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# LIQUEFIED PETROLEUM GAS AS AUTOMOTIVE FUEL IN ENVIRONMENTAL PROTECTION

*ABSTRACT*

*This paper considers the possibilities of using liquefied petroleum gas (LPG) as alternative fuel for propelling Otto engines in passenger cars. The advantages of using LPG compared to petrol are reflected in the reduced emission of harmful gases, lower price. The disadvantages include the costs of installing the gas equipment, occupying part of the boot, as well as few gas filling stations. In spite of the disadvantages, liquefied petroleum gas is claimed to be the fuel of the future.*

*KEY WORDS*

*liquefied petroleum gas, automotive fuel, environmental protection*

## 1. INTRODUCTION

The mass exploitation of gaseous fuels started during World War II, when there was a lack of liquefied fuels due to enormous consumption.

The real application of gaseous fuels began during the petroleum crisis of the 70s. Then the liquefied petroleum gas started to be used, which had until then burned in refineries as a torch. The liquefied petroleum gas is mainly a mixture of propane and butane gases, which are obtained as by-products during petroleum distillation. This fuel is very widely used and has great possibilities of application. During the recent decade, the natural gas methane has been used increasingly, and it is characterised by environmental friendliness and low price, efficiency and great application in working and industrial machines.

## 2. LIQUEFIED PETROLEUM GAS AS FUEL

Fuels are those substances that during oxidation generate a certain amount of heat which can be used in practice for various purposes.

If a certain substance is to be used as a fuel, it has to fulfil the following conditions:

- during the combustion process it should generate significant amount of heat over a short period of time, for efficient usage;
- it should be available in nature in sufficient quantities;
- its exploitation should be relatively easy and economical, in case of natural fuels, i.e. its production process should be technically feasible and profitable, in case of artificial fuels;
- it should not contain any non-combustible substances - ballast;
- it should not change significantly its composition and properties during storage, transportation and handling;
- it should be easy to transport and store;
- during oxidation it should not generate any harmful gases dangerous to people, animals and plants, and these should not have corrosive effect on equipment and devices made of metal;
- it should not be expensive.

If a substance fulfils all these conditions, it can be used as source of energy.

Fuels are usually divided according to their physical state and production method:

- according to their physical state they are divided into:
  - solid,
  - liquefied,
  - gaseous.
- according to the production method:
  - fossil (plants or animals),
  - mineral (inorganic mineral substances),
  - artificial.

Liquefied petroleum gas is mostly a mixture of propane ($C_3H_{10}$) and butane ($C_4H_{10}$) with a minor content of propylene ($C_3H_6$), butylene ($C_4H_8$) and isobutylene ($C_4H_8$). Liquefied petroleum gas is not toxic, but inhaling may have anaesthetic effect. It is an odourless gas, so that an odorant (characteristic odour) is added during production for easier detec-

tion in case of uncontrolled leakage. Whereas at normal temperatures and atmospheric pressure petrol hydrocarbons are mainly in liquid state, the "gas" hydrocarbons are in a gaseous state. However, already at a relatively low pre-pressure (from 1.7 to 7.5 bars) at room temperature they turn into liquid state. In such state, volumetrically compressed, they have acceptable heat energy for propelling purposes.

**Table 1 – LGP mixture contents in some countries**

| Country | Relation propane : butane (volume ratio) | |
|---|---|---|
| | In summer | In winter |
| Austria | 20:80 | up to 80:20 |
| Germany | mainly propane | |
| Switzerland | mainly propane | |
| Netherlands | 30:70 | 70:30 |
| Belgium | 30:70 | up to 50:50 |
| Denmark | 50:50 | up to 70:30 |
| Sweden | mainly propane | |

The share of propane, i.e. butane, and then possibly also some other related gases in the mixture differs from country to country, and often varies in the production during the year. Driving is possible using any of these mixtures, although the composition affects somewhat the consumption and the efficiency, and the composition of exhaust gases. Generally, propane is a better fuel than butane, first of all regarding resistance to knocking (octane number). If there are too many unsaturated hydrocarbons (propylene and butylene) in the mixture, then this may cause certain disturbances in the propulsion.

Propane and butane are lighter than petrol. Since the boiling point for both gases is at temperatures below 0°C, liquefied petroleum gas will be in a gaseous state above 0°C and at atmospheric pressure. Heat energy is lower by about 25% than with petrol, and therefore gas will generate respectively lower energy to the engine. Gas needs only a little more air for combustion than petrol.

Resistance to knocking in the engine, expressed by the octane number, is better with gas than with petrol, especially when the mixture contains a greater percentage of propane. The extent to which gas regarding its physical properties is or is not dangerous, can be seen from the above data. Every gas will ignite (explode) under the influence of heat (increased temperature or spark), but only when mixed with air in the correct proportion. As we can see, the explosion limit of both propane and butane is narrower than with petrol (especially compared to residential gas). This means that no ignition will occur when the concentration of propane in the air is lower than 2.0%, nor when it is greater than 9.5%. For butane this range is from 1.5% to 8.5%. Here the initial ignition temperatures are far higher with gases than with petrol, which means that gas requires much higher temperature (even sparks in the cylinder) to get ignited.

Regarding energy liquefied petroleum gas is more efficient than any other fuel.

## 3. LIQUEFIED PETROLEUM GAS IN AUTOMOBILES

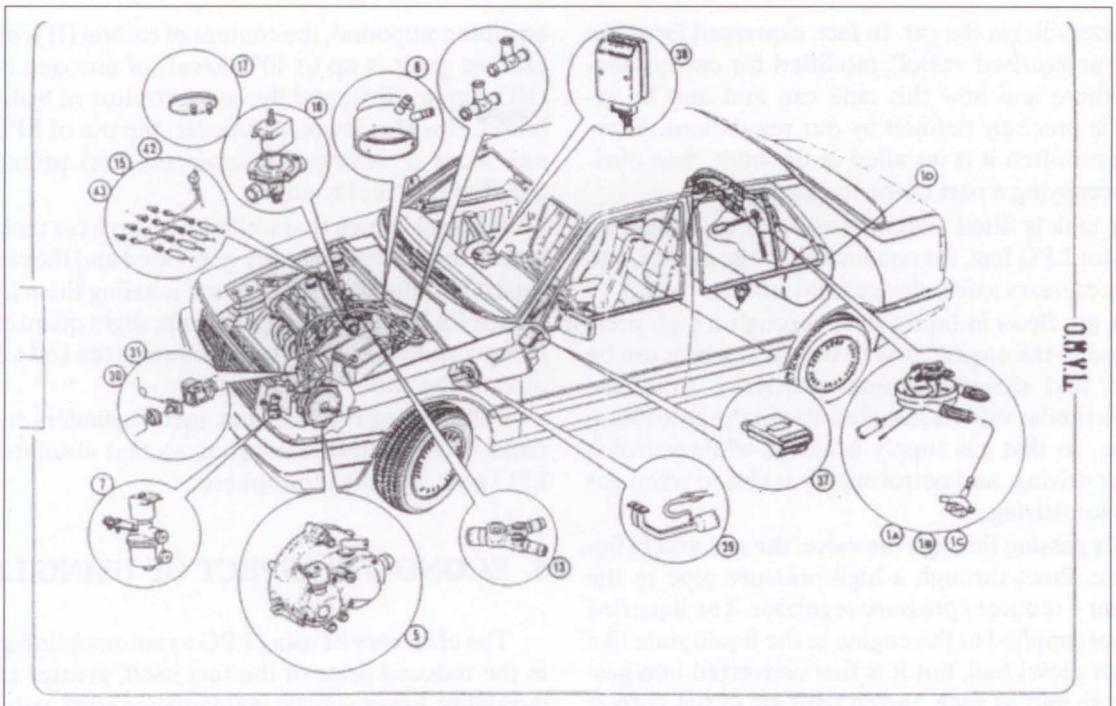
Liquefied petroleum gas can be used as fuel in all types of engines. Most frequently it is used in Otto engines of passenger cars, when the engine is propelled by petrol or liquefied petroleum gas, depending on the driver's preferences. Changeover from one fuel to the other is very simple and possible even during driving.

The use of liquefied petroleum gas as propelling fuel is based on its physical and chemical properties which are in many parts more favourable compared to petrol, particularly regarding high heating-energy, high octane number, easy evaporation, and easy formation of homogeneous mixture.

Liquefied petroleum gas in liquid state is under pressure and therefore it requires a specially made

**Table 2 – Basic features of liquefied gases compared to petrol**

| | Propane | Butane | Petrol-super | Petrol-normal |
|---|---|---|---|---|
| Specific mass ( kg/l) | 0.41 | 0.58 | 0.76 | 0.73 |
| Boiling point (°C) | - 42 | - 0.5 | 30-215 | 30-215 |
| Heat energy (Joule) | 23.5 | 26.3 | 32.8 | 32.2 |
| Need of air for combustion (kg/kg fuel) | 15.7 | 15.5 | 14.5 | 14.5 |
| Resistance to knocking (octane number) | 110 | 94 | 99 | 86 |
| Limit of flammability (explosiveness) - volume % gas in the air at 20°C and one bar | 2.0-9.5 | 1.5-8.5 | 0.6-8.0 | 0.6-8.0 |
| Ignition temperature in (°C) | below -42 | below -60 | below +21 | |
| Self ignition temperature (°C) | 490-510 | 400-430 | 220-500 | 220-500 |



1A LPG Filling Valve
1B LPG Drawing Valve
1C Multi-Valve Gas Tight Container
1D LPG Tank
3 LPG Filling Pipe
4 LPG Drawing Pipe
7 LPG Shut-Off Valve
8 Mixer
13 Maximum Flow Branch Pipe
14 Injection Manifold
15 Petrol Injectors
16 Vacuum Pipe
17 Vacuum Stabilizer
18 ECON-EC Stepper Motor
19 Reducer
21 Reducer Solenoid
22 Gas Inlet
23 Gas Outlet
25 Heater Radiator
26 Water Inlet
27 Water Outlet
29 Slow Running Adjuster
30 Exclusion Device (Bosch L Jetronic)
31 Air Flow Meter
32 Battery
33 Ignition Key
34 Ignition Coil
35 Fuse
37 Electronic Fuel Selector Switch
38 ECON-EC Electronic Control System
39 Lambda Probe in Exhaust
40 Heating Cable for Lambda Probe
41 Box Pipe for Lambda Probe
42 Relay for Injector Cut-Off
43 Injector Cables

**Electronic LPG System - For Injection Vehicles Fitted with Lambda Probe and Catalytic Convertor**

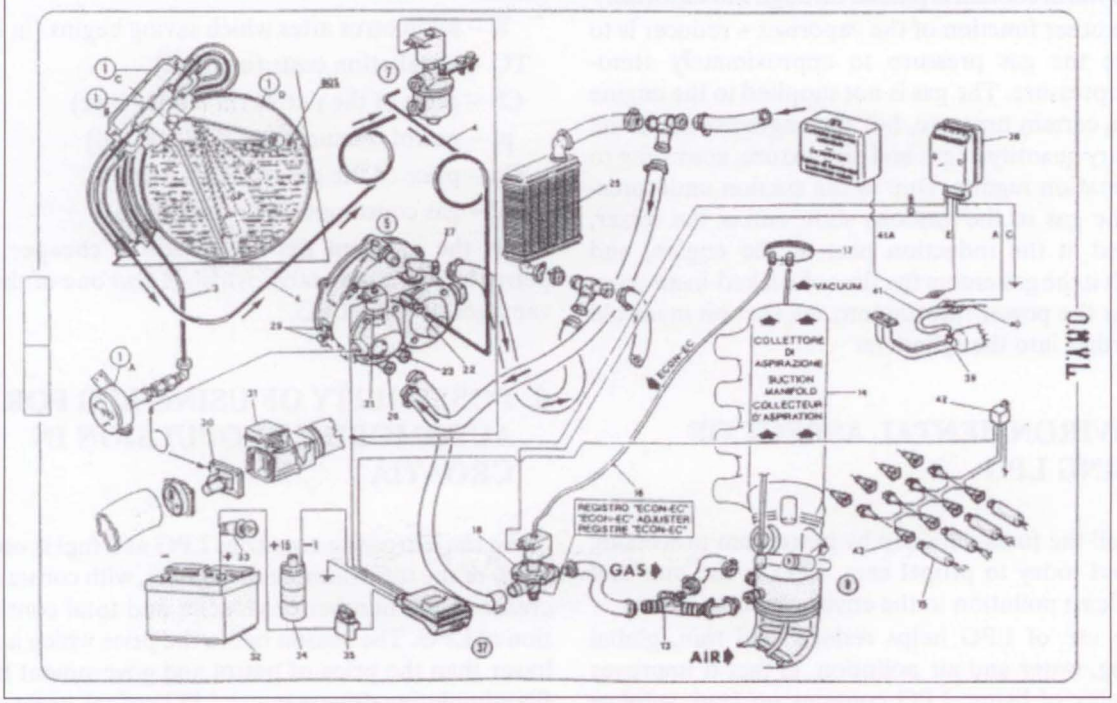



Figure 1 – Gas equipment for cars with catalysts

tank (reservoir) in the car. In fact, expressed formally, it is a "pressurised vessel" modified for car installation. Where and how this tank can and may be installed is precisely defined by our regulations. However, most often it is installed in the boot, thus obviously occupying a part of the luggage space.

The tank is fitted with accessories, i.e. a filling up system for LPG fuel, for conduction to the engine, and all the necessary safety devices and valves.

The gas flows in liquid state through a high-pressure pipe to the engine, first to the valve which can be opened and closed electromagnetically from the cabin. A similar valve is installed also in the petrol supply pipe, so that gas supply is closed while petrol is used for driving, and petrol supply is closed when gas is used for driving.

After passing through the valve, the gas, still in liquid state, flows through a high-pressure pipe to the vaporiser – reducer / pressure regulator. The liquefied gas is not supplied to the engine in the liquid state like petrol or diesel fuel, but it is first converted into gaseous state and as such, mixed with air in the correct proportions, is fed as gaseous mixture to the engine. It is this gaseous characteristic of the combustible mixture which provides it with one of its greatest advantages.

The vaporiser – reducer has two functions at the same time.

First, it converts gas from the liquid into the gaseous state. This is achieved by heating the gas, and therefore the vaporiser has to be heated. This is most frequently done by connecting it to a cooling system, and the warm coolant is passed through the vaporiser.

The other function of the vaporiser – reducer is to regulate the gas pressure to approximately atmospheric pressure. The gas is not supplied to the engine under a certain pressure, but the engine sucks in the necessary quantity of gas and air mixture, according to the operation regime. Due to the suction underpressure, the gas in the gaseous state enters the mixer, mounted at the induction part of the engine, and through it the gas enters the flow of sucked-in air passing over the power throttle into the suction manifold and further into the cylinders.

## 4. ENVIRONMENTAL ASPECT OF USING LPG

Of all the fuels obtained by petroleum processing and used today to propel cars, LPG is the one that causes least pollution to the environment.

The use of LPG helps reduce acid rain, global warming, water and air pollution, in fact it improves the quality of living. LPG contains no lead, sulphur and particulates. Regarding homogeneity of the combustible compound, the content of carbon (II) oxide in exhaust gases is up to 40% lower, of nitrogen oxides ($NO_x$) up to 20 %, and the concentration of hydrocarbons CH is also lower. Moreover, the use of LPG has one more advantage for environmental protection, and that is in fuel handling.

It is well known that while filling up a car tank with petrol, the petrol fumes are generated and they are released into the atmosphere, and inhaling them is dangerous for health. During filling up, slight quantities of fuel get spilled, thus directly polluting the soil and indirectly the underground waters.

Filling up of road tankers, metal cylinders and car tanks is completely leak-proof, so that absolutely no LPG goes into the atmosphere.

## 5. ECONOMIC ASPECT OF USING LPG

The efficiency of using LPG as automobile fuel lies in the reduced price of the fuel itself, greater engine durability, lower vehicle maintenance costs, extended oil and spark plug changes, greater catalyst durability. With 15-20,000 kilometres travelled annually, the capital invested in the gas installation can be regained already during the first year of exploitation.

The following mathematical expression can be used to calculate the number of kilometres after which the driving by gas becomes cheaper:

$$K = \frac{TU}{(Cb \cdot p_b) - (Cp \cdot p_p)} \cdot 100 \quad \text{km}$$

where:

K – kilometres after which saving begins (in km)
TU – installation costs (in HRK)
Cb – price of the petrol (in HRK / litre)
$p_b$ – petrol consumption (in l/100 km)
Cp – price of the gas (in HRK / litre)
$p_p$ – gas consumption (in l/100 km)

At the moment gas in Croatia is cheaper than petrol by more than 60%, which is also one of the advantages of using LPG.

## 6. POSSIBILITY OF USING LPG FOR AUTOMOBILE PROPULSION IN CROATIA

In the European countries LPG as a fuel is used in 4-8% of the total number of vehicles, with constant increase in the number of vehicles and total consumption of LPG. The reason lies in the price which is 50% lower than the price of petrol and government benefits stimulating drivers to use LPG as fuel, great number of filling stations and servicing places, and finally,

higher environmental awareness of the people using LPG.

In Croatia LPG is used only in 2% of the cars. The reason for stagnation in using LPG in vehicles lies in the new vehicles that have lower fuel consumption. Today LPG is used mainly to propel older vehicles that consume more fuel. There are several distributors of LPG car installations, and some twenty installers and servicing points. The price of the equipment including installation ranges from 2500 to 8000 kunas, depending on the type of equipment and make of vehicle.

For the driver, gas used for driving does not represent any great difference compared to petrol, since according to the manufacturer's data, the latest generation of devices allows equal properties for cars as with petrol, same maximum speed, acceleration and fuel consumption. In older equipment, driving by gas results in somewhat lower maximum speed and 10% greater gas consumption.

The main distributor of LPG is the INA company, which owns 20 filling stations, and private entrepreneurs own 5 more LPG filling stations. The car filling stations in Croatia are not evenly arranged, so that this also presents one of the reasons of the small number of vehicles that use LPG as fuel. There are 500 vehicles per one filling station in Croatia, whereas this number ranges from 100-200 vehicles in Europe. INA sells annually just about 10,000 litres of LPG as fuel.

LPG filling stations can be installed at the existing petrol stations, since there is such a provision in the legal regulations.

In order to promote the use of LPG, the Government should stimulate the drivers, which would be possible by introducing environmental fuel taxes, and tax exemption for the gas installations.

Most LPG filling stations are not located in towns nor on the main roads, but rather in industrial zones and distribution centres.

## 7. CONCLUSION

It is a well-known fact that transport is the greatest environmental polluter. It produces great quantities of carbon (IV) oxides, which is also called the "greenhouse" gas and which is directly responsible for the greenhouse effect.

In the developed west countries, the environmental awareness is highly developed, as well as government stimulation in raising the ecological awareness among its citizens.

Liquefied petroleum gas which is used as car fuel directly helps the environmental protection, so that LPG propelled cars are environmentally friendlier.


Figure 2 – Distribution of LPG filling stations in Croatia

Therefore, it is no wonder that precisely natural and liquefied petroleum gas, compared to other "alternative" solutions for propelling vehicles: alcohol, fuel cells, hydrogen and electricity, are considered as the only adequate substitute of the existing expensive and environmentally quite harmful fuels. The additional benefit is that the existing petrol engines can be adapted to gas propulsion with few modifications. They are most often of bivalent design, allowing changeover from petrol to gas and vice versa. For motor vehicles propulsion the LPG is used more often than the natural gas. The reason lies in the pressure at which the gas is stored in the tank, 6 to 7 bars with LPG, and 200 bars with natural gas. The supply is simple, provided by the network of 22,000 filling stations worldwide. In Croatia the LPG filling stations are distributed at some twenty locations, and as many as half of them are along the coast. This is to the advantage of the foreign tourists.

The disadvantage of cars using LPG is its relative density, it is heavier than air, gathers at the floor level and may produce an explosive compound. This is why such vehicles should not be parked in underground and closed parking garages.

*SAŽETAK*

*TEKUĆI NAFTNI PLIN KAO GORIVO ZA MOTORNA VOZILA U OČUVANJU OKOLIŠA*

*U ovom članku autori razmatraju mogućnosti korištenja tekućeg naftnog plina kao alternativnog goriva za pogon Otto motora osobnih vozila. Prednosti korištenja tekućeg naftnog plina u odnosu na benzin, ogledaju se u smanjenju emisije štetnih plinova, nižoj cijeni. U nedostatke se mogu ubrojiti troškovi ugradnje plinskog uređaja, zauzimanje dijela prtljažnog prostora, kao i mali broj auto punionica plina. Unatoč nedostatcima za tekući naftni plin može se reći da je gorivo budućnosti.*

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