

Automotive LPG and Natural Gas Engines

HIGHLIGHTS

- **PROCESS AND TECHNOLOGY STATUS** – Internal combustion engines running on liquid petroleum gas (LPG) are well-proven technologies and work much like gasoline-powered spark-ignition engines. Natural gas (NG) engines are also well-proven. They are typically used as spark-ignition engines for bi-fuelled (gasoline/CH₄) cars, but have also been used, for example, in compression-ignition (i.e. diesel-type) engines for heavy-duty vehicles. Both LPG and NG are not used alone, but always in bi-fuel vehicles, in combination with gasoline. In bi-fuel vehicles two fuels are stored in separate tanks and the engine runs on one fuel at a time. Bi-fuel vehicles have the capability to switch back and forth from gasoline to the other fuel, manually or automatically. In the past, most bi-fuel vehicles were derived from native gasoline vehicles by adding a tank and an electronic injection regulation system for the alternative fuel. In recent years, the offer of 'native' bi-fuel vehicles has increased; they have two separate tanks and two alternative injection regulation programs.
- **PERFORMANCE AND COSTS** – Bi-fuel LPG cars can reduce greenhouse gas (GHG) emissions by 15% as compared to petrol operation. NG cars can achieve GHG reductions of up to 25%. The energy efficiency of engines running on natural gas is generally equal to that of gasoline engines, but is lower if compared with modern diesel engines. The conversion costs for LPG vehicles range from €1130 to €2740 (10-15% incremental cost). The conversion costs for light-duty NG vehicles are currently between €1640 and €2190 (10-15% incremental cost). When running on LPG or NG, CO₂ emissions are at least 10% or 20% lower, respectively, if compared to gasoline. Actual emissions depend on the share of mileage run on petrol.
- **POTENTIAL AND BARRIERS** – In 2008, more than 7 million Natural Gas Vehicles (NGVs) were on the roads, most notably in Argentina, Brazil, Pakistan, Italy, India, China, and Iran, with South America leading the global market with a 48% share. The number of LPG/NG kits sold globally is estimated to reach 8.0 million by 2012. An appropriate infrastructure, along with governmental support, may accelerate the growth of LPG and NG as global alternative fuels. Bottlenecks that may slow down the development and deployment of LPG and NG technologies are the lack of appropriate infrastructure for fuel distribution and refuelling, the higher vehicle cost, and the competition from other fuel options (e.g. biofuels).

TECHNOLOGY STATUS AND PERFORMANCE –

Internal combustion engines running on liquid petroleum gas (LPG) and natural gas are well-proven technologies and work much like gasoline-powered spark-ignition engines [18]. They are normally used as spark-ignition engines for bi-fuelled (gasoline/CH₄) cars, but have also been used, for example, in compression-ignition (i.e. diesel-type) engines for heavy-duty vehicles. Both LPG and NG is not used alone, but always in bi-fuel vehicles, in combination with gasoline. In bi-fuel vehicles two fuels are stored in separate tanks and the engine runs on one fuel at a time¹. Bi-fuel vehicles have the capability to switch back and forth from gasoline to the other fuel, manually or automatically. In the past most bi-fuel vehicles were derived from native gasoline vehicles by adding a tank and an electronic injection regulation system for the alternative fuel. In recent years the availability of 'native' bi-fuel vehicles has increased; they have two separate tanks and two alternative injection regulation programs.

■ **LPG Vehicles** work much like gasoline-powered vehicles with spark-ignited engines. LPG is stored as a liquid in a separate steel or composite vessel at the pressure of 10 bar, although it can stand a pressure of

20-30 bar. LPG supply to the engine is controlled by a regulator or vaporizer, which converts the LPG to a vapour. The vapour is fed to a mixer located near the intake manifold, where it is metered and mixed with filtered air before being drawn into the combustion chamber where it is burned to produce power, just like gasoline. LPG injection engines, developed over the past 15 years, do not vaporize the LPG. Instead, the LPG is injected into the combustion chamber in liquid form. These systems have proven to be reliable in terms of power, engine durability, and cold starting.

In the 1970s Toyota made a number of LPG-only engines for cars. Today, most LPG vehicles are conversions from petrol vehicles. Many car makers offer conversion/bi-mode vehicles. LPG technology is rather popular in the European Union, Australia, Hong Kong, India, South Korea, Serbia, the Philippines, Turkey and Armenia. The world leader is probably Armenia where about 20-30% of vehicles run on LPG which offers a cheap alternative to diesel and petrol. LPG engines and fuelling systems are also available for medium- and heavy-duty vehicles such as school buses and street sweepers. For example, the school districts in Dallas, Denton, Texas, Portland and Oregon rely on LPG-fuelled school buses. [4].

¹ unlike flexible-fuel vehicles ("dual-fuel"), that store the two different fuels mixed together in the same tank, and the resulting blend is burned in the unique combustion chamber.

The LPG energy content (High Heating Value, HHV) is 46.23 MJ/kg (Table 1). The high octane rating and the low carbon and oil contamination characteristics of LPG result in a documented longer engine lifetime, up to twice that of the gasoline engines. Because the fuel mixture is fully gaseous, cold start problems associated with liquid fuel are eliminated. LPG has a relatively high energy content per unit of mass, but its energy content per unit volume is low. Thus, LPG tanks have more space and weight than petrol or diesel fuel tanks, but the range of LPG vehicles is equivalent to that of petrol vehicles. Bi-fuel LPG car tests show around a 15% reduction in greenhouse gas emissions (per unit of distance) compared to petrol operation. The best quality LPG bi-fuel engines produce fewer NO_x emissions and virtually zero particulate emissions if compared to petrol. [7, 8]

■ **Natural Gas Vehicles** (NGV) are typically bi-fuelled cars with a spark-ignition petrol engine. However, natural gas is also used in compression-ignition (i.e. diesel-type) engines for heavy-duty vehicles. Diverse engine technologies running on natural gas include: a) Stoichiometric combustion, b) Lean Burn; c) Single Point Injection; and d) Multi Point Injection. Natural gas is stored on-board as either compressed natural gas (**CNG**) or liquefied natural gas (**LNG**) - the latter at 190°C. CNG is the most common option for cars. The gas is stored in pressurized 200-270 bar cylinders, which are located within the boot space. Cars used to have a single steel cylinder; new cars contain several smaller composite cylinders. Being pressurized, it is heavier than conventional fuel tanks and increases the car total weight by around 60 kg. [1, 2, 3].

As of 2008 there were more than 7 million NGVs (Figure 1, and Table 2) running on the world's roads, mostly in Argentina, Brazil, Pakistan, Italy, India, China, and Iran, with South America leading the market with a 48% share. The US has some 130,000 vehicles, mostly buses. Italy, with a long tradition in using CNG vehicles, heads the European market with more than 500,000 CNG vehicles as of the end of 2008. Latest NGVs successfully brought to the market include the Honda Civic GX Samand (CNG), GM do Brasil (both CNG and E20-E25 alcohol/gasoline blends) aimed at the taxi market, the Fiat Siena Tetra (using CNG among others fuel), and the Volvo C30, S40, V50, S60, V70 and S80 (all bi-fuel cars). [3]

■ **Urban buses** are one of the most popular uses for natural gas, usually utilizing CNG but occasionally also liquefied natural gas (LNG). Because of the distance an urban bus travels does not vary much from day-to-day, the fuel requirements can be catered for quite easily. Storage cylinders for CNG and LNG are often installed on the roof of a bus, allowing the

weight to be distributed evenly over the chassis. Buses that run on natural gas include Volvo, Van Hool, Orion Bus Industries, New Flyer, Neoplan, MAN, Isuzu, Irisbus,

Dennis, EvoBus (Mercedes-Benz). In the past, the weight of CNG cylinders has often limited NG application to heavy vehicles (trucks). This is now less relevant as natural gas engines are becoming lighter compared with their diesel counterparts and lightweight composite materials CNG cylinders are available. In some applications, fleet operators may choose a dual-fuel natural gas engine over a dedicated natural gas engine, with the option of switching to diesel if natural gas supply becomes restricted. Trucks that run on natural gas include the Chevy Silverado (CNG), the GMC Sierra (CNG), the Volvo FL and the Ford F-150 (bi-fuel)

The HHV of CNG and LNG are 46-49 MJ/kg and 25 MJ/l, respectively (Table 1). The energy efficiency of engines running on natural gas is almost equal to that of gasoline engines in new cars, where dedicated injectors are used for the alternative fuel but are lower compared with modern diesel engines. Gasoline vehicles converted to run on natural gas suffer because of the engine low compression ratio, resulting in a cropping (10-15%) of delivered power while running on natural gas. In recent 'native' bi-fuel gasoline-NG vehicles, the efficiency loss is reduced to 5-10%. CNG-dedicated engines use a higher compression ratio due to the fuel's higher octane number of 120-130.

Compared to petrol, cars running on natural gas offer a CO emissions reduction of 90% to 97%, 25% reduced CO₂, 35% to 60% reduced NO_x emissions, and 50% to 75% reduced non-methane hydrocarbon emissions. In addition to this, there are fewer toxic and carcinogenic pollutants, little or no particulate matter and no evaporative emissions. Transit buses equipped with 2004 CNG engines models produce 49% lower NO_x emissions and 84% lower particulate matter emissions versus transit buses equipped with 2004 diesel engines. In a recent study on CNG and diesel vehicles, the United Parcel Service (UPS) delivery CNG trucks produced 75% lower CO emissions, 49% lower NO_x, and 95% lower particulate matter compared to diesel trucks of a similar age. [7, 8, 12]

CURRENT COSTS AND PROJECTIONS – In general, in the UK, the additional purchase price or conversion cost of a new **LPG** car or car-derived van is around €1130 for a 4-cylinder vehicle, €1300 for a 6-cylinder vehicle, €1528 for an 8-cylinder vehicle and €2740 for heavy duty vehicles. In the US, the average cost of converting a light-duty vehicle from gasoline to propane ranges from €2990 to €8960. [11, 14]

Fuel	CNG	LNG	LPG
Energy Content	37-40 MJ/m ³	25 MJ/l	25.4 MJ/l
High Heating Value	46-49 MJ/kg	45,5MJ/kg	46,23 MJ/kg
Octane Number	120	120	92

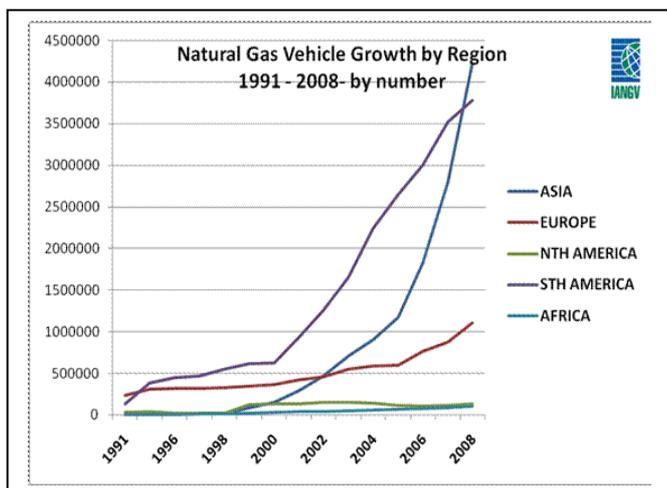


Fig. 1 - Natural gas vehicles by regions 1991-2008 (IANGV 2009 - <http://www.iangv.org/stats/NGV-Statistics08.htm>) [9]

Region	NGV Growth since 2000 (%)
Asia	52.50%
Europe	15.40%
North America	0.40%
South America	25.90%
Africa	19.30%
Total	29.80%

For natural gas cars and car-derived vans, typical incremental capital or conversion costs are between €1640 and €2740 in the UK. Additional capital costs are incurred if a refuelling compressor unit is installed, the cost of which is about €2740 or more. It should be noted that in some cases costs are considerably higher. For instance, in the US, the price premium of a Honda Civic GX compared with the gasoline version is €7090 and it is only mitigated by a tax credit of €2990. [8, 10]

NGV refuelling infrastructure includes onsite compression (or thermally insulated storage, in the case of LNG), storage facilities, containments, and vending equipment including monitoring, measurement, controls, and connections. Refuelling infrastructure for NGVs is currently expensive. Usually costs vary between €375,000 and €750,000 for a fast-fill CNG refuelling station for road vehicles with refuelling time comparable to diesel, while costs are between €150,000 and €450,000 for LNG [15].

In terms of future cost projections LPG and NG technologies will continue to experience price reductions with economies of scale and technological development. However, the majority of the technologies are relatively advanced and therefore will experience only a limited cost reduction over time.

Typical performance and cost figures for LPG and natural gas vehicles are summarized in Tables 3 and 4, and compared with similar figures for conventional gasoline vehicles.

POTENTIAL AND BARRIERS – It should be noted that the use of LPG as an automotive fuel varies very widely within a country and from one country to another, depending on the cost and availability of the fuel in relation to alternative fuels, notably gasoline and diesel. Major drivers for LPG and natural gas vehicles deployment are increasing oil prices, the availability of refuelling infrastructure, and governmental support (e.g. tax credits on capital investments). An evaluation of global market potential for LPG and CNG vehicles and alternative fuels reveals that the number of LPG and CNG kits sold globally was 2.9 million in 2006. It is estimated that they will reach 8.0 million by 2012. LPG kits will continue to dominate the market in the EU, Russia, Turkey, and other countries. India and Iran accounted for 20% of global sales of CNG kits in 2006. While aftermarket sales of LPG and CNG kits currently hold more than 85% of global kit sales, original equipment manufacturer (OEM) kit sales will steadily increase to reach more than 27% of the total number of units sold by 2012.

An appropriate infrastructure (i.e. a sufficient number of refuelling stations) along with the required governments' support will accelerate the growth of LPG and CNG as alternative fuels. Currently there are 14,563 NGV tank stations worldwide, with 3,044 located in the EU. The LPG refuelling network is more established, with more than 33,000 LPG stations in Europe, and Turkey and Poland in particular, are the leading countries. [8]. In the EU, CNG is currently a niche-market technology, but the growth potential is considerable because of increasing emission reduction targets. Asia, India and Pakistan have enforced mandatory conversion to alternative fuels for all public transport in certain regions. According to the International Association for Natural Gas Vehicles (IANGV), considering the European Community plans and ongoing developments in Asia, the global number of NGVs could reach 15 million by 2010 and 50 million by 2020 [5, 6, 8].

Some issues might slow down the sector growth [7]. Technical bottlenecks observed during NGVs tests included the durability of some components (i.e. natural gas regulators and on-board LNG tanks) and some engine failure problems. Other bottlenecks relate to storage and refuelling. Most of today's CNG vehicles

are dual fuelled and the CNG fuelling and storage equipment adds to the gasoline fuel system. The loss of storage volume in buses and commercial vehicles might be acceptable, however consumers would not accept a loss of space in private cars. Also, vehicle fleets are usually served from corporate-based filling stations, whereas consumers require CNG to be available at a large number of service stations. The cost of refuelling and storage infrastructure and facilities (including compression or cryogenic storage, in the case of LNG) is considerably high, but can gradually decrease over the next decade, most notably through manufacturing refinements and increasing scale-economies. In the coming decade, possible breakthroughs in storage systems based on natural gas adsorbents may occur and be applied to on-board storage. It is unclear whether this technology may be the dominant option over CNG for natural gas vehicles. The durability and reliability of CNG and LNG infrastructure can also be improved significantly within the next decade, primarily

through research and development of improved materials and manufacturing processes.

Consumers' awareness and education in safety issues associated to the use of new fuels may raise further problems as consumers are often confused about the difference between LPG and CNG/LNG. Safety regulations also differ. However, the main barriers for the development and deployment of both LPG and natural gas vehicles remain the higher investment costs and the lack of infrastructure for CNG vehicles. According to Shell, an estimated 20,000 stations at a unit cost of US \$350,000 need to be converted in the European Union to meet the potential demand for NGV. An investment of some €5 billion - plus the vehicle conversion cost - seems to be very high, especially if compared to competitors such as clean diesel technologies, where these investments are not necessary. Biofuels can also be competitors for natural gas and the LPG industry. [13].

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Table 3 - Summary Table: Key Data and Figures for LPG and Natural Gas Vehicles

LPG Vehicles, retrofit [19]			
Technical Performance	Small Cars	Medium Cars	Large Cars
Energy Input	LPG		
Base Energy Consumption (kg/km – KJ/km))	0.05 – 2.3	0.058 – 2.7	0.09 – 4.1
Technical Lifetime, yrs	12	12	12
Environmental Impact (for bi-fuel cars)			
CO2 and other GHG emissions, g/km	122.0	141.7	216.7
Costs			
Additional Capital Cost, overnight, Euro/unit	1,130	1,300 – 1,528	2,740
O&M cost (fixed and variable), Euro/km	0.03	0.04	0.05
Economic Lifetime, yrs	12	12	12
CNG/LNG Vehicles, retrofit [8, 10, 19]			
Technical Performance	Small Cars	Medium Cars	Large Cars
Energy Input	LNG/CNG		
Base Energy Consumption (l/km)	0.06 – 2.2	0.07 – 2.6	0.11 – 4.1
Technical Lifetime, yrs	12	12	12
Environmental Impact (for bi-fuel cars)			
CO2 and other GHG emissions, g/km	93.3	108.3	165.7
Costs			
Additional Capital Cost, overnight, Euro/unit	1,640 - 2,190	N/A	N/A
O&M cost (fixed and variable), Euro/km	0.03	0.04	0.05
Economic Lifetime, yrs	12	12	12
Baseline Gasoline Vehicles [19]			
Technical Performance	Small Cars	Medium Cars	Large Cars
Energy Input	Gasoline		
Base Energy Consumption (l/km – KJ/km)	0.062 – 2.00	0.072 – 2.32	0.111 – 3.58
Technical Lifetime, yrs	12	12	12
Environmental Impact (for bi-fuel cars)			
CO2 and other GHG emissions, g/km	143.5	166.7	255.0
Costs			
Additional Capital Cost, overnight, Euro/unit	10,279	16,643	25,505
O&M cost (fixed and variable), Euro/km	0.03	0.04	0.05
Economic Lifetime, yrs	12	12	12

The high octane rating, and low carbon and oil contamination of LPG result in up to twice the engine life of gasoline engines

Table 4 - Field Tests of Natural Gas Vehicle Emissions - US

(US-DoE - Energy Efficiency & Renewable Energy, 2009, http://www.afdc.energy.gov/afdc-/vehicles/emissions_natural_gas.html)

Vehicle Type	CNG Mail Delivery Trucks	LNG Buses	LNG Semi Trucks	LNG Refuse Trucks	LNG Dual-Fuel Refuse Trucks
Fleet	United Parcel Service	Dallas Area Rapid Transit	Raleys	Waste Management	Los Angeles Bureau of Sanitation
No of Alternative Fuel Vehicles	7	15	8	6	10
No of Diesel Vehicles	3	5	3	2	3
Drive Cycle	City Suburban Heavy Vehicle Route	Central Business District	Five-Mile Route	WM Refuse Truck Cycle	Air Quality Management District Refuse Truck Cycle
PM Reduction	95%	NSS	96%	86%	NSS
NOx Reduction	49%	17%	80%	32%	23%
NMHC Reduction	4%	96%	59% Less Than Diesel THC	64% Less Than Diesel THC	NSS
CO Reduction	75%	95%	-263%	-80%	NSS

NSS – Not Statistically Significant