WHAT IS LIQUEFIED PETROLEUM GAS?

The term Liquefied Petroleum Gas (LPG) comprises mainly the two gases propane and butane, and mixtures of the two, because of their properties and characteristics. Both gases exist in the liquid state under relatively low pressure, of less than 9 bar, at room temperature. That is why they are also known as liquefied petroleum gases. Liquefaction reduces the volume of LP gases by a factor of approximately 250 (Hempel 2007).

Propane and butane are both short-chain saturated hydrocarbons (alkanes). Propane is a molecule with three carbon and eight hydrogen atoms \((\text{C}_3\text{H}_8)\). Butane consists of four carbon and ten hydrogen atoms and has two isomers, normal butane and isobutane; n-butane and isobutane share the same chemical formula \((\text{C}_4\text{H}_{10})\), but display different spatial arrangements of their atoms and also have different properties, for example a boiling point at \(-0.5^\circ\text{C}\) for n-butane vs. \(-12.8^\circ\text{C}\) for isobutane. Due to their material and combustion properties, both liquefied petroleum gases suit many possible applications. When being used as a fuel in vehicles with an internal combustion engine, LPG is also called autogas.

Liquefied Petroleum Gas (LPG) should not be confused with Liquefied Natural Gas (LNG) or Compressed Natural Gas (CNG), both of which consist mainly of the natural gas methane \((\text{CH}_4)\). LNG is stored as a cryogenic liquid cooled at \(-161^\circ\text{C}\); CNG is kept under high pressure of at least 200 bar (Shell 2013).
LPG: ORIGIN AND MARKETS

A fundamental feature of liquefied petroleum gases is that they are not main products, but mostly occur as by-products or joint products in combination with other hydrocarbons (gases or liquids). They accure from crude oil and natural gas extraction and from processing of the crude oil into petroleum products in refineries. Worldwide, around 60% of LPG derive from crude oil and natural gas extraction and around 40% from refinery production. Whereas refining dominates in Western Europe, gas processing is the main source of LPG in North America and in the Middle East.

Gases occurring in crude oil extraction are also known as Associated Petroleum Gas (APG). In natural gas production, liquid hydrocarbon components are often extracted together with the natural gas. These components are known as Natural Gas Liquids (NGLs). Liquefied petroleum gases are obtainable both from APGs and NGLs. NGLs are increasingly important in global oil and gas supply. They currently represent 15% of global crude oil and 20% of global natural gas production (IEA 2010; IEA 2014b).

The other main source of LPG is crude oil processing. Using temperature and pressure, oil refineries convert crude oil into useful oil products. LPG is one of the lightest petroleum products (light distillate), boiling off at low temperatures. Its share in the range of oil products depends on the type of the refinery; on average LPG accounts for 2.5 to 3% of refinery output (FE 2014). In principle, LPG is also obtainable from biomass, though biogenic LPG has hitherto played no role on the market.

The largest producer of liquefied petroleum gases is by far the USA, at around 60 million tonnes per year. In the USA, substantial quantities of LPG are released in the extraction of unconventional natural gases. The USA are followed by the oil and gas producers of the Middle East (Saudi Arabia, United Arab Emirates), China and Russia. The largest consumers of LPG are the USA, China and Saudi Arabia, and other mainly Asian countries such as Japan, India, Thailand and South Korea (WLPGA/Argus 2014).

Nearly half the world’s supply of LPG is consumed by the domestic sector, in heating and cooking. Another major customer for liquefied petroleum gases is the petrochemical industry. By contrast, the transport sector accounts for only about one-tenth of world LPG consumption. Main centres for LPG applications to transport are Asia and Europe.

LPG STANDARDS & REGULATIONS

Liquefied petroleum gases do not occur in pure form, neither in oil and gas production nor in refineries. They generally contain other hydrocarbons, accompanying substances and also impurities. Therefore, as for other products, there are standards and technical rules which set requirements for LPG and how to handle it.

The International Standardisation Organisation (ISO) has developed two standards for LPG: ISO 8216 contains a classification of petroleum fuels including light distillates (Part 3), whereas ISO 9162 specifies required characteristics and additional information of commercial propane and commercial butane. ISO LPG standards are mainly meant for international trade and not specifically for product use. The American standard for Liquefied Petroleum Gases ASTM D1835 covers liquefied petroleum gases that are intended for use as domestic, commercial and industrial heating, and engine fuels (IEA/AMF 2008).

There are no global standards for gaseous fuels, only for liquid ones (WFCC 2013). However, there is a European LPG automotive fuel standard: ‘EN 589: Automotive fuels – LPG – Requirements and test methods’. For non-automotive applications, only national product standards have hitherto been valid. Moreover, when liquefied petroleum gases are used in public gas networks, certain quality requirements for combustible gases must be fulfilled.

Product standards directly determine the composition of liquefied petroleum gases. One way they do this is by prescribing maximum and minimum proportions of individual components, in particular respective shares of propane and butane as well as the shares of the alkenes propene \((\text{C}_3\text{H}_6)\) and butene \((\text{C}_4\text{H}_8)\).
The standards also specify certain characteristics such as density, vapour pressure or volatility. The aim is to assist trade in the product and facilitate the safe, technically reliable and environmentally friendly handling of LPG.

**NON-AUTOMOTIVE APPLICATIONS**

Liquefied petroleum gases are used in nearly all sectors of consumption, in almost all regions of the world, for a wide variety of applications. A distinction should be made between energy and non-energy (material) applications.

Apart from road transport, LPG is used as an energy source in cooking, domestic heating, hot water supply and heat generation for work processes. Flexibility of energy supply often plays a key role. As LPG is easy to store and carry, it can be deployed even at locations unconnected to public energy networks. LPG is therefore also known as a ‘mobile energy source’.

In industrialised countries, LPG plays only a subordinate role in heating and hot water for private households, while it is used for cooking primarily in the leisure sector. The situation is the opposite in many emerging and developing economies, where LPG offers an alternative to traditional biomass and open fireplaces. In these countries, LPG is widely viewed as a transition fuel pending a more sustainable energy future (IEA 2006; World Bank 2011; UN 2015).

For non-energy purposes, liquefied petroleum gases are used as coolants with low greenhouse and ozone depletion potential, in refrigerators and air conditioning systems.

Liquefied under pressure, propane and butane are also used as propellants in spray and aerosol cans.

Finally, as an alternative to or substitute for naphtha, ethane and others, LPG can be used as a feedstock in the production of intermediate petrochemicals, such as ethylene and propylene. Intermediate petrochemicals such as olefins and aromatic hydrocarbons are used to produce all kinds of plastic and other materials. Today (2013), petrochemical industry uses approximately 1.3 million barrels of LPG per day i.e. 60 million tonnes of LPG per year. As world demand for petrochemicals is growing, rising demand for LPG can be expected from the petrochemical industry (IEA 2013; IEA 2014b).

**LPG IN TRANSPORT**

After technical modifications, it is possible to use LPG (autogas) as a fuel and propellant in combustion drive systems (combustion engines and turbines). However, its suitability for use in individual means of transport varies. Though the application of LPG to rail transport and shipping is technically feasible, it has been used little (if at all) in practice. By far the most important application of LPG as a transport fuel are road transport vehicles with internal combustion engines.

There are estimated to be 16.7 million vehicles driven by LPG worldwide. Most LPG vehicles run in Europe and Asia. The main autogas fleets in the European region can be found in Turkey, Russia, Poland and Italy, while in Asia LPG vehicles are most numerous in South Korea, India and Thailand. In many of these countries, LPG cars are the most important alternative drivetrain, second to petrol and diesel cars, and ahead of e-mobility. In Turkey, the LPG consumption for road transport is even higher than the petrol consumption (IEA 2014a).

LPG vehicles are typically passenger cars. Apart from passenger cars, LPG is only used in significant volume in light commercial vehicles using powertrains similar to passenger cars. The LPG systems applied to passenger cars are all based on spark ignition engines. All LPG vehicles offered in Europe are technically bi-fuel capable, i.e. they normally run on LPG, but can also be fuelled with petrol from a smaller fuel tank. LPG systems for passenger cars, ex-works or as retrofits, are available in various technical configurations. So far, LPG systems have used LPG port injection in gaseous or sometimes liquid phase. More recently, LPG direct injection in liquid phase has entered the market; these systems use the existing petrol injectors also for LPG. Today’s LPG vehicles comply with the Euro 5 exhaust emission standard, and some even with Euro 6.

For heavy lorries, dual fuel systems based on diesel drivetrains have been developed. Dual fuel vehicles replace some of the diesel fuel with an air/LPG mixture. However, so far, they have been almost unknown in road haulage (trans aktuell 2013).

In emerging and developing economies, LPG vehicles are used for passenger and goods transport in the form of three-wheelers such as motor rickshaws and tuk-tukas (ICCT 2012). LPG is also of some importance as a

**GLOBAL DEMAND FOR PETROCHEMICAL FEEDSTOCK 2013**

The figures show that LPG is used for petrochemicals, primarily for olefins and aromatic hydrocarbons such as ethylene and propylene. This is also reflected in the share of LPG in the feedstock market.

LPG can be expected from the petrochemical industry (IEA 2013; IEA 2014b).

**LARGEST LPG FLEETS BY COUNTRY 2013**

The bar chart shows the distribution of LPG fleets by country, with the top ten countries listed:

- Turkey (TUR)
- Russia (RUS)
- Poland (PL)
- Korea (KOR)
- Indonesia (IND)
- Italy (IT)
- Thailand (THA)
- USA
- DE
- AUS
low-emission fuel for industrial lift trucks (forklift trucks).

In many European states, the LPG infrastructure is well developed, in particular in Central and Eastern Europe. A total of around 25,000 to 30,000 filling points exists in wider Europe.

In countries with larger LPG vehicle fleets, the number of LPG vehicles per LPG filling point ranges from about one hundred to several hundred vehicles per LPG filling point. However, there are some countries, where LPG filling stations are few and far between, e.g. in Scandinavia, Austria or Switzerland.

ENVIRONMENTAL BENEFITS OF AUTOGAS

For a long time, LPG was thought to have positive effects on the environmental impact of road traffic. To some extent, this view is still held. The environmental impacts of LPG fuelled passenger cars are largely determined by their energy consumption and emissions of greenhouse gases and air pollutants.

As engines for LPG vehicles are based on spark ignition engines, there is little difference in engine efficiency between LPG and petrol powertrains (DLR 2013; JEC 2014a).

However, there are some fuel-specific differences: The octane number of LPG is higher than for petrol, which can result in efficiency benefits at high engine loads. On the other hand, the additional LPG components (especially the LPG fuel tank) add weight to the vehicle which can lead to increased fuel consumption. Overall, the specific energy consumption of similar cars per kilometer (megajoule per km) is roughly the same. However, because LPG has a lower volumetric energy density, about 25% more LPG fuel is used, in litres per 100 km, than petrol.

Diesel vehicles are up to 20% more efficient than cars with spark-ignition engine. Only dual fuel lorries based on the diesel principle can approximate to the efficiency of a diesel lorry.

With regard to greenhouse gas emissions, a distinction must be made between direct emissions (Tank-to-Wheels) from fuel combustion, and upstream emissions from the production of the fuel (Well-to-Tank) (JEC 2014b; JEC 2014c).

In terms of direct greenhouse gas emissions, LPG generates about 10% less CO₂ per unit of energy (1 megajoule, MJ) than pure fossil petrol (E0) or diesel fuel (B0), due to its lower carbon content. Even when compared with petrol containing 10% bioethanol (E10) or diesel with 7% biodiesel (B7), fossil LPG shows lower direct greenhouse gas emissions per 1 megajoule (see graph above, biofuel advantage from biomass capturing CO₂ while growing allocated to direct greenhouse gas emissions).

A state of the art compact passenger car fuelled by petrol directly emits around 120 g CO₂/km vs. 105 g CO₂/km for an LPG vehicle, as shown in the figure on the next page. An LPG vehicle offers similar CO₂ advantages in relation to mileage as in relation to energy content, because petrol and LPG vehicles operate nearly equally efficient. However, LPG vehicles offer no greenhouse gas advantages over diesel cars, as the diesel engine is much more efficient and thus over-compensates the greenhouse gas advantage of the LPG fuel.

Around 15 to 20% of total or Well-to-Wheels greenhouse gas emissions originate from the Well-to-Tank part. As there is little difference in the Well-to-Tank emissions of LPG vs. fossil petrol and diesel fuel, LPG cars retain their advantage over petrol fuelled vehicles – 125 vs. 140 g CO₂/km. LPG vehicles emit even less
greenhouse gas per kilometre than a petrol vehicle operated with E10. In total, an LPG vehicle still emits slightly more greenhouse gas per km than a more efficient diesel vehicle (100 g CO₂/km).

With regard to local air quality, burning LPG (without exhaust cleaning technology) in principle generates fewer air pollutants than liquid fuels. In addition, stricter exhaust emission standards have been implemented. Exhaust gas cleaning systems for vehicles have become much more advanced and diesel and petrol fuels have been reformulated to burn cleaner.

Hence LPG vehicles in road transport offer hardly any advantages in terms of air pollutant emissions when compared to new state of the art petrol and diesel cars. Only the particulate emissions are significantly lower for LPG than for liquid fuels if no particulate trap is applied.

In summary, regarding energy and the environment, LPG vehicles offer two advantages: LPG vehicles may help to diversify the energy mix in road transport and LPG will reduce greenhouse gas emissions of road transport, if LPG vehicles replace petrol cars.

**OPERATING COST OF AUTOGAS VEHICLES**

An important criterion, though not the only one, for retrofitting a petrol car or buying a new car powered by LPG is an economic advantage over similar reference vehicles. The cost-effectiveness of LPG vehicles depends on the added costs of LPG engineering, on engine efficiency, fuel prices, and vehicle mileage (Wietschel et al. 2013, ADAC 2015).

A total cost of ownership analysis can help to calculate the economic advantage of a vehicle engine type. However, often a simplified ownership or operating cost comparison allows an approximation. It compares only the most important cost items. One is the one-off LPG retrofit cost, or the cost differential of a new LPG car vs. a reference vehicle. The other are running costs, consisting largely of fuel cost per kilometre.

At present, a new LPG compact car also requires an extra outlay of around 2,000 to 2,500 € compared to a similar petrol vehicle. A diesel car costs roughly the same as an LPG car. With fuel prices for LPG and petrol at 0.75 and 1.55 € per litre, the higher procurement costs of an LPG in comparison to a petrol car are again written off at a total of around 55,000 to 60,000 km driven.

Compared with a new diesel car, for a roughly similar procurement price and a diesel fuel price at 1.40 € per litre, LPG offers a slight energy cost advantage per kilometre. Despite the diesel engine’s greater efficiency, it is not competitive under these energy cost structures from the beginning.

The economic viability of LPG in road transport depends on the fuel price level and the...
relative fuel prices. With lower petrol and diesel prices, running an LPG vehicle becomes less attractive and vice versa. A further key factor for the economic attractiveness of LPG is the national energy tax on transport fuels; throughout Europe, there is a wide range of energy tax rates on road transport fuels. Often governments grant energy tax relief for LPG as a fuel. Mostly, some economic incentive such as an LPG tax rebate remains necessary to sustain a critical mass of LPG vehicles and LPG fuelling infrastructure (WLPGA 2014).

AUTOGAS SCENARIOS (FOR GERMANY)

After a sharp upturn in the past decade, the German LPG passenger car fleet has grown from approximately 20,000 units in 2005 to 500,000 vehicles today. With a share of 1.1% in the German passenger car fleet of more than 44 million, LPG vehicles are the most important alternative drivetrain to petrol and diesel cars. In fact, Germany owns one of Europe’s largest LPG fleets. However, the number of licensed LPG cars in Germany has recently recorded a slight decline. 95% of German LPG car registrations are private. Most are converted petrol vehicles. In the frequency distribution according to vehicle age, cars of ‘middle age’ predominate the LPG fleet. With an average age of just under ten years, the LPG vehicle fleet is therefore rather older than the fleet of cars as a whole (approximately nine years on average).

With a cohort model of passenger cars and scenario technique, future development paths for LPG vehicles in the German car fleet and possible repercussions on the sustainability of car transport in Germany, measured in terms of energy consumption and greenhouse gas emissions, can be explored. Based on the trend scenario for auto-mobility in Germany of the 26th Shell Passenger Car Study (Shell 2014), two mini-scenarios were considered up to 2030: a Pro LPG and a Contra LPG Scenario.

In the Pro LPG Scenario, supported by an LPG-favourable economic and fiscal environment, it is possible to double the stock of LPG cars to over a million vehicles by 2030, in particular through increasing the number of LPG vehicles entering the LPG fleet to more than 100,000 per year. By 2030, LPG would replace 40 petajoules or 1.3 billion litres of petrol equivalent of petrol and diesel. Annual Well-to-Wheels greenhouse gas emissions would be reduced by around 250,000 tonnes.

In the Contra LPG Scenario, the economic situation for LPG worsens significantly. This brings LPG retrofits and new registrations down to almost zero by 2020. As a result, the stock of LPG vehicles would be almost halved, to just 250,000 by 2030. Largely due to the high age of the vehicles and correspondingly lower LPG mileage, the savings of greenhouse gas from LPG vehicles compared with petrol and diesel cars would be reduced substantially.

Thus, LPG vehicles can contribute to the diversification of fuel supplies and to the reduction of greenhouse gas emissions of passenger car transport. Nevertheless, to achieve a substantial impact, the stock of LPG cars would have to grow considerably, even beyond the Pro LPG Scenario.
Liquefied petroleum gas (LPG) belongs to the family of hydrocarbons and consists mainly of the two gases propane and butane, which are easy to liquefy. Liquefied petroleum gases occur in crude oil and natural gas extraction and are produced in refineries during crude oil processing. LPG has versatile applications in all sectors of consumption and is used in nearly every area of daily life today.

LPG is used for non-energy or material purposes: as a propellant or coolant, or as a feedstock in the petrochemical industry. LPG often offers technical, ecological or economic advantages over alternative substances.

As an energy source, LPG has flexible applications and offers emission advantages over liquid and solid energy sources. In many emerging and developing economies, LPG is a transition fuel and serves as a transition fuel and a bridge to a more sustainable energy future.

In road transport, LPG cars are the most prevalent alternative type of drivetrain second only to petrol- and diesel-engined vehicles in many countries. Most of the LPG vehicles are retrofitted petrol vehicles. New LPG vehicles represent the latest state of the automotive art.

LPG can help to diversify the energy mix of road transport and reduce its greenhouse gas emissions. In leading LPG mobility markets, LPG cars offer an economic advantage over petrol-powered vehicles.

LITERATURE


