles could be expected.

- Fuel quality with propane remains a problem. Periodic cleaning of heavy hydrocarbons from regulators and fuel mixers adds maintenance expense and causes cold-start problems if not completed regularly.
- Lack of public refueling stations combined with inaccurate fuel gauges cause operator concern and limit operation to areas near central refueling facilities.
- Vehicle acceleration performance can be equivalent to gasoline vehicles.
- Emissions reductions are possible; however, achieving across-the-board reductions in all three regulated components (HC, CO, NO_x) is difficult with current conversion equipment. Vehicle emissions seem to be more dependent on vehicle design and state of tune than on choice of fuel. Propane does offer certain inherent advantages including: lower evaporative emissions, less reactive hydrocarbons emissions, and potentially lower refueling emissions.
- In laboratory testing, propane was able to provide similar fuel efficiency (on an energy equivalent basis) as gasoline.
- Vehicle reliability was high with little unscheduled maintenance. Even with the fuel contamination difficulties, overall fuel system reliability was high and required little maintenance.