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Propane Vehicles: Status, Challenges, and Opportunities

Energy Systems Division

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by
M. Rood Werpy, A. Burnham, and K. Bertram
Center for Transportation Research
Energy Systems Division, Argonne National Laboratory

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GENERAL ACRONYMS AND ABBREVIATIONS

AFDC	Alternative Fuels and Advanced Vehicles Data Center
AFV	alternative fuel vehicle
AFVi	Alternative Fuel Vehicle Institute
API	American Petroleum Institute
APTA	American Public Transit Association
ARRA	American Recovery and Reinvestment Act
BTS	Bureau of Transportation Statistics
CARB	California Air Resources Board
CEC	California Energy Commission
CO	carbon monoxide
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EIA	Energy Information Administration
ELPGA	European LPG Association
EPA	U.S. Environmental Protection Agency
GGE	gasoline gallon equivalent
GHG	greenhouse gas
GM	General Motors
GREET	Greenhouse gases, Regulated Emissions, and Energy Use in Transportation
ICFI	ICF International
LDV	light-duty vehicle
LPG	liquefied petroleum gas
LPI	liquid propane injection
MY	model year
NG	natural gas
NMHC	non-methane hydrocarbon
NO_x	nitrogen oxides
NYSERDA	New York State Energy Research and Development Authority
OEM	original equipment manufacturer
PERC	Propane Education and Research Council
PM_{10}	particulate matter measuring between 2.5 and 10 micrometers in diameter

SAFETEA LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
TCPA	Texas Comptroller of Public Accounts
TDOT	Texas Department of Transportation
UCS	Union of Concerned Scientists
VSI	vapor sequential injection
VOC	volatile organic compound
WLPGA	World LP Gas Association

Units of Measure

bbl	barrel
Btu	British thermal unit(s)
g	gram(s)
hp	horsepower
L	liter(s)
lb	pound(s)
mi	mile(s)
MON	motor octane number
mpgge	mile(s) per gallon gasoline equivalent
ppm	part(s) per million
RON	research octane number

PROPANE VEHICLES:
STATUS, CHALLENGES, AND OPPORTUNITIES

Marcy Rood Werpy, Andrew Burnham, and Kenneth Bertram
Argonne National Laboratory

1 STATE OF THE TECHNOLOGY

Propane is used widely in the industrial, residential, commercial, and agricultural sectors. The petrochemical industry uses propane as a feedstock; while in the residential and commercial sectors, it is used for ambient heating, water heating, cooking, and grilling. In the agricultural sector, propane is used for crop and food conditioning, power generation, pest control, and heat for biodigesters.

Propane also has a long history as a vehicle fuel. Globally, propane is the most widely used alternative vehicular fuel. Outside of the United States, propane—or liquefied petroleum gas (LPG)—is commonly referred to as “autogas” when used as an automotive fuel.

Experiments using propane began around 1910, and by the 1920s, fleets in California were operating on propane (Myers 2009). In 1950, the Chicago Transit Authority ordered 1,000 propane-fueled buses, and Milwaukee converted 270 taxis to run on propane (PERC 2009a). According to Energy Information Administration (EIA) estimates, roughly 158,000 vehicles operate in the United States using 152 million gasoline-equivalent gallons of propane fuel, while the World LP Gas Association touts more than 13 million propane-fueled vehicles plying the streets worldwide (EIA 2009a; WLPGA 2009).

In a naturally occurring state at atmospheric pressure, propane is a three-carbon alkane gas, C_3H_8, but can be liquefied when subjected to moderate increases in pressure. Liquefied propane has an energy density 270 times greater than gaseous propane, thereby making it practical and economical to store and transport as a liquid (EERE 2009a). Propane is a by-product of natural gas (NG) production and the oil refining process (EIA 2009b).

1.1 VEHICLE SPECIFICATIONS

Propane as an auto fuel has a high octane value and has key properties required for spark-ignited internal combustion engines. To operate a vehicle on propane as either a dedicated fuel or bi-fuel (i.e., switching between gasoline and propane) vehicle, only a few modifications must be made to the engine. Until recently propane vehicles have commonly used a vapor pressure system that was somewhat similar to a carburetion system, wherein the propane would be vaporized and mixed with combustion air in the intake plenum of the engine. This leads to lower efficiency as more air, rather than fuel, is inducted into the cylinder for combustion (Myers 2009). A newer liquid injection system has become available that injects propane directly into the cylinder, resulting in no mixing penalty because air is not diluted with the gaseous fuel in the intake manifold. Use of a direct propane injection system will improve engine efficiency (Gupta 2009). Other systems include the sequential multi-port fuel injection system and a bi-fuel "hybrid" sequential propane injection system. Carbureted systems remain in use but mostly for non-road applications.

In the United States a closed-loop system is used in after-market conversions. This system incorporates an electronic sensor that provides constant feedback to the fuel controller to allow it to measure precisely the proper air/fuel ratio. A complete conversion system includes a fuel controller, pressure regulator valves, fuel injectors, electronics, fuel tank, and software. A slight power loss is expected in conversion to a vapor pressure system, but power can still be optimized with vehicle modifications of such items as the air/fuel mixture and compression ratios. Cold start issues are eliminated for vapor pressure systems since the air/fuel mixture is gaseous.

In light-duty propane vehicles, the fuel tank is typically mounted in the trunk; for medium- and heavy-duty vans and trucks, the tank is located under the body of the vehicle. Propane tanks add weight to a vehicle and can slightly increase the consumption of fuel. On a gallon-to-gallon basis, the energy content of propane is 73% that of gasoline, thus requiring more propane fuel to travel an equivalent distance, even in an optimized engine (EERE 2009b).

1.2 SAFETY

Propane is a nontoxic, noncarcinogenic, and noncorrosive fuel. It poses no harm to groundwater, surface water, or soil. Because propane is odorless and colorless, an odorant, ethyl mercaptan, is added to it to enable leak detection.

Propane vehicles and their respective fueling systems are designed to perform safely during both normal operations and crash events. A pressure release device is designed to release propane gas if pressure rises in the tank beyond safe levels. Most propane vehicles also have a bleed or spitter valve attached to the tank (NYSERDA 2009). During refueling the valve is opened, releasing vapor from the fuel tank and making room for the liquid propane to enter the tank. Once the tank is filled with 80% liquid, any addition of more propane will cause the valve to vent liquid fuel. This system is used to supplement the automatic stop-fill system.

Concern has recently been expressed about fuel tanks being overfilled, potentially creating safety and emissions implications. The U.S. Department of Energy's (DOE's) Clean Cities Program conducted tests on 105 vehicles during fueling. According to the Alternative Fuels and Advanced Vehicles Data Center's (AFDC's) *Propane Tank Overfill Safety Advisory Technology Bulletin*, overfill prevention devices on nearly 16% failed to stop fueling at the necessary level. Other conditions such as rising ambient air temperatures can also cause potential incidents. If a tank is overfilled during a cool time of day and sits without being used, warmer temperatures later in the day will expand the fuel, which could lead to a fuel release or leak through the pressure relief device. The study concluded that while the 16% value is significant, tanks are equipped with pressure relief devices specifically to ensure safe pressure levels, and no incidents have been reported. Therefore, the following steps were recommended: (1) inspection of the overfill prevention devices in vehicle fleets as an ongoing process; (2) training and education of propane vehicle users to make them aware of the potential to overfill and all of the potential causes; and (3) implementation of standard maintenance and inspection by industry groups. DOE has been working in close coordination with the National Propane Gas Association Technology Standards and Safety Committee, the Propane Education and Research Council (PERC), and the Underwriters Laboratory to develop training and outreach strategies (EERE 2009c).

1.3 INFRASTRUCTURE

The fuel dispensing rate for standard propane vehicle refueling is similar to that for gasoline or diesel (i.e., about 10–12 gallons per minute). The storage tank of a propane station connects to the dispenser that fills the vehicle's on-board storage cylinder. Propane is stored and handled as a liquid at the fuel dispenser. New nozzles and valves have been introduced that meet vapor control standards and prevent volatile organic compound (VOC) emissions from escaping from refueling stations (Hyland 2007).

1.4 FUEL QUALITY

Three grades of propane may be used as a motor fuel in the United States, with HD-5 being the most widely used. The classification of propane grades using "HDxx" refers to "heavy-duty" propane, while the number represents the maximum percentage of propylene. For optimal performance, the fuel quality of propane should meet HD-5 requirements and contain at least 90% propane, no more than 5% propylene, and no more than 2.5% butanes (or heavier). HD-5 has superior antiknock characteristics (i.e., a high octane rating [110 RON/100 MON]), which can be exploited by adding turbocharging. Propane that meets the California Code of Regulations is commonly referred to as "HD-10," although this is not an official specification. HD-10 contains a minimum of 85% propane, a maximum of 10% propylene, 5% butanes, 2.5% butenes, and 0.5% pentenes (or heavier), and limited sulfur content (80 ppm vs. 123 ppm for HD-5). The third type of propane is commercial-grade LPG, which has no limit on propylene and can be used in forklift engines (Ross 2006).

Fuel quality has been an issue in some areas of the country where fuel standards were not being met by producers. However, this no longer appears to be of concern, with procedures now in place to ensure that specifications are met on a more rigorous basis (Donaldson 2009). Some experts believe contamination of propane is prone to occur in the fuel transport and distribution system and not at the point of production (Myers 2009).

2 CURRENT MARKET STATUS

2.1 WORLD AND U.S. TRANSPORTATION LPG USAGE, AVAILABILITY, AND PRICING

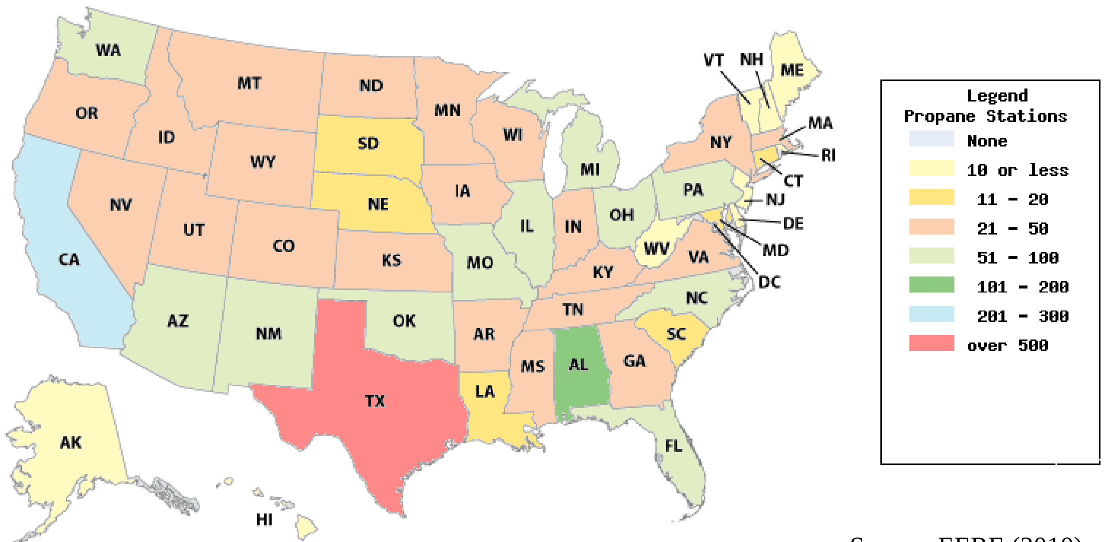
Autogas is Europe's leading alternative fuel, with 7 million vehicles, or 3% of the passenger fleet, using it. European countries using the largest percentage of autogas for passenger vehicles are Turkey (at 25%) and Poland (at 15%). Elsewhere around the world, some 6 million more passenger vehicles use LPG. The highest ranking countries are listed in Table 1.

TABLE 1 Countries Ranking Highest in LPG-Fueled Vehicles

Country	Vehicles	Dispensing Sites
South Korea	2.2 million	1,500
Poland	2.1 million	2,450
Australia	620,000	3,200
Russia	600,000	2,000
Mexico	550,000	2,500
India	500,000	550
Japan	292,300	1,900
The Netherlands	270,000	1,900

In South Korea, the autogas vehicle fleet grew from 400,000 in 1997 to 2.2 million in 2008. Among U.S.-headquartered manufacturers, Ford and General Motors offer propane vehicles in Europe and Australia (ELPGA 2009).

In contrast, transportation use of propane is far lower in the United States. EIA's *Annual Energy Review 2008* estimates that 158,000 propane vehicles operate in the United States, with a total transportation consumption of 152 million gasoline-equivalent gallons of propane fuel annually (EIA 2009a). Less recent (but still relevant) data indicate that this was about 1% of U.S. annual propane consumption in 2006 and equal to only about 4 days of annual U.S. propane supplies (EIA 2009c). The United States had 2,403 propane fueling stations as of May 17, 2010, according to AFDC (see Figure 1), with Texas (535 stations), California (214 stations), and Alabama (158 stations) each having more than 100 (EERE 2010).



Source: EERE (2010)

FIGURE 1 The Number of Propane Stations by State

The three states that consume the most propane as a transportation fuel are North Carolina (accounting for 16.4% of the total U.S. transportation propane consumption), California (12.1%), and Texas (7.3%), based on 2006 EIA data (EIA 2009c). Texas is the largest state consumer of propane for all usage sectors combined; however, it is also part of a national trend away from propane in the transportation sector and toward other alternative fuels and vehicle technologies, such as ethanol and hybrids. According to the Texas Comptroller of Public Accounts, in 2006 Texas propane vehicles represented 73% of the state's fleet of 7,400 vehicles using alternative fuels (TCPA 2008). The Texas Department of Transportation (TDOT), which had the largest component of the state fleet of propane vehicles, saw an abrupt decrease in propane vehicles: in 2001, TDOT had 4,677 LPG vehicles, but by 2006, it had only 2,938, a drop of 37%. Along with the rest of the state's fleets and many other fleets nationwide, TDOT was switching to vehicles using other alternative fuels. Contributing to this decline, moreover, was TDOT's discomfort with after-market conversions of gasoline-powered vehicles to propane and the limited availability of public propane fueling stations, which forced TDOT to operate and maintain its own fueling stations (TCPA 2008). Note that the DOE data cited earlier indicated that Texas, with its 535 stations as of May 2010, has significantly more stations than the next most serviced state, California, which has 214 stations (EERE 2010). The downward trend in Texas's propane use as a transportation fuel has occurred even though the state produced 36% of the nation's propane in 2002 (TCPA 2008).

Even though the Texas Comptroller of Public Accounts report indicates that propane transportation use is declining, it explains why it is still more widely used in Texas than in other states. While generally the price of propane is in direct correlation with crude oil prices, other factors play a role, such as transportation costs, supply and demand issues, and weather. When a major propane supply source or pipeline is not available, customers farthest from such sources generally must pay higher propane prices because of the high cost to transport propane.

California is an exception because it has no major pipeline, but the state does have a major LPG product import terminal and refineries span the coastline (Hanger 2006).

The transportation sector's position as one of the smallest users of propane places it in a highly unfavorable position for buying this fuel. In the United States natural gas liquids which includes propane but also ethane, butane, and pentanes is dominated by the petrochemical industry (49%), residential and commercial users (40%), farm users (5%), and other industrial users (3%), all of which have more buying power (API 2006). This advantage is especially true for the petrochemical industry, which is primarily located near major supply sources that deliver their propane by pipeline. This delivery system allows for a lower unit cost (cents per gallon) for these firms (and Texas transportation users) than for other propane users (EIA 2008).

Propane prices may spike when supplies are low due to high-volume summer purchases of propane by the petrochemical industry. Especially cold winters can severely reduce supply and create shortages. Price spikes exacerbate the price advantage of gasoline over propane that generally exists in all regions. Further, depending on the price in the world market, producers may find it more advantageous to export, driving up the price in the United States (EIA 2009d). According to the DOE *Clean Cities Price Report*, in October 2009 the average price of propane was $1.08 per gasoline gallon equivalent (GGE) higher than gasoline and $1.22 per GGE higher than diesel (EERE 2009d). See Table 2 for a recent history of average monthly prices for the three fuels.

TABLE 2 Monthly Average Price of Gasoline, Diesel, and Propane (per GGE)

Month and Year	Gasoline	Diesel	Propane
October 2009	$2.64	$2.50	$3.72
July 2009	$2.44	$2.27	$3.43
April 2009	$2.02	$2.26	$3.56
January 2009	$1.86	$2.19	$3.77
October 2008	$3.04	$3.27	$4.67
July 2008	$3.91	$4.22	$4.34
April 2008	$3.43	$3.71	$4.36
January 2008	$2.99	$3.05	$4.31
July 2007	$3.04	$2.65	$3.57
March 2007	$2.30	$2.35	$3.62
June 2006	$2.84	$2.67	$2.88
February 2006	$2.23	$2.48	$2.74

Source: EERE (2009d)

The propane industry has asserted that the prices in the *Clean Cities Price Report* more accurately reflect those associated with the refueling of recreational vehicles or home barbeque propane cylinders. Fleets, particularly those with their own on-site storage, can negotiate favorable long-term fuel prices, often times making it a cheaper vehicular fuel on a GGE basis than gasoline or diesel. In the case of data collected and reported by Clean Cities Coalitions, this appears to be true. In October 2009, the average price of propane at private stations was $1.56 per GGE less than propane sold at public stations. (See Table 3 for a recent history of average monthly prices for propane at public and private stations; Laughlin 2010).

TABLE 3 Monthly Average Price of Propane at Public and Private Stations (per GGE)

Month and Year	Public	Private
October 2009	$3.78	$2.22
July 2009	$3.49	$1.99
April 2009	$3.64	$1.87
January 2009	$3.80	$2.49
October 2008	$4.70	$3.10
July 2008	$4.37	$3.35
April 2008	$4.40	$3.18
January 2008	$4.36	$3.03
October 2007	$3.82	$2.82
July 2007	$3.60	$2.66
March 2007	$3.66	$2.31
October 2006	$3.25	$2.39
February 2006	$2.81	$2.27
September 2005	$3.72	$2.10

Source: Laughlin (2010)

2.2 CURRENT VEHICLE AVAILABILITY, PRICING, AND NICHE MARKETS

In the late-1990s, original equipment manufacturers (OEMs) offered three propane vehicle models, peaking at five in 1999, 2001, and 2002. Soon after, OEMs stopped producing propane-fueled vehicles (EERE 2009e). This left fleet users and other consumers interested in propane without product choices. Several years ago, PERC and its members developed a market strategy for working with OEMs and other manufacturers to develop OEM products or Tier II OEM products (aftermarket conversions) with a master dealer program, thereby establishing service, maintenance, and warranty support programs for dealers, fleet customers, and consumers. As a result, the market situation has changed to offer greater options to the fleet consumer and a continued steady increase in model availability through model year (MY) 2010.

With PERC partially funding development, a new propane product line emerged from Roush Industries: the Roush Ford F-150, powered by a 5.4-L V8 engine. Based on a retrofit system developed by ICOM of Italy, the liquid propane injection (LPI) system employed by Roush was developed for the North American market by CleanFUEL USA; the system is now trademarked by CleanFUEL USA as LPI™ (Parsons 2009). According to the manufacturers, this system results in more complete combustion, improved fuel economy, and a 300-mile range. At the end of 2009, Roush began offering the F-250 and F-350 using the LPI™ system with the 5.4-L V8 engine (Roush 2009). Ford E-150, E-250, and E-350 vans will be offered as propane options in 2010. By the end of 2010 Roush and Ford plan to release an E-450 cutaway with a 6.8-L V10 engine for shuttle van applications (Feehan 2010). All are expected to be certified to U.S. Environmental Protection Agency (EPA) and California Air Resources Board (CARB) emission standards for 2010.

The CleanFUEL USA LPI™ system and tank configuration were also chosen by Blue Bird Bus Corporation for its new Blue Bird Propane Vision Type C school bus, which uses the General Motors (GM) 8.1-L engine. PERC provided funding for the powertrain integration of this engine system. The LPI™ 8.1-L platform is currently available in GM cab chassis configurations from 17,500- to 33,500-lb gross vehicle weights; however, GM discontinued the 8.1-L engine platform at the end of 2009. In order to continue to provide propane school bus options, the propane vehicle industry and Blue Bird are working on a bridge strategy to find other partners to continue this important model (Feehan 2009b). PERC has also provided funding to procure enough engine inventory to allow Blue Bird to produce propane buses for the next three years (Myers 2009). In September 2009 Collins Bus Corporation, the largest builder of Type A school buses, announced a partnership with CleanFUEL USA that it would be developing a propane version with a liquid propane injection system in several of its GM dual-rear-wheel models, using a GM 6.0-L engine (Collins 2009).

With PERC funding for development, CleanFUEL USA recently certified the GM 6.0-L engine, with an improved LPI™ system, to 2010 EPA emission standards and is in the process of getting CARB certification (CleanFUEL USA 2010a). In addition to the Collins school bus, this engine will be used for cab van cutaways and a variety of applications, such as shuttles, passenger and walk-in vans, and utility vehicles (Donaldson 2009). The new engine system will be available in the summer of 2010 (automotive-fleet.com 2010).

Among heavy-duty engine manufacturers, Cummins Westport manufactured through MY 2009 a 5.9-L, in-line six-cylinder, spark-ignited lean-burn propane engine. However, Cummins has announced that this product line will end (Exel 2009). While still under consideration by its Board, PERC is seriously considering funding the development and certification of the Navistar International DT 466 diesel platform repowered to run on propane using Emission Solutions' technology. If the proposed plan is approved by PERC, engine development and certification will require one year (Moore 2009).

Through 2010, small-volume manufactures, such as IMPCO Technologies, are slated to offer new bi-fuel products for police and taxicab fleets and sedan and limousine applications. (Feehan 2009a). EPA defines small-volume manufacturers as companies that will sell or convert fewer than 10,000 vehicles or engines during the model year in question (Integrated Publishing

2009). The company must apply to EPA for this status. It is the responsibility of these small-volume manufacturers to ensure that equipment is properly installed and meets the emission standards of the original model year of the vehicle.

Some companies have formed marketing cooperatives, such as Alliance AutoGas, to offer conversion kits for existing fleets of vehicles, such as taxis and police vehicles. This concept relies on propane marketers and includes having certified conversion centers that install the Prins VSI (vapor sequential injection) systems (EPA/CARB certified for a variety of MY 2006–2009 vehicles) and provide on-site refueling, training, and maintenance support (Weidie 2009).

Also, the off-road forklift market offers OEM product offerings powered by propane. Kawasaki Motors has a lower nitrogen oxides (NO_x) option for non-road propane engines that yields at least a 40% improvement over mandatory standards and meets EPA's Blue Sky requirements. This system was also developed in partnership with PERC (Pack 2008). In addition, there are now eight manufacturers of propane-fueled zero-turn-radius mowers.

Table 4 lists currently available on-road propane vehicles, engines, and systems and their manufacturers, based on information in the *2009/2010 AFV Buyers Guide* (AFVi 2009). Not all model years have been certified by EPA or CARB. The cost of the Roush Ford F-150 LPI™ (MY 2007–2008) conversion kit with the in-bed 59-gallon fuel tank option is $7,795, while the kit for an F-250 or F-350 truck (MY 2009–2010) is $9,995 (Roush 2009). The propane Blue Bird bus costs roughly $13,800 more than a similar conventional model (Bogart 2009a).

2.2.1 Propane Niche Markets

With new bi-fuel light-duty vehicles meeting EPA and CARB 2010 standards, two target markets are considered prime candidates by PERC: taxi and police fleets. According to the U.S. Department of Transportation's Bureau of Transportation Statistics, in 2005 there were 162,000 taxi vehicles and 412,000 police vehicles in the United States (BTS 2009a). Police departments do not replace vehicles at uniform times/mileages, although one source has the target range estimated at 89,000–95,000 miles (Schmechel undated). One manufacturer, Carbon Motors Corporation, sees high potential for sales because 75,000 police cars are replaced annually (Indy.com 2009).

School buses are another key market for the propane industry. The number of such vehicles in 2006 was estimated to be 505,000 by the Union of Concerned Scientists (UCS 2006). In the recently released ICF International (ICFI) report, *2009 Propane Market Outlook*, Blue Bird had planned to sell 14,200 LPG buses by 2013. According to the ICFI report, there are currently 2,000 LPG school buses (Sloan and Meyer 2009).

Propane has also found success in the paratransit bus market. In 2006, according to the American Public Transit Association (APTA), 3.7 million gallons of LPG were consumed by paratransit buses (APTA 2009). A significant opportunity exists for this market segment with the certification of the 6.0-L engine.

TABLE 4 On-Road Propane Vehicles, Engines, and Systems

Manufacturer	Vehicle/Engine Type	Applications
American Alternative Fuel	Bi-fuel conversion, vapor sequential injection systems	Pick-up trucks, vans, utility vehicles, over-the-road vehicles, emergency vehicles, and land-side passenger vehicles, among others.
Baytech Corporation	Dedicated conversions: for 2009 8.1-L GMC/Chevy C4500/C5500 truck and shuttle bus; 8.1-L Workhorse Custom Chassis W62; 6.0-L GMC/Chevy W4500 and Isuzu NPR HD; 6.0-L Workhorse Custom Chassis W42 (over 14k-lb gross vehicle weight)	Low-volume manufacturing for trucks, shuttle buses, and workhorses
Blue Bird Corp	Vision, GM 8.1-L with CleanFUEL USA LPI™ system	Conventional Type C/Class 7 fully integrated and purpose-built OEM school bus; ended 2009, but working to find a replacement for the GM 8.1-L engine
Campbell-Parnell	Dedicated conversion	Conversions of various Ford, GM, Isuzu, and Dodge models
Cummins Westport	B LPG Plus 195, 5.9-L, in-line 6 cylinder, spark ignited-lean burn, 195 hp	Multiple medium-duty and heavy-duty applications (production ended in 2009)
E-bus	Propane Hybrid-Electric Transit Bus and Trolley	Class 6 transit buses and trolleys
ElDorado National	Passport, Vortec 8.1-L gasoline or 6.6-L Duramax diesel	Class 6 shuttle bus
ElDorado National	EZ Rider II 30/35, Cummins	Class 7 transit bus
ElDorado National	XHF 29/33/35, Cummins	Class 8 transit bus
Emission Solutions, Inc.	Potential product under consideration	Multiple medium-duty and heavy-duty applications

TABLE 4 (Cont.)

Manufacturer	Vehicle/Engine Type	Applications
Foton America	LD 1000, Foton Loval, 140 hp	Class 3 truck delivery
IMPCO Technologies	Vapor sequential fuel injection system conversion kit for internal combustion engines one-half to 5,000 hp	Low-volume manufacturing for bi-fuel 2008/09 6.0-L Chevrolet Silverado, Express, and G-Van Cutaway; 2008 GMC Savana; and 2008/09 GMC Sierra; and 3.5 and 3.9-L Chevrolet Impala; 4.8-L Chevrolet G-Van and GMC Savana; 5.3-L Chevrolet Silverado, Tahoe, and GMC Sierra, and Yukon; and 5.4-L Ford F150, Expedition, and Lincoln Navigator
Kalmar Ottawa	4x2 LPG, 5.9-L, 195 hp	Class 4 truck delivery
Krystal Koach	Ford F-550, 6.8-L V10 gas or 6.4-L V8 diesel	Class 5 shuttle van
Krystal Koach	Chevrolet KK36, 8.1-L V8 gas/6.6-L diesel	Class 6 shuttle bus
Roush	F-150, 250, and 350 liquid propane injection system – 5.4-L V8 engine; E-450 – 6.8-L engine (2010)	Multiple fleet and personal uses
Technocarb Equipment Ltd.	Dedicated and Bi-fuel Economy Sequential Injection Package for 3–8 cylinder engine applications on multiple Ford models for taxis, police, and other light-duty applications, and industrial equipment	Multiple fleet and personal uses
Trolley Enterprises	Propane Trolley Bus	Class 6 trolley
TYMCO	Model 600	Class 7 work truck

Source: *2009/2010 AFV Buyers' Guide*

2.2.2 Propane Stations and Cost

According to DOE's Alternative Fuels and Advanced Vehicles Data Center, there are 2,403 public and private propane stations in the United States. See www.afdc.energy.gov/afdc/fuels/stations.html for updates on these statistics (EERE 2010).

CleanFUEL USA has estimated the average cost for a propane fueling station with various tank sizes, based on the three scenarios described below (Bogart 2009b; estimate is the average price in California for equipment, installation, and permitting fees):

1. **Base Model Propane Fueling Dispenser**
   Non-electronic meter, 0.5-hp pump, low-profile basic cabinet that is very similar to the forklift or gas station dispensers typically used for filling RVs and BBQ bottles (not recommended for motor fuel applications but will work in most cases).

   Estimated Costs Installed—Based on Storage Tank Size:

   a. 500-gallon tank with a turnkey dispenser skid system: $25,000
   b. 1,000-gallon tank with a turnkey dispenser skid system: $33,000
   c. 2,000-gallon tank with a turnkey dispenser skid system: $48,000

2. **Propane-Autogas Fueling Station—Designed for Fleet Motor Fuel Applications**
   Fully integrated electronic dispenser with two wire interface capabilities for most of the major proprietary fuel management network cards, such as Fuel Man, Petro-Vend, and Gas Boy; records Word- or Excel-based fueling transaction data.

   Estimated Costs Installed:

   a. 500-gallon tank with a turnkey dispenser skid system: $37,000
   b. 1,000-gallon tank with a turnkey dispenser skid system: $45,000
   c. 2,000-gallon tank with a turnkey dispenser skid system: $60,000
   d. 15,000-gallon tank with two dispensers on the fueling island: $130,000
   e. 15,000-gallon tank with four dispensers on the fueling island: $155,000

3. **Propane-Autogas Retail Fueling Station—Also Designed for Large Fleet Applications**
   Fully functional electronic autogas dispenser with electronic point of sale (EPOS) credit card transactions—designed for retail and large fleet applications; seamless retail fueling dispenser system available in both Gilbarco and Dresser-Wayne models.

   Estimated Costs Installed:

   a. 1,000-gallon tank with a turnkey EPOS dispenser skid system: $92,000
   b. 2,000-gallon tank with a turnkey EPOS dispenser skid system: $102,000
   c. 15,000-gallon tank with two EPOS dispensers on the fueling island: $150,000
   d. 15,000-gallon tank with four EPOS dispensers on the fueling island: $175,000

Alliance Autogas has designed and manufactured its own turnkey solution for fleets, with a dispensing system offering a standard 1,000-gallon tank and dispenser with card reader capability for $21,000, or the same size tank capacity with a card reader for $30,000. Figures cited do not include permitting fees. Alliance provides the conversion equipment, a certified conversion center with trained technicians and follow-up diagnostics, infrastructure installation, and reliable year-round fuel supply (Bodie 2010).

2.2.3 World and United States-Canada Propane Supply Trends

Supplies of LPG come largely from natural gas processing, which accounts for about 60% of total worldwide production. Oil refineries accounted for nearly all of the remaining production, with other sources accounting for less than 0.5%.

The world supply of LPG grew steadily during the 2000–2008 period, from about 200 million tons in 2000 (about 6.2 million bbl/day) to 239 million tons (7.7 million bbl/day) in 2008. LPG prices had been steadily rising for most of the decade and during the summer of 2008, like crude oil prices, approached all-time highs, but subsequently the global recession has depressed natural gas and oil prices and, along with them, the price of their by-product, LPG (Hart et al. 2009).

Despite the issue of rising prices, Purvin and Gertz, a major international energy consulting firm, expects world LPG supplies to reach 270 million tons (about 8.4 million bbl/day) by 2012 (Hart et al. 2009). Through 2008, the United States and Canada remained the world's largest producers of LPG, together accounting for about 24% of supply. Production in this region has declined slightly between 2000 and 2008, from 59 million tons to 57.7 million tons, because of the decline in conventional natural gas production, which constitutes 61% of the region's production. Conventional natural gas production is still declining, but it has been offset somewhat by greater production of unconventional natural gas, including tight sands gas in the Rockies and the Barnett shale formation in the Fort Worth Basin in Texas (Hart et al. 2009; Airhart undated). Overall, LPG production in the region is expected to remain at 58–59 million tons through 2012 (Hart et al. 2009).

3 AVAILABLE FEDERAL AND STATE INCENTIVES

3.1 OVERVIEW

Details of federal incentives are provided in Table 5.

TABLE 5 Federal Incentives

Type of Incentive	Federal Law	Provision
Fuel	Emergency Economic Stabilization Act/Energy Improvement and Extension Act of 2008, P.L. 110-343 (10/03/08)	Section 204 amends the expiration date for the existing alternative fuel excise tax credit from September 30, 2009, through December 31, 2009. **Note: As of 4/28/10, an additional extension has not been granted to the excise tax credit provision, except in the case of liquefied hydrogen.**
	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users, P.L. 109-59 (8/10/05) (SAFETEA LU)	An excise tax credit is available for an alternative fuel that is sold for use or used as a fuel to operate a motor vehicle. The credit is $0.50 per GGE of compressed natural gas and $0.50 per liquid gallon of liquefied petroleum gas, liquefied natural gas, and liquefied hydrogen. The entity eligible for the credit is the one liable for reporting and paying the federal excise tax on the fuel. The tax credit is also available to nonprofit tax-exempt entities that fuel on site. The excise tax credit, paid from the General Revenue Fund, is partially offset by an increase in the motor fuel excise tax rate for LPG that is now on parity with that for other motor fuels. The sale of propane for use in forklifts is exempt from the federal excise tax on motor fuels. In providing further guidance regarding the legislation, the Internal Revenue Service made it clear that forklifts fit the definition of an off-highway business motor vehicle and, therefore, the fuel used in a forklift is eligible for the $0.50 cent/gallon credit. Moreover, the IRS indicated that in this instance it is the end user, namely the forklift operator, who is entitled to apply for the credit, rather than the propane marketer.

TABLE 5 (Cont.)

Type of Incentive	Federal Law	Provision
Vehicle	Energy Policy Act of 2005, P.L. 109-58 (8/8/05)	A “qualified alternative fuel motor vehicle” tax credit is available for the purchase of a new, dedicated, or repowered alternative fuel vehicle. It is for 50% of the incremental cost of the vehicle, plus an additional 30% if the vehicle meets certain tighter emission standards. These credits range from $2,500 to $32,000, depending on the size of the vehicle. The credit is effective on purchases made after December 31, 2005, and it expires on December 31, 2010. The vehicle must be acquired for use or lease by the taxpayer claiming the credit. Furthermore: (a) The credit is available only to the original purchaser of a qualifying vehicle. If a qualifying vehicle is leased to a consumer, the leasing company may claim the credit. (b) For qualifying vehicles used by a tax-exempt entity, the person who sold the qualifying vehicle to the person or entity is eligible to claim the credit, but only if the seller clearly discloses in a document to the tax-exempt entity the amount of credit. The seller may pass along any savings of the tax credit but is not required to do so. The Internal Revenue Service does not set limits on the amount of credits claimed by any one entity.
Infrastructure	American Recovery and Reinvestment Act of 2009, P.L. 111-5 (2/17/09)	This Act increases the value of the credit from EPACT 2005 for the purchase of equipment that is used to store and dispense qualified alternative fuels and is placed in service during 2009 and 2010. The credit for these years is $50,000 or 50% of the cost, whichever is smaller, for business property and $2,000 or 50% of the cost, whichever is smaller, for home refueling.
	Emergency Economic Stabilization Act/Energy Improvement and Extension Act of 2008, P.L. 110-343 (10/3/08)	Section 207 amends the existing alternative fuel infrastructure tax credit through December 31, 2010.
	Energy Policy Act of 2005, P.L. 109-58 (8/8/05)	An income tax credit is available. It is equal to 30% of the cost of propane refueling equipment—up to $30,000 in the case of large stations. The credit is effective on purchases placed in service after December 31, 2005, and it expires on December 31, 2010 (see above for modifications).

Sources: EERE (2009f) and PERC (2009b)

3.2 MODEL STATE EXAMPLE

According to Stacy Noblet of the Clean Cities Technical Response Center, Texas is the only state that offers an incentive program specifically for propane vehicles. The Low Emissions Propane Equipment Initiative, offered through the Railroad Commission of Texas's Alternative Fuels Research and Education Division, gives buyers the opportunity to replace aging medium-duty diesel school bus or delivery vehicles with LPG vehicles that meet or exceed EPA emission standards. The incentive is dependent upon the calculated reduction in emissions. This program also offers incentives to buyers who want to replace aging internal combustion engine forklifts with new propane forklifts that meet or exceed 2008 EPA emission standards (Noblet 2009).

4 EMISSION BENEFITS

Because of regional differences in fuel composition and engine configurations, potential "in-use" emission reductions from the deployment of propane vehicles can vary (certification test results are based on standard fuels, which are generally not the same as used in the field). EPA examined the benefits of propane, based on its inherent chemical properties with respect to gasoline, used in a properly calibrated vehicle. The EPA concluded that propane has the potential to have lower toxic, carbon monoxide (CO), and non-methane hydrocarbon (NMHC) emissions, but that emissions vary depending on whether an engine is calibrated to run rich or lean. When running rich, higher NMHC and CO emissions, but lower NO_x, were observed; when running lean, lower NMHC and CO emissions, but slightly higher NO_x, were observed (EPA 2002).

Argonne researchers examined the fuel-cycle energy use and emissions of transportation fuels produced from natural gas and projected the tailpipe emission changes of LPG vehicles compared with Tier 2 gasoline vehicles (Wang and Huang 1999). They estimated no change in exhaust VOCs or NO_x, a 90–95% reduction in evaporative VOCs, a 20–40% reduction in CO, and an 80% reduction in exhaust coarse particulate matter (PM_{10}). Unfortunately, without recent light-duty vehicle testing, the exact benefits of LPG vehicles over their gasoline counterparts are unclear.

Recent heavy-duty engine dynamometer tests by EPA show similar emissions for propane engines compared with compressed natural gas engines (the Cummins B LPG Plus and the B Gas Plus). It remains to be seen whether heavy-duty LPG engines will be developed that will meet the strict 2010 EPA NO_x standards. (See EPA or CARB for vehicle and engine certification updates.)

5 PETROLEUM AND CARBON BENEFITS

We estimated the petroleum and carbon benefits of propane vehicles using Argonne's GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation) model. GREET estimates the full fuel-cycle energy use and emissions for alternative fuels and advanced vehicle systems for light-duty vehicles. It can be used to approximate larger (i.e., medium- and heavy-duty) vehicles. When LPG vehicles are examined, a key assumption is whether the feedstock is petroleum or natural gas. GREET uses the default assumption that currently 60% of LPG in the United States comes from natural gas, and that the percentage could increase in the near-term. Obviously, while petroleum-based LPG does not reduce petroleum use, it does diversify fuel use by reducing the consumption of conventional petroleum transportation fuels (i.e., gasoline and diesel).

On a miles-per-gasoline-gallon equivalent (mpgge) basis, GREET assumes that a dedicated light-duty LPG vehicle will have the same fuel economy as a comparable conventional gasoline internal combustion engine vehicle. However, with regard to heavy-duty vehicles, the Alvin (Texas) Independent School District provided fuel economy data for 12 vapor injection LPG buses, 12 liquid injection LPG buses, and 12 diesel buses, all with similar passenger loads. The Alvin school district, which covers communities just south of Houston, has operated propane-fueled school buses since 1980. As of 2009, the district has 82 propane buses in its total fleet of 160; however, it stopped purchasing propane buses in 2002 and only just in 2009 resumed acquisition of new propane-fueled school buses. The new buses use liquid injection systems (Ralph 2009).

The Alvin data showed vapor-injection LPG buses with a 40% lower diesel-equivalent fuel economy than their diesel counterparts. The new liquid-injection buses, which have been running for only a few months, showed a 40% improvement in diesel-equivalent fuel economy over their diesel counterparts. This difference in vapor and liquid injection is quite dramatic, but since this was not a scientific study, the results and the fuel economy of liquid injection systems should be further examined. The comparison is not an apples-to-apples comparison because the vapor-injection LPG buses were acquired before 2002 and the diesels are likely from older model years as well, though such details are unclear. In addition, we do not have the details about the routes taken by each bus; factors outside the actual vehicle efficiency could be influencing these values.

On the basis of default GREET assumptions, a 23.4-mpgge light-duty gasoline internal combustion engine vehicle's full fuel-cycle fossil-energy use in 2010 would be 5,928 Btu/mi, its petroleum energy use would be 5,274 Btu/mi, and its greenhouse gas (GHG) emissions would be 478 g/mi. The results for comparable vehicles using natural-gas-based LPG and petroleum-based LPG are shown in Table 6. The natural-gas-based LPG vehicle resulted in significant (about 99%) petroleum displacement and modest reductions (about 18%) in GHG emissions. The petroleum-based LPG vehicle uses similar amounts of petroleum as compared to a gasoline vehicle, but GHG reductions (about 15%) are similar to those of a natural-gas-based LPG vehicle.

TABLE 6 Energy Use and GHG Emissions of Gasoline and LPG Vehicles

Vehicle	Fossil Energy (Btu/mi)	Petroleum Energy (Btu/mi)	GHG Emissions (g/mi)
Gasoline Light-Duty Vehicle (LDV)	5,928	5,274	478
LPG (NG) LDV	5,453	55	393
LPG (Petroleum) LDV	5,539	5,170	404

If liquid injection systems show similar fuel economy improvements to those seen in the limited school bus testing, the carbon benefits of LPG could be greater than in the light-duty vehicle example above. This is a major factor in determining the carbon footprint of LPG vehicles; therefore, more concrete details are needed on the fuel efficiency of new LPG systems compared with conventional vehicles.

6 CURRENT AVAILABLE RESOURCES, ACTIVITIES, AND STRATEGIES

6.1 PERC RESEARCH AND DEPLOYMENT INITIATIVES

In 2007, with propane vehicle options declining, PERC members agreed to invest more than $5.1 million to facilitate the development of new propane technologies, with 21% of this investment targeted to on-road engine research and 2% for off-road vehicles. The following year, PERC raised its research and development budget to more than $7 million. PERC's goal is to conduct research with a commercialization focus to advance propane technology and products. PERC intends to support that effort through communications initiatives to expand propane's position as a leading alternative fuel and to increase sales of propane for on-road, off-road, and stationary engines (Pack 2008).

The objectives listed in PERC's 2008–2012 Strategic Plan include:

1. Enhance propane's position in the forklift market.

2. Pursue research to develop platforms, engines, vehicles, and certified fuel systems.

3. Improve the fuel market for engines through internal and external marketing and communication mechanisms.

4. Increase knowledge by developing maintenance and training programs.

5. Develop programs that are easily replicated across the country in multiple markets.

6. Facilitate cooperative interaction among market sectors.

7. Collect data to identify potential market opportunities and emerging needs to benchmark propane's engine fuel market share, and to measure trends in fleet managers' and other consumers' attitudes toward propane vehicles and engines.

8. Emphasize the economic and environmental benefits of propane as an engine fuel.

9. Educate target markets on how propane can contain costs and meet increasingly stringent environmental regulations (PERC 2009c).

Research funding is enabled by the Propane Education and Research Act of 1996, which allows up to one-half cent per gallon of odorized propane to be allocated toward PERC activities (PERC 2009d). This funding led to the development and commercialization of an OEM propane school bus, the Blue Bird Vision (PERC Docket 11943), and the propane-powered Roush Ford F-150 (PERC Docket 11942). PERC has also funded market research for fleet managers. The data help determine how propane can best meet and exceed fleet managers' needs as an engine fuel (PERC Docket 12465).

PERC has invested in other engine products, including the performance evaluation of propane injection for diesel engines to optimize engine performance and reduce emissions. PERC has also funded the engine emissions certification and durability development of the GM 6.0-L engine designed for a dedicated LPI™ system (PERC Dockets 12195 and 12413). The research and commercialization of an EPA-certified zero-turn-radius mower was also another priority of PERC, with a 3,000-unit production goal by year three of engines that run about 40% cleaner than engines that meet the mandatory emission standards (PERC Docket 12466). In addition to research and development, PERC has sponsored "road shows" to showcase product lines. In partnership with the DOE's Clean Cities Program and the Maryland Energy Administration, PERC has been offering 20 webinars on a monthly basis to retail marketers and Clean Cities managers.

The propane industry has entered into a partnership with ConocoPhillips to build propane infrastructure in approximately 20 key cities at existing ConocoPhillips stations and to market the fuel and product line to fleets in the surrounding areas. The goal is to link these cities into corridors across the country (Feehan 2009a). This project was awarded funding by DOE's Clean Cities through the American Recovery and Reinvestment Act (ARRA) of 2009 with money leveraged by industry (DOE 2009, CleanFUEL USA 2010b). (See Texas State Technical College project below.)

6.2 CLEAN CITIES

DOE's Clean Cities program has been a key partner with industry. The program provides grant opportunities to increase the propane vehicle market, by both buying down the incremental cost of vehicles and paying for the associated costs of infrastructure. From 1999 to 2006, Clean Cities has awarded more than $3.2 million toward these activities. More recently, ARRA has boosted funding for AFVs and infrastructure in 25 Clean Cities areas to historic levels. For propane projects, nearly 3,000 LPG vehicles are estimated for purchase, with the construction of an extensive refueling network of approximately 250 propane stations.

A few of the notable propane projects include (1) *Railroad Commission of Texas' Propane Fleet Pilot Program*, which will deploy nearly 900 propane vehicles in Texas, including more than 240 school buses and 35 propane refueling stations; (2) *Texas State Technical College's Development of a National Liquid Propane (Autogas) Refueling Network, Clean School Bus/Vehicle Incentive & Green Jobs Outreach Program*, resulting in the purchase of dedicated propane school buses and the construction of more than 180 autogas stations in the following metropolitan areas: Atlanta, Chicago, Houston, Denver, Sacramento, Los Angeles, Dallas, Phoenix, Indianapolis, Seattle, Orlando, San Diego, St. Louis, San Antonio, Austin, and Oklahoma City, as well as along I-10 in Louisiana; and (3) *Virginia Department of Mines, Minerals, and Energy's Paving the Way with Propane: The Autogas Corridor Development Program*, targeting the construction of nearly 20 propane stations along high-traffic corridors from Washington, D.C., to Florida to Mississippi to create the nation's first propane corridor (DOE 2009).

Clean Cities coalitions are also involved in numerous outreach activities in their communities to encourage fleets to switch to propane. In 2008, 86 of 87 Clean Cities coalitions reported 22,300 LPG vehicles from a total inventory of 632,000 alternative fuel vehicles (AFVs) operating in their communities. While only 4% of the total inventory, two-thirds of these LPG vehicles were reported to be heavy-duty, resulting in 13% of total fuel displacement by AFVs fuel displacement — second only to CNG vehicles. For the 2,333 nonroad vehicles reported, propane was clearly the fuel of choice, accounting for 84% of total fuel use from these vehicles (Johnson and Bergeron 2009).

6.3 OTHER AGENCIES

Additional support for propane vehicles has come primarily from the U.S. Department of Transportation and EPA. Within the Department of Transportation, the Federal Highway Administration has, through its Congestion Mitigation Air Quality Program, funded propane projects in nonattainment areas. To obtain this funding, propane vehicle projects must be part of an approved State Implementation Plan. Local governing boards ultimately determine whether a project is funded. The EPA has also funded competitive grant programs under the SmartWay umbrella. In particular, the Clean School Bus Program has funded natural gas and propane buses, although funds have gone primarily to clean diesel technology.

7 BARRIERS IN THE MARKETPLACE AND TECHNOLOGY NEEDS

7.1 PRODUCT AVAILABILITY AND CONVERSION TECHNOLOGY PROCESS AND COST

As with natural gas vehicles, but more pronounced within the propane vehicle industry, a lack of product availability is a major impediment. However, this situation has been improving. The OEMs ceased production of propane light-duty vehicles and trucks after 2002. Furthermore, EPA and CARB emission regulations have limited the number of compliant conversion kits and made it cost prohibitive for some small-volume manufacturers to compete. Beginning in 1997, propane vehicle conversions were negatively affected by the EPA's addendum to Memorandum 1A, which led to sharp decreases in the number of vehicle conversions. However, in 2010 the EPA has proposed to streamline the certification requirements of low-mileage vehicles and clarify the procedure to convert high-mileage vehicles. This effort is expected to reduce costs and expand the availability of alternative fuel aftermarket conversion systems.

Many of the existing propane fleet vehicles from the 1990s have been retired, which has led to a further decrease in propane vehicles on the roadways. School buses are a prime candidate for propane, but the pullout of GM in manufacturing the 8.1-L engine will slow progress in this key niche market. As previously mentioned, Cummins Westport ended its North American LPG engine line in 2009.

Despite these barriers, the propane industry has initiated several partnerships that have increased product choices for MY 2010. Roush is now offering F-250 and F-350 conversions, and CleanFUEL USA will be debuting the 6.0-L engine platform. Small-volume manufacturers, such as IMPCO Technologies, are expected to certify their conversion kits to EPA and CARB 2010 light-duty standards, thereby offering police and taxi fleets new choices. Other companies (American Alternative Fuel, Campbell Parnell, and Technocarb Equipment) have certified products available to convert existing police and taxi fleet vehicles to propane (model year certification information is available from EPA or CARB).

7.1.1 Lack of Emission Data

The lack of recent testing and evaluation data of on-road propane vehicles is problematic. Studies of the LPI™ system have been showing significant gains in efficiency over the older vapor system and diesels. Drawing conclusions would require more data points and a consistent testing procedure. These types of studies, to yield more conclusive data, would benefit Clean Cities coalitions and fleet managers by helping to influence the decision-making process.

7.1.2 Lack of Interest or Knowledge to Promote Propane Vehicles by Small-Scale Propane Fuel Distributors

The propane industry has been criticized for not promoting propane in a cohesive fashion as a vehicular fuel. Many small-scale distributors prefer to deal strictly with retail customers and fear that an increased demand for propane would raise prices. Some distributors are unaware that propane can be used as a vehicular fuel, or are aware but not knowledgeable about the benefits, product choices, and so forth. In addition, some states or insurance companies require certification to dispense LPG as a vehicular fuel, a situation that may also prevent distributors from entering the market.

7.1.3 Volatile Organic Compound Emission Leaks in Refueling Infrastructure

In the 2007 California Alternative Fuels Energy Plan, one of the immediate actions listed for the propane industry was to facilitate and resolve VOC emission leaks during the fuel transfer process at 700 to 900 existing LPG stations. Five years ago, as a proactive step, the Western Propane Gas Association Low Emission Equipment Rebate Program was instituted to allocate funding to remove existing equipment, such as valves and nozzles, and replace it with new, low-emission equipment. A closer examination may be needed to determine whether this is a serious issue for existing infrastructure in other states. The new dispensing equipment that is currently installed uses low-emission valves and nozzles. Considering that 10 states follow CARB emission standards, and given the possibility of future more stringent EPA regulations, it may be prudent to implement a program similar to that of the Western Propane Gas Association.

7.1.4 Adequate Number of Refueling Stations

While the AFDC reports 2,403 propane stations in the United States, this number pales in comparison to the number of gasoline stations available to the public, at roughly 164,000 in 2007 (Davis et al. 2009). As previously noted, the Clean Cities Program and industry are trying to address this issue by building refueling infrastructure, which will link cities together in key markets.

7.1.5 Price of Fuel

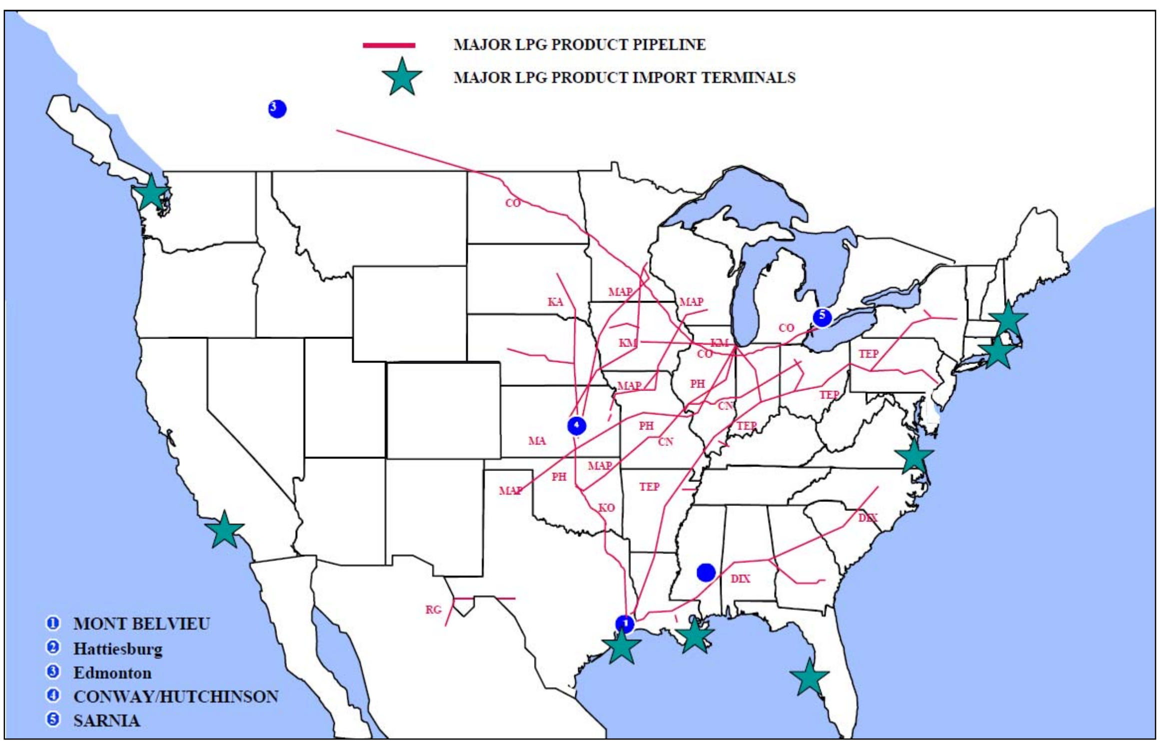
If a fleet has not secured a long-term contract for a lower price of propane, then the cost of propane fuel could be a deterrent to adoption. The higher price of propane, which can be seen at public stations (Table 3), would also be a disincentive to the general public should propane be marketed to this segment.

8 OPPORTUNITIES IN THE MARKETPLACE

8.1 PROPANE SUPPLY AND PRICE OF FUEL

The good news for propane use in transportation is that supply should not be a problem in the near future, neither worldwide nor in the United States and Canada, because of ample natural gas and petroleum processing. However, transportation users must compete for supply with petrochemical, residential, commercial, farm, and other industrial users. As such, transportation users are highly vulnerable to price spikes, especially during early and unusually cold winters, unless they have locked in a yearly fixed price. However, had a price lock-in been negotiated in late 2007, all benefits of the subsequent recession-based price declines that occurred during the 2008–2009 in oil and its derivatives, including propane, would have been lost.

Given the sensitivity of propane costs to delivery distances, propane fleets are most cost effective when located near major natural gas liquid pipelines and/or the large, pressurized aboveground storage tanks found at approximately 25,000 retail propane dealers nationwide. The pipelines, in particular, can maintain high deliverability during peak demand periods, thereby helping to mitigate price spikes. Figure 2 shows the U.S. LPG pipeline system and (in blue dots) the major North American trading hubs that feature major underground storage with high-volume connections to the transmission and distribution system (Hanger 2006).



Source: Hanger (2006)

FIGURE 2 United States LPG Distribution System

Clean Cities could partner with PERC and the existing network of 25,000 retail propane dealers, which would educate dealers about the use of propane as a vehicular fuel and encourage them to promote the product to potential fleet customers.

8.2 NEW PRODUCT AVAILABILITY AND THE COST OF VEHICLES AND INFRASTRUCTURE

The recent introduction of new-generation propane vehicles, which use liquid propane injection systems or improved vapor pressure systems, along with other factors discussed by ICFI, are expected to contribute to a near-term increase in propane sales (Sloan and Meyer 2009). The ICFI report projects an increase in the on-road vehicle sector of between 10% and 15% per year from 2012–2020. This projection included the discontinued Type C propane school bus and the Cummins Westport engine. If we assume that new products take their place, such as the Emission Solutions engine and a new partner for the Type C school bus, and if the Collins Type A school bus proves successful, then these figures could be representative. However, percentages at these levels may be delayed because of lags in the research and development for the new engines and the subsequent certification process.

The U.S. propane industry could benefit from the development of a LPG hybrid-electric vehicle. Examples exist in international markets, where propane hybrids offer advantages in emissions and fuel economy. The Avante, which is sold in the Korean market and manufactured by Hyundai, runs at 17.8 kilometers per liter of LPG, or equivalent to 42 miles per gallon of LPG or 57 mpgge—and costs 40% less than the competing Honda Civic Hybrid (Deok-hyun 2009). Kia has released an LPG hybrid version of its Forte sedan in South Korea that reportedly achieves fuel economy comparable to the Avante. Kia hopes to sell 2,000 of these units in 2009 and 5,000 in 2010. In South Korea, LPG is sold at less than half the cost of gasoline (Green Car Advisor 2009).

The new 2010 heavy-duty emission standards create an opportunity for propane heavy-duty engine development. Heavy-duty diesels will require engine and after-treatment upgrades that will increase the cost of compliance, thereby offering an opportunity for the propane industry. Recently, Daimler Trucks North America announced an additional cost of $9,000 for the Detroit Diesel® BlueTec™ technology that is necessary to achieve compliance with the 2010 emissions regulations. Furthermore, a surcharge of $7,300 will be added to vehicles equipped with the Cummins ISC 8.3-L engine, and a $6,700 surcharge to the price of vehicles equipped with the Cummins ISB 6.7-L engine. Daimler Trucks states, “The surcharges reflect costs associated with adding selective catalytic reduction, which has been proven to significantly improve fuel economy compared with EPA 2007 engines, while reducing long-term operating costs and meeting the stringent, near-zero emission standards set by EPA that take effect January 1, 2010” (Daimler Trucks NA 2009). Also adding to the operational cost of vehicles employing selective catalytic reduction technology is the required use of a urea-based solution, “diesel exhaust fluid,” to meet emission standards. Industry experts estimate diesel exhaust fluid will cost around $2.70 per gallon and will be consumed at a rate of 2 to 3 gallons per 100 gallons of diesel consumption (Bennink 2009).

In addition, the cost of propane refueling infrastructure is comparatively low, with an estimated range from $25,000 to $175,000 according to one manufacturer, depending on the station design. This is less expensive than the infrastructure for gaseous fuels like hydrogen and natural gas. Federal and state tax credits can help deflect some of the cost.

8.3 NICHE MARKETS

One potentially vigorous driver of greater propane use in transportation is the 2007 California State Alternative Fuels Plan (CEC 2007). The California Energy Commission (CEC) developed a scenario of alternative fuels usage in 2022, of which 5% is propane. The CEC report encourages fleet and market niche purchases of propane vehicles, so we have examined some markets where propane could succeed with a concerted effort: school buses, taxicabs, police vehicles, and paratransit vehicles. The CEC report includes scenarios to 2050, one of which includes a high penetration of natural gas (36%) into heavy-duty transport. Although propane is not projected to make this type of penetration, we estimated petroleum reduction benefits if propane could achieve such penetration in certain niches.

By applying a 36% penetration by 2030 to EIA projections of U.S. school-bus energy consumption (EIA forecasts extend only to 2030 and not to 2050) in a run of the GREET model that assumes in a future scenario of 70% natural gas and 30% petroleum for the LPG feedstock, a reduction of approximately 16,000 barrels of oil per day could be achieved. We did not have future projections for the other markets (taxicabs, police vehicles, and paratransit), so we are assuming no growth from the data we have.

In 2005, there were 162,000 taxicabs according to the Bureau of Transportation Statistics. On average, these vehicles travel between 60,000 and 80,000 miles per year (we use 70,000 miles) (EERE 1998). We do not have fuel economy data for this fleet but know that taxicabs are often driven in dense traffic. We assume 17 miles per gallon fuel economy, which is close to the U.S. average light-duty fuel economy (BTS 2009b). Applying a 36% penetration to this fleet would reduce oil demand by approximately 10,000 barrels per day.

Bureau of Transportation Statistics reported 412,000 police vehicles on the road in 2005. We do not have reliable mileage or fuel economy data, but anecdotal evidence shows that these vehicles are driven more miles per year than the average passenger vehicle (Indy.com 2009; Schmechel undated; Sheriff 2008). We assume 30,000 miles per year of driving and a fuel economy of 17 miles per gallon. A 36% propane penetration of this fleet would result in a reduction in oil demand of approximately 10,000 barrels per day.

If a 36% penetration of total paratransit fuel use reported by APTA for 2007 were achieved, a reduction of approximately 2,000 barrels of oil per day would occur (APTA 2009).

8.4 TAX CREDITS EXTENSIONS

As with the natural gas vehicle industry, tax credits provide a significant incentive to fleet users to purchase propane vehicles, invest in refueling equipment, and give manufacturers the confidence that they will have future markets in which to sell their products. The major issue is long-term availability. Because the credits for fuel, vehicles, and infrastructure are set to expire in the 2009–2010 timeframe (some have already expired), extensions will be needed to ensure industry and fleet customers continued use and purchase of AFVs and to justify long-term investments in vehicle research and development. If credits are not extended, this issue appears to be a significant barrier to future deployment.

8.5 INCREASED INTEREST IN TRANSPORTATION PROPANE BY FUEL DISTRIBUTORS

According to the ICFI report, the biggest challenge facing the propane industry in the next 10 years could be maintaining the current market share in the residential and commercial sectors, which account for 40% of the total odorized propane demand. Propane is expected to see a decline in the manufactured housing sector and home and commercial space heating market due to the increasing competitiveness of electric and geothermal heat pump products, as well as improvements in appliance efficiency. Erosion of these markets could lead fuel distributors to promote aggressively propane as a transportation fuel. At least one trade association has already observed a generational shift in attitude, leading to greater responsiveness to the use of propane in the transportation sector. The shift should prove beneficial to propane's development in this market sector.

8.6 REBATE PROGRAM FOR LOW-EMISSION REFUELING EQUIPMENT

Regulations to reduce fugitive emissions could become a reality. A national rebate program, in partnership with industry and the states, to exchange existing valves and nozzles for low-emission refueling equipment would be viewed by regulators and industry alike as a proactive step. The Western Propane Gas Association's program could serve as a model. This association's rebate funding allowed for up to 75% of the purchase price of the new equipment; however, the $350,000 funding for the program was exhausted by the end of 2009 (Brown Garland 2009). In total, 1,600 pieces of low-emission equipment from major distribution points have been installed to retrofit existing tanks. An analysis should be conducted to determine whether reducing fugitive emissions is a significant need for the rest of the country.

8.7 CLEAN CITIES

In the 15-year history of the Clean Cities program, the propane industry has partnered with the Clean Cities network to help deploy vehicles, build infrastructure, and conduct outreach to fleets and the public. In addition to partnering with industry to deploy vehicles and build infrastructure through the ARRA grants and participating in propane road shows, some possible near-term opportunities for Clean Cities include:

1. **Renewing Emphasis on Key Markets, such as School Buses, Taxicabs, Police Vehicles, and Paratransit Vehicles**

   The program could develop new tools for fleet managers in these targeted niches and for fuel distributors, including tools that address:

   - Supply of propane
   - Results from new testing of emissions and durability
   - Product offerings that meet 2010 emission standards
   - Fuel economy and performance
   - Safety concerns for fleets and the overfill prevention device issue
   - Payback period for the total investment by a fleet, including the initial vehicle cost and operating costs (i.e., fuel, maintenance, product longevity, insurance rates, and resale value)

2. **Focusing on Rural Markets**

   Some coalitions whose bases extend beyond major metropolitan areas may want to approach smaller cities with propane vehicle options, such as paratransit vehicles, school buses, taxis, police cars, and forklifts and trucks in manufacturing facilities. An analysis of where the existing 25,000 propane fuel distributors are located, the population sizes of the communities, and whether the communities are within a coalition's jurisdiction could identify opportunities in smaller markets.

3. **Partnering with Targeted Niche Market Associations**

   While Clean Cities has over time participated in relevant trade shows and placed articles in association newsletters, there may be better opportunities that could be defined by renewing contact directly with key associations, such as the Taxicab, Limousine, and Paratransit Association; National School Transportation Association; and National Association for Pupil Transportation. The tools developed for these markets would be of interest to many of their members. In addition, courses on propane could be offered, with topics including: how to build an alternative fuel fleet, safety, maintenance, and driver training.

4. **Cooperating with State Propane Associations**

   While some state propane associations are not greatly interested in the transportation market, there may be ways to engage them, such as partnering in efforts to train fire marshals about permitting and to educate fleets on overfill prevention device inspection and overfill issues. Outreach to schools that heat with propane could highlight the benefits of adding a fleet of propane school buses (Brown Garland 2009). Such an effort may help to meet the needs of the state propane associations that favor commercial heating markets over transportation markets for propane.

5. **Examining Market-Based Trading of Carbon Emissions for Propane Vehicle Projects to Encourage Investment in Alternative Fuel Fleet Projects**

   Clean Cities coordinators and stakeholders appear to be interested in measuring the carbon benefits of propane and other AFVs and using the reductions to meet future carbon legislation goals and other voluntary efforts.

6. **Developing a Corporate Imaging Program**

   Clean Cities could develop a corporate imaging program that includes issuing awards to fleets that make significant purchases. This corporate imaging program could be promoted to national media outlets.

9 CONCLUSIONS

Enough propane to fuel targeted fleet vehicles appears to be available, with expansion opportunities apparent in the school bus, taxicab, police, and paratransit markets. A 36% penetration rate clearly constitutes a high-case scenario, but as a long-term goal, it could be reached if challenges identified in this report are overcome and new strategies are adopted. It is possible to secure long-term contracts for propane at a lower price than conventional fuels, infrastructure is relatively inexpensive to build, new vehicle products are coming online, and an extensive network of 25,000 propane fuel distributors already exists; these facts underscore the very favorable opportunities in place to expand the use of propane in transportation.

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Energy Systems Division
Argonne National Laboratory
9700 South Cass Avenue, Bldg. 362
Argonne, IL 60439-4815

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