LPG for Heavy Duty Engines

Buses, Trucks, Marine
and
Other Applications

Innovation & Technology

The World LPG Association

The WLPGA was established in 1987 in Dublin, Ireland, under the initial name of The World LPG Forum.

It unites the broad interests of the vast worldwide LPG industry in one organisation, it was granted Category II Consultative Status with the United Nations Economic and Social Council in 1989.

The WLPGA exists to provide representation of LPG use through leadership of the industry worldwide.

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Some views in this report may not necessarily reflect the opinion of all contributors.

Key contributors:

George Nikolaou, Natco/AEGPL
Cameron Ure, Elgas
David Tyler, WLPGA
Makoto Arahata, Japan LPG Association
Rubens Basaglia, X-Tech
Luis Fernandez, Westport/Prins
Tucker Perkins, PERC
Warring Neilsen, Elgas

Nikos Xydas from WLPGA coordinated this project.

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Contents

Chapter One

Introduction

LPG or Autogas, when used as an engine fuel, has numerous advantages and a great, largely untapped potential for Heavy Duty Engines. The aim of this report is to **promote understanding amongst the LPG industry and beyond, of the technical possibilities, applications and market potential of LPG for HDE**. Ultimately this is to inform the LPG community of the numerous opportunities in the various related segments.

The report scope includes:

A scan of the market for **LPG HDE** primarily in Europe, US, Japan and other parts of the world (plus any highlights from the rest of the world).

- Some other engines that can easily be converted to run on LPG are also included.
- Identification of market characteristics and engine applications which are more promising for LPG in Heavy Duty Engines.
- Coverage of commercial and industrial sectors as well as emerging developments in transportation, construction, mining, agricultural, marine, power and other sectors.

This report contains:

- **A 'fact sheet'** for each LPG HDE technology giving an overview of the current technologies, the main players, and the market status.
- **A 'roadmap'** exploring the market outlook for each technology and identifying the drivers and barriers for future growth.
- **Recommendations** for association members on how to overcome the barriers and maximise the market opportunity.

Chapter Two

Executive Summary

LPG used as an engine fuel is the most commonly used and accepted alternative fuel in the world today. Global consumption of LPG as engine fuel, primarily Autogas, has been rising rapidly in recent years, reaching 26.7 million tonnes in 2016 – an increase of 5.5 million tonnes (Mt), or 25%, over the 2009 level. There are now more than 30 million vehicles in use around the world that use LPG, yet LPG as an engine fuel and even more so for HDE and vehicles is still concentrated in a small number of countries.

The transport sector is characterised by distinct rises in energy consumption both throughout Europe and globally. In addition to its dependency on limited fossil resources (e.g. mineral oil), the transport sector is further recognised as a key contributor to the anthropogenic greenhouse effect. On a global scale, transport is responsible for about 22% of greenhouse gas (GHG) emissions.

The world's increased production of natural gas ensures an LPG surplus ranging from 15 to 27 million tonnes per year, which is either used or it is "lost".

Environmental and health concerns, quality of air, pollution, emissions, become increasingly important and legislation adapts to reflect lower emission limits and even establish zero or near zero emission zones. This translates to a rapid need for better and cleaner engine technology to replace older polluting (mainly diesel) engines and it represents a very significant opportunity for those technologies and fuels that can offer this. Diesel emissions are a group one carcinogen to human (WHO July 2012). Autogas out-performs gasoline and, especially, diesel, as well as some other alternative fuels in the majority of studies comparing environmental performance that have been conducted around the world. Autogas emissions are especially low with respect to noxious pollutants. With respect to greenhouse-gas emissions, Autogas performs better than gasoline and, according to some studies, out-performs diesel, when emissions are measured on a full fuel-cycle basis and when the LPG is sourced mainly from natural gas processing plants.

There are various technologies available for the use of LPG as engine fuel. It can be used as single fuel in mono fuel engines, as single fuel in bi-fuel engines that can switch between gasoline and LPG, or as a mix together with diesel in dual fuel engines. In addition, it can be used in various forms of hybrid powertrain technologies. The choice depends on application, availability of technology for the specific application, as well as regulatory framework, costs and other regional factors.

On engine technology, the systems are driven by increase in efficiency, reductions in consumption and emissions and towards near zero emissions and alternative fuel configurations. In addition, renewable fuels are increasingly in the focus of decision makers. Downsizing of spark ignition engines has been a trend up to now but not sure it will continue. Sustainable and new engine systems will be focusing on future powertrain technologies for increased combustion efficiency, hybridisation and electrification. These are the key drivers also for LPG HDE's market development.

Spark ignition engine technology is fully compatible with LPG, and LPG used in light or even medium duty engines will be probably following the latest trends, including partly adoption of Liquid LPG Direct Injection (DI) as a way of improving engine efficiency. For the time span to 2020 it is most likely that the above-mentioned technologies will further evolve and will feature advanced, adaptive control of these flexible sub-systems, using new sensor technologies. It is not known however if and to what degree the above technologies will be used in HD engines. Dual fuel diesel-LPG technologies will follow the trends of the diesel engine, where/when this technology i.e. proven advantageous, with greater emphasis on emission control but a stronger market desire for efficiency in order to

reduce operating cost. The development of the regulations on dual fuel engines may allow growth of this relatively new LPG application sector.

At present, the range of available LPG engines, and applications that use these engines is relatively small and there are no clear signs of major improvement with the exception maybe of the US and some specific projects in Europe. At the same time, technologies on other alternative fuels and energy sources (mainly CNG, electrics, DME) are advancing and engines and applications that use them are gaining fast parts of the market.

LPG presents an alternative for simultaneous application with a special focus on means of transport that require an extended operating range or a demand for high performance output.

2.1. Key Messages - Fact Sheet

Globally, LPG is the most widely used alternative fuel for vehicles, and the WLPGA estimates there were more than 30 million LPG-fueled vehicles on the streets worldwide.

Advances in automotive technology and a growing supply have combined to make LPG an enticing option for fuelling bus and truck fleets and in other heavy duty applications.

- LPG as engine fuel is a green, clean burning alternative
- It is less expensive than gasoline or diesel in many countries
- It is available everywhere
- It is intrinsically safer than many other fuels
- It is reliable
- It is an alternative energy source that is ready now

There are five basic engine technologies available today related to the use of LPG as a fuel.

- Spark ignition (Otto cycle) engines dedicated (mono fuel) engines
- Spark ignition (Otto cycle) engines bi-fuel gasoline-LPG engines
- Diesel compression ignition diesel/LPG dual fuel engines (HDDF in HD engines)
- Turbine engines

These can also be combined with hybrid electric powertrain technologies. Spark ignition engines can be easily converted to run on LPG and this is the case also particularly with existing dedicated HD CNG engines.

Mono fuel dedicated engines have the advantage that they use only LPG and are equipped with only one type of fuel system and one fuel tank thus saving on costs, although a disadvantage might be the lack of flexibility of fuel option where the LPG refuelling network may not offer a complete coverage. Such systems had been developed largely in the past in Europe and used in public transport, buses, and are being developed also currently and used in the US.

Bi-fuel gasoline-LPG engines are less common in HD use and vehicles, but largely used in light duty and medium duty vehicles.

Compression ignition dual fuel diesel/LPG engines could be suited to HD applications, but the technology is still relatively under development and remains to be proven for which particular applications this technology is best suited, in order to assess its future potential. Any running cost savings depend on relative price diesel/LPG and the proportion of LPG used in the mix. Improvements vs diesel only mode of operation could also be seen in emissions performance of these engines, depending on application. Regulatory framework is largely still under development (only a few only national or regional examples exist).

Turbines are excellent for some applications as is power generation, although these turbines are relatively expensive and they still face difficult times to be more generally adopted.

Hybrid are latest and future powertrain technologies. The combination of LPG with electric motor propulsion in hybrid configurations is very promising for various types of applications and vehicles, even trains and boats. The advantages of combined electric - battery propulsion especially suited in low emission zones with the excellent emissions performance of LPG in range extender engines, can offer spectacular results.

Regarding fuel injection systems, the major trend in light duty engines and vehicles is the shift from port injection (PI) to direct injection (DI) in the combustion chamber, offering significant advantages in terms of performance, lower consumption and lower emissions, with the exception of particles. LPG however, can offer even better performance

than gasoline in this respect, with lower carbon emissions, yet negligible particle emissions. This presents LPG industry with a great opportunity in a world changing rapidly towards DI. However, DI technology is not extensively used at the moment in HD and industrial gas engines and applications.

At present, the range of available LPG engines for HD applications is relatively very small, LPG engines available are only a few and engines developed in the US cannot be used as such in Europe and vice versa. Some LPG HD engines of OEMs have also been taken out of their catalogue as not being able to meet anymore the stricter emissions requirements.

In terms of potential applications that can use LPG HD engines, the list is vast ranging from buses and trucks of all kinds, to construction and mining equipment and vehicles, agricultural uses as irrigation engines and farming tractors, a variety of machinery and vehicles for sea port and airport facilities, marine applications and even possibly trains and also static uses such as power generation, or air-conditioning.

The main players in the HD Engines segment consist of engine only manufacturers, technology developers, as well as manufacturers of equipment, machinery and vehicles that use these engines.

The global dual fuel engine market is moderately fragmented, with clear dominance of the large international players. The market is highly capital-intensive therefore it poses a stiff challenge to the local players. Small players find it quite difficult to compete with the international vendors in terms of quality, features, functionalities, and services. With the introduction of products with new features and technologies, the competition will intensify.

Several players exist in developed countries; some have grown to regional giants in their market. Others are appearing in emerging markets that have the potential to outgrow their current positions as regional giants or niche players. The current group of regional giants may shrink to include just a few Chinese and Indian OEMs. Consolidation among global groups is also taking place.

The number of OEM quality platforms for HD fleet applications is growing with partners in the US such as **Roush CleanTech, CleanFuel USA, Freightliner Custom Chassis, Blue Bird, Collins Bus, Thomas Built Bus, Alliance Autogas, ICOM North America, Isuzu** and others.

The role of various stakeholders is instrumental in driving growth of LPG in the Heavy-Duty Engines sector.
All principal stakeholders from Policy makers, regulators, governments, LPG distribution companies, engine manufacturers, OEMs, independent system developers, vehicle manufactures, national and international industry associations to emissions experts need to be addressed with coordinated actions.

Decarbonisation, reliability and safety are the drivers for HDE's market development.

Regulations are also changing rapidly to meet the environmental challenges, therefore, technology development must keep up which requires further investments. This is true for all sectors, in which there is a potential of applications of LPG engines, including land and sea transport.

- Difficult regulatory challenges must be addressed to enhance market opportunities.
- HDV efficiency standards have been adopted in a few of the largest vehicle markets, but important markets remain unregulated.
- Environmental demands in emerging markets are tightening.

Certification regulations in force. UN level regulations for OEM and retrofit technologies provide a mandate or model for National certification and will significantly enhance availability of high quality dual-fuel systems

The IMO recent emissions limits imposed on fuels used in the shipping industry and particularly ECAs (Emission

Control Areas), force the industry to look at alternative fuels as a way of complying with the new limits.

Other initiatives include Low Emissions Zones (LEZ), Clean Cities are effective and increasingly popular measures.

Complying with environmental standards and requirements will entail however costly technologies, for which fleet and other operators may be unwilling to pay the price.

The significant price advantage and abundant supplies of LPG reinforce the notion that LPG HD engines can play an important role as a major part of a clean fuel portfolio for the years to come towards reductions of GHGs, NOx and PM emissions and near zero emissions objectives in particular combined with hybrid technologies.

Safety represents a top priority for any professional Heavy Duty LPG application. HD engines and applications are often related to uses where safety incidents would have severe consequences. Highest level of Safety level should be integrated at the design stage of any HD LPG application as well as during its use and operation.

Currently, the market for HDEs is highly variable depending on the application and the region. Heavy Duty Engines market in general is mature and relatively well established in USA. It is developing slowly elsewhere, most notably in Asia.

The number of OEM quality platforms for heavy duty fleet applications is growing in the US for companies looking to save money on fuel costs as well as make their operations more sustainable.

LPG refuelling infrastructure offers the most economical solution compared to all fuels, making the case even stronger for continued growth in this market space.

2.2. Key Messages - Roadmap

The market for overall HDE is estimated to grow 15% by 2025, and LPG can take a variable share in different regions (1-4%).

Heavy Duty engines will remain strongest in Asia, North America and emerge slowly in other markets. Heavy Duty engine technologies will dominate at smaller scales and in Europe.

There are inherent market characteristics, which support the LPG HDEs opportunities.

- The regulatory drive towards stricter emissions standards in force around the world.
- Replacement of old buses/fleets with new ones to comply with new regulations create market opportunities.
- Attractive LPG price.
- Governments incentives for switching to alternative fuels.
- Business and industrial market growth.
- Adequate availability of refuelling infrastructure.
- Sufficient supply of affordable LPG over the forecast horizon.
- Increasing awareness of the advantages of new technologies.

LPG as fuel for Heavy Duty Vehicles faces several strong barriers which need to overcome.

- Upfront investment cost is the greatest challenge.
- Customer economics: Overall costs for fleet operators are often favourable but challenging.
- Positioning LPG to policy makers and decision makers: need to be on a level playing field with competing technologies.
- Difficult regulatory challenges must be addressed to enhance market opportunities.
- Technology development: Slow rate will limit or stop growth.
- Commercialisation and getting products to market: Trained installers, distribution/servicing/maintenance networks are required.
- Other barriers such as filling connectors, fuel quality and aftermarket conversion quality have also hindered growth and therefore should be addressed adequately.

2.3. Key Messages – Recommendations

The future of HD Engines to ensure sustainability and global acceptance, requires the development of systems that reduce the dependence on oil and minimise the emission of greenhouse gases. **All market key players, who are need to work together in a coordinated way to overcome the barriers and create opportunities in the LPG HDE sector.** Recommendations have been compiled with the ultimate intention of changing present trend, which is not in its favour and improving the future prospects.

Overcoming the economic challenge of upfront investment and running cost of HDEs is important. Various ways to overcome this barrier could include governmental incentives, subsidisation, financial support, competitive price by LPG companies, technology development which results in more efficient and reliable engines or fuel running savings.

Policy/regulatory framework is key, therefore, it needs to be ensured that LPG fuelled engines in all their configurations static or mobile are included in regulatory framework and incentive schemes. Global standards and certification regulations for OEMs and retrofit technologies should be developed to ensure safe and reliable LPG fuelled engines and in compliance with emissions requirements.

Accelerate technology development of new engines in R&D, conducting market studies of market sectors and applications. As major manufacturers are hesitant in developing LPG versions of their engines, an intelligent grouping of applications and their potential per engine type is recommended in order to achieve better prioritisation and focus as a large verity of applications use the same type of engine.

Filling connectors need to be standardised. Filling connectors especially in Heavy Duty applications must be able to provide robust, reliable and safe filling with fast filling speeds to suit large tank capacities required in HD applications and vehicles.

Fuel quality needs to be further harmonised and improved, particularly in some countries, in order to meet closer, the requirements of modern engine applications, serve as basis for global engine and technologies development and ensure reliable and consistent engine performance. Technological advances should help provide higher quality of product and adequate controls to maintain it.

Aftermarket conversion quality needs to be further improved to offer consistent and high-quality conversions well adapted to the specific engine applications. Besides, **warranty and customer care** needs to be provided by training and certification of the technical personnel, to provide reliable and sustainable service and solutions. There is a need for a well-developed, effective trained, and extensive distribution network worldwide based on successful and strong cooperation.

Facilitate commercialisation and get engines to market could be achieved by developing training support and developing distribution partnerships in new regions.

An extensive refuelling infrastructure has to be developed. The situation is sometimes described as a “chicken-and-egg” dilemma. Until the extensive infrastructure is in place, fleet owners may not commit to LPG fuelled vehicles and vice-versa.

Lobbying to positioning LPG to policymakers and decision makers is crucial. Regulations and international standards need to be issued to support emissions requirements and legal compliance.

Raise LPG awareness for decision makers. This communication could be done through participation in market specific conferences or new project developments for different applications.

Chapter Three

Fact Sheet

This Fact Sheet provides an overview of the product, the major LPG engine technologies and their major applications in global regions and various market segments. It provides a snapshot of the main players on the global market and details on the most important ones.

3.1. The Product – LPG as Engine Fuel

LPG is produced either from natural gas processing – mainly – or from oil refining. At present, more than 60% of global LPG supply comes from natural gas processing plants, but the share varies markedly among regions and countries. It is not only available and abundant in supply, but it is also economical and environmentally sound.

LPG is a viable alternative gaseous fuel. It consists predominantly of propane and butane (normal butane and iso-butane), propylene and other light hydrocarbons and its chemical composition can vary. In some countries, the mix varies also according to the season. LPG can be liquefied at low pressures at atmospheric temperature hence its storage and transportation is easier than of other gaseous fuels. It is stored under pressure in tanks or cylinders.

Its characteristics have made it a popular fuel for domestic heating and cooking, commercial, agricultural and industrial uses, including as a feedstock in the petrochemical industry, and increasingly so as an alternative and very attractive fuel for engines. Of all LPG uses, its use as an engine fuel is one of its largest and fastest growing globally. Its low emissions and virtually zero particulate emissions have an immediate positive impact on local air quality.

It has high energy density compared with most other oil products and other alternative fuels and burns cleaner in the presence of air. It has high calorific value compared to other gaseous fuels and also high octane number (but a low cetane number). Its high-octane number makes it suitable for spark ignition engines (SI), while its low cetane number makes it less favourable for use in large proportions in compression ignition engines (CI) – diesel engines. When used as an automotive transport fuel it is most commonly called Autogas and there are millions of vehicle engines worldwide fuelled by LPG

Benefits:

- Available in large quantities everywhere in the world and in production surplus.
- Cheaper than gasoline and diesel in most cases making it the most affordable alternative fuel.
- Offers the longest running range of any alternative fuel option. Due to a higher octane rating and efficient combustion, LPG engines can use higher compression ratios resulting in higher power and better fuel efficiency.
- With modern systems, the horsepower and torque of LPG is greater than or equal to its gasoline equivalent.
- LPG is stored at lower pressures than i.e. CNG making storage tanks lighter and more economical.
- LPG tanks are 20 times more puncture resistant than gasoline or diesel tanks.

The reduction in maintenance costs, increase of engine life and that pilferage is much more difficult are some of the reasons for LPG's popularity with professional users like bus fleets, utility vehicles, forklifts and others. Since LPG is a low-carbon, clean-burning fuel, a switch to LPG has significant potential in emissions reduction of hydrocarbons, CO, CO2, also NOx, GHGs and PM in general. In addition, LPG is nontoxic, so it is not harmful to soil or water when spilled or leaked. With respect to greenhouse-gas emissions, LPG performs better than gasoline and, according to some studies, out-performs diesel, when emissions are measured on a full fuel-cycle basis and when the LPG is sourced mainly from natural gas processing plants. In most cases, an existing engine running on a conventional fuel is converted to run on LPG by installing a separate fuel system that allows the engine to switch between both fuels. This equipment can be installed at the time the engine is manufactured (in which case, the engine is known as an OEM).

3.2. Engine Technologies

There are various categories of engines and HDE related to the use of LPG as a fuel. These engines find their use in both static and also mobile/transport applications and could be categorised as below:

- Spark ignition (Otto cycle) dedicated, mono LPG fuelled engines
- Spark ignition (Otto cycle) gasoline/LPG bi-fuel engines
- Compression Ignition Diesel/LPG dual-fuel engines (LPG/HDDE)
- Turbine engines (mainly turbogenerators)

Engines of interest in this study include also those that can be easily converted to run on LPG such as:

- Dedicated CNG fuelled Heavy Duty engines, relatively easily convertible to dedicated LPG fuelled engines
- Hybrid technology powertrain configurations, as dual Heavy Duty Hybrid engines with LPG.
- Range extender power units for electric vehicles using HDLPG or LPG/HDPE engines.

In most cases, an existing engine running on a conventional fuel can be converted to run fully or partially on LPG. This is particularly true and easier with gasoline engines. In this context, LPG engines follow largely the trends of gasoline engines or dedicated CNG engines.

In diesel engines and HD diesel engines, LPG can be used in either a mixed diesel-LPG fuel configuration by adding an LPG fuelling system or as single fuel LPG through a modification of the cylinder heads. A HD diesel engine that combusts both diesel and LPG together in the cylinder is referred to as Heavy Duty Dual-Fuel engine (HDDF).

A major trend in light duty gasoline engines is their shift from port injection (PI) to direct injection (DI). Whereas in 2005 nearly the majority of new European gasoline engines were (PI), many of today's light duty new gasoline engines are (DI). Forecasts from car manufacturers (OEMs) and suppliers suggest that DI's market share will continue to rise. DI is a significant change for gasoline engines, offering possibly better consumption and some emissions. However, these engines generate much higher particle mass (PM) and particle numbers (PN), in excess of Euro 6 emission regulations. In this context, LPG can outperform gasoline in (DI). Improvements in fuel consumption and carbon emissions are greater than those for gasoline, yet particle emissions are negligible. This presents LPG with a great opportunity. However, again, DI technology currently is not applicable to HD engines.

In the case of Diesel-LPG dual fuel engine, the diesel engine itself is little modified, the diesel combustion principle is maintained, but a second fuel system for LPG is mounted on the engine. The LPG burns like a conventional diesel engine burns diesel fuel (HDDF, Diesel-LPG Dual Fuel). To prevent two phase flow of LPG, we need to control well the pressure of LPG. A variation of this system that uses only a small pilot injection of diesel fuel to ignite LPG in the cylinder is known as wet spark ignition system.

Turbine engines can also easily be powered by LPG. If the fuel used has changed to one that has a lower calorific value, as it is in case of replacement of kerosene by LPG, the fuel flow rate could easily be increased in order to supply engine with comparable energy. The LPG is two times cheaper than aviation kerosene and could be used in stationary power units.

Hybrid engine technologies are also a major opportunity for LPG. Hybrids use two different energy sources, typically referred to for vehicles as hybrid electric vehicles (HEVs). These combine a conventional internal combustion engine with an electric motor. The batteries or supercapacitors, which the electric motor uses, are continually recharged by the engine or from energy generated during braking.

A final, and extremely promising, is the solution of LPG range extender power units for electric vehicles that can combine a dedicated LPG engine with a generator to maintain the charge of the batteries on board of an electric vehicle.

3.2.1. Spark Ignition (Otto cycle) dedicated (Mono) LPG Fuelled Engines

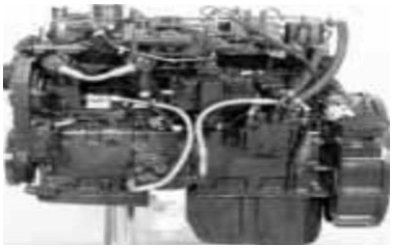
Spark ignition dedicated mono LPG fuelled engines operate much like gasoline engines. The primary advantage of these engine is that they use 100% LPG as fuel. Without additional gasoline or diesel systems on board, vehicles and applications that use such engines carry only one type of fuel and there is no need for a second fuel delivery system.

Such engines had been developed earlier in Europe, the US and elsewhere and had found their use mostly in the sector of public transport in countries like Denmark, Austria, Italy, France etc. However, development did not continue at the same pace of other type of engines like diesel, gasoline or CNG/LNG power units, due to the many and serious unresolved problems occurred over time. An exception to this is the US where such engines continue to be developed and are becoming increasingly popular in many applications.

Engine examples

Ford V10 6.8L

Cummins Heavy-Duty LPG Engine B5.9 LPG



PSI 8.8L or 8.0L

Cummins ISB6.7 G

Case studies

LPG busses in Vienna

In 2005, in cooperation with the Wiener Linien in Vienna, MAN developed, an environmentally friendly engine, model number G 2876 DUH02, following which Wiener Linien started to establish LPG as an alternative-fuel for their buses.

The emissions of the engine were almost 50% below the EU-5 standard, in force since 2008. It was possible to decrease the fuel consumption and CO2 emissions by 14% compared to the previously used engine (G 2866 DUH05). In 2007 the development of a further stage of the LPG engine was completed. Due to a different fuel injection, the noise of the engine was even lower and the fuel consumption was reduced further.

Engines:

- MAN NL 273 LPG / Type MAN NG 273 LPG.
- MAN G2876 DUH01, MAN G2876 DUH02 6 cylinder four-stroke.

These were initially used in 20 articulated buses, 44 2-door solo-buses and 37 3-door solo-buses and were followed later by 148 articulated buses, 16 2-door solo-buses and 58 3-door solo-buses by 2012.

The emissions of a number of pollutants were lowered, including NOx with three-way catalytic converters. The new engines went below the EEV Norm (Environmental Enhanced Vehicle) on CO, NMHC and NOx, only on CO2 the emissions with the LPG engines were higher than diesel.

However, the eventual overall experience of this project did not, for various reasons, lead to the degree of success that would allow the renewal and even increase of this fleet with further LPG fuelled buses and today this fleet is being replaced by alternative technologies.

Icom North America has secured California Air Resource Board certification of its dedicated liquid LPG autogas fuel system for the Ford 6.8-liter Ford V-10 engine for E-450 vehicles.

Owners and operators of shuttle vehicles and buses in California that utilize the Ford E450 V-10 engine will be able to significantly reduce operating costs and dramatically improve their emissions profile by converting to LPG using Icom's system.

In addition to the recent CARB approval, ICOM holds U.S. EPA certifications on over 1200 vehicle platforms. Customers include UPS, Yale University, Super Shuttle, Ace Parking, Metro Cars, the U.S. National Park Service, and the cities of Boston and Springfield, Ill.

3.2.2. Spark Ignition (Otto cycle) Gasoline-LPG Bi-Fuelled Engines

Bi-Fuel gasoline-LPG engines exist in the market either as OEM engines or as conversions from existing gasoline models. Most LPG conversions today especially in light duty engines, involve gasoline fuelled spark- ignition engines, which are particularly well suited to run on LPG.

Each car maker uses a different strategy regarding when to use port, direct, or both injectors. Combining the benefits of both injection technologies you obtain an improved balance between power, emissions, mileage and durability.

In order to have these engines run on LPG/Autogas and maintain the benefits of this technology next-gen alternative fuel system is required.

Examples

Prins Dual Injection Technology

- Innovative bi-fuel LPG solution for car engines with both MPI/PFI and DI/GDI fuel injection.
- Combining the state of the art Prins components with Keihin injectors in order to create the best LPG system for this combination of injection technologies.
- Introducing the Prins eVP-500 electronic variable pressure reducer able to deal with dynamic technologies like dual injection.

Case study

Prins VSI-2 Bi-Fuel Kits for Sky Harbor Parking Shuttles

Blue Star Gas is helping Pre-Flight Parking convert its fleet of 14 shuttle buses to LPG operation at Sky Harbour International in Phoenix.

Blue Star Gas converted three Ford E-450 shuttle buses operated by Pre-Flight Airport Parking to LPG -gasoline bi-fuel operation at Sky Harbour International Airport in Phoenix.The goal is to eventually convert all 14 shuttles used at Sky Harbor International Airport.

3.2.3. Compression Ignition Diesel-LPG Dual Fuel Engines

A dual fuel engine is a type of engine that can operate on both liquid, such as diesel, and gaseous fuels such as LPG. In case, the supply of gas is hampered, the engine can run on diesel fuel alone. These are engines that use a mix of diesel and LPG as a fuel and are mostly modified diesel engines to accept a certain proportion of LPG in the fuel mix typically of the order of 30% to 55%.

Dual-fuel technology enables Heavy Duty Engines to combust diesel and LPG simultaneously, saves 20%+ on fuel costs and reduces some emissions by up to 90%.

Diesel engine fuelling with LPG represents a good solution to reduce the pollutant emissions and to improve its energetic performances. The high auto ignition endurance of LPG requires specialised fuelling methods.

From all possible LPG fuelling methods, the diesel-gas method is the most common solution for retrofitting existing diesel engines because of the following reasons:

- It is easy to be implemented even at already in use engines
- The engine does not need important modifications
- The LPG-air mixture has a high homogeneity with favourable influences over the combustion efficiency and over the level of the pollutant emissions, especially on the nitrogen oxides emissions.

The theoretical and experimental investigations on operation of a LPG fuelled heavy duty diesel engine at two operating regimens, 40% and 55%. For 55% engine load is also presented the exhaust gas recirculation influence on the pollutant emission level. It was determined the influence of the diesel fuel with LPG substitution ratio on the combustion parameters (rate of heat released, combustion duration, maximum pressure, maximum pressure rise rate), on the energetic parameters (indicate mean effective pressure, effective efficiency, energetic specific fuel consumption) and on the pollutant emissions level. Therefore, with increasing substitute ratio of the diesel fuel with LPG are obtained the following results:

- The increase of the engine efficiency
- The decrease of the specific energetic consumption
- The increase of the maximum pressure and of the maximum pressure rise rate (considered as criteria to establish the optimum substitute ratio)
- The accentuated reduction of the nitrogen oxides emissions level.

These diesel engines are converted to dual fuel - diesel blend – through specific systems, kits that allow replacing of a certain quantity of diesel by LPG. Such systems can be installed besides the original engine management system, and in principle they can be used with all diesel engines (as from Euro 3).

These alternative fuel systems communicate with the ECU via CAN-bus to ensure fully computer-controlled injection of the correct amount of LPG, depending on the specific characteristics of the diesel engine.

Making use of parameters such as engine speed, turbo pressure, amount of diesel injected, position of the accelerator pedal, engine torque and coolant temperature, the systems determine the optimum balance between diesel and LPG.

The key components of these alternative fuel systems are specially designed for the specific engines and their installation is relatively easy. Their dedicated diagnostic software enables fine tuning the diesel blend system for

optimal performance and emission reduction.

Dual fuel diesel-LPG operation has certain advantages compared to diesel only and spark ignition (SI) engines, higher thermal efficiency resulting from faster burning, less toxic emissions, high fuel power density. Harmful emissions due to diesel and greenhouse gases can significantly be reduced (10-15%). However, this is very dependent on the application and use offering highest advantages at constant loads.

Such conversions can present however also technical problems particularly with availability of specific fuel supply system, fuel injection control and engine optimisation to ensure that the engine performance is maintained and the exhaust emissions are indeed minimised.

Sustainable future of this technology can be best achieved with OEM solutions, since modern diesel engines Euro 5 and more recent, have very complex and sophisticated electronic controls that any changes in the operation of the engine may cause "ECU recovery" of the vehicle. Furthermore, many recent regulations do not allow changes to engine components without new approval, resulting to expensive, complex and long procedures, same as the homologation of a new engine.

Diesel-LPG dual fuel engines have a good thermal efficiency at high output but the performance is less during part load conditions, although this problem can be mitigated with various techniques.

Some examples of Dual Fuel engines that recently developed.

- MAN D20 in LPG in the UK with Containerships (UK) Ltd and other leading customers. Euro 6 models have been available since June 2016 and will be fully Euro 6 compliant for emissions in 2017.
- Mercedes Axor in LNG and LPG also. Euro 6 models have been available since June 2016 and will be fully Euro 6 compliant for emissions in 2017.
- Cummins QSK 19 for off-road use in rail, marine and power generation (USA)p
- CAT C.18 for off-road use in rail, marine and power generation; n DAF Euro 5 has been tested in the UK; and
- Isuzu and Hyundai duel fuel engines are in development.

Example Prototype Bus

REPSOL engineering department has partnered with Polytechnic University of Valencia (CMT) and TRANSDIESEL in order to develop an environmentally friendly Euro-6, fully Autogas-Powered Urban Bus solution.

The project was funded by private investors as well as the Centre for Industrial and Technological Development from Spain (CDTI). The initiative also includes Spanish engine manufacturer Begas and Chinese company King Long, and is working on building a prototype of this vehicle, built for the Valladolid City Council. Valladolid has urban transportation vehicles powered with LPG, but plans to update its fleet. The engine is being developed in Spain and will have an innovative gas injection system that will improve efficiency.

Due to their low emissions, Autogas vehicles carry the ECO label under the classification of the Spanish General-Directorate of Traffic (DGT), which is the reference for traffic regulations established in different cities. The Madrid City Council, for example, exempts all Autogas vehicles from traffic restrictions when high-pollution measures are activated.

It is expected to have a production price similar to a diesel-powered bus, and thus meet the demand for heavy-duty LPG engines, which can be a competitive alternative for urban transport.

Key points

- Bus platform representative profile suitable for medium and large cities in the European Market.
- 100% Autogas Euro VI emission levels were achieved or improved, especially low PM, HC and NOx emissions
- Full OBDII HD compliance was attained.
- Spark ignited
- Variable Valve Timing (VVT)
- Multi-Port Liquid LPG Injection
- 8 cylinders
- 7.4L supercharged
- Coil on Plug Ignition.
- Rated Power: 360 kw at 4500 rpm
- Engine Torque comparable to that of a diesel engine. Rated torque: 778 NM at 3687 rpm
- Engine validation and final testing are currently being done in two fronts;
  Engine test bench at the Centre for Thermal Engines of the CMT in Valencia for Engine Certification
  A representative Mule of a City Bus being tested in Madrid and Valladolid area.

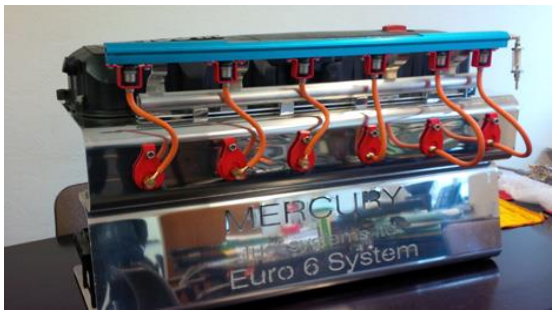
Case Studies

Heavy-Duty Diesel-LPG - Master Truck 2013

The Volvo VNL as presented in the 9th International Tuned Truck Show "Master Truck" took place in Poland at the end of July 2013. It is semi-trailer truck with a protruding bonnet, typical of American trucks. The six-cylinder 12-litre engine is fitted with the Oscar N-Diesel installation by Europegas. A 180-litre LPG container dedicated to trucks, painted bright orange to match the colour of the chassis, was mounted to the frame.

Innovative LPG/Diesel system, a success for Heavy Duty fleets in the U.K.

The first multipoint and fully sequential LPG/diesel fuel system ever designed is now being manufactured in the United Kingdom. The technology, called Quicksilver AFI, offers a dual fuel solution for trucks using an LPG/diesel blend, and helps to cut fuel costs as well as carbon emissions.



Designed specifically for the HD (HGV) transport sector, the system manufactured by Mercury Fuel Systems Ltd. blends both fuels in precise quantities optimising emissions and economy. It introduces a parallel set of injectors alongside the diesel ones and an ECU (engine control unit) to control the blending of diesel and LPG into the cylinder. A secondary LPG storage tank is fitted to the vehicle to maintain the correct daily working range for the vehicle. With savings on fuel costs of between 10-15% the system claims a payback of around 18 months.

Driving improvements with LPG

LPG distributor Calor UK Ltd has converted part of its own HGV fleet to this system – from August 2014 to August 2015, and in doing so has saved on average over £5,000 per vehicle/yr. At a time when there are large amounts of

evidence suggesting that more needs to be done to improve air quality, this technology is a real opportunity for HGV to contribute towards this drive for cleaner air.

Recent independent test work carried out by Millbrook and Horiba Mira attests carbon emission savings of 5 tonnes per 100,000 kms travelled and a 15% fuel cost reduction. This would result in a total of 37.5 tonnes of carbon saved over a typical five-year operation. These tests have resulted in the production of a certification scheme for aftermarket low carbon technologies, which will support UK Government policy and the achievement of CO2, air quality and energy security targets.

Recently the Freight Transport Association claimed cities across the UK could impose charges for the operation of polluting vehicles in congested areas in a bid to tackle air quality, particularly affecting diesel-fuelled HGVs. There is no escaping the fact that HGV companies are facing increasing pressure to cut carbon emissions.

While switching fuel may seem complex, Calor works with OEMs and retrofitting companies to take care of the project, from initial specification, to trials and operational delivery. Where relevant, Calor will ensure storage and dispensing facilities are installed professionally, helping to minimise disruption to daily haulage operations.

Upgrading to dual fuel technology older vehicles can be retrofitted to take advantage of dual fuel technology, achieved through a simple conversion to an existing diesel engine. This allows the engine to burn a mixture of LPG and diesel in the combustion chambers. By displacing a proportion of the diesel fuel with LPG, a vehicle will reduce both its fuel costs and carbon emissions.

Noble Foods

As part of its logistics, Noble Foods operates more than 200 vehicles from seven sites across the UK, with the fleet travelling over 11 million kilometres a year and consuming three million litres of fuel. In a move to improve efficiency and reduce cost, the company has upgraded to dual fuel technology.

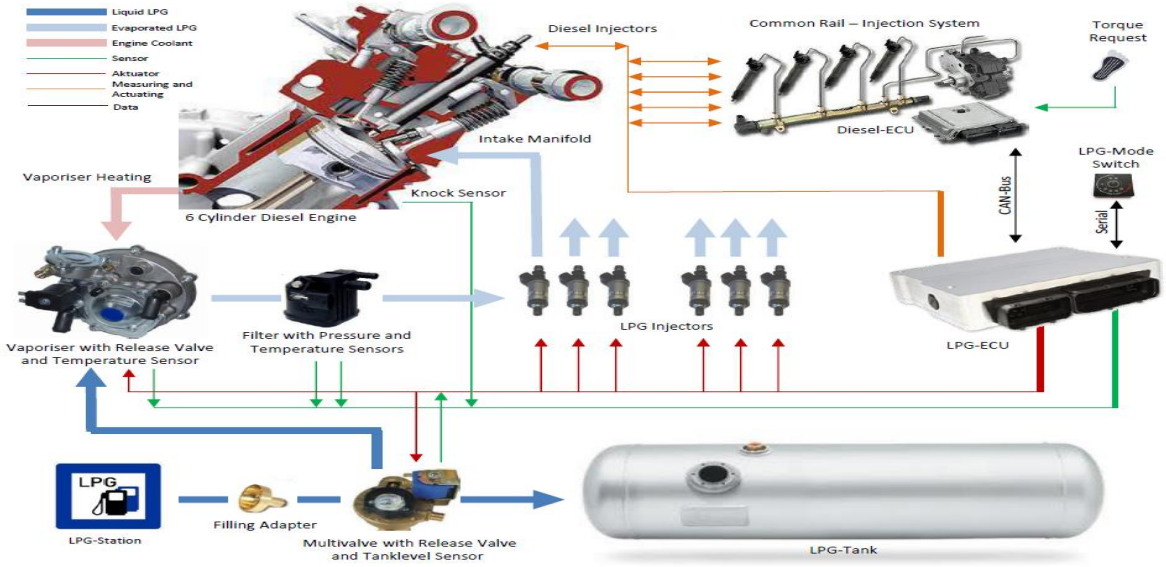
Michael Tucker, Transport Manager at Noble Foods, said: “Since changing to LPG duel fuel, we have reduced our annual fuel bill by 14 per cent. Dual fuel systems have given us the best of both worlds, lower fuel bills and lower CO2 outputs.”

Turkey: Heavy Duty Dual – Fuel Technology introduced in the second biggest Autogas Vehicle market

Market leader Aygaz has converted 13 HD trucks and tested on road of one million km. Road tests proved that there are no mechanical problems after visual inspection of combustion chamber at 100k intervals.

Key advantages:

- 6% decrease in CO2 and 35% decrease in PM emissions
- Up to 10% fuel cost reduction
- Similar performance and drivability compared to diesel
- Easy installation, no mechanical revisions needed
- Easy to switch between diesel – LPG and diesel –only modes
- Compatible with regulations.

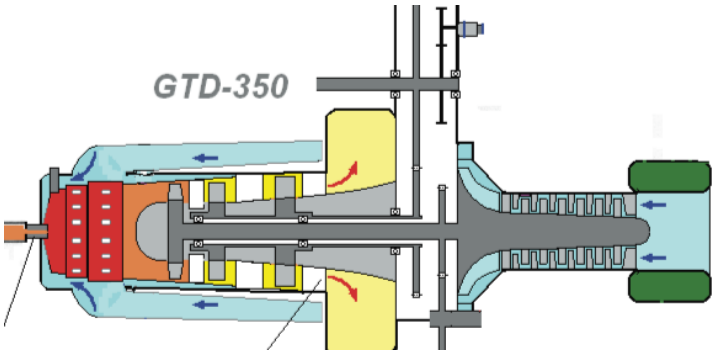


Key challenges:

- Unable to convert new vehicles in warranty period
- Perception of LPG in vehicles owners and drivers that LPG means less power
- LPG decreases second hand value of the vehicle
- OEM support

3.2.4. Turbine Engines - Turbogenerators

These engines are used mostly in stationary power generating units in turbogenerator applications, although they have also been seen in range extender generator units, in electric HD transport vehicles, buses.



Gas turbine engines – in comparison with reciprocating engines – have some advantages that favour their use amongst others in stand-alone power units.

Such advantages, especially in comparison with diesel engines, include:

- Better use at low temperatures due to the rapid start-up possibilities
- Significantly lower heat transfer through the engine oil and lack of liquid cooling system, which significantly reduces the number of vulnerable assemblies and essentially lowers power losses through the cooling system
- Significantly less maintenance and repairs
- Reduced amount of oils and lubricants required to operation
- Mild torque characteristic, without pulsation typical for reciprocating engines
- Significantly lower weight and size compared to reciprocating engine

However, some features of gas turbine engines, mainly higher specific fuel consumption and higher costs have been restricting their wider use. Major companies have been involved in modification of such engines and their application in hybrid electric power systems, some also for transport.

3.2.5. Hybrid systems – LPG Range Extender Engines for Electric Vehicles

Hybrid systems make part of the latest developments in engine and vehicle technologies. A hybrid system or vehicle is one, which uses two different energy sources, typically referred to as hybrid electric vehicles (HEVs), which combine a conventional internal combustion engine, a generator, an electric storage unit, and an electric motor. In a hybrid system, there is an electric storage element in the system.

Hybrid LPG can be the new benchmark in fuel economy and environmental performance and hybrid LPG conversion possibilities are technologically already available now.

The batteries or supercapacitors which the electric motor uses are recharged by the engine or from energy generated during braking – energy that would otherwise be wasted as heat. Although standard diesel is the most common fuel used to power the conventional internal combustion engine, gasoline, ethanol and CNG hybrids have also been developed. Plug-in hybrid electric vehicles (PHEVs) are also being developed in which the electric batteries can be charged by being plugged in to the electricity grid. These are often fitted with a larger battery which allows them to travel further in electric only mode.

However, using the best automotive technology – electric hybrid drive – and combining it with the cleanest and most economical commercial fuel – LPG engine technology – can give results that can be nothing short of spectacular. The gasoline-electric hybrid drives are already of the most economical engines configurations on the market. By adding a state-of-the-art LPG liquid injection system, can result to an ultra-efficient tri-fuel vehicle that is truly revolutionary.
Such a vehicle can have two energy sources, LPG and HV battery (LPG-electric) or three energy sources, Gasoline, Diesel or CNG, LPG and HV battery) sources (LPG Hybrid Tri-Fuel).

Configurations of Hybrid-Electric Systems
The performance of a given hybrid propulsion system is heavily affected by its specific configuration.

This section describes the three general arrangements of hybrid options: parallel hybrid drive, serial electric drive, and a hybrid drive with an LPG engine as “Range Extender” generator.

Parallel Hybrid Drive
This configuration consists of an internal combustion engine working together with an electric motor both connected to the transmission system. The LPG in this configuration is used in a direct injection engine and the powertrain also uses an electric motor that can capture brake energy.

Serial Electric Drive
The main components of a LPG electric serial drive are the LPG engine, generator and electric motor.
In a hybrid serial system, there is an electric storage element in the system.

In a serial hybrid setup, the electric motor is the only means of providing power to the transmission system. The motor receives electric power from either the battery pack or a generator run by an ICE. This lets a HDE continue to operate even after the batteries are discharged.

Hybrid Drive with “Range extender”
The new generation of hybrid vehicles are in reality only electric, since they use an internal combustion engine as “Range Extender” generator. Only the electric motor is connected to the powertrain.

Case Study

Calor Gas has launched recently a new LPG range extender for electric trucks in partnership with EMOSS, the Dutch electric vehicle manufacturer.

Calor Gas will be unveiling the world's first liquid petroleum gas (LPG) range extender for an electric, rigid cylinder truck, at this year's Freight in the City Expo. 25 October 2017 Hayley Pink.

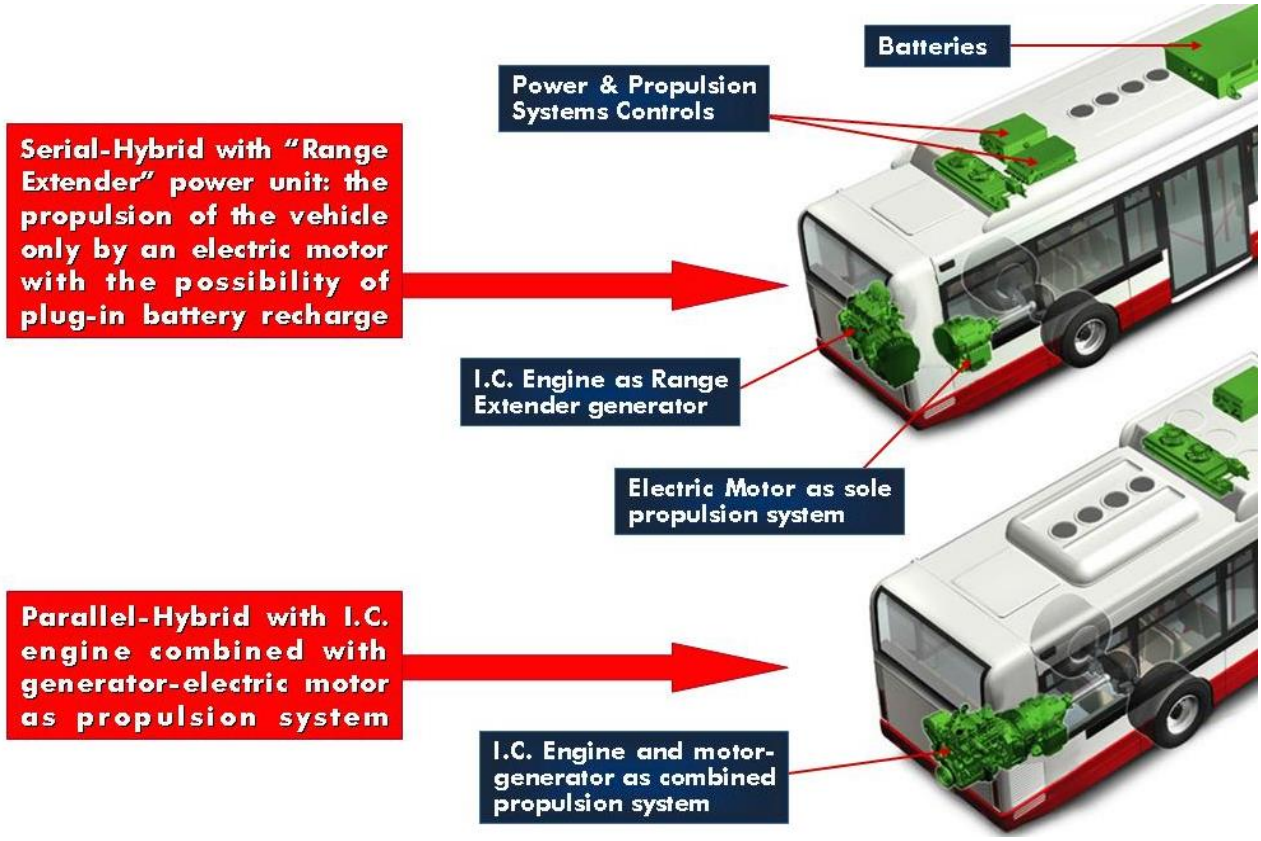
As the UK government continues to put pressure on the transport industry to find cleaner ways of operating, the new LPG range extender with EMOSS presents an exciting opportunity for rigid trucks. Calor, a major UK supplier of LPG to the transport industry, believes that as proposals for clean air zones and zero-emission zones gather momentum, vehicle OEMs will look to use range-extending technology to make electric trucks viable for fleet operators. The new truck has been developed in response to the government's air quality and emissions-reduction strategies.

The range extender uses LPG to drive the vehicle's electric generator, which charges the battery that is supplying the motor with electricity. LPG range extender will deliver lower carbon emissions than petrol and provide the capability to increase a vehicle's battery-only range from 40 to 250 miles. The technology also offers the opportunity for GPS ring-fencing to cut emissions to zero when operating in city centres. Trucks fitted with LPG range extenders are able to switch entirely to electric when operating in city centres or air quality zones, while already offering improved emission performance when compared with conventional fuels.

Calor will be offering Bio-LPG, from early next year 2018, which offers significant environmental benefits over existing range extension technologies, such as diesel and petrol. Chemically identical to conventional LPG, but created from renewable, ethically sourced feedstocks, Bio-LPG will play an important role in improving the LPG range extender's environmental credentials further still in the future.

It is important to point out that a leap forward in hybrid LPG engine development and battery technology will instantly make hybrid-electric propulsion systems a more viable alternative to traditional ICE

The three systems described above are demonstrated in the following figures:



Source: X-TECH R&P SA.

Serial electric drive hybrids combined with LPG fuelled range extenders present a major opportunity for the LPG industry today to establish itself as a credible partner in the generation of the electric vehicles of all kinds for the future.

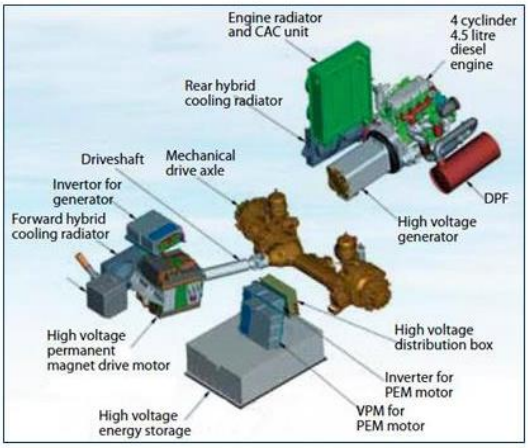
Hybrid London bus with Diesel engine range extender that can easily be modified to use LPG engine range extender instead.

Source: X-Tech R&P SA.

Driveline
- Cummins 4 cylinder iSBe
- Siemens ELFA® II electric drive system
- Latest generation Valence Lithium-ion battery technology

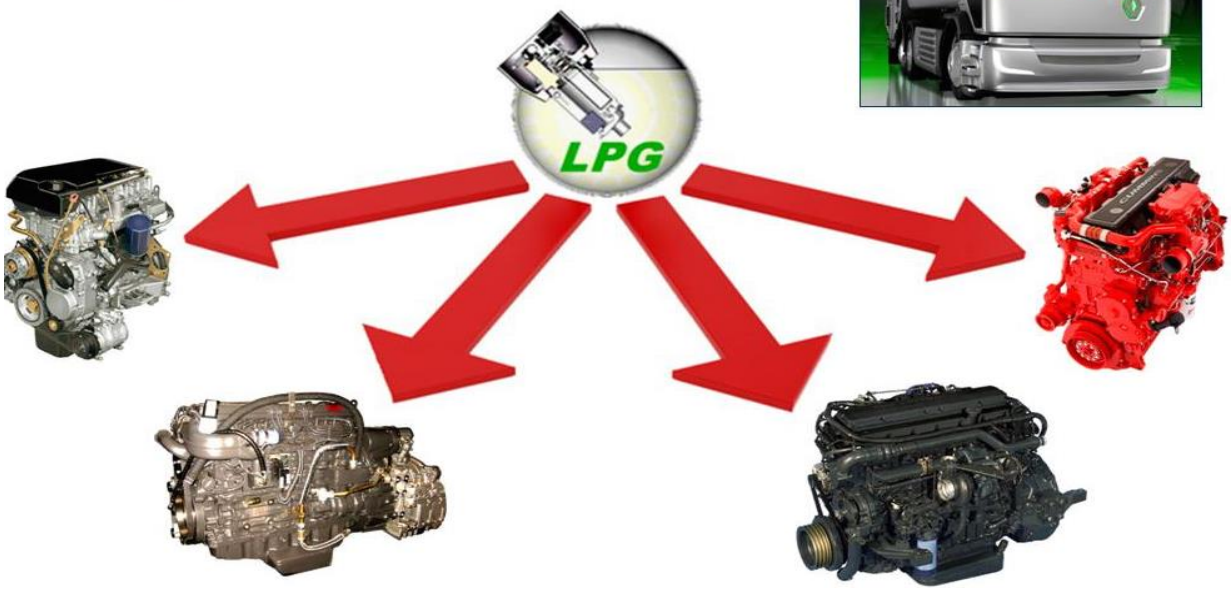
Specification
- Overall length: 11232mm
- Overall width: 2520mm
- Overall height: 4420mm

Features
- 100 vehicles already in service, with a total of 600 vehicles due to be in operation in London by mid 2016
- Fuel consumption of 11.6mpg - 47% CO_2 reduction



The 4.5 L engine can be the equivalent gas model fueled by LPG with the LGI System

"Range Extended" heavy-duty hybrid electric vehicles can be realized with LPG power units developed starting from very low emissions CNG engines already on the market.
LGI System allows to use smaller and cheaper engines.

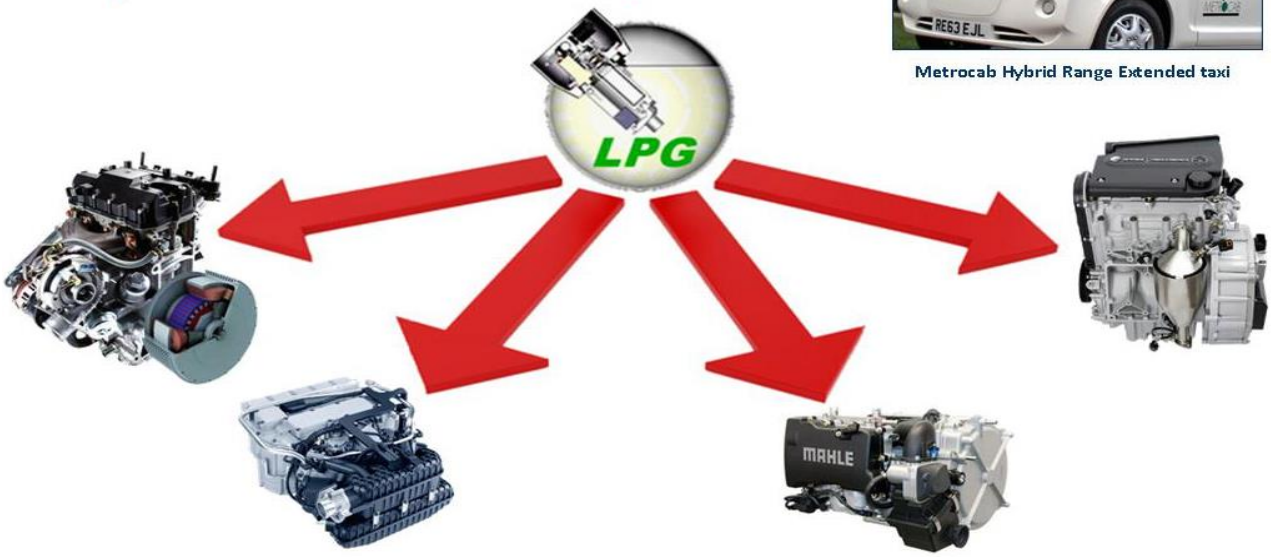


Source: X-TECH R&P SA.

Plug-in "Range Extended" Light-Duty

The new generation of "hybrid" pure electric vehicles will be developed using very efficient small gasoline engines integrated with generator, specifically designed to satisfy the requirements as dedicated "Range Extender" power unit.
LGI System makes such cars cleaner and cheaper to use.

Metrocab Hybrid Range Extended taxi



Examples of Diesel Hybrid vehicles in USA – Target for LPG Hybrids

Hybrid bus	Orion VII Hybrid electric bus	New Flyer Hybrid-Electric bus
Image of bus		
Type of hybrid drive	BAE Systems HybriDrive™ Serial hybrid	ISE ThunderVolt® TB40-HD Serial hybrid
Engine	Cummins ISB, ULSD, 5.9-litre, 194 kW, with a 120 kW traction generator	
Electric motor/generator	AC induction motor, Rated Power 250 hp continuous (320 hp peak)	Dual AC Induction motors, Rated Power 170 kW, Peak Power 300 kW
Energy Storage	Lithium-ion battery	Ultra capacitors
Bus Characteristics	Improve fuel economy 30% and reduce emissions: 90% PM, 40% NO_x, 30% CO_2	Reduce emissions: 25% PM, 32% NO_x and lower fuel consumption and CO2 emission

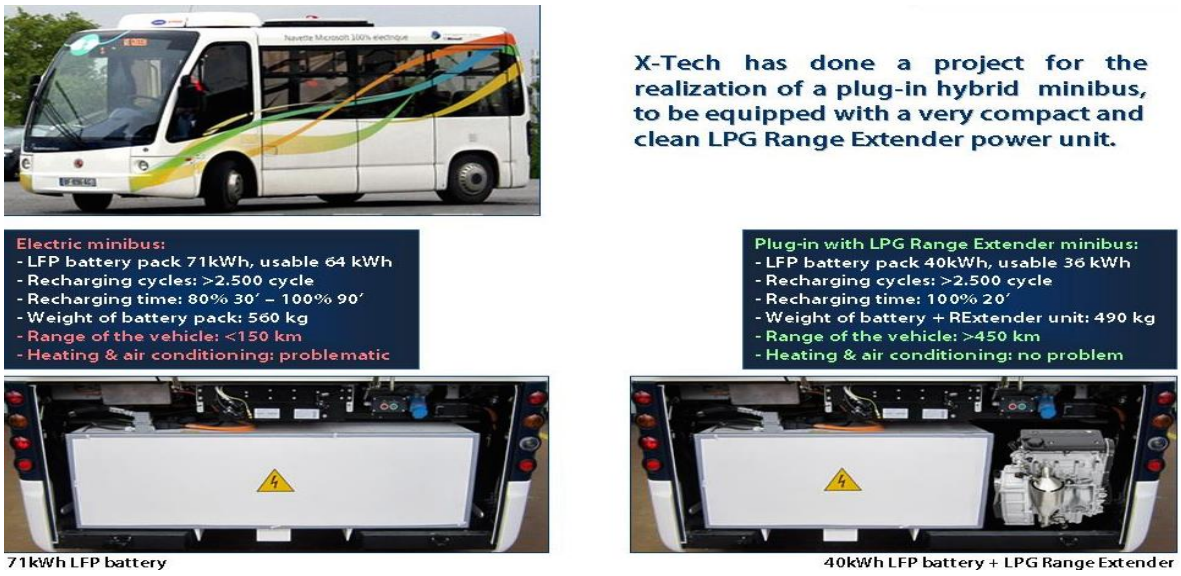
Source: X-TECH R&P SA.

Examples of Diesel Hybrid vehicles in EU – Target for LPG Hybrids

Hybrid bus	VOLVO 7700 Hybrid	SOLARIS Urbino 18 Hybrid
Image of bus		
Type of hybrid drive	Integrated Starter Alternator Motor (I-SAM) , Parallel hybrid	Voith DIWAhybrid, Parallel hybrid
Engine	New Volvo D5E, 5,0 litre capacity, rated at 210 hp	Cummins ISB6.7 250H engine, 181 kW (246 hp), 6.7 litre capacity
Electric motor/ generator	AC permanent magnet motor, power rating of 160 hp and 90 hp continuous	The motor provides 85 kW of power with a maximum output of 150 kW
Energy Storage	Nickel- Metal-Hydride battery	Ultra capacitors
Bus Characteristics	Fuel savings up to 35 % Lower exhaust emissions	Average fuel saving up to 16%

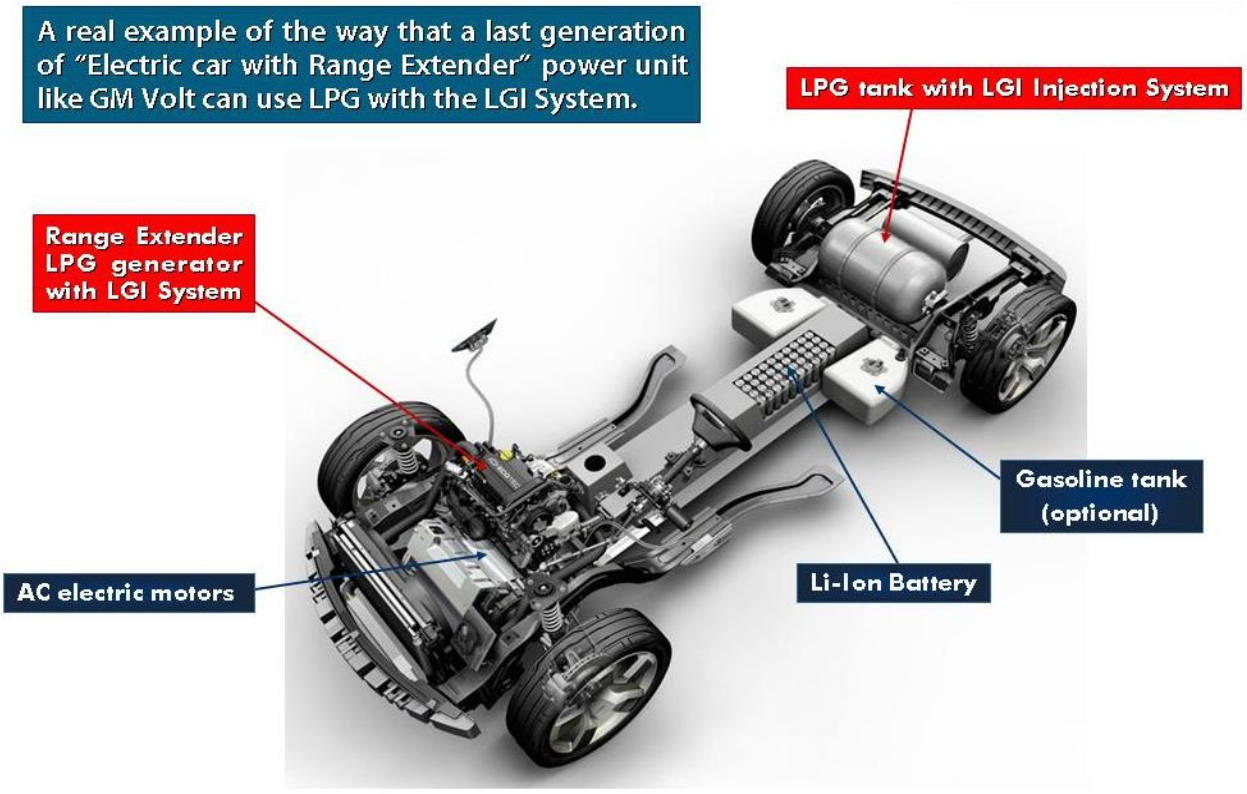
Example of project LPG Hybrid vehicle

LPG Range Extender on electric minibus

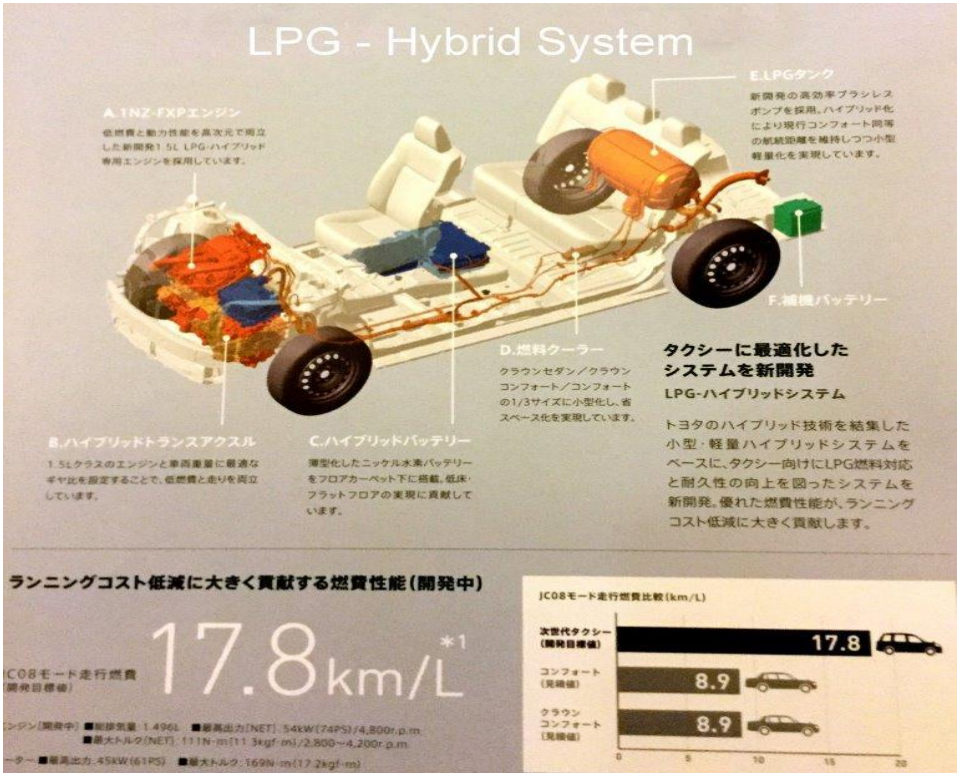


Source: X-TECH R&P SA.

The image below, although based on light duty vehicle application, demonstrates how a hybrid electric LPG range extender system can operate:

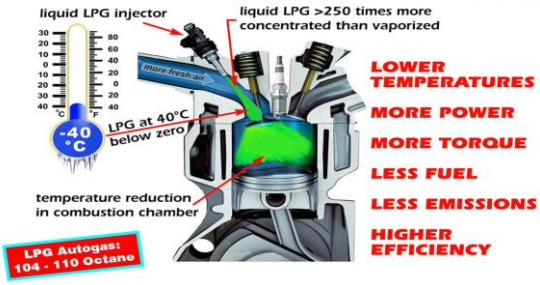


Source: X-TECH R&P SA.



Source: Japan LPG Association

3.2.6. Fuel system technologies, Liquid/Vapour



Source: X-TECH R&P SA.

Fuel system technologies are key in engine development. The technology around fuel delivery in gasoline and diesel engines has been developed significantly over the years.

Consequently, such technologies, also related to LPG use as an engine fuel, have evolved and several such advanced systems are today present in the market. However, not all are equally applicable at present to HD engines.

The most common fuel system technologies available today are listed below:

3.2.6.1. Venturi systems

Also, known as converter and mixer or vacuum type systems, these are mechanically the simplest of all systems and can be made to work without any electronics. They consist of the three basic elements: fuel tank, converter (vaporiser/regulator) and mixer. While no longer conforming to the newest emissions regulations they can still be used to convert older carburated engines, vehicles or other machinery.

3.2.6.2. Vapour Port Injection

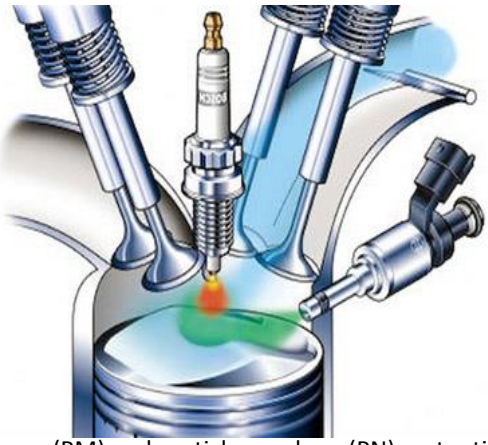
This system uses a converter like that in the converter-and-mixer system, but the gas exits the converter at a regulated pressure and it is then injected into the air intake manifold via a series of electrically controlled injectors, allowing for more accurate metering of fuel to the engine than is possible with mixers, improving fuel economy, increasing power and reducing emissions. The injector opening times are controlled by the LPG control unit, which works in a similar way to a gasoline fuel-injection control unit. Most vehicles of recent vintage use this type of fuel system.

3.2.6.3. Liquid Port Injection (LPI)

This type of system delivers the liquid fuel directly into a fuel rail at high pressure via a liquid LPG injector in much the same manner as a gasoline-injection system. As the fuel vaporises in the intake, the surrounding air is substantially cooled; this increases the density of the intake air and can potentially lead to substantial increases in engine power output improving engine efficiency and performance. The system is controlled by an electronic control unit (ECU), a dedicated computer that regulates the various components working in tandem with the vehicle's engine own gasoline computer to optimise the injection timing. LPI systems have proven that they can achieve better fuel economy and power as well as lower emission than VPI systems and are gaining popularity today.

3.2.6.4. Liquid Direct Injection (GDI in gasoline)

A major trend in gasoline engine technology is the shift from port injection to direct injection. Whereas in 2005 nearly all new European gasoline engines were PI, a large part of today's new gasoline engines is DI, perhaps as much as 50%. Forecasts from car manufacturers (OEMs) and suppliers suggest that DI's market share will continue to rise, with new cars in Europe being nearly 100% DI by 2025. This is the most advanced system today, and possible in the future LPG could also follow the trend. **However, at present this engine technology is not applicable to HDE.**



In liquid direct injection (DI) liquid gasoline is injected directly into the combustion chamber. The fuel vaporises instantly, cooling the charge prior and during the compression stroke. This increases the anti-knock behaviour of the fuel, potentially yielding further efficiency and emission gains. This promising technology has been commercialised for a few years and showed good results both in terms of performance and emissions. It allows lower consumption and lower carbon emissions. However, it generates much higher particle mass (PM) and particle numbers (PN), potentially in excess of Euro 6 emission regulations.

However, LPG could offer better performance in this respect and can outperform gasoline in DI. Reductions in fuel consumption and carbon emissions can be greater than those for gasoline, yet particle emissions remain negligible.

3.2.6.5. DI Gasoline and PI LPG

Some OEMs are offering bi-fuelled gasoline-LPG engines where the gasoline mode runs with DI (liquid injection directly in the cylinder chamber) and the LPG mode runs with PI (liquid injection in the port). The performance of these cars in LPG mode is not known because there is a lack of data. Nonetheless, intuition suggests that PI LPG and DI gasoline would be comparable in carbon emissions whereas, if both are DI, LPG will be significantly lower. This type of conversion, in effect, 'wastes' LPG advantages with DI. It is unclear how emissions of other pollutants would compare, except for PM, which almost certainly would be lower in PI LPG than in DI gasoline.

Case Studies

Integrated pump, controls and injection system of X-Tech

A new innovative and revolutionary LPG "fuel system for pressurised fuels" is a solution recently developed by X-Tech. The system is a "complete fuel system" that integrates all the components needed to inject liquid LPG in an internal combustion engine.

Source: X-TECH R&P SA.

It injects LPG as a liquid at high pressure, rather than the often currently used low tech low pressure gas introduction systems. The new system is designed to be used on various engine and vehicle types from passenger cars, taxis but also very much on Heavy Duty engines in buses, trucks, agricultural and construction machinery etc. as well as marine engines and applications, simplifying the conversion of gasoline and specifically CNG engines to LPG.

It is to be noted that advanced fuelling systems for modern engines today, which is also the case of the X-Tech system, require the LPG fuel to be of high and consistent quality to protect the LPG pump and injection components from damaging impurities.

Tri-Fuel system from Niyato

In 2016, Niyato Industries developed of a tri-fuel system based on a Ford F-350 4X4 vehicle, capable to run on gasoline, LPG, and CNG. The LPG Autogas application of the new tri-fuel system only needs a different tank for storage and a vaporiser. The tri-fuel system will operate with both high and low pressure.

This developmental vehicle is now undergoing rigorous testing. This Tri-Fuel system will operate flawlessly when testing is complete with both high and low pressure. The EPA (Environmental Protection Agency) and CARB (California Air Resources Board) certifications will cover all weight configurations for the Ford F-250 and Ford F-350 6.2 litre engine families.

Tri-Gas truck from Greenkraft

In 2015, Greenkraft introduced a new G-series line of CNG, LPG, or Gasoline cab-forward trucks. The trucks are available with six litres or eight litre GM engines with fuel capacities ranging from 20 to 60 GGE. Greenkraft designs, develops, and manufacturers alternative fuel commercial vehicle products powered by CNG, LPG, gasoline and also Hybrids in classes 3, 4, 5, 6 and 7.

3.2.7. Summary

Probably the two strongest forces in engine technology development over the past years have been **fuel economy** and **emission reductions**. The first is driven mainly by the 'energy crises' of the 1970s-80s and the 2000s, the latter by a chronic worsening of air quality in urban areas and in reaction to global warming and subsequent strengthening of environmental control regulations. Meeting more demanding emission requirements implies also fuel economy.

The development of Heavy Duty LPG Engine technology, once significant in the past, has not been advancing in recent years at the same pace as other alternative fuel technologies like CNG, electrics, hybrids.

There are many technologies that allow the use of LPG as a fuel in engines and particularly in HD Engines. The technology to use depends on the specific application, availability and suitability of OEM engines for the application, complexity of conversion if OEM engines not available, and certainly the capability of each technology to meet present and future national and regional regulations.

DI technologies can offer significant advantages and these can be even more significant with the use of LPG as a fuel. However, these DI technologies have not been used yet in any HD engine.

Hybrid technologies and especially those with range extender engines fuelled by LPG are very promising for a variety of HD engine applications and particularly well aligned with the upcoming zero emissions or low emissions regulations of the future.

Diesel/LPG dual fuel technologies while already existing in the market for HD engines and vehicles, they are yet to prove if they can offer significant advantages in economical savings and emission reductions to establish themselves as viable technologies for the future.

3.3. Heavy Duty Engine Applications

Heavy Duty Engines are unparalleled in their versatility and range of applications. There are over one hundred possible applications of LPG Heavy Duty engines. This section below describes the variety of these applications, with case studies and best practices, in both static and mobile applications in commercial business, industry, transportation, farming, power generation and other sectors.

On Road Vehicles segment
These include all vehicles and their engines that operate on national roads, and local highways, some also in airports, including buses, and heavy-duty trucks.

Off Road Vehicles segment
These include all vehicles and their engines LPG engines that are used in a wide variety of off-road equipment, including commercial mowers, airport ground support equipment, mobile sweepers, commercial compressors, pumps and generator sets, industrial saws, and construction loaders and tractors.

In many of these, LPG as an engine fuel is already present varying amongst countries and regions, in others it presents a significant opportunity that needs to be developed.

3.3.1. Heavy-Duty Vehicle Applications Overview

The use Autogas technology for on-road use for fleets of HD vehicles is already proven and available.

The following list provides an overview of some popular alternative fuel and advanced vehicle options for several common HD vehicle applications. For some of these LPG variants exist already, for others it remains to be developed.

School Bus | Compressed natural gas (CNG) and propane (also known as liquefied petroleum gas, or LPG) are popular alternatives to gasoline and diesel fuel for school buses. Hybrid electric buses and plug-in hybrid electric buses are also available.

Shuttle Bus | CNG, propane, hybrid electrics, and fuel cells are potential options for shuttle buses and large passenger vehicles that provide transportation on standard routes.

Transit Bus | Hybrid transit buses, along with those powered by CNG or liquefied natural gas (LNG), are available. Fuel cell demonstrations are also in progress.

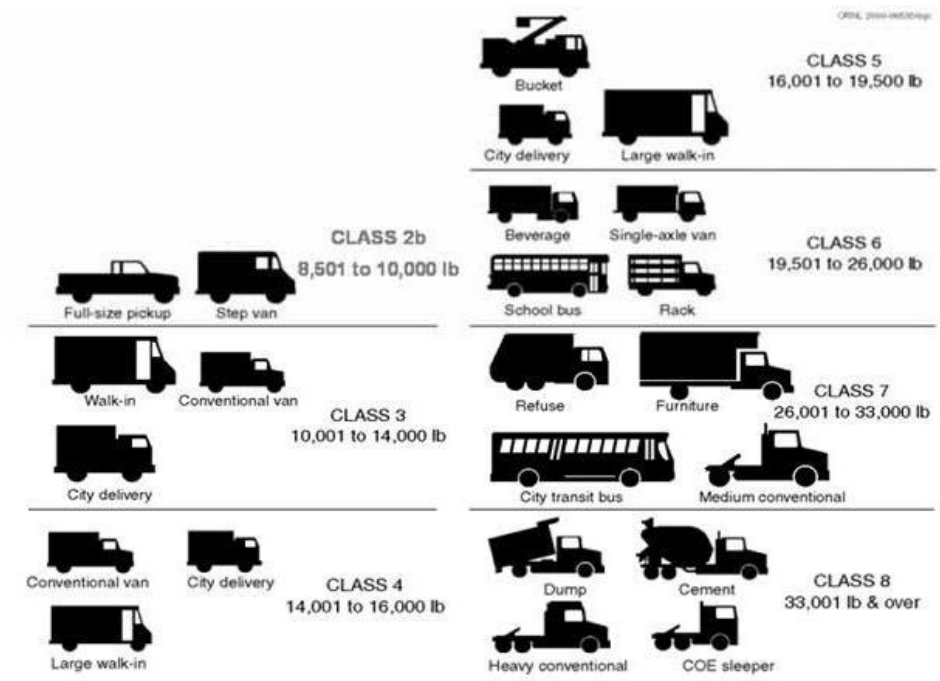
Refuse Truck | Many fleets have refuse trucks with CNG engines, and they can even run on landfill gas where biomethane processing facilities are in operation. Regular routes and stop-and-go operation make refuse haulers a good application for hybrid operation as well. Hydraulic hybrid systems are well suited to refuse service.

Tractor | Diesel electric hybrids offer fuel-saving hybrid operation with the convenient availability of diesel. CNG and LNG systems are also attractive options.

Van | Step vans that service a set route, such as a package delivery service, may find all-electric battery operation an effective alternative to conventional vans. CNG and propane operation are also popular alternatives.

Vocational Truck | CNG, LNG, propane, all-electric, and hybrid vehicles operate in a variety of roles, from beverage delivery to utility boom trucks, paint striping trucks, and merchandise delivery.

3.3.2. Vehicle segments Overview in USA



The table above gives also the picture of the potential powertrain options considered for different vehicle market segments.

- In the case of Class 3-6 trucks, powertrain options include diesel, gasoline, hybridised-diesel, and natural gas.
- Hybrid options are also included in Class 7 & 8 single-unit trucks.
- LPG options are assumed to be available now for all classes of trucks although in varying extent.

In hybrid options, a significant opportunity for the future, many options, while technically available in limited niches, tend to be a poor match for truck duty cycles. In particular, battery challenges already faced by plug-in electric cars are multiplied many-fold by HD requirements, which include extended life, increased power, and higher energy storage.

In the USA, Class 3-6 trucks represent almost four million vehicles today, and one study shows them growing to over 11 million by 2050. Applications range from minibuses, step vans, and utility vans to city delivery trucks and buses in Classes 4, 5, and 6. These vehicles consume as little as 1,000 gallons per year for some lighter, low-duty cycle applications up to 7,000 gallons per year for the heaviest Class 6 applications. Class 3-6 trucks are used in rental, retail, leasing, wholesale, waste management, utilities, manufacturing and mining.

Class 7 & 8 trucks account for over 4.5 million vehicles and are expected to grow to over seven million by 2050. Class 7 and Class 8a trucks include buses, dump trucks, trash trucks, and other hauling trucks. These trucks represent heavy working trucks consuming typically 23,000–30,000 lt of fuel per year for Class 7, and 38,000–50,000 lt of fuel per year for Class 8a. Class 8b trucks are typically long-haul trucks weighing more than 15,000 kg. that have one or more trailers for flatbed, van, refrigerated, and liquid bulk. Class 7 represents some 200,000 vehicles, while Class 8a and Class 8b consist of 430,000 and 1,720,000 respectively. These trucks consume typically 72,000–102,000 lt of fuel per year and account for more than 50% of the total fright tonnage moved by trucks.

Class 8b trucks consume two-thirds of the fuel used by trucks overall. The high fuel use by these trucks is due to their heavy weight and their very high mileage. The average new Class 8b truck travelling over 160,000 Km per year with some trucks travelling more than 200,000 or more per year.
The potential and the opportunities based on the above, and the estimated consumptions, as seen in the table below, with examples of annual consumption of various categories, can be significant:

- Freight truck 16-20K Gas Gallon Equivalent (GGE)
- Transit buses 12.5-15K GGE
- Refuse trucks 7.5-10K GGE
- Municipal sweeper 5-6K GGE
- Airport shuttle service 5.5-7.5K GGE
- Food and beverage, textile services, household goods 3-5K GGE
- Taxi 4.5-5.5K GGE
- School Bus 2-3K GGE

If LPG manages to capture even a small part of the market of new HDV engines, it will be an enormous success.

Advantages of using LPG/Autogas as a fleet fuel:

- **Range**: Superior to ethanol, LNG and CNG. A 95-litres LPG tank, as motor fuel, will last longer than any other alternative motor fuel
- **Consumption, Miles Per Gallon**: Delivers up to 90 percent of gasoline's MPG, 54 percent of methanol's and 70 percent for ethanol's
- **Cost**: LPG costs less than gasoline in most cases and may be the lowest priced alternative fuel for fleet use. In the USA, municipal and state tax incentives and rebates are available for LPG powered vehicles, similarly also in other countries
- **Availability:** There are hundreds of public and private refuelling stations for LPG. Modern, 24-hour stations are also being installed in many countries and do not need to be close to a gas grid
- **Safety:** LPG tanks, fuel lines, and carburetion components meet strict specifications. Autogas vehicle tanks are constructed from carbon steel under highest standards and are 20 times as puncture-resistant as gasoline tanks. Autogas tanks are tested to four times their standard operating pressure. Built-in safety devices automatically shut off fuel in case of an accident. Autogas ignites at 920 to 1,020 degrees Fahrenheit (493 to 549 degrees Celsius), compared to 495 to 535 (257 to 280 Celsius) degrees for gasoline, i.e. there is a decreased possibility that Autogas will accidentally ignite. Autogas only burns at a small fuel-to-air ratio and it dissipates quickly into the open atmosphere, making ignition less likely. Of all the alternative motor fuels, LPG has the lowest flammability range—making it a safe motor fuel.
- **Environmental friendly:** LPG is a non-toxic, non-poisonous, and insoluble in water, clean-burning fuel that can be used to safely power today's technically advanced, spark-ignited engines. With Autogas, there is no spillage loss during refuelling.
- **Emissions:** LPG is inherently cleaner than gasoline and can meet or exceed those emission levels from other alternative fuels. LPG can easily meet or exceed current and future emission standards.
- **Infrastructure:** Autogas is already produced commercially in natural gas and oil refineries across the globe. No new technology or capital investment for such technology is required.

3.3.3. Buses/Fleets

LPG as an engine fuel, and in particular for HD applications, is a robust technology and has been proven to meet the demanding requirements of severe-duty use in vehicles such as buses and various types of fleets.

LPG has similarities to CNG but can offer advantages in terms of performance, overall cost and can be best suited to power heavy duty vehicles. It has higher energy density than CNG and can meet transit-bus range needs with lower storage tank requirements. LPG also offers good emissions performance, including low NOx levels in engines optimised for LPG. It is environmentally superior to gasoline and diesel, providing life-cycle Greenhouse Gas (GHG) emissions reductions of approximately 26% relative to gasoline and providing significantly less emissions of criteria air contaminates (CAC's) and air toxics when compared to diesel.

Although there are far fewer Heavy Duty Vehicles than cars on the road, HD trucks are a significant factor in overall transportation energy consumption. HD trucks consume over 20% of the fuel used in transportation in the United States and this share is expected to grow to almost 30% in 2050.

3.3.3.1. LPG School Bus Fleets

LPG is a promising alternative fuel for school buses. Widely available even in rural areas and it can cost less than diesel or gasoline. In the USA, a growing number of school districts are shifting parts of their fleets from diesel fuel to LPG to stretch strained budgets and promote cleaner air. According to officials from school districts and private companies that operate school fleets, LPG seems to be the school bus alternative fuel of choice. School districts began seeking cleaner alternatives to diesel about ten years ago, after studies found that the air inside school buses was often five to ten times dirtier than the air outside, partly because of fumes wafting into the bus every time the door opened and closed.

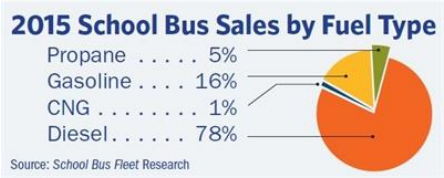
From a recent school bus sales data for 2015 in the USA, some interesting trends in fuel types have been identified:

- 15,000 LPG school buses in operation.
- Diesel still accounts for the lion's share of new school buses, in 2015, 31,262 (78%) of the total 40,190 school buses sold in the USA and Canada were diesel.
- Sales of LPG school buses have been steadily increasing in recent years, in 2015 2,160 LPG school buses were sold, i.e. 5% of the total school buses sold.
- LPG school buses sold in 2015 increased by 340 units, or 19%, compared to 2014.

Many fleets are buying more LPG buses after testing them for the first time, for example, Bibb County (GA) School District recently added 22 new LPG buses to its fleet after being satisfied with the performance of their previously purchased 31 LPG buses. Now, the LPG units make up 25% of the district's total school bus fleet. Two other school

districts in Nebraska (Omaha and Millard) are buying 434 new LPG buses, probably making the largest LPG school bus fleet in the USA.

The share of LPG school buses by fuel used in the USA is shown below:



Advantages of school buses using LPG:

- **Cost Savings** – Some of the school districts save nearly 50% on a cost per mile basis for fuel and maintenance relative to diesel.
- **Payback Period** – The incremental cost of the LPG buses and fuelling infrastructure can be recouped in 3–8 years.
- **Improved Efficiency** – The newest LPG engine technologies are more efficient than older technologies still in use.
- **Typical Usage** – LPG buses travel around 23,600 Km per year on average and achieve fuel economy of 11.6 miles per diesel gallon equivalent (DGE).
- **Energy & Environmental Impact** – The total petroleum displacement in a study was 212,000 DGE per year for 110 buses, while greenhouse gas (GHG) reductions were approximately 770 tons per year.
- **Uncompromised Safety** – LPG school buses provide unmatched peace-of-mind for parents. Compared with diesel buses, Autogas buses are noticeably quieter when operating. With significant noise on the bus eliminated, a driver can pay better attention to children in the rear of the bus — and the road ahead. Diesel cannot deliver a similar experience. In addition to significantly quieter operation, all LPG powered buses are equipped with automatic shut-off valves cutting fuel flow to the engine when it's not running.
- **Cleaner for Students and Communities** – The shorter height of younger students puts them face-to-face with a black cloud of diesel smoke every school day. With Autogas buses, students are not exposed to the harmful particulate matter of diesel exhaust gases.

Manufacturers

The main manufacturers of LPG fuelled school buses in the US include IC, Thomas Bus Built and Collins

Case Studies

Chicago area school district goes green with 80% LPG bus fleet

Orland School District 135 partnered with school bus contractor Cook-Illinois Corporation to add 79 Blue Bird Vision.LPG buses that will help lower the district's carbon footprint while reducing transportation costs. These Autogas buses make up 80% of its school transportation fleet.

Cook-Illinois subsidiary, American School Bus Company, won the bid for regular education bus services for the 2016-17 school year.

Among those benefits, that cites the LPG buses are better cold weather starts, ability to heat up fast, and the removal of diesel fumes around the students and community. The buses emit 80% fewer smog-producing hydrocarbons and virtually eliminate particulate matter when compared with conventional diesel. These buses, which run almost 400 routes per day, will reduce nitrogen oxide emissions by over 44,500 kg and particulate matter by almost 1134 kg each year compared with the diesel buses being replaced. Equipped with Ford Motor Company's 6.8L V10 engine, each bus is powered by a ROUSH CleanTech LPG fuel system.

More than 600 school districts across the nation are experiencing the environmental and economic benefits of Blue Bird's LPG buses.

"Cook-Illinois' adoption of Autogas buses for its school district customers is good for the company as well as the
These buses operate on a fuel that is domestically produced, abundant and affordable.

Tennessee's CMCSS Got LPG Buses

The Clarksville-Montgomery County School System in Tennessee launched its new fleet LPG fuelled Type C Blue Bird school buses. CMCSS boasts a large alt fuel bus fleet which helped fund the purchase via a Reducing Diesel Emissions for a Healthier Tennessee grant.

3.3.3.2. Public transport

Public transport is another potentially significant market for HD LPG engines, particularly in buses within the cities where the buses can return every day to their base for refuelling.

3.3.3.2.1. LPG Buses in City Capitals – Clean Fleets

There have been some very successful examples with LPG buses in the past, and still existing today, although to a much lesser extent and under threat by other alternative fuels.

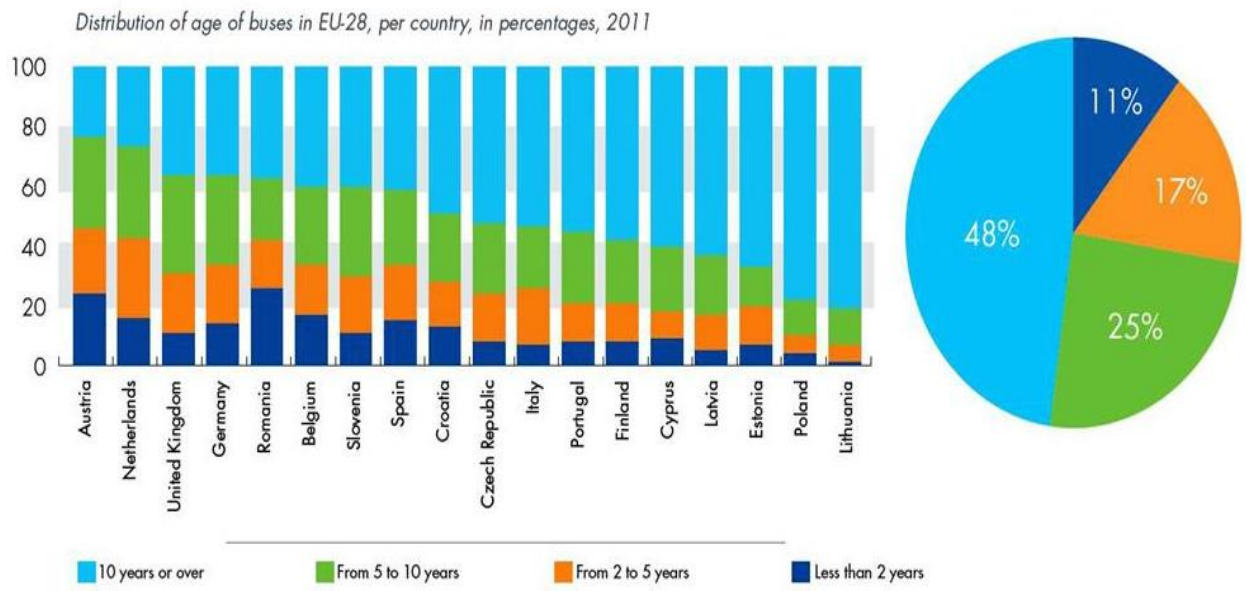
One of **Vienna's** public transport operators, Wiener Linien, runs an entire fleet of LPG buses. The introduction of LPG as an alternative fuel began in the sixties and since 2001 LPG engines have been successively replaced with even better performing LPG models. Compared to traditional diesel engines, it was found that the LPG models emitted less CO and NMHC than traditional diesel models, and significantly less NOx and PM, even if CO2 emissions were higher. However, this fleet is being reduced in number as the existing buses are being replaced with other technologies

In **Romania,** Braila and Iasi have been operating LPG buses since 2009. Overall, their experience has been quite positive, but Braila found that fuel consumption is increasing annually, potentially due to the wear rate. No new acquisitions on such fuel are foreseen for the coming years.

Other European cities had also adopted LPG as fuel for their public transport, in France, Italy, Denmark etc. However, the lack of technology development in LPG Heavy Duty engines, and the hesitation of manufacturers (OEMs) in Europe to invest in LPG technology, has led to gradual withdrawal of these buses and for those still remaining, a lack of plans for replacement of the vehicles with LPG fuelled models in the future.

In **China,** a significant portion of the domestic part of the medium-sized city buses use LPG as fuel, as is the case for example in Guangzhou.

An indicative age profile of bus fleets in various countries is shown below, hence the potential for replacement of existing buses in the various countries in Europe demonstrates the big opportunity for the replacement of these buses with LPG fuelled engine alternatives, if the technology exists and provided there are available in the market OEM LPG engines and OEM LPG buses.



3.3.3.2.2. Transit Buses

Transit buses are also a target segment for LPG fuelled HD engines. These usually operate longer distances amongst cities and they either also return to their base location daily or less frequently.

Such transit buses are found in the USA operating in various locations.

Case studies

Michigan transit authority rolls out Autogas bus fleet

The recent delivery of LPG vehicles to the Flint, Michigan Mass Transportation Agency signals the largest rollout of Blue Bird LPG Visions for commercial use. The new alternative fuel buses cut costs, reduce harmful emissions and take advantage of a domestically produced fuel. Compared with the diesel buses they replaced, each bus cuts down on 363 kg of nitrogen oxide and 16 kg of particulate matter annually. These new buses allow Flint to provide green, affordable public transportation while saving taxpayer dollars. Flint MTA purchased the buses with Federal Transit Administration funding. The FTA New Model Bus Testing Program (known as Altoona testing) rates new buses on safety, structural integrity and durability, reliability, performance, maintainability, noise and fuel economy. These federal funds cover 80% of the alternative fuel vehicle cost, with a 20% local match. The commercial version of the Blue Bird LPG Vision, which comes with a five year, 160,000-km warranty, is Altoona-test rated for 560,000 kg or ten years. Each 39-seat bus is equipped with a 6.8L Ford engine, a ROUSH CleanTech fuel system and a 380-lt fuel tank. In addition to providing cleaner operations, the Autogas, medium-duty buses cost only one-third of the price of heavy-duty transit buses, so they are an extremely cost-effective way to augment a transit bus fleet.

3.3.3.2.3. Tourist City buses

Tourist city and other tourist buses are another segment of potential application and growth of LPG HD engines. These they operate within cities for tourist city tours and other routes serving the tourist sector, as well as country-wide, returning to their base daily or not. The availability of LPG refuelling facilities and network allows these buses to refuel either in their base location or en route at Autogas stations.

Such LPG fuelled buses, besides being less polluting than their diesel or gasoline equivalents, they also compare more favourably to their CNG equivalent as they can easily operate and be refuelled in areas when natural gas is not present, of the grid and remote areas such as islands.

Case studies

Travel Plaza Transportation Converting Tour Bus Fleet to Zero Emission Commercial Vehicles By 2020

Kansas-based ElDorado Bus Co. built the 25-seat LPG buses on a Ford E-450 6.8-liter gas chassis, equipped with a Roush CleanTech LPG Autogas fuel system. Hawaii Gas was chosen as the fuel supply partner for the conversion project. According to TPT, the LPG-powered tour buses, as well as any new bus entering the fleet, will reduce its carbon footprint by 73 percent and 78 percent, respectively, per bus, compared to diesel and gasoline powered vehicles. TPT adds that it expects to realise fuel and maintenance cost savings of about $5,000 annually per bus.

3.3.3.3. Taxis

Taxi engines are not of the size of HD engines used in other public transport vehicles as buses, however, their heavy use and their operation under heavy duty continuous conditions, requiring continuous and reliable performance justifiably can put these engines under the category of HD engines.

Taxis are a major source of urban air pollution and in their diesel version have been largely accused in big cities for contributing to air pollution. However, such taxis can easily and economically be converted to run on Autogas, enabling taxi drivers to run cleaner vehicles which still meet their operational needs now and in the future. Drivers of LPG taxis can experience savings of the order of 20% on their fuel bills, meaning the operator would recoup the cost of conversion after driving approximately 110,000 km.

Conversions of existing gasoline fuelled taxis to LPG are easy, conversions of existing diesel fuelled taxis are also possible with various options. Original LPG fuelled OEM models exist in some countries, whereas Hybrid technologies, bring the latest advances in the sector.

There are many cities in the world where LPG taxis are in operation contributing to cleaner air, for example, Tokyo, Seoul, Hong Kong, New York, Istanbul, Athens, and several cities in China and elsewhere.

Case studies

LPG Taxis in the UK

The Transport for London's ULEZ plans require all taxis and new private hire vehicles new to licensing from January 2018 to be **Zero Emission Capable (ZEC)**. This will have unintended adverse consequences for metropolitan areas across the rest of the UK. Unable to operate in London, the worst polluting diesel taxis will be displaced to other areas of the country. The cost of buying a new electric taxi is unaffordable for many taxi drivers (a ZEC model may cost around £42,000). Converting however an existing taxi to LPG can deliver immediately lower vehicle emissions. TFL have agreed to extend the life of a diesel taxi by 5 years (to 20 years) if it converts to LPG, and in doing so meeting Euro 6 emission standards.

Birmingham City Council in the UK facilitates the conversion of 80 black cabs to LPG.

Developed as part of the Birmingham NOx reduction champions project, the ionic Black Cab normally powered by a diesel engine, is improved dramatically by replacing the diesel engine with a gasoline engine converted to run on cleaner Autogas. The engine is quiet and runs with almost no vibrations, plus the fuel costs are reduced by more than 20% by running on Autogas. The gasoline engine fitted as a replacement for the diesel engine, is also tuned to match the character and power of the replaced diesel engine, and a bit more. The effect on the replaced diesel is quite impressive; 80% less NOx and 99% less Particle Matter, added to the 20% fuel savings.

With a conversion cost of around £8,000 plus VAT, it is far cheaper for taxi drivers to convert their TX4s to LPG than to buy a new electric model. In order to better demonstrate the environmental performance of LPG taxis, Calor recently converted a TX4 diesel to run on Autogas– similar to many of the taxis that will be pushed out of London (if the ULEZ consultation fails to recognise the benefits of LPG taxis in London as a support technology to the total introduction of an electric fleet). With refuelling sites in abundance across the UK (1,400) and similarly across many other countries and cities that may wish to adopt these technologies, the LPG fuelled taxi can be an ideal solution much wider.

Toyota next-generation LPG-powered Hybrid taxi for the Japanese market

Toyota has developed an LPG/Electric hybrid, the JPN Taxi, which will be sold to Tokyo's taxi drivers from 2018. At present, 90% of Tokyo's taxis run on LPG. The power of the future Toyota JPN Taxi comes from an innovative parallel hybrid drivetrain made up of a small electric motor and a four-cylinder engine that runs on LPG. Toyota plans to launch a new taxi for the Japanese market before April 2018. In keeping with recent trends both in and outside Japan, the taxi will achieve excellent environmental performance by featuring an LPG hybrid system, which aims to be highly economical offering excellent environmental performance optimised for taxi driving conditions.
On 23 October, Toyota Motor Corporation has launched the "JPN Taxi," a new Autogas hybrid vehicle, which is now available for order at Toyota dealers all over Japan. The JPN Taxi, assembled at Toyota's Higashi-Fuji Plant in Japan, features a newly developed LPG hybrid system (THS II), combining an LPG engine with an electric motor. It offers a 19.4 km/L fuel economy and sharply reduced CO_2emissions.

Toyota expects to sell about 1,000 units of the JPN Taxi monthly in Japan. The manufacturer will exhibit the new vehicle at the 45thTokyo Motor Show 2017, and also plans to use the taxi to greet visitors from around the world in 2020, when Tokyo hosts the Olympic and Paralympic Games.

3.3.4. Trucks-Fleets

Transport trucks, hauliers, truck fleets represent another important target for the LPG industry for the use of LPG and an engine fuel.

With increasing pressure on the haulage industry to reduce carbon emissions with the introduction of carbon reduction commitments and taxation, there is a real need to adapt to this pressure without increasing costs. It is estimated that fuel represents 30-35% of the total cost of haulage. With the industry firmly entrenched in most parts of the world (partial exception the USA) with diesel fuel technology and infrastructure, what is required is not a costly and lengthy change in dynamic, but a system change that will mostly utilise the current diesel or gasoline Infrastructure whilst reducing carbon emissions.

For existing diesel engines, diesel/LPG mix technology does just that, offering significant carbon reductions and as an added incentive fuel cost savings of up to 16%.

For HD engines that run on gasoline or CNG, the conversion to LPG is based on well-known technologies which however still require specific development for specific engines, homologations etc.

3.3.4.1. City Delivery Trucks

There are many examples around the world of showing the positive effects of LPG powering delivery trucks, especially those operating within cities. The additional advantage related to city deliver trucks is that these always return to their local base after deliveries, thus not needing public refuelling Autogas network facilities. Hence refuelling facility and product can be optimised to the fleet needs.

Case studies

UPS – the biggest purchase yet of LPG vehicles

The world's largest package delivery company, UPS, has a strong record of environmentally sound practices, including the use of alternative fuels for its delivery fleet. Globally, UPS operates 2,022 alternative-fuel vehicles - one of the largest "green fleets" in the transportation industry. UPS is spending $70 million adding 1,000 LPG trucks to its delivery fleet, the biggest bulk purchase of LPG fuelled vehicles yet. The fleet, made of Daimler AG's Freightliner Custom Chassis Corp, is replacing gasoline and diesel vehicles in Louisiana and Oklahoma.

The investment includes 50 new fuelling stations. The fleet, which adds to its 900 LPG trucks already running in Canada, is expected to displace about 13.3 million lt of gasoline and diesel per year. The company has set a goal to reach one billion miles in alternative fuel and technology vehicles by the end of 2017.

Nestle Waters Expands Autogas Fleet with 155 New Trucks

Environmental stewardship is the main reason Nestlé Waters North America is adding more than 150 medium-duty beverage delivery trucks fuelled by LPG: over the vehicles' lifetime, the 155 Ford F-650 trucks will reduce carbon dioxide emissions by more than 24.6 million pounds. Each delivery truck is equipped with ROUSH CleanTech LPG autogas fuel system with a 45-usable gallon fuel tank. The Nestlé Waters North America LPG trucks deliver products across the country including Los Angeles, San Francisco, Washington, D.C., Milwaukee and Fort Lauderdale and the 2016 deployments includes New York, Boston, Dallas, Houston, Chicago, Philadelphia and Baltimore.

Large Fleet AmeriGas Converted to Autogas

The largest LPG retailer in the USA has operated fleet vehicles with LPG for well over 30 years. AmeriGas Propane, Inc., will more than double its medium-duty Autogas fleet. The company purchased 50 new ROUSH CleanTech Ford F-550s equipped with cranes to deliver LPG tanks to customer sites across the USA in addition to the 35 that were deployed at the end of 2013. The AmeriGas' fleet is one of the largest in North America. The company's Autogas fleet demonstrates the viability of LPG as an on-road vehicle fuel, lessens noise in neighbourhoods being serviced, and lowers harmful emissions. Over the lifetime of the Ford F-550 vehicles, more than 5.76 million kg of carbon dioxide are being eliminated from AmeriGas' total carbon footprint.

British firm debuts Euro LPG conversion for large vans, Oct. 2016

Fuel savings, along with CO2 and NOx emissions reductions, are among the promises from Alternatech for its LPG conversion system using Prins technology, designed for larger vans running with Euro 6 engines.

LPG conversion systems for larger vans running with Euro 6 engines are now available in the UK, and are designed and manufactured by Southampton-based Alternatech Fuel Systems Ltd.

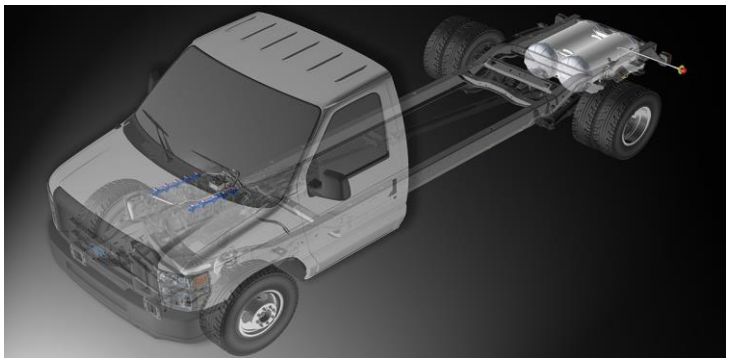
Apollo Cradles has become the first British operator to implement this innovative technology, leasing seven new Euro 6 Mercedes Sprinter vans converted to run on Autogas. It is the first time LPG has been available to UK customers at Euro 6, and urges van fleet operators to consider the environmentally friendly, cheaper fuel. Many companies are now realising that diesel is not the only answer to their fuel needs but until now no one has been able to source them on leased vehicles.

Alternatech's conversion system uses a VSI (vapour sequential injection) which is suitable for the latest generation direct injection engines.

New Autogas fuel system available for the 2018 Ford E-350

The Ford E-350 single-rear-wheel and dual-rear-wheel cutaway offers public transit agencies a smaller Autogas vehicle option for servicing routes with fewer customers. The Autogas Ford E-350 cutaway, whose fuel system has been developed by ROUSH CleanTech, will be available in 2018, with deliveries beginning by late spring.

In addition to transit shuttles, the Autogas Ford E-350 cutaway is well suited for Type A school buses and delivery trucks in markets such as food and beverage, and parcel. The vehicles maintain the same horsepower, torque and towing capacity as their Ford gasoline-fuelled counterparts, and are powered by a Ford 6.8L V10 2-valve engine. They will be certified by the U.S. Environmental Protection Agency (EPA) and California Air Resources Board (CARB) and compliant with heavy-duty on board diagnostics.



Each of the extended-range shuttles will emit about 90,000 fewer pounds of carbon dioxide over its lifetime compared to gasoline counterparts. In the United States, Autogas costs up to 40% less than gasoline and 50% less than diesel, and reduces maintenance costs due to its clean-burning properties.

3.3.4.2. Refuse and Garbage Trucks

Many niche market fleets, which operate specially designed vehicles that serve very specific functions, are ideal for the adoption of alternative fuels and advanced vehicle technologies. One prime example is the refuse hauler sector that could substantially decrease its petroleum consumption through the use of alternative fuel or advanced technology vehicles.

3.3.4.3. Utility Trucks

Spanish laundry commits to sustainability adding new Autogas vans

Las Palmas-based laundry El Cardon has converted part of its vehicle fleet to LPG as a major step towards improving air quality in the Island of Fuerteventura (Canary Islands).

Autogas is the only practical option with immediate results to cut emissions in the energy model of Fuerteventura, where power is always generated with fossil fuels.

The company, dedicated to laundry service on the island for 28 years, has converted its vehicles with the cooperation and expertise of DISA Gas. With this transition, El Cardon has obtained a double advantage: cost savings and increased contribution to the environmental protection and sustainability.

3.3.5. Forklift Trucks

Forklift trucks exist in various sizes, from small models operating in warehouse environment to large models found in seaport and airport areas serving container handling. Small size engines as those used in small forklift trucks, can justifiably also be assumed falling in the category of HD engines due to their heavy use and operation under heavy duty conditions, which require continuous and reliable performance.

LPG forklifts are used to engage, lift, and transfer palletised loads in warehousing, manufacturing, materials handling, and construction applications both indoors and outdoors and in their larger sizes handling container operations. Diesel, electricity and LPG are the 'big three' when it comes to fuel for fork lift trucks and each of the options has advantages and disadvantages but electricity and diesel do not compare well to the cleaner, greener LPG option.

Operators of forklift trucks choose LPG because it is the safe, cost-effective, clean and reliable solution, easy to refuel their needs and reduces the pilfering of fuel.

Advantages of LPG powered forklifts:

- **Affordable & cost effective**: LPG forklift trucks are significantly less expensive than their diesel equivalents and the LPG as a fuel is often more economical. They require less maintenance as they have less carbon build-up than gasoline and diesel engines. Spark plugs and engine oil last much longer contributing to these engines lasting up to twice as long as gasoline engines.
- **Effective:** LPG as a fuel source provides constant power to consistently lift, push and pull loads throughout the forklift's work shift. It allows for uneven surfaces and steep inclines to be tackled and also for operation times.
- **Fast**: LPG forklifts achieve higher acceleration and travel faster than their electric counterparts.
- **Strong & silent**: LPG forklifts are stronger than electric forklifts and significantly quieter than a diesel forklift.
- **Reliable**: They have the ability to push heavy loads at full capacity, faster, and for a longer amount of time than electric forklifts and maintain consistent, 100 % power throughout operation, with faster ground speeds than electric forklifts.
- **Quick to refuel**: It takes less time to fill a LPG tank than to switch or charge a battery. CNG powered trucks may take six hours to refill after as little as two hours of operation, and electric forklifts can take up to eight hours to recharge. It takes only five minutes to change a LPG cylinder or refill the tank.
- **Versatile:** LPG forklifts can be used in both indoor and outdoor applications, unlike their electric counterparts. They can even operate in temperatures as low as -20oC.
- **Environmentally friendly**: LPG has a smaller carbon footprint than diesel and gasoline, whilst it produces fewer PM10 particles (associated with respiratory problems) than diesel, and, if fitted with a 3-way catalyst, LPG forklifts are lead and soot free. LPG forklifts also carry their fuel in a sealed, pressure-tight system, eliminating a significant source of secondary pollution found that is with gasoline- and diesel-fuelled forklifts. Overall, LPG forklifts produce can produce up to 19% fewer emissions than gasoline forklifts and 7% fewer emissions than diesel forklifts.
- **Clean**: LPG produces fewer engine deposits than gasoline and diesel fuel, resulting in lower maintenance costs and extending engine life. Properly maintained LPG-powered forklifts produce significantly less emissions of carbon monoxide, nitrogen oxide, hydrocarbon, and particulate matter than comparable gasoline or diesel-powered forklifts. LPG-powered forklifts carry their fuel in a pressure-tight, sealed system that avoids any spillage

or evaporation into the atmosphere thus being suitable to be used also in semi closed warehouses.

- **Safe**: LPG forklift tanks, fuel lines and carburetion components meet strict specifications. Built-in safety devices automatically shut off the flow of fuel in case of an accident. There is no risk of spillages or contamination with LPG as it vaporises.
- **Secure:** LPG is less likely to be stolen from on site storage tanks than gasoline and diesel.

Main forklift manufacturers include:

Case Studies

New LPG Industrial Engine for Forklift

John Deere Power Systems (JDPS) has partnered with Crown Equipment to develop a 2.4L LPG industrial engine for the new Crown C-5 Series forklift. The new engine was designed specifically to power material handling equipment in demanding applications. The engine integrates John Deere's extensive experience in engineering and manufacturing of industrial diesel engines and Crown's five decades of material handling experience. The result of this collaboration is an innovative engine that is built specifically for IC forklifts. The new 2.4L LPG engine features a cast-iron head and large, robust components that are designed for reliability, durability, and long engine life. It also offers increased horsepower and low-end torque, enabling improved performance during acceleration, incline-loaded travel, and when carrying or pushing heavy loads. It can be used in Terminal Tractors, Side Loaders, Cranes and Generators.

3.3.6. Automated Guided Vehicles (GVs)

Wheelift engineered and built an LPG powered AGV system with continuous power, 140-ton load capacity, and self-loading capabilities. A consistent and repeatable manufacturing process that operates 24/7 traditionally calls for a hard automation solution. However, long distances, load variations, heavy loads, restricted facilities, and process disengagement lead a Midwest aluminium manufacturer to evaluate the flexibility and responsiveness that an AGV solution would offer. One decision led to the next and ultimately to a massive AGV design.

With Wheelift's LPG powered AGV, gone are the untimely battery drains, swap outs, deep cycle maintenance, safety compromises, cycle degradation, and opportunity charging facility intrusions, and born is the capability for 24/7 heavy-load, long-distance operations. The facility saw the following benefits immediately:

- Eliminated untimely battery drains, swap outs, deep cycle maintenance, safety compromises, cycle degradation, and other process intrusions with the continuous power LPG AGV.
- Cost reduction with the addition of a new furnace to handle throughput.
- Improved safety in a constricted working environment.

3.3.7. Construction Equipment

Construction equipment in general are amongst the largest energy and fuel consumers as well as amongst the largest polluters. Traditionally this sector has been occupied by diesel engines but in light of increasing environmental concerns, stricter emission regulations and also changing costs of related fuels, the scene may be changing towards other alternative fuels and LPG can play also a major role.

One of the most common for example dry bulk handling equipment is the excavator or loader that uses a bucket on the end of its movable arms to lift and move material. Any type of off-road tractor type machinery can in fact be considered under this category that is another potential target of large use of LPG.

This type of machinery, in terms also of conversion capabilities to LPG could be categorised into:

- Heavy Duty as e.g. the Volvo wheel-loaders and dump-trucks, that have engines made for on-road trucks and buses, with power from 320 to 480 hp.
- Super Heavy Duty as the CAT dump-trucks with 2,100 hp and the wheel-loaders and dump-trucks with Cummins QST30 and QSK60 engines, with power ranging from 1,200 hp (diesel fuel consumption till to 275 l/h) to 2,500 hp (diesel fuel consumption till to 570 l/h).

3.3.8. Mining Vehicles & Equipment

Mines and the mining industry is one more significant potential area of use of LPG. The high fuel consumptions involved in such heavy duty off road machinery, raise significant concerns related to health impact for the workers and the environment. Cost reduction and cost optimisation is also a significant added benefit for using LPG. The remoteness also of such operations, make LPG an ideal fuel that can be transported easily to the site in large quantities.

Off-road very heavy-duty dump trucks are being used to carry ore/stone on steep inclinations up from the quarry pits, very heavy duty equipment used also for the excavations. Within these pits, the concentration of NOx and other pollutants is always very high. Similar is the case also in tunnelling operations with underground mining equipment.

Diesel exhaust gases in a mine are a major concern for the health of the workers, both in terms of particulate matter and NOx, besides the general environmental pollution produced.

In addition, significant cost reductions can be achieved by using LPG either as a single fuel in LPG dedicated engines or as Diesel-LPG mix in diesel engines. This is an area that has not been well exploited but with new stricter regulations, e.g., the Non-Road Mobile Machinery (NRMM) regulation in Europe and other similar developments in other parts of the world, it needs to be more closely focused since it has the potential of delivering significant growth and benefits.

While serving as fuel for the HD machinery engines, LPG can also fuel smelting furnaces on site for materials such as gold, chrome and vanadium, furnace reline kits, crucibles and boilers. The presence of LPG on a mining site can also ensure adequate supply of energy for power generation, burner, heating and drying solutions as well as of course cooking and hot water services for the personnel and in general all operations of mine site mess halls, kitchens, ablution blocks and other workforce amenities.

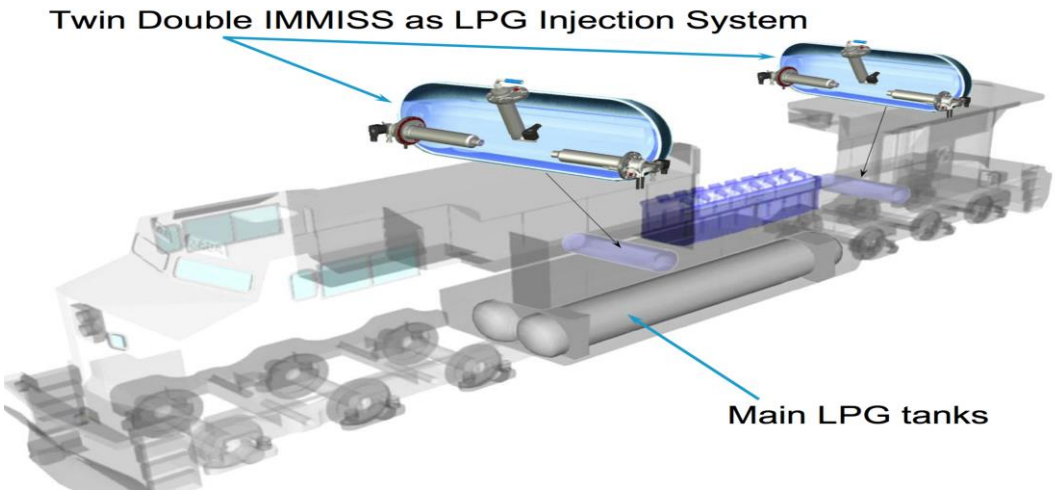
3.3.9. Trains

Train locomotives do heavy work - often 24 hours a day, seven days a week - sometimes operating in cities near residential areas, schools, hospitals, and other sensitive areas. Trains at non-electrified routes normally use diesel fuel and can emit high levels of air pollutants such as particulate matter (PM), oxides of nitrogen (NOx), and carbon monoxide (CO).

LPG can be used as a fuel either through diesel-LPG conversion technologies, or by converting already existing LNG/CNG engines to run on LPG.

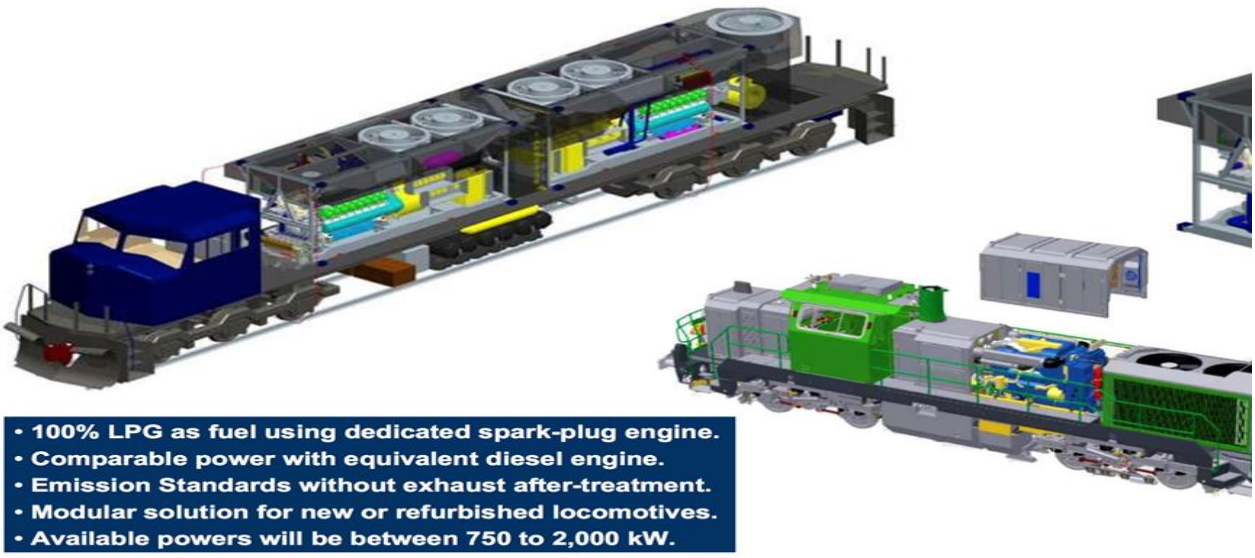
Trains are large consumers of diesel fuel and the benefits of converting them to run even partially on LPG would be very substantial. With locomotives on set routes, it is easy to build LPG infrastructure for supply.

The technology exists, schematic locomotive LPG installation diagrams below courtesy of **X-Tech**



Solution for 2,850hp LPG Locomotive, Twin Double LPG injection systems

Source: X-TECH R&P SA



Case studies

Solaris Diesel Dual Fuel Pilot

Solaris Diesel Dual Fuel developed the first engine for locomotives, a Solaris Diesel Dual Fuel system in the TEM2-278 diesel locomotive. TEM2 is a manoeuvre locomotive equipped with a diesel fuel tank with capacity of 5,400 litres. The installed Solaris Diesel Dual Fuel system is accompanied by five LPG tanks (180 litres each), three LPG reducers and special telemetry system made especially for the locomotive. Thanks to the Solaris Diesel Dual Fuel solution, the locomotive does not require direct support from technicians to set up the gas system parameters, all settings can be performed through remote connection. The locomotive will work in an environment friendly way, and additionally its owner – one of the largest logistics and transport companies in Kazakhstan – will start saving money on diesel costs.

LNG Fuelled Locomotive Engine

LNG/CNG fuelled engines can easily be converted to run on LPG. BNSF Railway Co., one of the largest consumers of diesel fuel in the US is testing such an LNG engine. It will use natural gas as fuel for the locomotives in the 6900 unit BNSF fleet. BNSF, in conjunction with GE and Caterpillar, is working on the technology. If the tests are successful, it could change the landscape of much of the transportation fuel market.

Omnitec CNG

LNG/CNG fuelled engines can easily be converted to run on LPG. Omnitek is using its CNG technology in two TEDOM natural gas locomotive engines powering a Czech Railways train in a pilot program with scheduled service three times daily between the Czech cities of Opava and Hlucín. The low-emission dedicated natural gas engines from TEDOM are certified to the Euro5 EEV emissions standard. The pilot program was developed by the transport division of Vitkovice Machinery Group and the Czech Railway Research Institution in cooperation with engine manufacturer TEDOM s.r.o. Ltd. The pilot program is seeking to demonstrate the economic, environmental and practical applications of CNG for

rail transportation.

3.3.10. Power Generators

Power generation, the supply of electrical power, is key to every activity today. With several developing areas still lacking consistent electrical grid power supply, power generators have become increasingly crucial to fill the consequent energy gap.

Heavy Duty LPG engines are a particularly well suited solution for the back-up / standby generation, for commercial and industrial sector. These engines operate on the same principles as gasoline and diesel automotive engines. They enjoy high volume mass production and are often the lowest capital cost per kW of capacity. In various forms, they suit the majority of decentralised power generation units for continuous use and for back-up power. Like automotive engines, they exist as compression ignition engines (diesel cycle, diesel-LPG) and spark ignition engines (mono fuel LPG Otto cycle).

Modern system developers typically launch products based on a natural gas engine first, but then they adapt it to an LPG version too. The differences between the two are minimal, exemplified by how they come off the same production line. Spark ignition engines have lower efficiencies due to the possibility of knocking - caused by over rapid combustion of fuel in the cylinder and they are usually also smaller in size.

Main Applications

- Peaking power plants in larger sizes to balance intermittent renewable energy generation.
- Back-up/standby generators in various sizes (typically diesel-LPG due to cheaper upfront cost).
- In mCHP units, in residential use (multi-family homes).
- In CHP units for commercial sites with high/higher than average heating demands, and a greater demand for heat relative to electricity.
- In CHP units for small industrial sites (e.g. food & drinks industry, textiles industry).
- In CCHP units to also provide cooling, but to date such installations have been in the minority.

They are available in a wide range of models with varying power output for continuous or standby use, even portable in their very small sizes. As standby generators, they are permanently connected to the existing power lines, ensuring power continuity even in the event of power failures coming from simple service disruptions or a natural disaster, such as a storm. A standby generator can even serve as a primary energy source for homes and businesses off the main grid.

Generator features tend to vary with size, manufacturer and model however there are several notable features and capacities that have been more recently developed that make LPG generators the top choice for off-grid power generation.

- They are versatile and often offer multiple fuelling options; LPG, natural gas (NG), combined LPG/NG and even biogas.
- Newer back-up generators include a transfer switchboard which monitors utility power levels and automatically transfer the electrical load to the generator if power is lost, protecting the home or business.
- Manufacturers of larger stand-by units tend to provide also bespoke noise-cancelling housing units and are ideal for sensitive environments, such as events and urban areas.
- Cogeneration units are now available that produce heat in addition to electricity.
- Premium generator sets can work also in tandem with off-grid renewable energy power generation technology, combined with solar, wind, or other renewable energy resources to create reliable, environmentally friendly hybrid systems

Larger portable and rental offerings are also an interesting segment in LPG power generation. Portable units can be delivered immediately to minimise downtime and keep facilities or industrial production running. Rented systems can be used for emergency outages, a planned project, or a temporary surge in demand.

The global power rental market is estimated to be a multi-billion-dollar market. Market growth will be driven by factors such as the growing demand for power, ageing grid infrastructure, lack of access to electricity, and increasing construction and infrastructural activities across the globe. Data is limited but it is estimated that much less than 10% of this market value accounts for the LPG rental and portable power generation market globally.

Main manufacturers active in this rental sector include companies like Caterpillar, Cummins, Aggreko, and Kohler for rental power needs of all sizes, from temporary, single-site power, to baseload-scale, multi-megawatt power for regional grids.

Manufacturers in in all sizes/sectors include: GE, Caterpillar, MAN, Cummins, Wartsila, Yanmar, MTU, Kohler, Perkins, Generac

Smaller portable units have started appearing also recently in the market manufactured by companies like Greengear/Cavagna.

3.3.11. Agricultural

Engines are used all over farms to power irrigation pumps and other motors. Their ubiquitous nature illustrates the important role of engines in agriculture and the large potential market in agriculture for LPG as an engine fuel.

There are indeed several agricultural applications related to the use of HD engines. Due to the substantial rise in the cost of gasoline and diesel in recent years, together with growing concerns about growers on environmental pollution, farmers are exploring alternative fuels and the LPG industry is assisting in their efforts to upgrade to more economical, more efficient and more environmentally friendly fuels. LPG provides a cleaner, greener, versatile energy source for farmers, whatever the application, it is a viable alternative fuel ready to power modern agriculture all across the world.

3.3.11.1. Irrigation Systems

Irrigation is an energy-intensive farming operation. In the USA, from 2008 to 2013, 25 % more farmers added LPG irrigation engines to their operations; there are more than 6,000 farms in the USA, irrigating 1.1 million acres.

Portable LPG engines are a convenient and economical way to drive irrigation pumps. These engines can also be disconnected from the pumps and used for other power needs such as generating electricity, powering mechanical grinding mills, and driving various types of manufacturing equipment.

Advanced LPG-fuelled stationary irrigation engines offer increased efficiency and reliability with reduced maintenance requirements.

Main advantages

- Farmers who switched to new LPG irrigation engines in the USA saw overall reductions of the order of 40% in fuel consumption, 75% in fuel costs and 48% in maintenance costs.

- LPG usage frees farmers from the task of transporting the fuel while eliminating diesel thievery in isolated locations.
- LPG produces 24 %fewer emissions, on average than comparable gasoline irrigation engines and 11 % fewer GHG emissions than diesel engines.
- It reduces maintenance costs by decreasing deposits on engine components and thus extending engine life, fewer oil and filter changes.
- It ensures reliable irrigation without grid-related power interruptions.
- No risk of spillage or groundwater contamination.
- Quieter running.
- LPG is a clean-burning, high-octane fuel (105 octane).

Manufacturers

More than 15 LPG-powered irrigation engines are now available in the USA from 1.5 lt to 21.9 lt, from various manufacturers as Bucks, EDI, Origin, PSI and SRC Power Systems.

3.3.11.2. Farming Tractors

Tractors are used intensively in farming operation. The development and adoption of HD LPG engines for these tractors can be for the farming industry a significant step forwards towards more economical, more efficient and more environmentally friendly operations.

A picture of the potential market of a list of countries is given by the sales of tractors in recent years:

Sales of new tractors in the Agrievolution countries (in units)

	2012	2013	2014
Canada	25.449	27.542	28.144
United States	185.333	201.851	208.274
Brazil	55.810	65.089	55.537
Japan (> 22 kW)	19.001	24.721	20.944
China (> 18 kW)	416.000	524.500	524.600
Korea (> 22 kW)	13.471	12.853	12.000
India	529.956	619.159	592.942
Russian Federation	41.827	40.158	37.500
Turkey	50.320	52.285	58.500
European Union	184.255	184.335	169.500
of which: France	38.754	42.656	33.127
of which: Germany	36.264	36.248	34.611
of which: Italy	19.343	19.018	18.178
of which: United Kingdom	14.964	13.490	13.526
World	**1.950.000**	**2.200.000**	**2.130.000**

China: statistic definition changes in 2013 and 2014
Source: Agrievolution, VDMA

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Advantages in the US market

- LPG is an already existing fuel in many agricultural operations
- Farmers are subject to tightening federal and state environmental regulations. LPG offers farmers a way to meet their energy needs without polluting the air, water, or soil. Using LPG instead of diesel reduces air pollutants like CO, NOx, SOx, volatile organic com- pounds (VOCs), and particulates, which are subject to strict air quality regulations. LPG also will not contaminate the land or water with spills or residues as other fuels can
- Increasing adoption of LPG vehicles
- New fuelling solutions in US (EN13760)
- Tier 4F impact on diesel engines

The LPG industry must embrace several challenges and opportunities to develop growth in agricultural markets and help farmers increase profitability.

LPG is already ideally suited in field applications that require energy away from natural gas mains or electricity, where diesel and gasoline are frequently used today. However, since LPG is a clean fuel, it can replace diesel and gasoline in engine uses, while generating a fraction of their emissions. In such applications, the LPG industry will have to justify a fuel switch with LPG technologies on cost, productivity, or environmental performance.

Case studies

New Prototype Farmer Tractors

Mid-size tractor

- New Holland T6050
- Rated engine horsepower: 125 hp
- PTO horsepower: 120 PTO hp
- NEF 5.9L, 6-cylinder in-line, turbo
- Fuel system: Direct vapor injection
- Fuel tank size:
  - Diesel = 79.3 gal
  - LPG cylinders = 43 gal
- Working run time estimation:
  - Diesel = 10+ hrs
  - LPG = 5.5+ hrs

Compact tractor

- New Holland Boomer 25
- Rated engine horsepower: 27 hp
- PTO horsepower: 19.9 PTO hp
- Fuel system: Indirect mechanical
- Fuel tank size:
  - Diesel = 8.7 gal
  - LPG = 7.9 gal
- Working runtime estimation:
  - Diesel = 10 hrs
  - LPG = 7.5 hrs

3.3.11.3. Forklifts

Forklifts represent also a large segment of the LPG agricultural market. They are widely used to engage, lift, and transfer palletized or other loads around the farm, both indoors and outdoors.

3.3.12. Heavy Duty Lawn Mowers

Commercial mowers are used on a daily basis to maintain residential lawns, sports fields, golf courses, parks, roadsides, and other public and commercial lands. Due to the vast amount of lawns and turf grass in some countries like the USA, mowing contributes significantly to greenhouse gas emissions to the point that many cities have banned the use of gasoline-fuelled commercial mowers before 1 p.m. on Ozone Action Days. As a result, cleaner commercial mowers are highly desirable and sometimes mandated by law.

Commercial LPG fuelled mowers are equipped with large LPG tanks/cylinders mounted on the mower to the engine through a clean, closed fuel system. Adoption of LPG in these engines results in fewer burned hydrocarbons entering the crankcase oil, which extends oil life, reduces maintenance needs, and improves overall system efficiency.

The following lawn equipment manufacturers offer LPG-powered EPA- and/or CARB-certified applications in 8 to 37 bhp levels.

Case studies

Forest preserves shifts to LPG
The Forest Preserves of Cook County converted 16 new gasoline-fuelled large riding lawn mowers to LPG power.

Maintaining 69,000 acres of open space requires a lot of vehicles and fuel. To mow the lawns in picnic groves and along roadsides, the agency maintains a fleet of 65 large riding mowers (16 of which are now LPG-fuelled), 102 push mowers and 108 line trimmers, all in heavy use from April through October. The factory conversion of 16 new Gravely Pro-Turn 472LP mowers to LPG lowered significantly the environmental impact of grove maintenance. By converting to LPG from unleaded gas in these mowers, the Forest Preserves will save approximately $0.89 per gallon. The use of LPG also extends engine life and reduces refuelling time in the field.

3.3.13. Marine engines

Given that onshore applications and onshore industry have been cutting emissions continuously, ship emissions are becoming a proportionally more significant part of total emissions. It is estimated that the ship emissions account for 2-4% of global CO2 emissions, 10-20% of global NO_X emissions and 4-8% of global SO2 emissions.

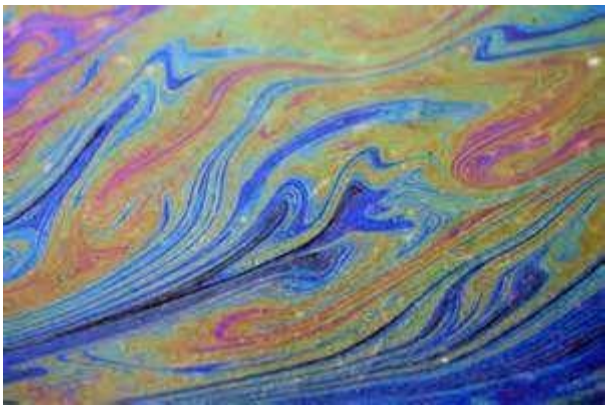
LPG is used as a fuel for power generating equipment in engines as small as 1kw generating capacity up to the largest gas turbines that can produce over 100MW. There is therefore no technical reason why LPG cannot be used in any water borne vessel; from the smallest recreational craft to the largest ocean going tankers.

With the further development of stringent regulations on ship emissions there is an opportunity for developing a future market for LPG as a marine fuel. LPG emissions are significantly lower compared with conventional fuels like HFO and MDO. Consequently, there are very good environmental reasons for using LPG in coastal areas and on inland waterways.

The environmental argument to convert from gasoline and diesel to LPG is strong because narrow boats, speed boats and fishing boats are frequently found on inland waterways, rivers and lakes where any form of fuel pollution can cause serious consequences to wild life, fish and the local environment.

Any spillage of gasoline and diesel will float on top of the water. The visual impact of a fuel spillage can be disturbing and lasting. Fuel spillages are most likely to occur during the refuelling or bunkering operation. The movement of a

boat connected to a refuelling hose is challenging enough but if the refuelling is being done from a floating fuel barge, or bunkering barge, it is even more so. There have been several incidents involving fuel spillages from bunker barges over the years and most have resulted in some form of environmental damage.



The result of an oil spillage on water

The use of LPG in boats and ships is being discussed at a time when there is great attention on diesel emissions and pressure has been put on the sulphur levels in traditional maritime fuels such as marine gas oil, and marine fuel oil.

- 90% of the world's goods are carried by sea.
- CO2 emissions from shipping are double those of aviation.
- Maritime CO2 emissions could rise by 75% in the next 15 to 20 years.
- Sulphur level in marine fuel oil being reduced from 3.5% to 0.5% by 2020 (IMO Oct 2016).
- CO2 monitoring for all ships to establish a base line for future reduction.
- EU leading the way but a global system is under negotiation within the IMO.
- Large ships using EU ports will from 2018 be required to report verified annual emissions.
- Pressure on marine fuels provides opportunities for gas to displace them.

Two sets of emission and fuel quality requirements are defined by MARPOL 73/78 Annex VI: global requirements, and more stringent requirements applicable to ships in Emission Control Areas (ECA). An Emission Control Area can be designated for SO_2 and PM, or NO_X, or all three types of emissions from ships.

From 2010, Annex VI to MARPOL 73/78 limited the sulphur content of marine fuel oil to 1.0% per mass in designated SO_X Sulphur Emission Control Areas (SECA) and 0.1% by 2015. In addition, from 1 January 2010 the directive 2005/33/EC came into force, limiting all ships on European inland waterways and in ports to use fuel with a sulphur content of 0.1% of mass.

The IMO emission standards for NO_X are commonly referred to as Tier I, II and III standards. On January 1, 2011 Tier II went into effect. From this date, onward, marine diesel engines may emit no more than 7,7 to 14,4 g/Kwh of NO_X depending on rating. Tier III enters into effect on January 1, 2016 with NO_X limit of 2,0 to 3,4 g/Kwh.

The International Maritime Organization's Marine Environment Protection Committee plans to implement a global sulphur cap on shipping by January 1, 2020. The years leading up to 2020 must now be used effectively to alleviate the consequences of the unprecedented disruptive change in supply of marine fuels by (January 1, 2020) and ensure a continued level playing field in the industry.

LPG has a significant potential in certain sectors including small tankers, container vessels and ro-ro ships that operate in coastal areas and on inland waterways.

As LPG is a by-product of LNG production, the existing price level for LPG is expected to reduce, making it more

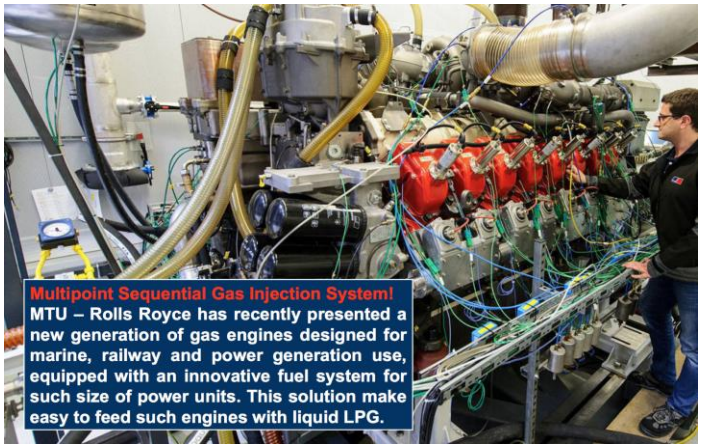
competitive with MDO and MGO. Since LPG is already a well-established fuel that enjoys a mature, global supply network with less-costly terminals and comparatively minor safety issues, older LPG carriers could function as bunkering stations as all have on board reliquefication plants installed which are less demanding and less expensive to run than such LNG systems. Furthermore, ship-to-ship loading of LPG is not considered complicated.

There is a major opportunity today for the LPG industry to establish the LPG as a credible alternative fuel to displace gasoline and diesel fuel in the marine market since:

- Emissions and utilisation of marine engines contribute to a number of very serious water and air pollution problems Gasoline and diesel fuels in the water are harmful to humans and in many cases fatal to aquatic life. Floating fuels and oils are also particularly noxious because they reduce light penetration and the exchange of oxygen at the water's surface
- The LPG is the most widely used and accepted alternative to the conventional oil-based transport fuels: gasoline and diesel
- The recent emissions regulations today dictate the use of low sulphur fuels in the water
- Alternative fuels like LPG are a very viable choice – as they are almost all sulphur free
- There are many questions and concerns about the cost of low sulphur diesel today and even more in the future
- The higher costs of low sulphur diesel could make the use of alternatives a reality much sooner

The LPG for marine use is a major opportunity for the LPG industry and it constitutes a credible alternative to the conventional fuels gasoline, diesel and heavier alternatives. Emissions regulations today dictate the use of low sulphur fuels and alternative fuels like LPG are a viable choice being comparably almost all sulphur free. There are many questions about the cost of low sulphur diesel and the higher costs of low sulphur diesel could make the use of alternatives a reality much sooner.

In larger ships, substantial emission benefits can be obtained, especially with regard to SOx, PM and CO2. NOx emission reductions and IMO Tier 3 targets can be achieved if LPG operation is combined with either an SCR or EGR system. Additionally, LPG sulphur levels are naturally minimal. The use of LPG as a marine fuel can play a significant role in certain sectors including small tankers, container vessels and ro-ro ships that operate in coastal areas and on inland waterways.



V16 - 2000 kW gas engine
one injection rail each 4 cylinders

There are many other advantages related to the use of LPG as a marine fuel and especially for small boat engines:

- It is more reliable for occasional used equipment as are often the outboard engines.
- It reduces VOC evaporative emissions/ a new requirement in commercial ports around the world.
- It meets local/regional/global emissions standards for inland water ways lakes rivers.
- It is not a marine pollutant.
- It has lower lifecycle costs - lower cost of ownership.
- It minimizes maintenance costs.
- It eliminates ethanol problems.

- It meets worldwide emissions standards/IMO (International Maritime Organization) requirements.
- An LPG filling station installed on pontoons for marine use, with tank and dispenser unit, costs few thousand Euro and can be easily and quickly positioned at any place at very limited cost without any environmental and pollution risk. LPG tanks are usually not regulated by the Environmental Authorities.
- In the UK, many seaports have LPG filling stations and more are located around Europe e.g. Germany, Venice etc.

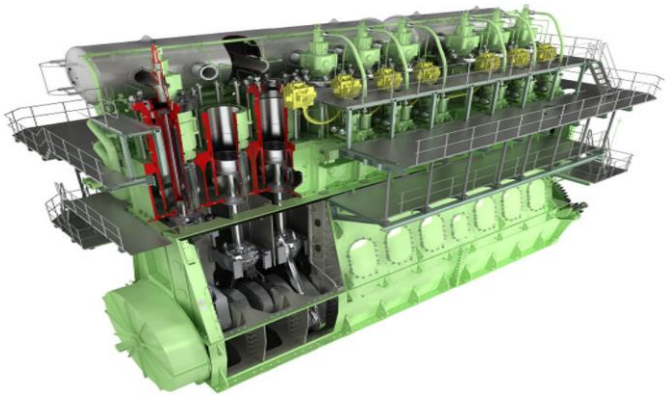
Case Study

MAN has launched new LPG engine in 2013

MAN Diesel & Turbo has introduced a new Liquid ME-GI (liquid gas injection) engine, which is powered by LPG. This engine is called Liquid ME-GI. With increasing fuel prices and upcoming shipping regulations, the company identified the need to develop an engine that can enable ships to run on alternative fuels with enhanced environmental benefits. The ability of the ME-LGI engine to run on sulphur-free fuels offers great potential.

The Liquid ME-GI is a variant of MAN Diesel & Turbo's ME-GI engine, which uses a control and safety system based on experience gained at working gas plants, including a 12K80MC-GI-S in Japan, and the development of a VOC (volatile organic compound) engine in the late 1990s.

The Liquid ME-GI engine's performance is equivalent in terms of output, efficiency and rpm to MAN's ME-C and ME-B series.



The ME and ME-B series provide the design basis for the ME-GI dual-fuel engine, in both its LNG and LPG variants. However, as the density of LPG in liquid form is higher than the density of natural gas in its gaseous state, some changes to components and auxiliaries are necessary in the ME-GI/LPG version. GI/LPG engine components can be smaller, but the LPG has to be pressurised to 550bar compared with 250bar to 300bar for natural gas. The higher pressure is necessary to achieve complete atomisation of the liquid fuel at the injector nozzles.

Dual-fuel operation requires the injection of both pilot fuel oil and LPG fuel into the combustion chamber via different types of valves arranged in the cylinder head. The ME-GI engine head is fitted with two valves for LPG injection and two for pilot fuel.

Advantages

- LPG-fuelled engines experience safe and reliable running with comparatively low maintenance costs while gas valves and gas pipes are smaller but similar to those of the well-known ME-GI engine.
- The Liquid ME-GI engine uses liquid gas for injection all the way from tank to engine and non-cryogenic pumps can be used to generate the required pressure, comprising standard, proven equipment readily available from a large number of suppliers within the LPG industry.
- Operation on LPG seems also to solve the logistics problems that LNG has at this time since LPG, in principle, is accessible over almost all the planet. Furthermore, cryogenic technology is not required, which makes LPG auxiliary systems less expensive compared with LNG.
- By introducing LPG as fuel to the dual-fuel GI system, substantial emission benefits can be obtained, especially with regard to SOx, PM and CO2. NOx emission reductions and IMO Tier 3 targets can be achieved if LPG operation is combined with either an SCR or EGR system.
- LPG sulphur levels are naturally minimal.

- In the case of an ME-GI engine designed to run on LPG, the dual-fuel capability offers the owner or operator the opportunity to shift between HFO and LPG in accordance with price changes and varying emission controls and regulations, depending on where the ship is trading.
- LPG supply network is far easier because LPG terminals are less costly
- Older LPG carriers could be brought into use to function as bunkering stations. These all have on board reliquefication plants, which are less expensive to run compared to LPG reliquefication systems.
- Ship to ship loading of LPG is uncomplicated and is a realistic prospect for bunkering LPG from an LPG carrier. Some MAN DIESEL & TURBO gensets already run on LPG abroad LPG carriers.

Market potentiality

Low-grade ship bunker fuel (or heavy fuel oil) has up to 2,000 times the sulphur content of diesel fuel used in US and European automobiles. This presents a strong case for action. Although the engines on recreational vessels typically run on gasoline and diesel they all have the capability to be converted to LPG. Some manufacturers have already designed engines to run on LPG for recreational vessels.

In some cases, there might be some compelling environmental reasons to switch to LPG. Perhaps restrictions on the use of gasoline or diesel in certain inland waterways. Or perhaps the justification to convert these engines to run on LPG will be mainly based on the relative cost of LPG to diesel or gasoline.

A key concern for users in this category - either choosing, or switching to, LPG - would be performance. Power output and torque from the engine is important for these types of applications and engines running on LPG would be under scrutiny for comparable performance.

Operation on LPG solves the logistics problems that LNG has since LPG is accessible almost worldwide. Furthermore, cryogenic technology is not required, which makes LPG auxiliary systems less expensive compared with LNG. It is expected the development of gas liquid injection to have sizable impact on the market in the near future. Other market segments targeted for such plan are small tankers engaged in coastal and waterway transportation.

Additional cases

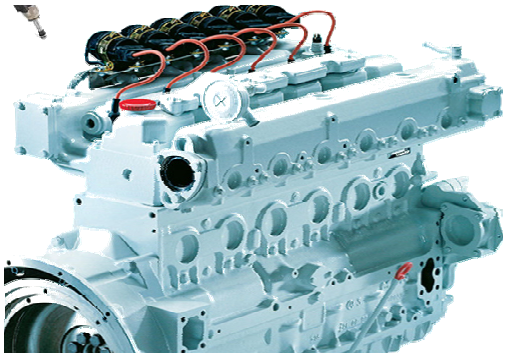
It was announced that a Japanese LPG importer will introduce VLGC fueled by LPG into their fleet around 2020.
Also, KLPGA Korean LPG Association is discussing a project to develop a ferryboat fueled by LPG.

Smaller Commercial Boat Engines

LPG is a very attractive fuel in many segments of the commercial marine market. Its undeniable environmental benefits make it an ideal fuel for use in environmentally protected areas, lakes, rivers but also largely in fishing fleets where water contamination from the marine fuel can have severe adverse effects. The use of LPG as an engine fuel is particularly popular in boats operating in salmon fishing farms.

Besides its environmental benefits, in many countries the use of LPG in the marine segment provides also significant cost saving opportunities for fleets and other boat operators.

LPG is also very attractive fuel also in smaller commercial boat engine segment and it constitutes an ideal fuel for use in environmentally protected areas, lakes, rivers but also largely in fishing fleets where water contamination from the marine fuel can have severe adverse effects. The use of LPG as an engine fuel is particularly popular in boats operating in salmon and other fishing farms. Besides its environmental benefits, in many countries the use of LPG in the marine segment provides also significant cost saving opportunities for fleets and other boat operators.



LPG and natural gas have major advantages over the use of MDO and HFO when it comes to emissions and provide a solution to these restricted areas.

Benefits

Significant benefits associated with the use of LPG in marine engines:

- Fuel cost savings.
- Reliability and maintenance advantages in the both commercial and recreational market.
- Significant environmental advantages.
- Being an ideal engine fuel by solving major engine reliability and maintenance issues and avoiding ethanol related engine and fuel tank issues.
- Allowing amongst an increasingly environmentally conscious base of users, safe use of marine engines in environmentally sensitive areas and particularly in state and local marine fisheries, harbour patrol and safety vessels.

Advantages: LPG vs. CNG

	LPG	CNG
Recreational Marine Use	✓	
Commercial Marine Use	✓	✓
Efficiency	✓	✓
Operating Cost		✓
Investment Cost	✓	
Ease of Refueling	✓	
Existing Refueling Infrastructure (Commercial)	✓	
Installing Refueling Infrastructure	✓	
Safety	✓	✓

(courtesy Lehr)

3.3.14. Static uses, other

3.3.14.1. Combined Heat and Power (CHP)

Combined Heat and Power (CHP) Systems (or mCHP -micro-CHP- in smaller sizes), are relatively new systems that allow simultaneous generation of electricity, power and also heat. These systems use also HD Engines and HD LPG engines.

This process, also commonly referred to as 'cogeneration', allows for heat and electricity to be produced simultaneously using a single fuel source and constitutes an energy efficient solution that can cut both carbon emissions and energy costs by generating electricity on site.

The component of the CHP system that converts fuel to useful work (prime mover) can be an internal combustion engine running on LPG. This prime mover is in turn connected to an electricity generator. Heat exchangers capture the residual heat produced and transfer for space heating or water heating purposes. LPG-fuelled CHP systems hence produce thermal and power output, addressing both heating and electrical needs for institutional, agricultural, commercial, and industrial facilities.

Micro-combined heat and power (micro-CHP) systems are such systems of a smaller scale. They are used mainly in residential developments and small businesses

Features

- CHP systems are compatible with a variety of HVAC (heating, ventilation & air conditioning) systems and can be easily added or retrofitted to an existing CHP system, helping it to operate more efficiently
- They run quietly and are vibration free, emitting marginally sounder than a typical refrigerator
- Micro-CHPs have a very small footprint and are typically no larger than a regular air-conditioning unit/gas boiler

Benefits

- CHP systems provide heat and generate electricity with higher efficiency and lower emissions levels than conventional heating and grid-supplied power. Thermal energy generated by the Micro-CHP unit can be used for many different needs including space-heating, water-heating, as well as pool & spa heating
- Cheaper electricity: Depending on geographical region, electricity produced on-site can cost less than half of what it would if bought from a power supplied
- Self-Dependence: Another benefit is that CHP systems offer a degree of independence from external providers
- Greater efficiency: On-site electricity production also avoids the typical losses that are associated with national/regional transmission and distribution networks effectively making CHP electricity more efficient than grid electricity. This makes CHPs up to 70-90% energy efficient (electric and thermal), significantly reducing carbon emissions
- Avoided Costs: The avoided use of the wider electricity network reduces (in principle) the maintenance requirements of such infrastructure from the electric utilities/network operators, which (in theory) has a positive effect on standing charges. In some countries, this aspect is rewarded through a utility payment
- Potential additional income: electricity can be fed and sold back to the grid, often at a reasonable price

- Heat Storage: Excess thermal energy may also be stored, in a buffer, for consumption at a later time (in the order of days)
- Back-up assistance: CHP systems can be quickly fired-up to assist with electricity production at times of peak demand. This helps cuts fuel bills. Many parties are now looking into the idea of a 'virtual power plant' of many connected CHPs
- Controllability/predictability: CHP generation is controllable. It provides electricity on demand, in contrast to other low-carbon but inherently intermittent technologies like e.g. solar PV or wind power

3.3.14.2. Freezing Units-Refrigeration, Air Conditioning

Climate change and global warming have demanded accessible, affordable and environmentally-friendly cooling systems - not just in the form of refrigerators but also air conditioners. LPG can fuel the engines of a variety of cooling systems, freezing units and air conditioners in commercial, industrial, retail and other applications, including in refrigerated trucks as those shown in the picture below.

3.3.15. Airport-Aircraft Ground Support

With both the cost and environmental challenges facing the aviation industry in recent years, LPG remains a very viable solution that can mitigate the two daunting challenges. LPG influence is growing in the sector. Fuelling LPG HD engines can power a variety of ground service vehicles and equipment. It can also be used for electricity generation through mobile, portable or backup generators, as well as heating and lighting purposes. Existing engines on various equipment at the airports can also be converted to run on LPG that is more economical, providing better reliability and ease of maintenance.

The benefit of such a switch shows LPG ground service equipment engines powered by LPG performing reliably and producing fewer emissions than similar equipment fuelled by gasoline or diesel.

Ground Service Equipment

Ground service equipment include vehicles that service and support the operations of aircraft between flights on the airport apron. Examples include pushback tugs, baggage carts and handlers, air starters, belt loaders, airplane tow trucks, catering vehicles and others.

Ground service equipment frequently sit unused for long periods of time, during which traditionally used diesel fuel tends to stratify, creating performance issues. Additionally, daily usage of ground service equipment in the busy aviation industry has created increasing emissions concerns.

In 2003, US Congress established the Voluntary Airport Low Emission Vehicle Program (VALE) to reduce airport ground emissions at commercial service airports located in air quality nonattainment and maintenance areas.

3.3.16. Sea Port Handling Machinery

While every port is different in terms of the mix of cargo handled, most ports have a variety of diesel-powered equipment to move freight and provide key services to the port. These include heavy-duty trucks, cranes, FLT, and other vehicles and yard equipment used to move freight.

About one in ten of the ports are located in areas classified as non-attainment for one or more pollutants including particulate matter, or soot, and oxides of nitrogen, a smog forming compound. Today, every aspect of the shipping industry is being developed and upgraded to tackle with the problem of environmental pollution. Several regulations along with modern technology are being used to counteract this problem.

A sector where the shipping industry and related services is concentrating more is the cargo handling sector. Modern and efficient operations in this sector can definitely bring environmental benefits. A well-planned cargo operation both in port and on ship can reduce the level of emissions and reduce costs.

Significant emission reduction benefits may be achieved by the adoption of alternative fuel technologies that power the engines of the vehicles and of the various machinery and equipment in port operations. New LPG engines technology is available in commercial trucks and material handling equipment. Below is a description of the most common equipment types.

Container Handling Equipment

Yard Truck

The most common type of cargo handling equipment at ports and intermodal rail yards is a yard truck. Yard trucks are also known as yard goats, utility tractor rigs (UTRs), hustlers, yard hostlers, and yard tractors. Yard trucks are very similar to heavy-duty on-road truck tractors, but historically, the majority has been equipped with off-road engines. There is limited availability of those powered by LPG, CNG or LNG.

Yard Truck

Top Handler

Side Handler

Top Handler

Another very common type of container handling equipment is the top handler. Also, known as top picks, top handlers are large truck-like vehicles.

Side Handler

Like the top handler, side handlers (or side picks) are used to lift and stack cargo containers. They look very similar to a top pick, but instead of grabbing the containers from the top, their boom arm extends the width of a container to lift it from the front face (or side). Side handlers are most often used to lift empty containers; however, some are manufactured to lift loaded containers.

Reach Stacker

Another member of the cargo container handling family is the reach stacker. Similar to a top pick, the reach stacker has a telescopic boom (usually attached behind the cab) that moves upward and outward in order to reach over two or more stacks of containers. Reach stackers lock onto the top of the containers in a similar fashion to top handlers.

Reach Stacker

RTG Crane

Gantry Crane

Rubber-tired gantry cranes (RTGs) and rail-mounted gantry cranes (RMGs) are very large cargo container handlers that have a lifting mechanism mounted on a cross-beam supported on vertical legs which run on either rubber tires or rails.

Shuttle and Straddle Carriers

Shuttle and straddle carriers are large cargo container handlers that have a lifting mechanism mounted on a cross-beam supported on vertical legs which run on rubber tires. The propulsion of the crane is slow (less than 20 miles per hour).
The majority of shuttle and straddle carrier engines have horsepower ratings on the order of 200 to 400 hp with a lift capacity range of approximately 40 to 60 tons.

Automated Guided Vehicles (AGVs)

Automated Guided Vehicles (AGVs) utilise a variety of guidance technologies (guide wire, laser positioning, embedded magnets, etc.) to deliver freight from Point A to Point B without hands-on human control. AGVs can be employed at a broad range of freight handling facilities. AGVs used for freight transport are battery electric vehicles that typically either have freight handling capabilities similar to small forklifts or which perform duties similar to yard trucks.

There are additional types of lifts operating at warehouse distribution centres in California, USA. These include stackers, aerial lifts, and man lifts. This equipment is mainly powered by electricity (battery or fuel cell) or LPG to maintain indoor air quality.

3.3.17. Other Heavy Duty Engine Applications

LPG Screeners

Lake Erie Portable Screeners introduced an LPG-powered screener as a clean and cost-effective alternative to diesel power. The new Pitbull 2300 LPG Screening Plant is one of the first of its kind, delivering maximum efficiency and high outputs with a wide range of materials. Units are ideal for processing topsoil, mulch, gravel, stone and asphalt, and with proper setup and screen combinations, are efficient in composting and C&D recycling applications specifically. The machine's low-emission LPG components provide an alternative to diesel equipment affected by the spike in prices caused by Tier 4 Final emission standards.

The Pitbull 2300P is featuring a Zenith 1.6-liter, 4-cylinder, 48-horsepower LPG engine that's easier to maintain, allowing it to run longer with fewer repairs. That combination makes the machine a valuable and cost-effective tool for landscapers, energy facilities, contractors, municipal workers or as part of rental fleets. In addition, T4F diesel engines of the same size typically cost at least 30 percent more.

The extremely low emissions make the Pitbull 2300P ideal for operation in confined spaces, such as buildings and mine shafts, and eliminate the need to obtain special permits. The Pitbull 2300P also provides a significant return on investment by making it unnecessary to buy or rent expensive ventilation systems and masks that would be required to run a diesel model in a tight space. The LPG engine is also quieter than most diesels.

Industrial Sweepers

Floor cleaners

Ice resurfacer

3.4. Main Players

The main players in the HD Engine segment consist of engine only manufacturers, technology developers, as well as manufacturers of equipment, machinery and vehicles that use these engines.

Several players exist in developed countries; some have grown to regional giants in their market. Others are appearing in emerging markets that have the potential to outgrow their current positions as regional giants or niche players. The current group of regional giants may shrink to include just a few Chinese and Indian OEMs. Consolidation among global groups is also taking place.

The number of OEM quality platforms for HD fleet applications is growing with partners in the US such as Roush CleanTech, CleanFuel USA, Freightliner Custom Chassis, Blue Bird, Collins Bus, Thomas Built Bus, Alliance Autogas, ICOM North America, Isuzu and others.

Some manufacturer and engine developments:

- A new LPG product from Roush Industries: the Roush Ford F-150, powered by a 5.4-L V8 engine using a retrofit system by ICOM of Italy. The liquid LPG 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 LPITM. The system claims to result in more complete combustion, improved fuel economy, and a 300-mile range.
- In 2009, Roush began offering the F-250 and F-350 using the LPITM system with the 5.4-L V8 engine. Roush and Ford released an E-450 cutaway with a 6.8-L V10 engine for shuttle van applications.
- Blue Bird Bus Corporation also chose the CleanFUEL USA LPITM system and tank configuration for its new Blue Bird LPG 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.
- Collins Bus Corporation, the largest builder of Type A school buses, announced a partnership with CleanFUEL USA that it would be developing a LPG version with a liquid LPG injection system in several of its GM dual- rear-wheel models, using a GM 6.0-L engine.
- CleanFUEL USA certified the GM 6.0-L engine, with an improved LPITM system. In addition to the Collins school bus, this engine is used for cab van cutaways and a variety of applications, such as shuttles, passenger and walk-in vans, and utility vehicles.
- Off-road forklift market offers OEM product offerings powered by LPG. Kawasaki Motors has a lower nitrogen oxides (NOx) option for non-road LPG 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.
- There are now eight manufacturers of LPG-fuelled zero-turn-radius mowers.

Natural gas engines (CNG/LNG) made by FPT/IVECO, Cummins, MAN, Mercedes, Doosan and Liebherr could easily be converted to LPG with better results regarding emissions. Below a list of engine makers, including some information about the CNG and LPG heavy-duty vehicles available on such market, with indication of type of gas engine in use there.

FPT/IVECO
Develops and manufactures engines for buses, trucks and other applications as well as various types of HD vehicles. The largest 8.0 l Cursor is now offered in a new version with 400 hp power, for trucks use.

Cummins Westport
Developer of gas engines, including LPG. Cummins Westport is also interested in the European market for its engines.

MAN

One of the most important manufacturers of HD engines. Today they focus on promoting the use of the smallest and modern gas engine on 12 m buses. For the articulated 18 m buses, they still use the large 12 litre engine, the same up-dated model they have been using for 20 years, also in a LPG version on the buses in Vienna.

Mercedes

Mercedes currently only produces the M-936 7.7 l model, which is planned to be made in the U.S. by Detroit Diesel. It appears that the older Mercedes 12 l model (like the MAN equivalent), used on 18m articulated buses is being stopped from production.

Doosan

This South Korean manufacturer has been licensing engines from MAN in the Far East for some time. The majority of their engines are very similar to MAN engines, but the most recent CNG engine models for buses and trucks are Doosan designed. The industrial gas engines models can easily be converted on LPG and used on various types of machinery, marine and for electricity generation.

Liebherr

This Swiss renowned manufacturer of super heavy-duty machinery also has its own interesting production of gas engines, sold mainly for cogeneration. The 12 lt model has been developed for Kamaz to be used on heavy-duty trucks, and the entire range is excellent for installation on earth-moving machinery, construction and mining, along with top quality machineries that use diesel twin engines. In addition, the cogeneration models are also ready for marine, for example, the many barges around major European rivers.

There are several other engine manufacturers of natural gas engines that could potentially be converted to LPG for heavy-duty purpose with varying size capacities. These manufacturers include:

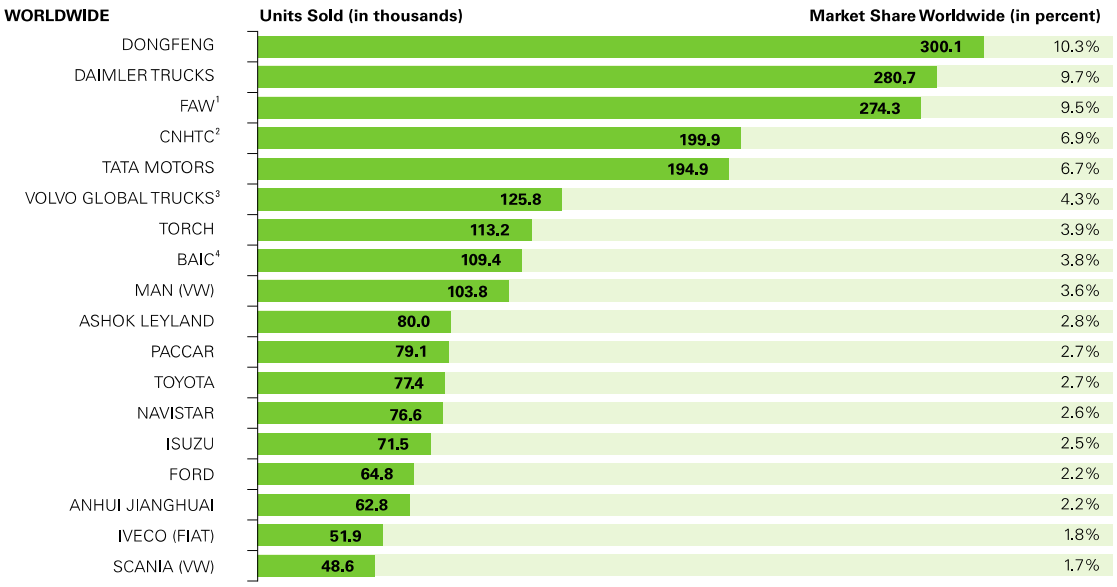
- Caterpillar
- MTU/Rolls Royce
- Baudouin
- MWM
- Deutz
- Kubota
- Yanmar

The table below summarises the brands and corporate parent manufacturers along with the segments and region of focus. Daimler, Volvo, and Paccar all have heavy stakes in both the EU and US market, whereas Iveco and Volkswagen are focused on the EU market and the cornerstone market for Navistar international is North America.

The manufacturers must take advantage of synergies between US and EU markets. EU fleets and US are not identical. There are, however, opportunities to take advantage of the ability to achieve greater economies of scale, including the development of technologies by common manufacturers and suppliers, and learning lessons from the approach of the US to increasing HDV efficiency. There is a significant amount of new publicly available research on HDV efficiency technologies in the US that could be utilised to educate the EU market. There are only a handful of manufacturers that sell HDVs in both the North American and EU markets. Each global manufacturer typically sells vehicles under a number of different brand names as shown below.

Corporate Parent	Brands	Main segment	Key market
Daimler	Freightliner	Tractor/Rigid	N. America
	Western Star	Tractor	N. America
	Mercedes –Benz Trucks	Tractor	EU/Int'l
	Mitsubishi - Fuso	Rigid	EU/N. America/Other
	Thomas Built	Bus	N. America
	Setra	Bus	EU/Other
	Bharat Benz	Rigid	Other
	Mercedes-Benz Omnibusse	Bus	Other
	Mercedes Benz Vans	Vans	Other
Volvo	Volvo	Tractor/Rigid	EU
	Mack	Tractor	N. America
	UD	Rigid	N. America/Other
	Renault Trucks	Tractor/Rigid	EU/Other
	Prevost	Bus	N. America
	Nova Bus	Bus	N. America
PACCAR	Kenworth	Tractor	N. America
	Peterbilt	Tractor	N. America
	DAF	Tractor	EU
Volkswagen	MAN	Tractor/Rigid/Bus	EU
	Scania	Tractor/Rigid/Bus	EU
	VW	Vans	EU
Navistar International	Navistar International	Tractor/Rigid	N. America
Iveco	Iveco	Tractor/Rigid	EU
Isuzu	Isuzu NPR HD	Rigid truck	N. America

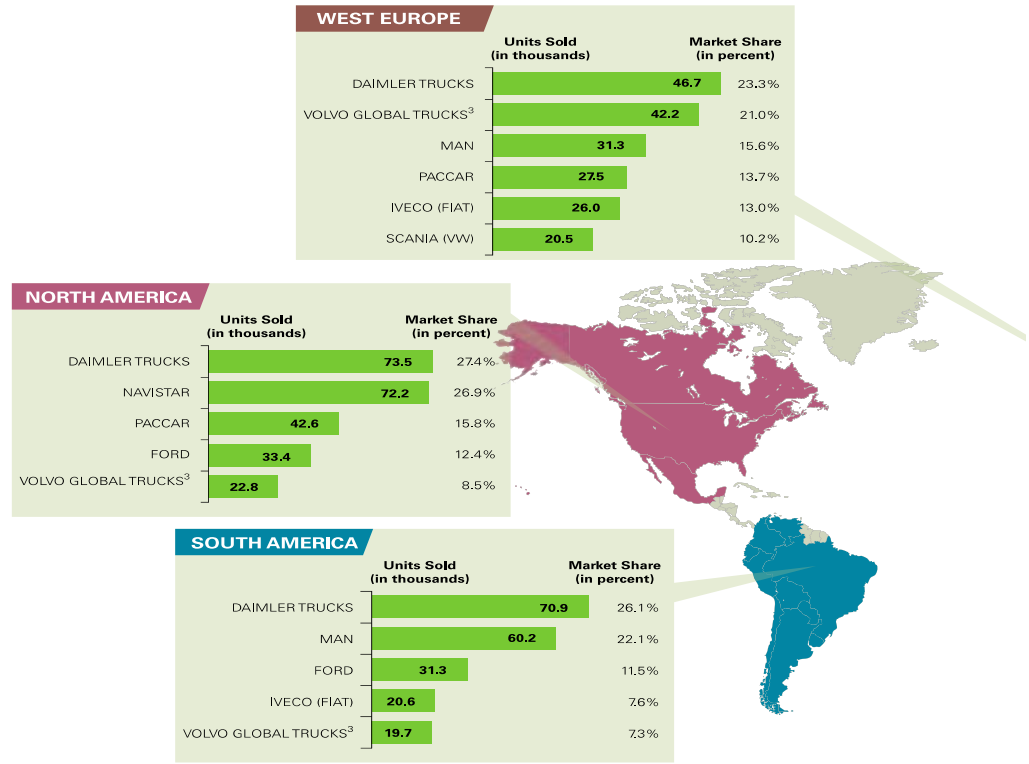
International key players in heavy commercial vehicle in 2010 (GVW > 6 tons)



[1] First Automotive Works
[2] China National Heavy Duty Truck Corp.
[3] Volvo, Renault Trucks, Mack
[4] Beijing Automotive Industry Corp. (Auman, EuroV, Beiqi Foton)

Source: IHS Automotive, KPMG International

Leading players in key regions and markets in 2010 (GVW > 6 tons)



Source: IHS Automotive, KPMG International

The table below summarises known OEM engines and LPG developers in various applications.

MANUFACTURER	VECHICLE OEMs	FLTs	TRUCKS	SWEEPER	BUSES	SCHOOL BUSES	MARINE	TRAINS	AGRICULTURAL	TRACTOR	INDUSTRIAL ENGINES	STATIONARY
	UNICARRIERS	DX15-GX50										
	MAN						B&W ME-LGI					
	CATERPILLAR	1.5-3.5 tn										30eKW-235eKW
WESTPORT	CUMMINS					B LPG 195						
WESTPORT	CUMMINS			ISL G8 9L								
	FORD MOTOR CO		5.4L V8,2.0L I4	2.5L								
	GENERAL MOTORS		6.0 L V8	3.0L								
	MERCEDES											
	LIEBHERR											
	FPT/IVECO											
	eNGINES										15 hp - 350 hp	
	KUBOTA										23.5hp-31hp	
TEDOM												TP 90 G5V NX 86, TP 145 G5V TX 86,TP 160 G5V TW 86
	SUBARU										2.8-36 hp engines	
POWERTRAIN INTEGRATION,CLEAN FUEL USA	FREIGHTLINER		S2G,LPG MT-45		PIthon™, the 8.0L							
CLEAN FUEL USA	GENERAL MOTORS		8.0L V8 LPI									AGM30Si
	JOHN DEERE									John Deere 5.9L 6-cyl LP gas		
	WINNEBAGO INDUSTRIES & ICOM				ICOM Bi-Fuel and Mono-fuel Liquid Propane Injection System							
SOLARIS DIESEL DUAL FUEL	GREEN AUTO SERVICE							TEM2-278				
ROUCH CLEANTECH	BLUE BIRD VISION/FORD		6.8L V10 LIQUID			6.8L V10 LIQUID						
POE SOLUTIONS INTERNATIONAL	IC BUS CE SERIES				PSI8.8L V8	8.8-L LP p						
CLEAN FUEL USA	CROWN EQUIPMENT CO	2.4L LPG										
POWERTRAIN INTEGRATION,CLEAN FUEL USA	THOMAS BUILT BUSES				PIthon™, the 8.0L	Minotour® PSII6.0L V8						
	KALMAR OTTAWA		Class 4 truck delivery									
	KRYSTAL KOACH				Class 6 shuttle bus							
	TROLLEY ENTERPRISES				Propane Trolley Bus							
	TYMCO		Model 600 Class 7 work truck									
	FOTON AMERICA		LD 1000 FOTON LOVAL 140hp,Class 3 truck delivery									
	BAYTECH CORPORATION		W62 6L W42		GMC CHEVY C4500/C5500							
	E -BUS				Propane Hybrid-Electric Transit Bus and Trolley							
	EL DORADO NATIONAL				EZ Rider II 30/35 Cummins Class 7 Transit Bus XHF29/33/35 Cummins Class 8 transit bus							
BI PHASE TECHNOLOGIES	ALCANE TRUCK CO		LLC LPEFI8.1L V8									
AMERICAN ALTERNATIVE BI FUEL	GENERAL MOTORS		6.0L V8									
AMERICAN ALTERNATIVE BI FUEL	FORD MOTOR CO		6.8L V10									
CLEAN FUEL USA	COLLINS				6.0L V8 LPI	6.0L V8 LPI						
	BUCKS								IRRIGATION			
	EDI								IRRIGATION			
	ORIGIN								IRRIGATION			
	PSI								IRRIGATION			
	SRC POWER SOLUTIONS								IRRIGATION			
	GREENGEAR											GENERATOR
	MITSUBISHI	1.5-5.5 tn										
	LIUGONG	3.5-5 tn										
	KOMATSU	1.5-3.5 tn										
	HYUNDAI	1.5-7.0 tn										
	DOOSAN/MAN	4.0-5.5 tn										
	HAMECH	1.5-9 tn										
WARTSILA HAMWORTHY							X				34 SG	
KEM			5.7L									
X-TECH			X				X				MARINE,TRUCKS	

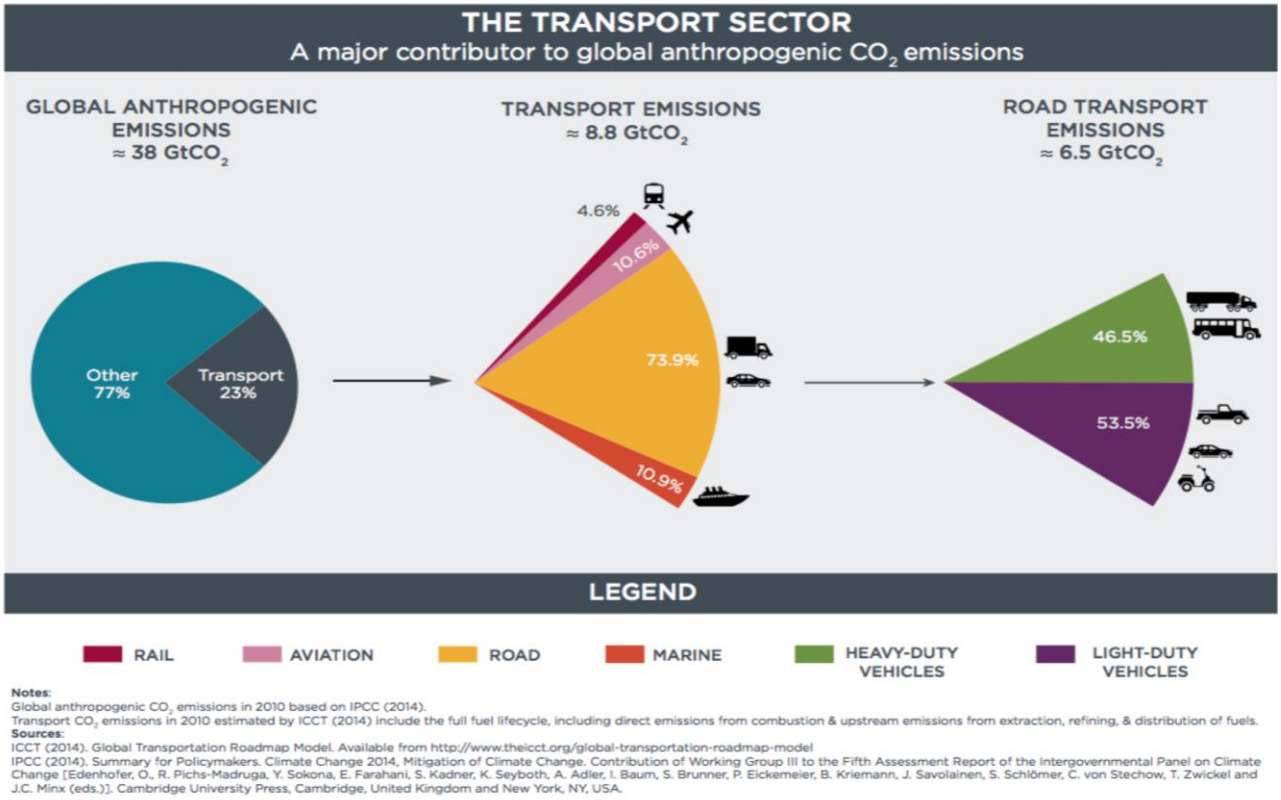
3.5. Regulatory Framework

3.5.1. Regulatory Framework in the Transport Sector

The transport sector has seen substantial global growth in the past two decades, in the form of increased vehicle ownership, freight activity, and energy use across all transport modes. Despite the evident economic benefits from increased mobility and freight trade, such activity has negative consequences such as increased petroleum use and associated climate and health impacts. Driven largely by transport sector growth, world oil use, including its unconventional oil and other fossil replacements, is expected to surpass 100 million barrels of oil per day (mbd) in the 2020-2025 timeframe (IEA, 2013).

In 2010, the global transport sector was responsible for almost a quarter of all anthropogenic CO_2 emissions, resulting in the release of 8.8 $GtCO_2$ into the atmosphere and consuming 47 mbd (millions of barrels per day).

To help mitigate the associated environmental effects, many governments have developed transport sector policies to improve the environmental and energy performance of vehicles and fuels.



Carbon Intensity of On Road Fuels

Governments have developed new policies aiming at promoting alternative fuels in the transport sector. Prominent alternative transport fuels that governments are encouraging to support their climate mitigation goals also include LPG.

The diversity of Heavy Duty fleets both in vehicle characteristics and duty cycles, makes regulating their fuel consumption and GHG emissions very challenging. Key components of Heavy Duty Vehicles regulations include the metric for efficiency or GHG emissions, vehicle types covered (segmentation), test methods for certification, and means of enforcement.

The table below summarizes major efforts over the last ten years to promote alternative fuels.

	Policy name	Biofuel-related targets
EU	Renewable Energy Directive (RED)	10% renewable energy in transport by 2020
	Fuel Quality Directive (FQD)	6% reduction in fuel GHG intensity by 2020
	Deployment of alternative fuels infrastructure Directive	Minimum levels of infrastructure for refuelling and recharging stations by 2020/2025
US	Renewable Fuel Standard (RFS)	36 billion gallons/year of biofuels by 2022
California	Low Carbon Fuel Standard (LCFS)	10% reduction in fuel GHG intensity by 2020
China	National Plan	4 billion gallons/year by 2020, E10 in 10 provinces.
India	National Policy on Biofuels	Increasing to 20% by 2017.
Canada	Renewable Fuel Standard	5% ethanol in 2010 gasoline, 2% biodiesel in 2012 diesel
Mexico	Law for the promotion and development of bioenergy	2% biofuel usage in selected areas (Guadalajara, Monterrey, Mexico City) by 2011-2012
Japan	Biomass Nippon Strategy	1 billion gallons/year by 2030
Australia	Energy Grants Scheme; Ethanol Production Grants	0.1 billion gallons/year biofuels by 2010
Brazil	Mandatory Biodiesel Requirement; Ethanol fuel program	5% biodiesel by 2010; 25% ethanol by 2007

Source: Malins et al. (2014). "E10" = 10% ethanol, 90% gasoline

Summary of policies to promote alternative fuels in transport

From a GHG mitigation perspective, the most significant of these global alternative fuel policy efforts are those in the US and EU. The EU's Fuel Quality Directive (FQD) similarly utilises a performance standard to require a reduction in the average on-road fuel supply's GHG intensity. Policies in the EU, US, and specifically in California have moved toward greater rigor, analysis of more fuel pathways, and comprehensive lifecycle accounting of land use effects to better differentiate the sustainable fuels that are reliably low-carbon.

Although not listed in the table, a number of EU member states (e.g., Germany, United Kingdom) are developing programmes within the EU directive framework. In addition, several Canadian provinces (e.g., British Columbia) and other US states (e.g., Oregon) are also developing low-carbon fuel policies.

Additional Heavy Duty efficiency regulations are under consideration in major markets around the world. Beyond the existing four regulated markets (i.e., Japan, US, Canada, and China) there is also activity towards Heavy Duty Vehicle efficiency standards in the EU, India, South Korea, and Mexico.

Region and Country Overview

Europe

The EU has adopted standards for light commercial vehicles 1 (LCVs) through 2020 but has not accomplished the standards for heavier vehicles, which account for a greater share of energy consumption. To promote climate change mitigation across the EU, the EU's current target is a 40% reduction in greenhouse (GHG) gas emissions by 2030 (European Commission 2015). The European Commission is calling for GHG reductions across all sectors of the economy, and thus HDVs sector overall will need improvements in efficiency in order for the EU to achieve its goal. Trucks, buses and coaches produce about a quarter of CO_2 emissions from road transport in the EU and some 5% of the EU's total greenhouse gas emissions Stage V non-road from 2019.

China

Euro VI from 2017, Tier 4a/b non-road from 2018, NEV targets for EV China is also working toward its next phase of standards for 2020 for Heavy Duty Vehicles and has formed a high-level committee to formulate an action plan.
Euro VI from 2017, Tier 4a/b non-road from 2018, NEV targets for EV.

India

Euro VI from 2020 to 2025.

Canada and USA

Canadian regulations follow the USA standards: Heavy Duty Vehicle and engine greenhouse gas emission Regulations (SOR/2013-24). The objective of the Heavy Duty Vehicle and Engine Greenhouse Gas Emission Regulations is to reduce greenhouse gas (GHG) emissions by establishing mandatory GHG emission standards for new on-road HD Vehicles and engines that are aligned with U.S. national standards. The development of common North American standards will provide a level playing field that will lead North American manufacturers to produce more advanced vehicles, which enhances their competitiveness. The Regulations will apply to companies manufacturing and importing new on-road Heavy Duty Vehicles and engines of the 2014 and later model years for the purpose of sale in Canada including the whole range of on-road heavy-duty full-size pickup trucks, vans, tractors and buses, as well as a wide variety of vocational vehicles such as freight, delivery, service, cement, and dump trucks. The regulations also include provisions that establish compliance flexibilities, which include a system for generating, banking and trading emission credits. Companies will also be required to submit annual reports and maintain records relating to the GHG emission performance of their vehicles and fleets. Specifically, California, but on the whole in the US, and Canada have begun work on Phase 2 efficiency standards, which are anticipated to apply to new 2019 and later models.

Argentina

Bases its emission regulations on Euro standards.

Australia

Regulations in Australia generally follow the European Union (EU) regulations, including exhaust emissions standards. Currently, Australia follows Euro V Heavy Duty Diesel Engine Emissions standards, as specified in ADR 80. Europe implemented Euro VI standards for Heavy Duty Diesel Engines in 2013, Australia is yet to set a date.

Heavy Duty Diesel Vehicle Emission Standards													
COUNTRY	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
EUROPE	EURO IV			EURO V					EURO VI				
AUS	EUR	EURO IV				EURO V							

A major consideration for regulatory bodies for diesel fuel quality is sulfur content. The progression to more stringent regulations is shown in the following table.

Diesel Fuel Quality - Maximum Sulfer Content													
COUNTRY	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
EUROPE	350 ppm					50 ppm				10 ppm			
AUS			500 ppm				50 ppm			10 ppm			

In Australia 295 tests between 2011 and 2012, reported an average sulfur content of 7.2ppm.

Some parameters under the Australian standards are less stringent than European. The Australian Department of the Environment tested Diesel parameters during 2011 and 2012 from the forecourt. In all cases, the average value was within the specified range. The following table outlines the results.

Average Diesel Testing Results - 2011 & 2012			
Parameter	Average value Australia	Diesel standard Australia	Diesel standard Europe
Cetane Index	54	46 min	51 min
Density kg/m^3	838.7	820 min, 850 max	845 max
Distillation T95 °C	347.3	360 max	360 max
Sulfur Content ppm	7.2	10 max	10 max

Cetane Index is a measure of the combustion speed of diesel fuel. This is an important indicator of the quality of the fuel. Higher cetane fuels will have a shorter ignition delay (in the same engine), and generally cause the engine to run

Distillation Temperature determines the quality of the fuel. The boiling range influences properties such as the viscosity, flash point, auto-ignition temperature, cetane number and density.

Sulfur Content reduction enables the use of advanced emission control devices, resulting in large exhaust emission decreases.

Precedents for PEMS as an Alternate Test

Australia is lagging behind with significant barrier to market for retrofit alternative fuel systems due to costly testing.

	OEM				Retrofit			
Country/ Authority	ETL	& or	PEMS	Comment	ETL	& or	PEMS	COMMENT
USA EPA		&		PEMS testing introduced in 2007		or		Testing of one vehicle or engine allows engine family type approval of retrofit system
USA CARB		&		CARB is more closely aligning vehicle emission regulations with EPA		or		Testing of one vehicle or engine allows engine family type approval of retrofit system
EUROPE		&		PEMS testing introduced in 2013		or		Testing of one vehicle or engine allows engine family type approval of retrofit system
AUSTRALIA	E5 ESC & ETC			Following European legislation (lags slightly). US and Japan test standards are accepted as alternatives				Only ETL testing required to meet current ADRs. AS 1425 standard requires that retrofit LPG systems on compression ignition heavy vehicles meet ADR emission limits and are tested to the ADR test standard.

Chile

Has its own regulations that generally follow USA and Euro standards but are not necessarily equivalent, and, in some cases, allow certification to either regulation.

Japan

Japan has adopted its own regulations, which generally follow the USA and EU standards.

Peru

Regulations have switched from a combination of USA and Euro standards to base its regulations on Euro standards.

Russia

Regulations follow the EU standards for Heavy Duty Engines and off-road equipment.

Turkey

Regulations also follow the EU standards, with the Euro 4 light-duty gasoline and diesel regulations being implemented in 2008. The allowable sulphur content of fuel of 50 ppm was enforced in 2008, with higher levels (1000 ppm) for agricultural equipment.

Heavy Duty Vehicle efficiency standards have been adopted in a few of the largest vehicle markets, but important markets remain unregulated

Although HDVs represent more than 40% of on-road fuel consumption in most vehicle markets and more than 50% in Brazil, China, and India (ICCT, 2014), standards for HDVs have only just begun implementation in China, the US, Japan, and Canada. In many cases, data limitations, challenges to tackle a diverse set of vehicle types (e.g., long- distance heavy-duty trucks, interurban buses, garbage trucks), and insufficient industry engagement prevent more immediate progress in HDV efficiency standards. Because of increased demand for freight truck and transit bus activity, HDV emissions are projected to continue to grow substantially; current estimates indicate that CO_2 emissions from the sector will grow nearly 60% by 2030 from 2010 levels (ICCT, 2014).

Expanded adoption of HDV efficiency standards could stabilise HDV emissions after 2025 and save 0.65 $GtCO_2$ and 3.4 mbd in 2030 compared to a scenario without these policies in place. While the EU has not yet adopted standards, it has conducted extensive data collection and laboratory investigation, which could provide a strong foundation for mandatory HDV standards to reduce HDV CO_2 emissions. Such a standard in the EU could save on the order of 70 MtCO2 and 0.4 mbd in 2030 and serve as a step toward similar policies in markets around the world that are following EU emission standards. Leveraging technical developments (e.g., technology costs) in the US and EU could also reduce some barriers for adoption in developing countries. Voluntary “green freight” programs could also offer an important opportunity for early action and data collection for entire fleets while regulations for fuel efficiency of HDVs are being considered

Environmental demands in emerging markets are tightening

Environmental demands are rising in emerging markets, as seen with the local equivalent of Euro IV already introduced in China, India and Russia. Interestingly, China, India and Russia all introduced Euro I to III at around the same time. However, India’s pace now seems to have slowed, as the most stringent limits of Bharat Stage IV (equivalent to Euro IV) only apply to the national capital region of Delhi and another eleven cities. Hence, registering vehicles outside large cities can easily circumvent them.

Other Initiatives

Low Emission Zones (LEZ)

LEZ are effective and increasingly popular measures. The core concept of LEZs is to prevent vehicles with higher emission levels accessing specific areas, or to charge them to access such areas. There are almost 200 LEZs across Europe, with different levels of restriction, managed by local authorities. Some LEZs explicitly allow the circulation of vehicles running on alternative fuels in addition cars having a certain Euro emission standard.

Clean Cities

The LPG industry has partnered with the Clean Cities network to help deploy vehicles, build infrastructure, and conduct outreach to fleets and the public.

London, creating a low emission megacity

Central London has much of the capital's poorest air quality and is forecast to continue to do so in 2020. Half of its emitted pollution is from road transport. This is why in early 2013 the Mayor of London set out his vision to create the world's first big city Ultra Low Emission Zone (ULEZ) in central London by 2020. The overarching aim is to deliver dramatic benefits in air quality and provide a spur for the mass take-up of zero and low emission vehicles. From 2018, all new hackney carriages in London will have to be zero-emission capable as part of the city's drive to reduce air pollution.

Milan

The LEZ is active every day of the week during day time. Euro 0 gasoline and Euro 0 to 3 diesel vehicles are prohibited. Residents can access the "area C" for free 40 days/year. Starting from the 41st day they access it, they pay 2 euro/day. Non-residents pay 5 euro/day. LPG, CNG, hybrid and electric vehicles can enter for free.

Naples

The LEZ applies during certain time slots on weekdays, to the entire municipality of Naples, where almost 1 million people live. Only diesel and gasoline cars, complying with Euro 4 and subsequent standards can enter the city during application hours. Zero emission electric vehicles and those powered by LPG and CNG are fully allowed.

Summary

The Heavy Duty emission standards create an opportunity for LPG Heavy Duty Engine development. Old Heavy Duty diesels will require engine and after-treatment upgrades to comply with the new regulations and this will increase the cost of compliance, thereby offering a great opportunity for the LPG industry.

In UNECE (United Nations Economic Commission for Europe) a new regulation is developed and approved, which includes the requirements for the type approval of retrofit systems intended to be fitted on a Heavy Duty diesel vehicle to enable its operation either in diesel mode or in dual-fuel mode.

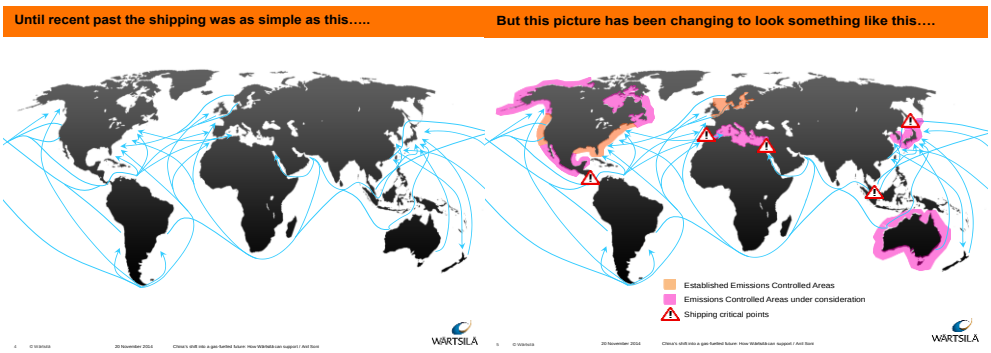
3.5.2. Regulatory Framework in the Marine Sector

The International Maritime Organization (IMO) is the specialised agency acting on behalf of the United Nations (UN). IMO has the responsibility for international improvement of maritime pollution and safety standards (IMO 2008b).

The original guidelines for regulations to limit airborne emissions from international shipping resulted from the entry into force of the Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL) in May 2005, MARPOL was adopted in its first state in 1973 by the IMO. The Annex VI to the convention regulates several pollutants, including NOX from newly built ships, and SOX.

Certain maritime regions are designated emission controlled areas (ECAs) where the regulated emission levels are lower than in the rest of the ocean.

Accordingly, regulations of air pollution from ships are only effective for certain aspects of the present shipping activities. The regulations will become tighter in a stepwise manner and additionally, the number of emission control areas will potentially increase.



There are two grades of marine fuel allowed in the SECA area:

- Low Sulphur Heavy Fuel Oil (LSHFO) with maximum allowed sulphur content of 1.0% by mass and
- Low Sulphur Marine Gas Oil (MGO DMA) with maximum sulphur content of 0.1% used in European inland waterways and in ports in the (SECA) areas.

In 2013, the Energy Efficiency, Design Index (EEDI) entered into force, becoming the first regulation to establish CO_2 emission standards across a global sector. EEDI essentially requires new ships to be progressively more efficient from 2015 through 2025, as compared against the average 2000-2010 ships of the same type.

For non-CO_2 pollutants, 2014 saw the successful implementation of the newest emission control area (ECA), the US Caribbean Sea ECA, to regulate NOX and SOX emissions. ECAs are sea areas that are specially designated by the IMO for enhanced mandatory measures to control air pollution from ships, including maximum fuel sulphur content and exhaust NOX emission levels. Today, ships traveling in ECAs must meet stricter fuel sulphur requirements than elsewhere; and from 2016, new ships will be required to meet special NOX emission standards (Tier 3) when traveling within ECAs. Following Russia's proposal to delay the implementation of Tier 3 NOX standards in ECAs, the IMO upheld the 2016 implementation date for existing ECAs (including the US Caribbean ECA), but delayed this date for NOX ECAs entering into force in later years.

The table below provides background on major regulatory developments within the IMO toward improving marine efficiency. These developments cover formal invitations to regulate harmful pollutants, major technical studies, adoption, and implementation of policies. Established implementation dates are also included beyond 2014. As shown, the critical benchmarks for increased new ship efficiency are 2015 (10% increased efficiency), 2020 (20%), and 2025 (30%).

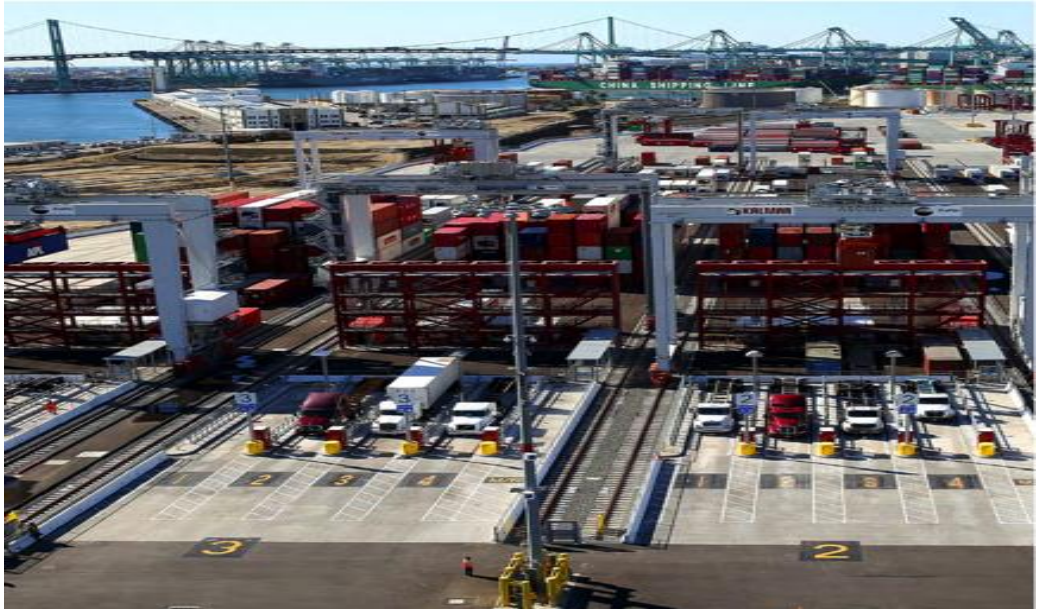
Table 10. Timeline of regulatory developments for marine efficiency within the IMO

Year	Regulatory Development
1997	International Convention for the Prevention of Pollution from Ships (MARPOL) invites MEPC to consider feasible CO_2 reductions for ships
2000	First IMO study on GHG emissions from ships
2003	IMO urges MEPC to develop mechanisms to limit GHG emissions
2009	MEPC finalizes a suite of technical and operational GHG reduction measures
2010	MEPC considers mandating technical and operational measures irrespective of flag and ownership
2011	First ever mandatory GHG reduction regime for an entire industry, including technical (EEDI) and operational (SEEMP) measures
2013	EEDI and SEEMP enter into force for all ships over 400 gross tonnage
2015	New ships must be **10%** more energy-efficient (EEDI)
2020	New ships must be **20%** more energy-efficient (EEDI)
2025	New ships must be **30%** more energy-efficient (EEDI)

In addition to existing policies, there is potential for much greater climate mitigation from new IMO policies that promote efficient shipping technologies and practices. Additional policy progress to improve shipping technology beyond the current EEDI requirements and extend leading operational practices to the full fleet could stabilise shipping emissions at 2010 levels despite a significant increase in the demand for global goods transport. Such policies could reduce 0.4 GtCO2, or 2.1 mbd, in 2030, equivalent to a 30% reduction in global shipping emissions.

Clean Air Action Plan (CAAP)

In 2011, the City of Los Angeles Harbour Department and the Port of Long Beach released a Zero Emission Technologies Roadmap to establish an initial plan for identifying technologies to pursue demonstrations to advance zero emission technology development. With important greenhouse gas reduction deadlines approaching in the next few years, the Harbour Department has identified zero emission equipment as an important element to be integrated into marine related goods movement in the future.



3.6. Safety

The development of any new technology and especially so if the new technology involves engines and equipment, machinery, vehicles that use LPG as a fuel, requires uppermost attention and consideration of safety implications. LPG, same as any other engine fuel can be entirely safe as long as the equipment is designed correctly with all safety aspects taken into account and the operation is equally carried out in the same manner. New technologies require thorough assessment of all potential safety risks.

LPG tanks, fuel lines, and carburetion components must meet strict specifications. As an example, LPG tanks used in vehicles are constructed to the highest standards, are many times more as puncture-resistant as gasoline tanks and they are tested to four times their standard operating pressure. Built-in safety devices automatically shut off fuel lines in case of an accident.

3.7. Training

Training of personnel in new technologies, new equipment and particularly in areas where safety is of prime concern is key. This is the case when LPG is introduced as a new alternative fuel in any equipment and operations. Adequate training is a prerequisite before any such new engine and equipment is put into service.

3.8. Quality of Fuel

The manufacturers of all types of engines for light, medium, heavy-duty vehicles, also for those for marine use and other industrial or other uses have specific requirements for the quality of the fuel used in their engines.

Modern equipment and advanced technologies come most often with increased requirements as far as the quality of the fuel is concerned. The same holds also for LPG and in particular even more so when this is used in Heavy Duty Engines that need to provide continuous and reliable service.

Currently the quality of LPG used as an engine fuel can vary significantly from country to country.

As a consequence, to qualify and maintain LPG as a leading alternative fuel for today and for the future for transportation and for industrial machinery, it is becoming increasingly important to ensure to manufacturers, OEMs, a constant composition and quality of the fuel, together with improved controls in the distribution chain to maintain it free of impurities and contaminants. The further development of the market of LPG fuelled engines depends on the availability of OEM engines and vehicles, and this in turn depends on the availability of reliable, good quality fuel in the market.

The reasons for such a mandatory need are related to a few but very important aspects:

- The fast development of the engine technology, with large production of high efficiency ultra-low emissions turbocharged solutions for light and heavy-duty vehicles.
- The adoption in the main industrialised countries of very demanding emission standards, with the main changes due to the adoption of Euro 6 in Europe and soon some equivalent standards outside Europe.
- The introduction in many countries of new reformulated fuels with controlled very low sulphur content (less than 10 ppm), to respect very stringent emission standards.

Development in the markets worldwide of new generation high performance turbocharged engines takes place largely in the field of heavy-duty vehicles, where today CNG/LNG are promoted as clean and economical alternative fuels. Such Euro 6 CNG/LNG heavy-duty engines, to be in condition to grant very high efficiency and to be competitive with equivalent diesel units (as the same of the new generation of turbocharged gasoline engines for cars), are utilizing very advanced ECU - Electronic Control Units - capable to manage sophisticated fuel strategies utilizing many precise sensors.

Some of such sensors and components, strategic for the reliability, the efficiency and also the “usability” of the engine/vehicle, as the “lambda” sensors and the catalyst, are strongly influenced by the fuel composition in their capability to survive for the required 160,000 km of the rules. LPG must also be present in these markets with same high fuel offerings to meet the requirements of modern components.

“Octane” number becomes also a strategic factor for the reliability of such engines, as the high compression ratio and the turbocharging adopted to obtain efficiency and reduce the CO_2 requires reliable fuel composition to avoid heavy damage from knocking phenomena.

There are certain key conditions and features of the LPG fuel quality that can be considered as extremely critical and if respected and well controlled, they can ensure problem free performance of a modern engine.

- **Octane**: at least 93
- **Sulphur**: 10 ppm max (what is required by the OEMs)

The sulphur content in the fuel is today a very important factor, as more than 40 countries around the world, including all the EU and Turkey, has adopted gasoline with less than 10 ppm of Sulphur. The reduction of Sulphur levels in the fuel is needed for the new engine technologies, like the direct injection of gasoline - GDI – and the lean burn injection strategies, to grant the life of the oxygen sensors, to maintain the catalysts more efficient for longer times and to reach the life of the engine for the 160,000 km as required from the Euro 6 standards, without needs of expensive maintenance costs.

The higher level of Sulphur can be very dangerous for such new engines, because in concrete this will influence the operative life of the vehicle with or without maintenance needs, strictly related issue with the OEM warranty concerns.

Sulphur poisons catalysts such as NOx absorbers and contributes significantly to sulphate PM emissions. Sulphur will store on the lean NOx trap and high temperature regeneration will be required to remove it. The higher the sulphur level in the fuel, more frequent regeneration is required with a higher CO_2 penalty, higher emissions and shorter life of the NOx trap. If the Automotive industry could design emission control devises that were less sensitive to sulphur, then engines could have the potential for lower emissions without having to mandate very low sulphur fuel.

As result, for having the LPG as acceptable competitive alternative fuel for the today gasoline and CNG/LNG fuelled engines, the right "formula" can be based on the U.S. HD5 standard, but with low Sulphur (% by volume):

- **LPG**: 93% min
- **Butane**: 3.5% max
- **Propene/propylene**: 3% max
- **Other Olefins**: 0.5% max
- **Sulphur**: 10 ppm max

Such LPG composition can ensure more than 101 Octane and if not contaminated by plasticizers, rust particulates, sodium dioxide, water and other dirt, can be an excellent fuel in condition to be adopted by OEMs as reliable fuel for the last generation of high efficiency, very low emissions engines.

Granted quality of LPG becomes particularly mandatory for professional and heavy-duty vehicles and also for marine outboard engines.

For Heavy Duty Vehicles, due to the high amount of fuel used if not properly formulated and clean, in short time/mileage it can be the cause of malfunctions of sensors and catalyst, taking the vehicle out of service by the OBD - On Board Diagnostic – with all the related costs of stop and required expensive maintenance, influencing the warranty concerns by OEM.

For marine outboards, the high technology adopted by the last generation of such engines, comparable in many cases to the high-performance motorbikes – very high power in a compact and very light unit – added to the need of high-efficiency, means high compression ratios joint with very advanced fuel strategies, in many cases with sophisticated lean-burn technology. For this type of engines, the fuel quality can't be an option, because any damage to the power unit can be source not only of very high cost of maintenance, but because the utilization in water environment can affect the safety of the boat users themselves.

However, to be in condition to satisfy the needs of the last generation of engines/vehicles of the Euro 6 era and of the powerful marine engines, and to make the LPG efficient enough to compete in the ROI – Return Of Investment – with gasoline, diesel and CNG/LNG, it is necessary to utilize the technology **of the "Liquid LPG Injection" system**. This is the only technology in condition to satisfy the very demanding fuel strategies of the new generation of engines, utilised to satisfy the Euro 6 rules for 160,000 km and of the today generation of outboard marine engines.

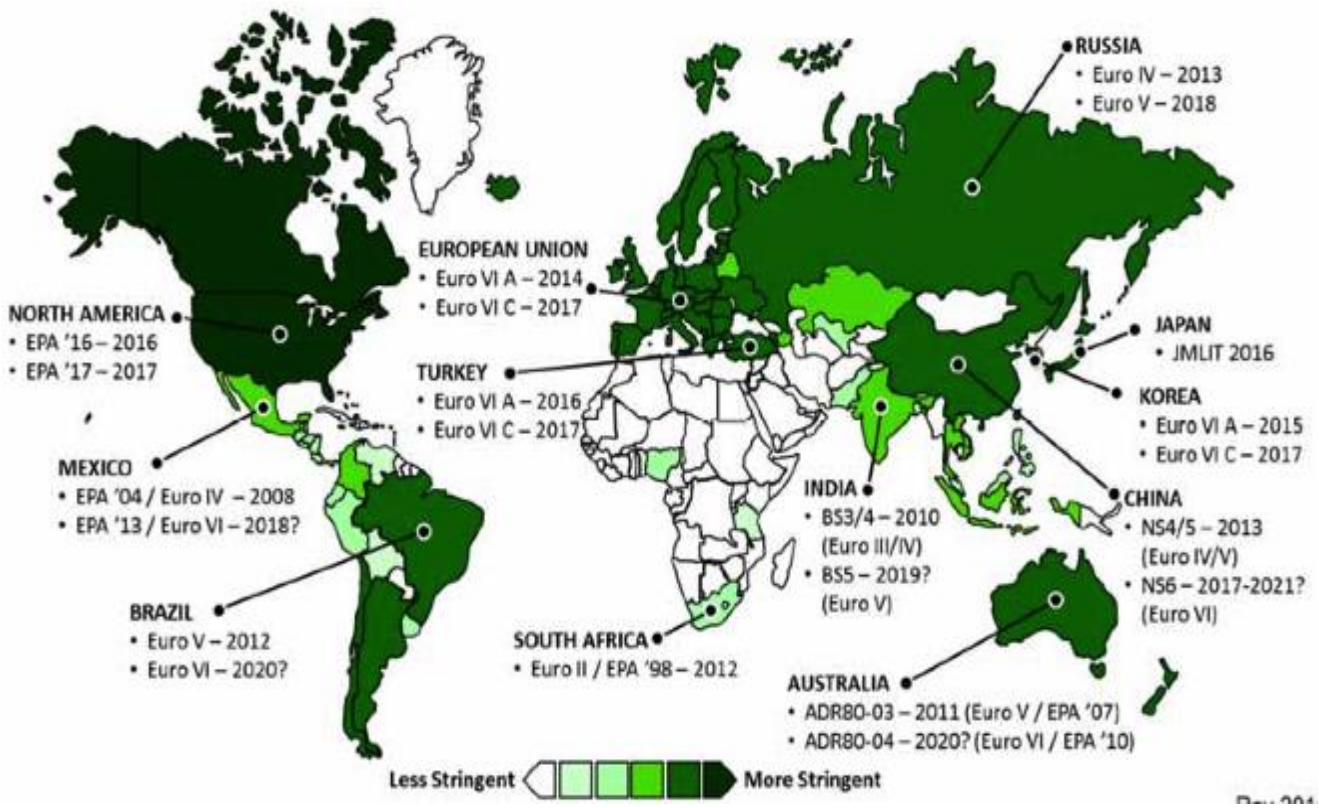
3.9. Environmental Aspects

Protection of the environment and improvement of air quality is an important objective of the regulators today. This is particularly the case in the US and Europe, European Commission where new legislation and standards aim to reduce the emission of all pollutants, CO2, NO2 and particulate matter.

Road transport is a major source of greenhouse gas emissions, producing around 15% of the EU's CO2 emissions.
The EC Commission focuses on the reduction of emissions from the following vehicle categories in particular:

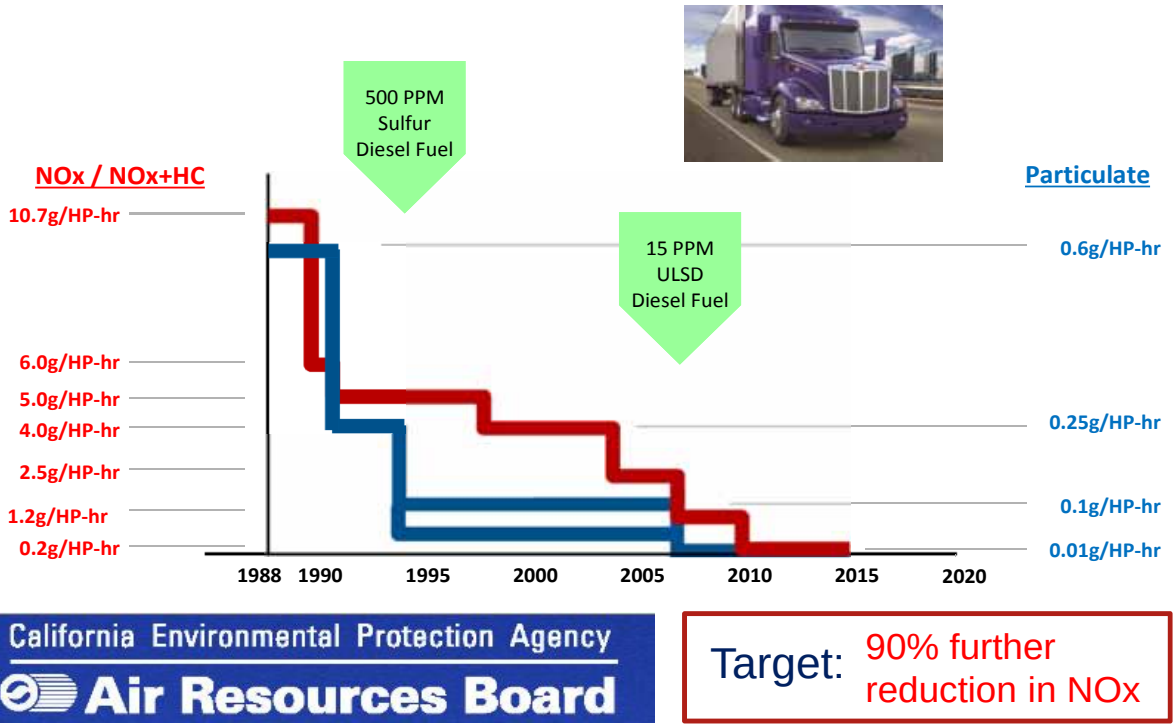
- Light-duty vehicles (cars and vans)
- Heavy duty vehicles (coaches, buses, trucks)
- Non-road mobile machinery (excavators, bulldozers, front loaders etc.).

Binding emission limits were already introduced for light and heavy-duty vehicles. Environmental requirements for agricultural and forestry tractors, and two or three-wheeled vehicles will be included in future regulations.



Emission Reduction
Global Heavy Duty on Highway Regulations

The diagram below demonstrates the reductions in the regulations of the allowable limits in NOx (in red), particulates (in blue) and sulphur in diesel fuel over the years.



Emissions Reductions
Lower NOx

In Germany, the draft of the 38th Ordinance on the Implementation of the Federal Emission Control Act (BImSchV), which covers both the low-emission combustion of the alternative fuel LPG and the potential of bio-LPG, was recently unveiled (end 2016). The regulation underlines the contribution that LPG, -as a widely available alternative fuel, already contributes to CO2 reduction today and will do in the future. LPG lowers greenhouse gas emissions and thereby helps achieve climate mitigation targets. The fact that the regulation also includes bio-LPG confirms the sustainable development of LPG as a modern fuel. The draft of the 38th BImSchV implements European guidelines on the greenhouse gas ratio of fuels into national law. For the first time, it recognises the contribution of LPG as a fuel for greenhouse gas reduction. With a value of 73.6 kg of CO2 equivalent per gigajoule, LPG falls below the European reference value to control the greenhouse gas ratio of conventional fuels by 22%.

The role of LPG as an alternative fuel in reducing engine emissions when it is used as an engine fuel and in improving air quality is well proven and accepted today. In addition, the proven difficulties of diesel fuelled engine technologies to keep up with the required emission reductions, pave the way for LPG to play a key role in the future as a fuel for all types and sizes of HD Engines.

3.10. Main Stakeholders

The role of the various stakeholders is instrumental in driving growth of LPG Heavy Duty Engines in the market, supporting products commercialise and raising customer and policymaker awareness.

Key stakeholders include:

- Policy makers, regulators, governments
- LPG distribution companies
- Engine manufacturers, OEMs
- Independent system developers
- Vehicle manufactures, OEMs
- National and international industry associations
- Emissions experts

3.11. Engagement of Main Stakeholders

Coordinated engagement of the stakeholders is important to work towards the key objectives:

- Development of advanced and innovative applications.
- Standardisation and other environmental regulations.
- Working on new engines technologies.
- LPG companies must work with specific communities such as the agricultural community to identify and develop equipment, practices, and infrastructure needed to use LPG fuel safely, economically, and reliably.
- LPG companies, marketers, equipment suppliers, and vehicle manufacturers must work together to ensure LPG-powered systems remain ahead of other competing fuels in terms of both environmental performance and cost-efficiency.
- Equipment and other systems must have a cost advantage and be timely in development. A general challenge for the LPG industry is meeting the cost and time requirements of users as they continuously seek to drive costs down and improve productivity. By meeting this challenge, the LPG industry can create a robust, growing market in the Heavy Duty Engines sector.
- Cultivate retailer, end-user, and government awareness of LPG as an exceptional energy source. The LPG industry must work vigorously to create and maintain a high level of awareness regarding LPG's unique benefits among LPG retailers, consumers, and lawmakers.
- OEMs and system developers should view heavy engine markets as attractive sources of revenue that are strategically important because of growing figures.
- Farmers, truck drivers and municipalities should be educated to see LPG as an exceptional fuel that they can use cleanly and cost effectively in nearly every application.
- Lawmakers must understand LPG's advantages, particularly its superior environmental performance, to ensure proper consideration in environmental regulations.

Some examples of stakeholder activities are listed below:

Propane Council Donates $25K to Schools Using LPG Buses

As part of a campaign to teach communities about the benefits of LPG-powered transportation, the Propane Education & Research Council (PERC) has donated $25,000 to teachers at schools that use LPG buses. PERC's donation has benefit teachers at four school districts in San Antonio, Texas; Indianapolis, Indiana; Orlando, Florida; and Reno, Nevada.

The transition from diesel to LPG buses has been reported in at least 20 of the top 25 designated market areas, and four of the ten largest school districts in the country are using them, according to PERC.

Clean Public Transport

As the "City with most LPG buses globally", Guangzhou, China has put over 31,000 LPG vehicles into operation since the general promotion of Autogas, accounting for more than 95% of the city's total buses and taxis. 8000 buses run on LPG.

Free Trips in LPG-powered buses in Spain

In the context of the European Mobility Week, trips on LPG powered buses routes were offered free of charge during the "Car Free Day" in the city of Valladolid, in the autonomous region of Castile and Leon. Most city buses in Valladolid move with Autogas (103 out of a fleet of 150 vehicles). This "free bus trips" initiative was sponsored by the Energy company Repsol. During the European Mobility Week, Valladolid citizens were also made aware of the main features and benefits of Autogas, the most popular alternative fuel in the automotive sector and used by more than 13 million vehicles in Europe. Autogas vehicles have been recently ranked by the General Directorate of Transport as ECO, a system that aims at becoming the basis on which local authorities can regulate traffic in their municipalities in order to reduce pollution. In Valladolid, this fuel has a 65% bonus on Vehicle Tax (IVTM). Repsol also organised a booth located on the main square of the capital, where several LPG vehicles were exhibited, with the objective of raising awareness on this alternative fuel.

3.12. Market Status

The market for HDEs is highly variable depending on the application and the region. Heavy Duty Engines market in general is mature and relatively well established in USA. It is developing slowly elsewhere, most notably in Asia.

LPG powered Heavy Duty Engines currently take only a marginal share of the market. This varies by region, but overall LPG product makes up only 0,5-1% of the Heavy Duty engines in circulation to date.

LPG Heavy Duty engines represent a tremendous growth opportunity for the industry in terms of **LPG fuel potential** and **new vehicles on the road.**

The number of OEM quality platforms for Heavy Duty fleet applications is growing in the US with partners such as Roush CleanTech, CleanFuel USA, Freightliner Custom Chassis, Blue Bird, Collins Bus, Thomas Built Bus, Alliance Autogas, ICOM North America, Isuzu and others. Demand for these products is growing as small business owners to large companies to school districts are looking to save money on fuel costs as well as make their operations more sustainable.

LPG refuelling infrastructure offers the most economical solution compared to other fuels, making the case even stronger for continued growth in this market space.

3.12.1. Heavy Duty Vehicle segment (HDVs), On Road vehicles

Regarding the HD Vehicle segment (HDV), the global truck manufacturing industry is on the cusp of major change. After consistent but volatile growth over the past decade, the global truck market for medium- and heavy-duty trucks is estimated to grow by 4.8 percent annually until 2020. By 2030, there will be more global truck makers. Several players in emerging markets have the potential to outgrow their current positions as regional giants or niche players, while the current group of regional giants will shrink to include just a few Chinese and Indian OEMs. Consolidation among global groups is already well under way.

Europe Market Highlights

The Figure below shows the 2014 market shares of the major HDV manufacturers in the EU. This includes all Heavy Duty vehicles, buses, vans, tractors, rigid trucks, etc. The HDV market is dominated by five manufacturers, with Volkswagen and Daimler responsible for more than half the HDV sales and Volvo, PACCAR and Iveco responsible for another 40%. Everything told, the top five manufacturers are responsible for more than 90% of the HDV sales in the EU. Three of these manufacturers (Volvo, Daimler, and PACCAR) are also dominant in the US market.

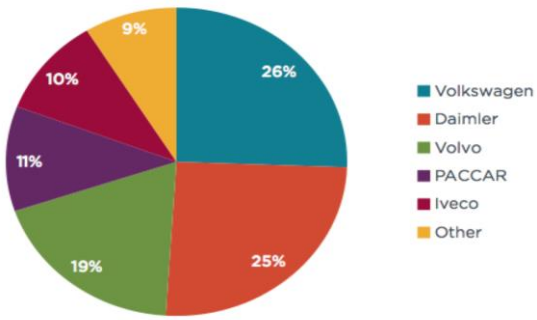
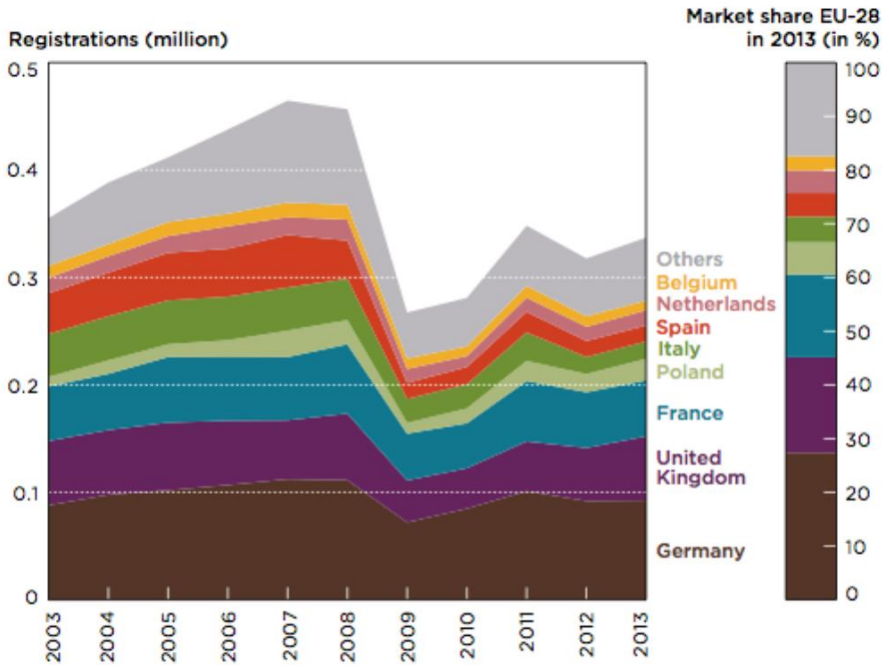


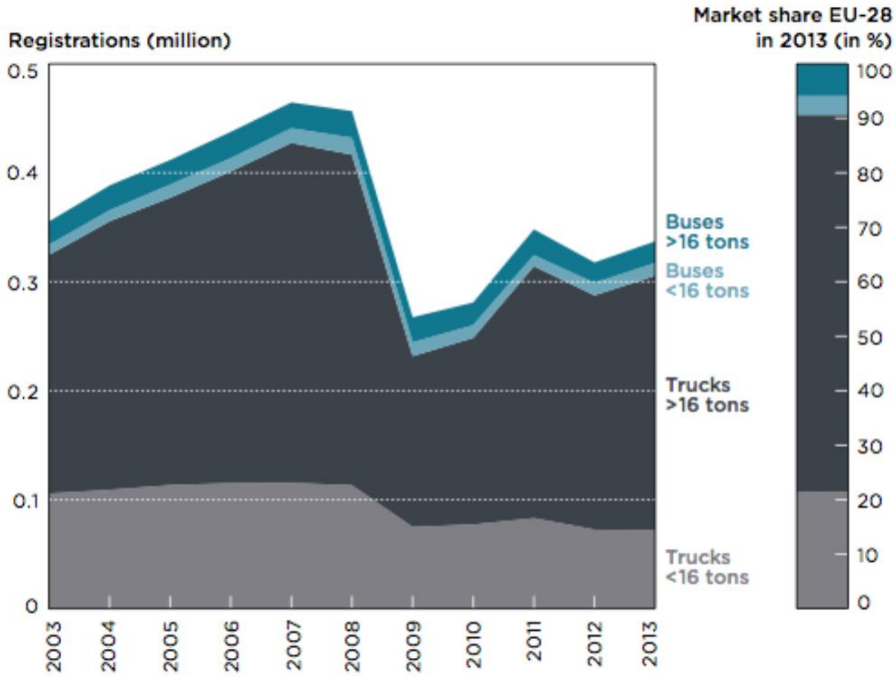
Figure 10. 2014 HDV market share for EU manufacturers

Market size over 3.5 ton in Europe (trucks and buses over 3.5 ton)

Registrations in Europe (EU 28) of buses and trucks

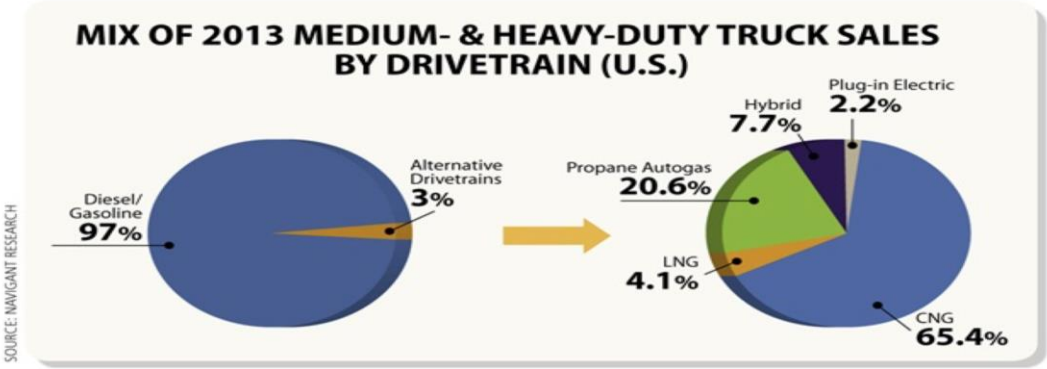


Data source: ACEA; data until 2007 is for EU-25 only

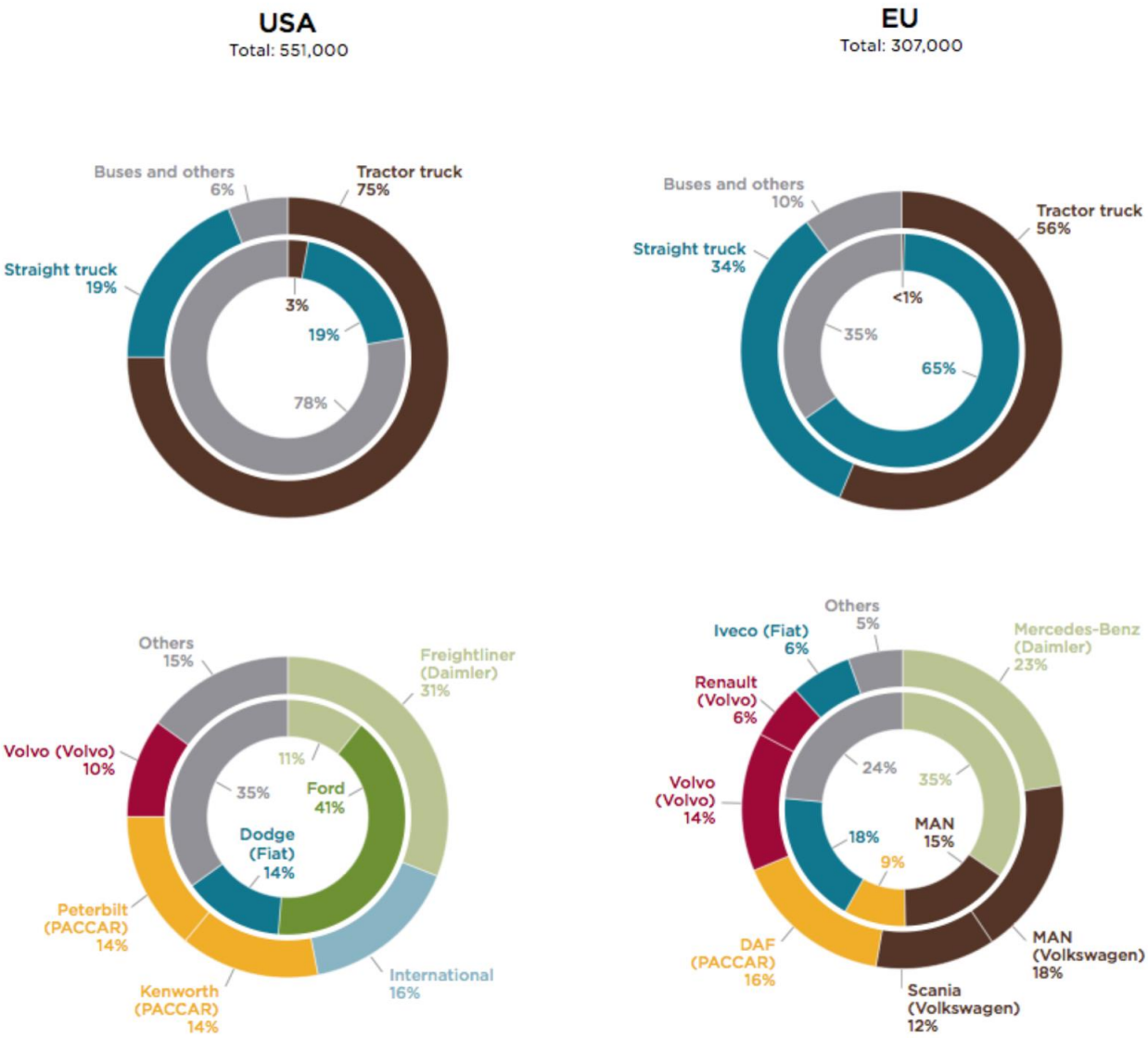


Data source: ACEA; data until 2007 is for EU-25 only

The total number of newly registered heavy trucks and buses in the EU was 0.3 million in 2013.



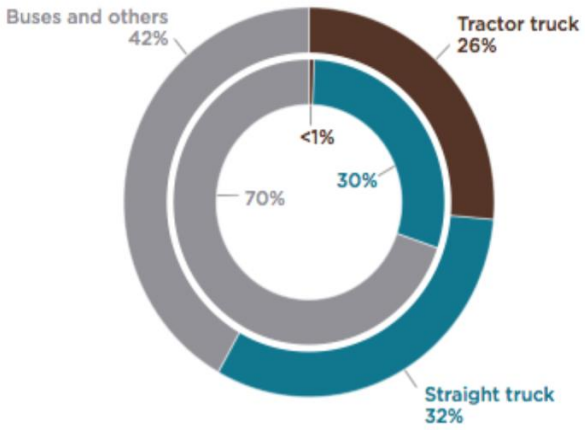
Currently, only 3 percent of medium- and heavy-duty truck drivetrain sales use alternative fuels, but the fleet demand for those vehicles is growing.

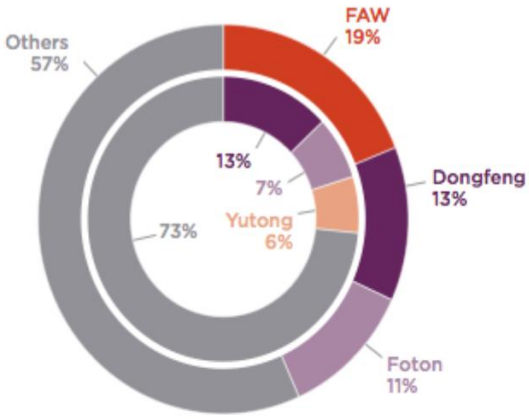


The Heavy Duty Vehicle market in China is growing quickly, with annual registrations that are about twice as high as in the US. The Chinese market is much more fragmented.

China

Total: 1,169,000





3.12.2. Forklifts

Market Size by Region

Global sales on forklift trucks are compiled in the following regions based on accurate statistics available.

Region	Orders			Shipments		
	2014	2015	% Increase	2014	2015	% Increase
Europe (53 countries/territories)	344,533	373,321	8.4%	338,378	359,096	6.1%
Americas (55 countries/territories)	267,716	277,542	3.7%	255,549	259,907	1.7%
Asia (43 countries/territories)	438,327	413,777	-5.6%	432,098	409,630	-5.2%
Africa (56 countries/territories)	19,346	16,337	-15.6%	18,480	16,950	-8.3%
Oceania (29 countries/territories)	18,444	18,903	2.5%	18,524	18,641	0.6%
Total (236 countries/territories)	1,088,366	1,099,880	1.1%	1,063,029	1,064,224	0.1%

Source: The World Industrial Truck Statistics (WITS) organisation

Highlights of 2015 on this segment include:

- Following a nearly flat year, orders and shipments to Europe spiked in 2015, up 9% and 7% respectively. Europe has again enjoyed the largest growth with a year-over-year increase of 8% and reaching more than 370,000 orders in 2015.
- The America's also continued robust orders with 4% growth over 2014 and reaching an all-time high of more than 270,000 orders.
- Asia accounts for 40% of global shipments and is still the largest region with around 410,000 orders. However, following two consecutive years of 10% growth, Asia is down 6% from 2014, when it recorded more than 435,000 orders. This is mainly due to the slowing economy in China and can be reflected in the decrease in sales of the top Chinese lift truck manufacturers ranging from -14% to -27%.
- In Oceania (Australia and nearby islands), shipments and orders rebounded after falling more than 20% in two years from 2012 highs.
- The lift truck market in North America is at an all-time record high in the material handling industry. Total retail orders in all classes, excluding exports, totalled 225,534 units in 2015. It is the first-year lift truck sales are higher than the industry's pre-recession level of 215,000 units in 2006.
- LPG powered forklifts take a global 1 % though the proportion and is greater in some regions.

Chapter Four

Roadmap

4.1 Market Outlook on Technology

Vehicle propulsion system technology development is driven by customer needs, legislative conditions like emission and safety standards, energy resources and prices, influenced by production/distribution costs and taxes. The general targets for technology trends are **energy consumption reduction, near zero emissions and alternative fuel-compatible power systems**.

The importance of downsized spark ignition engines is increasing considerably. Boosting (supercharging and turbocharging) is combined with displacement reduction, sometimes with new, redesigned engines. The feasible reduction in cylinder displacement is up to 40%, with a corresponding benefit in fuel consumption and carbon dioxide emissions of up to 20%. Variable compression ratios (VCR) in combination with downsizing, offered also (for supercharged engines) a potential up to 25% CO2 reduction.

Spark ignition engine technology is fully compatible with LPG, and if energy policy promotes these fuels into the marketplace, combustion systems tailored to these fuels will emerge. Extreme-charged, lean-burn, spark-ignited combustion processes are promising in this respect. This combustion technology achieves extremely low NOx emissions and only needs an oxidation or three-way catalyst (no further NOx after treatment systems).

4.1.1 Spark Ignition Engines, Liquid injection, Vapour injection

The adoption of Liquid LPG Direct Injection could be a way of improving engine efficiency. However, in terms of costs, these engines with stratified combustion are more expensive than conventional spark ignition engines due to the need for advanced injection technology and additional nitrogen oxide after treatment. As an interim step, direct injection with homogeneous combustion (enabling conventional emission control) in combination with supercharging, could be growing market share.

For the time span to 2020 it is most likely that the above-mentioned technologies will further evolve and will feature advanced, adaptive control of these flexible sub-systems, using new sensor technologies.

New combustion systems such as controlled auto-ignition with very low engine-out emissions of NOx and particulates will be realised to be effective in a wide engine map area and without full-load penalties. Some evolution of fuel properties may support this new combustion philosophy.

Advanced fuel injection systems in conjunction with LPG, which allow an adapted injection characteristic such as pilot, split and post injection as well as rate shaping, will reduce the local emissions substantially, perhaps avoiding the need for additional particulate and NOx control devices in medium to heavy duty vehicles. Also, injection nozzles with variable injection-hole size will be a part of these advanced SI engine concepts.

However Liquid LPG Direct Injection systems (LDI) are not available yet in the light duty vehicles market and even more so for use for Large Heavy Duty Engines.

4.1.2 Diesel-LPG Dual Fuel

The challenges for the Diesel Heavy-Duty Engine and Diesel-LPG Dual Fuel are similar, with greater emphasis on emission control but a stronger market desire for efficiency in order to reduce operating cost. Fuel consumption and NOx/PM emission will be addressed by combustion process improvements, including application of flexible high-pressure fuel injection, improved boosting, electronic control and low oil consumption.

In order to obtain further reductions in emissions and fuel consumption, sub-system variability will increase for both Heavy Duty and Light Duty Diesel Engines, enabled by advanced control systems. To increase the degree of downsizing, in-cylinder peak pressure will increase, calling for new engine design concepts including supercharging and improved materials. With single cycle control strategies, emissions will decrease further. A greater step in NOx emission reduction in a wide mapping area will be expected for homogeneous charge compression ignition (HCCI) in the part-load range without full- load fuel consumption penalties.

Regarding after treatment technologies, a very key subject, advanced after treatment systems for Diesel Engines will be the greatest challenge. Key technologies for the most stringent NOx and PM control are cooled EGR, high -pressure direct fuel injection, Diesel oxidation catalyst, Diesel particulate filter, catalytic reduction of NOx by SCR or NOx-adsorber as well as the LPG use and combinations of these, depending on needs of market and exhaust emission regulation for world-wide emission development strategies. System integration including electronic on-board diagnostics (EOBD) is an absolute must, i.e. combustion systems, mechanical systems, control systems, after treatment systems, and measurement systems have to be optimized as a whole to meet market demands and legislation requirements. Durability and reliability of the various systems still need to be proven. This applies particularly to after treatment systems for NOx and PM, since NOx-adsorbers and Diesel particulate filters for Heavy Duty Diesel engines are still in the laboratory development phase. The combination of NOx trap and particle trap in one system offers cost and fuel consumption advantages. Improved SCR technology with improved reduction agents can reduce the cost of NOx after treatment systems.

The technology on Diesel-LPG Dual Fuel systems will further develop, however, as mentioned in earlier chapters, the future of this technology is still to be proven.

4.1.3 Hybrids and Range Extenders for Electric Vehicles

Hybridisation of IC engine powertrains will be significant in 2020. An evolutionary approach from mild to full hybrids is likely. Hybrid technologies will play a significant role. In particular, smaller classes of trucks, subjected to stop-start or urban use are likely to see the greatest uptake of this technology, while urban delivery vans will probably adopt a technology profile more similar to that for passenger cars. Especially for buses, the stop-start nature of the duty cycle and the environmental needs of cities suggest a greater penetration of Hybrid technologies.

These factors create the **greatest opportunity for LPG bus and truck applications** being the only type of vehicle where is expected over 1% penetration.

LPG can be an ideal fuel for parallel hybrid systems and range extender power units on serial Hybrid configurations.

Hybrid technology and LPG IC engines could play a role also to improve economy and emissions in regional trains in some countries.

4.2 Market Outlook on Regions

Several high-level market characteristics are identified which create strong potential for Heavy Duty Engines powered with LPG. These characteristics are used to rate the overall market potential in each global region.

If a region has all of these characteristics, the potential market is attractive. If it has several of these factors, the potential is moderate, and if it has none of these characteristics the potential is weak.

Market Characteristics	Drivers accelerating LPG growth in HDE market
New regulations	The stringent emissions standards for Heavy Duty Engines in force around the world can easily be met with adoption of modern LPG systems.
Cost and Complexity of emission Compliance	Replacement of old buses / trucks with new ones to comply with new regulations could increase the demand for HDV LPG fuelled.
Attractive LPG price	The decline in oil prices and the corresponding decline to LPG prices in 2015 and 2016 provides a window of opportunity for fleet operators.
Government incentives for switching to alternative fuels	Green grants and tax credits are in place in many countries.
Business and industrial growth	The growth in the global consumption of liquid fuels is driven by transport and industry, with transport accounting for almost two-thirds of the increase. The growth in transport demand reflects rapid increases in vehicle ownership in emerging economies, partially offset by sustained gains in vehicle efficiency, which slow the sector's growth post-2025. The other major source of demand growth for LPG is industrial use and new markets that create great potential to use LPG in different applications.
Adequate Availability of refuelling infrastructure	Extensive refuelling infrastructure network is in place thus supporting the development of fleets in trucks applications. Countries which are already consuming large volumes of LPG are likely to have the necessary infrastructure in place to facilitate the use of LPG within the autogas and industrial sector.
Sufficient supply of affordable LPG over the forecast horizon	The global LPG fundamentals in 2017 are shaping up to be bullish. USA LPG output from NG processing plants more than doubled between 2010 and 2017 as a result of the shale boom. With domestic demand effectively static, the surplus is largely destined for overseas markets. Iran confirmed the increase in LPG production. It is expected the market to continue to move to surplus.
Increasing awareness of the advantages of new technologies	Customers are aware of the advantages of new technologies. The most important for higher market entry is the growth of confidence of LPG among all stakeholders and end users.

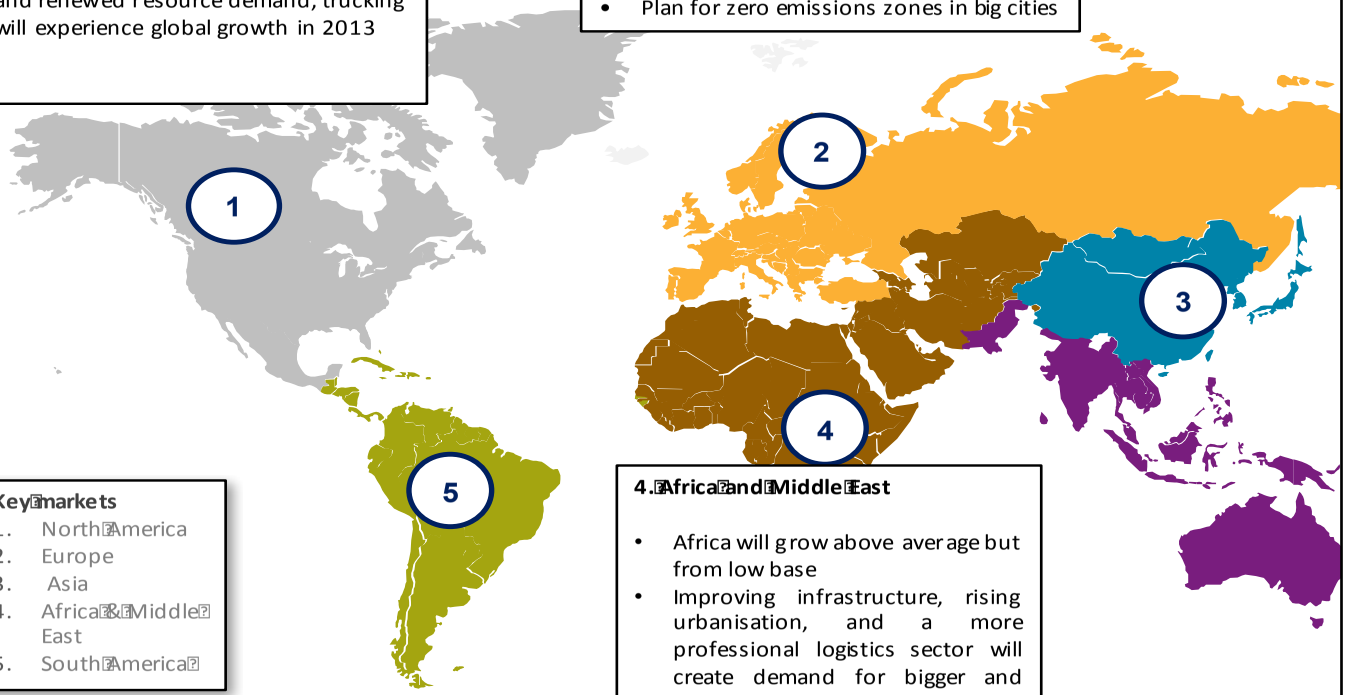
Global Strategic Trends

1 & 5 North & South America

- High investment in alternative fuel technologies and innovation
- School buses fleets are changing to propane going green to stretch strained budgets and promote cleaner air
- Pioneering role on environmental restrictions
- With the recovering Brazilian economy and renewed resource demand, trucking will experience global growth in 2013

2. Europe

- High investment in alternative fuel technologies and innovation
- Plan for zero emissions zones in big cities



Key markets

1. North America
2. Europe
3. Asia
4. Africa & Middle East
5. South America

4. Africa and Middle East

- Africa will grow above average but from low base
- Improving infrastructure, rising urbanisation, and a more professional logistics sector will create demand for bigger and more sophisticated trucks alongside the traditional low-price segment

3. Asia

China, Japan & India

- Stricter emission standards will lead to a slight increase in technological sophistication
- High demand for lower emissions in big cities
- Leading manufacturers are state owned companies
- Customer demands for commercial vehicles focus mainly on functionality and purchase costs
- Western manufacturers are showing an increased interest in producing commercial vehicles in China.
- This slightly increasing regulatory stringency will slowly but steady force the technological development of Indian manufacturers
- India's pace now seems to have slowed, as the most stringent limits of Bharat Stage IV (equivalent to Euro IV) only apply to the national capital region of Delhi and another eleven cities. Hence, they can be easily circumvented by registering vehicles outside large cities.
- NG bus market also growing: tripled from 2009 to 2015

Rest of Asia

- The truck market is expected to grow and countries such as Indonesia, South Korea, Vietnam and the Philippines that will contribute significant to this growth.
- Asia is now by far the largest region for commercial vehicle sales, accounting for nearly one in two commercial vehicles sold worldwide.

4.3 Barriers to Growth

There are several specific barriers/drivers, which determine the size of the market opportunity. Key issues are highlighted below. The Recommendations Chapter proposes suggestions to overcome these barriers.

4.3.1. Upfront Cost: The Greatest Challenge

Upfront cost is consistently raised as the single biggest barrier to market entry for new technologies. Cost is the primary decision factor for the majority of users, fleet operators, public authorities and businesses in this sector. Many alternative fuel/technology options may have higher upfront investment costs, both in terms of the vehicles and the infrastructure required. With strict budgetary pressures, many customers remain focused on immediate cost rather than long-term savings.

4.3.2. Customer Economics: Overall Costs - For Fleet Operators Often Favourable but Challenging

Overall costs besides the initial acquisition cost or the cost of the fuel system modification depend largely on the relative price of LPG vs other fuels. In the case of dual fuel diesel LPG engines, the economics and cost benefits depend also on the amount of diesel fuel that is substituted across the full operational cycle of the vehicle. For vehicles, steady, over the road driving might substitute 40% diesel with LPG, possibly 30% or less in urban traffic. For dual diesel LPG systems, the highest substitution rates tend to be about 45%.

The dual fuel LPG diesel systems developed in conjunction with OEMs tend to have higher first costs than retrofit systems due to their complexity and superior performance and emissions compliance. But with LPG being often 30-50% cheaper than diesel, savings for high fuel-consuming vehicles tend to provide attractive cost advantages over dedicated diesel vehicles despite the different diesel substitution factors. Additionally, LPG tends to have less price volatility than diesel. Since the profit margins of line-haul trucking tend to be relatively low of the order of 3-10% savings benefits tend to outweigh the higher initial costs of the engines and vehicles.

Relative cost of LPG to alternatives; if the user, fleet operator or other has not secured a long-term contract for a lower price of LPG, then the cost of LPG fuel could be a deterrent to adoption in some cases. The higher price of LPG, which can be seen at public stations, would also be a disincentive to the general public should LPG be marketed to this segment.

4.3.3. Policy/Regulatory Framework: Need to be on a Level Playing Field with Competing Technologies

If LPG Heavy Duty Engines are to reach potential market they need to be recognised and given fair treatment to other technologies e.g. based on their primary energy efficiencies carbon saving potential. This is an on-going process in many regions. Regulations need to be finalised for inclusion of LPG diesel engines in Clean Cities or Zero Emissions Zones etc., incentives and regional schemes. These regulations have to take into account the use of LPG as a fuel. In some areas, the use of LPG and an engine fuel is not even permitted today.

4.3.4. Difficult Regulatory Challenges must be addressed to enhance market opportunities

Regulations regarding use of LPG as an engine fuel for various types of applications and vehicles varies largely and even more so when it concerns duel fuel diesel/LPG systems. While the market for engines and vehicles is global, international regulations do not exist. Currently for dual fuel LPG-diesel engines and vehicles, only national type approvals exist and even these are still very few. In the absence of clear regulatory guidelines, some countries allow dual-fuel vehicles, some provide „exemptions" on a case-by-case basis, and other countries prohibit the systems altogether. The national approach is not cost effective and is only sustainable when small volumes of engines are

being converted. If OEMs are to produce engines and vehicles in volume then, new international certification regulations are needed, most likely at the UN level. Such international standards or regulations are also important to help ensure that these systems are safe, reliable and in compliance with emissions regulations.

In most dual-fuel systems, the base diesel engine is unchanged. Should these engines be tested only as a diesel, as a diesel with multi-fuel capability, as a gaseous engine, or both, and under what conditions and which emissions test cycles should be used (ESC, ETC, other). If governments and the industry move to create dual-fuel engine regulations for OEMs, this likely would apply to current Euro V and VI standards while older vehicles at Euro IV or below require retrofit certification under UN/ECE Regulation 115.

4.3.5. Technology Development: Slow Rate Will Limit or Stop Growth

At present, there are limitations on the range of applications for which LPG HD systems can be implemented. There has been very limited development of HD LPG Engines recently (with the exception of the US) resulting to a serious lack of LPG HD engines. The development of HD engines on other competitive fuels and technologies has largely overpassed those on LPG. A significant part of the market potential for LPG HD Engines is currently based on the expected technology developments, which will widen applicability. If this does not happen as expected the market potential will be very limited and growth may even stop altogether. Major branch and manufacturers are hesitant in developing LPG versions of their models. This is probably the most important blocker today. R&D investment is absolutely key.

4.3.6. Commercialisation and Getting Products to Market: Trained Installers, Distribution/Servicing/Maintenance Networks are required

For conversion systems, new distribution channels and partnerships with OEMs to reach the customer need to be developed or acquired through partnerships with bigger companies. These needs to ensure an effective network and adequate servicing and maintenance support. It is critical convincing performance of FLT salesmen who can influence fuel choice.

4.3.7. Awareness/Perception: LPG HD engines, Equipment and Vehicles Need to be Considered by Policy-Makers, OEMs and All Types of Users as a Preferred Option

Raising awareness of the existence of HD Engines possible applications and their market potential is the first major challenge. The way LPG HD Engines are perceived by the market is critical to their success. These engines need to be seen as a carbon reduction tool (particularly for policy-makers), as a reliable and efficient transportation for end-users, and as a revenue opportunity. This is equally relevant for all applications in all regions. We have seen some success with school buses and generators in USA, but in other regions, awareness is still very low. Besides, communications initiatives are needed in order to expand LPG's position as a leading alternative fuel and to increase sales.

4.3.8. Other Barriers

Some other issues can also be considered as barriers, they have also hindered growth in the past and may continue in the future if not addresses adequately.

Filling connectors

The lack of a single harmonised connector, perceived complexity, the use of adaptors has been cited always in the past by OEMs, developers, users as a major obstacle in wider acceptance of LPG as an engine and vehicle fuel. Filling

connectors especially in Heavy Duty applications must be able to provide robust, reliable and safe filling with fast filling speeds to suit large tank capacities required in HD applications and vehicles.

Fuel quality

The large variation in the quality of LPG in terms of composition and even contaminants, has been the cause of engine performance issues in the past and still today. This is the case not only amongst countries but also within same country, distributors, retailers, even with the season This is a serious concern for engine manufacturers.

Aftermarket conversion quality

In cases of aftermarket conversions, this can vary significantly, including suitability of systems used for the specific engine and engine applications.

4.4 Market Potential: Target Regions

Global energy demand is expected to increase by about 45 percent from 2014 to 2040, with about 85 percent of the growth coming from non-OECD32 countries, where economic activity is increasing most rapidly. The Global liquefied petroleum gas (LPG) market size was 278 million tons in 2015 and is expected to exceed 380 million tons by 2024, growing at a CAGR of 3.6% from 2016 to 2024.

Increasing government initiatives in emerging economies such as China, Indonesia, and India to encourage LPG applications on HDEs account of its extended benefits, could drive the market growth over the coming years till to 2040. This may be attributed to the numerous benefits such as non-toxic, easy accessibility, portable, clean, convenient, and cost-efficient, on well to wheel base (WTW), as compared to other alternative fuels.

LPG is also expected to witness significant growth in near future owing to **increasing alternative fuels demand mainly in the transportation sector** to minimize environmental concerns such as carbon emission levels and pollution levels. In addition, it is one of the cheapest energy sources, which is making it suitable over diesel and gasoline in the global transportation industry.

LPG market in Asia is anticipated to witness the highest growth in the coming years and this is further supported by the **expanding petrochemical capacities in China, India, South Korea, and Thailand.**

Mature economies of North America and Europe however are anticipated to witness sluggish growth owing to increasing awareness towards reducing reliance on fossil fuels.

The majority of the companies have been focusing on expanding their HDEs capabilities owing to rapidly increasing fleet count primarily in the Asia and Europe. Some of the other initiatives undertaken by the companies include **long-term collaborations with distributors and OEMS** for sustainable supply over the next few years.

Fleets are the fastest growing HDEs subsectors.

Marine is also a sector with great potential.

As Hybrid vehicles become more widely accepted, integration of LPG into advanced hybrid vehicle development may occur in all LPG Vehicles markets.

For LPG HD Engines and the applications that use them, the potential varies amongst regions and is dependent on factors like regulations, market growth in general, availability of refuelling infrastructure, cost of product etc.

The map below is an attempt to qualify these parameters per region.

Market potential for HDE using LPG

This figure provides analysis of market barriers in each region In addition to inherent market characteristics described above.

North America

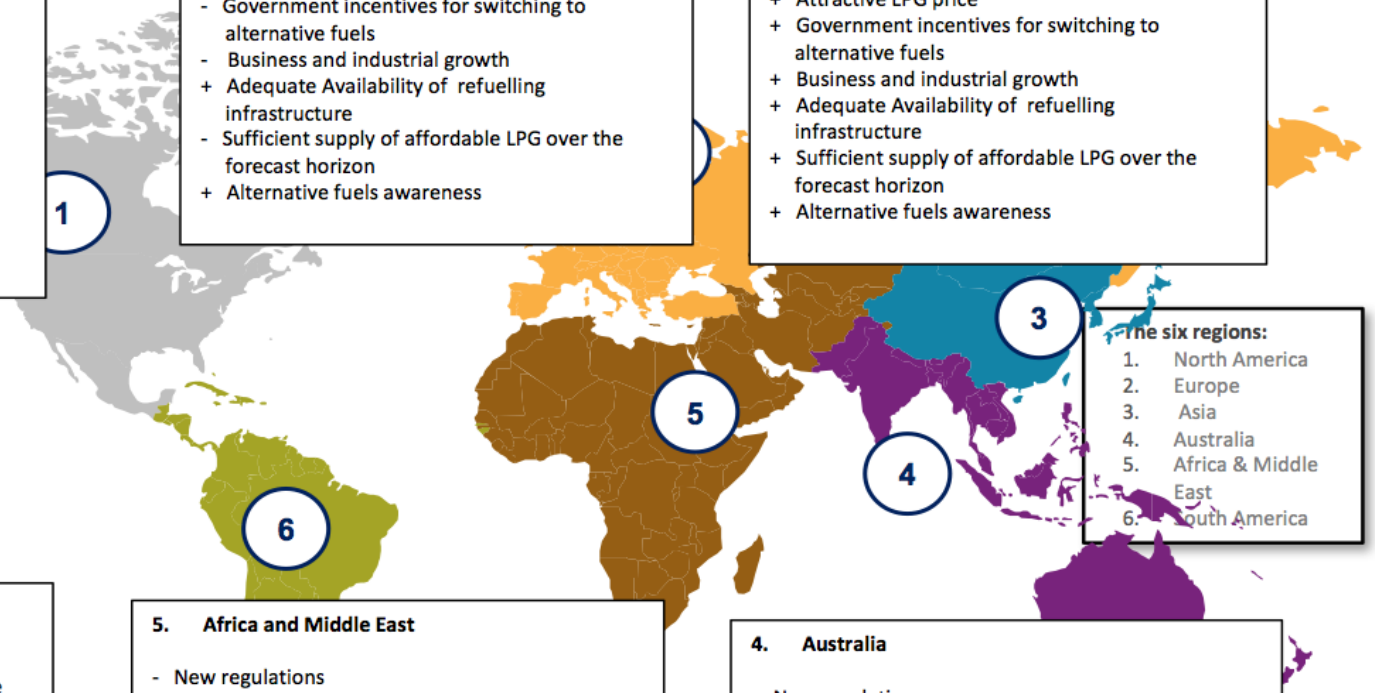
+ New regulations
+ Cost and Complexity of emission Compliance
+ Attractive LPG price
+ Government incentives for switching to alternative fuels
- Business and industrial growth
+ Adequate Availability of refuelling infrastructure
+ Sufficient supply of affordable LPG over the forecast horizon
+ Alternative fuels awareness

2. Europe

+ New regulations
+ Cost and Complexity of emission Compliance
+ Attractive LPG price
- Government incentives for switching to alternative fuels
- Business and industrial growth
+ Adequate Availability of refuelling infrastructure
- Sufficient supply of affordable LPG over the forecast horizon
+ Alternative fuels awareness

3. Asia (China and Japan)

+ New regulations
+ Cost and Complexity of emission Compliance
+ Attractive LPG price
+ Government incentives for switching to alternative fuels
+ Business and industrial growth
+ Adequate Availability of refuelling infrastructure
+ Sufficient supply of affordable LPG over the forecast horizon
+ Alternative fuels awareness



The six regions:

1. North America
2. Europe
3. Asia
4. Australia
5. Africa & Middle East
6. South America

Attractiveness based on these factors:
High to Low
Asia
North America
Europe
South America
Australia
Africa

6. South America

+ New regulations
+ Cost and Complexity of emission Compliance
+ Attractive LPG price
- Government incentives for switching to alternative fuels
- Business and industrial growth
- Adequate Availability of refuelling infrastructure
+ Sufficient supply of affordable LPG over the forecast horizon
+ Alternative fuels awareness

5. Africa and Middle East

- New regulations
- Cost and Complexity of emission Compliance
+ Attractive LPG price
- Government incentives for switching to alternative fuels
+ Business and industrial growth
- Adequate Availability of refuelling infrastructure
+ Sufficient supply of affordable LPG over the forecast horizon
- Alternative fuels awareness

4. Australia

- New regulations
+ Cost and Complexity of emission Compliance
+ Attractive LPG price
+- Government incentives for switching to alternative fuels
- Business and industrial growth
- Adequate Availability of refuelling infrastructure
- Sufficient supply of affordable LPG over the forecast horizon
+ Alternative fuels awareness

Chapter Five

Recommendations

LPG can play a major role in this changing environment and re-establish itself in the position that it deserves as an ideal alternative clean fuel.

The Roadmap section above identified the critical barriers to market uptake for Heavy Duty Engines with LPG. In this section are presented the recommendations on how each of these barriers can be overcome, and which type of market actors have a role to play.

All relevant players need to work together in a coordinated way to maximise the market opportunities for Heavy Duty Engines.

Such an integrated approach aims to create long-term sustainable market to:

- Increase customer awareness of the benefits of alternative fuels concerning GHG emissions
- Encourage consumers to buy carbon saving engine, equipment and vehicle technologies
- Create planning security from supply side for investments by fuel suppliers and OEMs
- Encourage fuel customers to choose LPG by introducing taxation incentives and other benefits

The summary table below indicates the varying roles of each type of player in overcoming the barriers to market growth. We differentiate between "Lead Role" (the actor is critical in overcoming the barrier), and "Support Role" (the actor can support but is not the critical element in overcoming the barrier).

Key: XX = Lead Role; X = Support Role.

Barrier	**Market Actor**			
	Industry Associations	LPG Companies	Engine Manufacturers/LPG System Developers	Government
Upfront Cost	**X**	**XX**	**XX**	**XX**
Economics for fleet operators	**X**	**X**	**XX**	**XX**
Policy/regulatory framework	**XX**	**XX**	**X**	**XX**
Technology development	**X**	**XX**	**XX**	**X**
Commercialisation/getting products to market	**X**	**XX**	**XX**	**X**
Awareness/perception	**XX**	**X**	**X**	**X**
Fuel Quality	**X**	**XX**	**X**	**X**

5.1. Upfront Cost the Greatest Challenge

- **Providing subsidisation** could bring down the upfront cost. ROLE OF GOVERNMENT
- **Offering financing packages**, via LPG distributors or other players, which could shift the upfront investment & risk away from the end user. This approach could create significant market growth. ROLE FOR LPG DISTRIBUTORS
- **Providing incentives** will bring down either the upfront cost or running costs (depending on the structure of the incentive - a grant or a tariff). ROLE OF GOVERNMENT
- **Lobbying** to ensure that LPG as engine fuel in transportation for HDV and other applications receive a fair incentive rate to be on a level playing field with other competing technologies such as diesel, CNG, LNG, will ensure that an LPG engine is considered as a preferable option. ROLE FOR INDUSTRY ASSOCIATION
- **Manufacturers of engines, equipment, vehicles, OEMs,** to integrate from the beginning LPG options in their product range to avoid subsequent modifications and added costs. ROLE FOR MANUFACTURERS

5.2. Economics for Fleet Operators is Favourable but Challenging

- **Engines manufacturers and new system technologies developers** will create cost-reduction potential by improving system efficiencies, with running cost benefits. Market potential of LPG dual-fuel technologies increases significantly when the capital cost of the vehicles is reduced, vehicle and engine offerings expand, and fuelling availability is facilitated. ROLE FOR ENGINE MANUFACTURERS and OEMs.
- **Customer adoption of dual-fuel engines** is more challenging than using dedicated diesel engines and vehicles due to initial uncertainty regarding engine durability, maintenance costs, operational aspects of new engines, and unfamiliarity of using different fuelling technologies and practices. ROLE FOR ENGINE MANUFACTURERS, OEMs and LPG COMPANIES.
- **Providing incentives** will bring down either the upfront cost and / or running costs (depending on the structure of the incentive). ROLE OF GOVERNMENT

5.3. Policy/Regulatory Framework: Heavy Duty Engines powered with LPG in single of dual LPG/Diesel mode to be on a Level Playing Field with Competing Technologies

- **Lobbying** to ensure that LPG powered engines in single or dual LPG/diesel mode are included in regulatory framework and incentive schemes. This should cover all types of uses, static and mobile/transport. Primary role for the associations and LPG companies to make policy-makers aware of the benefits of these systems using LPG, their safety and the potential of this technology. ROLE FOR ASSOCIATIONS
- **Lobbying** to ensure worldwide standards and certification regulations for OEMs and retrofit technologies. Associations, LPG companies and manufacturers must ensure that policy-makers and regulators develop safe, reliable regulations and in compliance with emissions requirements. ROLE FOR ASSOCIATIONS

5.4. Technology Development: Slow Rate Will Limit or Stop Growth

- **Investment in R&D** to support and accelerate the development of LPG fuel technology in Heavy Duty Engines and maximise its potential market applications. This is probably the most important enabler at present since development on other competitive fuels and technologies has largely overpassed those on LPG resulting to a serious lack of LPG HD engines. If this does not change rapidly, enormous opportunities will be lost and LPG may even disappear in some parts of the world as a HD engine fuel option. This could include investments to adapt existing natural gas fuelled engines to run on LPG. Besides investment, a long-term vision of what the market requires on such is needed. Primary role for manufacturers and developers but also largely for LPG companies.

There could be a role also for policy makers by making R&D funding available to develop new product concepts suited to their markets. ROLE FOR MANUFACTURERS (to develop), LPG DISTRIBUTORS (to assist with funds), ASSOCIATIONS (to facilitate)

- **Market analysis** to identify which markets, market sectors & applications have most potential, types of HD engines needed and what R&D developments should be made to ensure that the technology is well-suited to future needs and trends. ROLE FOR MANUFACTURERS AND ASSOCIATIONS
- **Filling connectors** to be developed and harmonised. Filling connectors especially in Heavy Duty applications must be able to provide robust, reliable and safe filling with fast filling speeds to suit large tank capacities required in HD applications and vehicles. ROLE FOR WORLD ASSOCIATION
- **Fuel quality** to be harmonised to serve as basis for engine and technologies development and reliable and consistent engine performance. Technology should help providing higher quality of product and adequate controls to maintain it. ROLE OF LPG COMPANIES
- **Aftermarket conversion quality** to be improved to offer consistent and high-quality conversions well adapted to the specific engine applications, this includes developers, manufacturers and installers. ROLE OF ENGINE MANUFACTURERS

5.5. Commercialisation & Getting Products to Market: Sales Channels and Supply infrastructure are Required

- **Support with developing partnerships in new regions** for distribution and sales of HD LPG engines, equipment and vehicles. Role of the associations to put their members in touch with local partners to develop sales channels and distribution networks. ROLE FOR REGIONAL ASSOCIATIONS AND ENGINE MANUFACTURERS
- **Expanding offerings** to include LPG HD engines, equipment and vehicles via existing sales channels, to develop these new relationships. ROLE FOR MANUFACTURERS AND ASSOCIATIONS
- **Market research** to identify which customer segments to target and what drives and motivates those customers in their decision-making process about acquiring a new engine. To educate distributors and other customer front actors. ROLE FOR ASSOCIATIONS and MANUFACTURERS
- **Expand refuelling network** to develop extensive refuelling infrastructure and dedicated refuelling fleet bases. ROLE OF LPG DISTRIBUTORS

5.6. Awareness/Perception: LPG HD engines, Equipment and Vehicles Need to be Considered by Policy-Makers, OEMs and All Types of Users as a Preferred Option

- **Developing a consistent vision** for HD Engines to be shared across the industry. Technology adaptations or developments needed, and any policy interventions to facilitate this. ROLE FOR ASSOCIATIONS and LPG DISTRIBUTORS.
- **Marketing/awareness-raising activities** involving for example information dissemination demonstrating real technology performance, applicability and potential, targeted marketing events for end-users, information/training events, sector exhibitions, etc. ROLE FOR ALL MARKET ACTORS – ASSOCIATIONS, LPG DISTRIBUTORS.
- **Collection of market data** of LPG HD Engines emission data to demonstrate the contribution LPG engines are making to carbon saving targets etc., to be targeted at governments. ROLE FOR ASSOCIATIONS.

5.7. Fuel Quality

Standardisation and harmonisation in fuel quality is key for succeeding in the engines market

- **Developing international standards** for HD Engines to be shared across the vehicle industry. ROLE FOR ASSOCIATIONS/ GOVERNMENT
- **Ensuring good quality fuels.** The LPG companies should always and everywhere ensure good quality fuels and customer satisfaction with continuous and reliable service. It is important to provide the OEMs with a constant quality chemical composition. ROLE FOR LPG COMPANIES
- **Improved controls** in the distribution chain so as LPG to maintain its prime qualities and keep it free of impurities and contaminants. ROLE FOR LPG COMPANIES/GOVERNMENT
- **Lobbying to support the emissions requirements/technologies and to ensure legal compliance.** ROLE FOR ASSOCIATIONS.

Abbreviations

AEGPL	European LPG Association
AFV	Alternative fuel vehicle
CI	Compression ignition
CHP	Combined Heat and Power (CHP)
CO_2	Carbon dioxide
DEF	Diesel exhaust fluid
DGE	Diesel gallon equivalent
DI	Direct injection
DI-PI	Direct injection gasoline and port injection LPG
ECAs	Emission controlled areas
ESC	European Stationary Cycle
ETC	European Transient Cycle
EV	Electric vehicle
GDI	Gasoline direct injection
GGE	Gas Gallon Equivalent
GHG	Greenhouse gases
CNG	Compressed natural gas
HC	Hydrocarbons
HDE	Heavy duty engines
HDDF	Heavy duty dual fuel
HDV	Heavy duty vehicle
HGV	Heavy goods vehicle
ICE	Internal combustion engine
IMO	International Maritime Organization
LDI	Liquid direct injection
LDV	Light duty vehicle
LEZ	Low emission zones (LEZ)
LGI	Liquid gas injection
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
LPI	Liquid port injection
LSHFO	Low Sulphur Heavy Fuel Oil
MMBtu	Mcf Millions of BTUs
NGV	Natural gas vehicle
NMHC	Non-methane hydrocarbons
NO_x NO and NO_2	Nitric oxide and nitrogen dioxide
OEM	Original equipment manufacturer
PI	Port injection
PM	Particle mass
PN	Particle number
PPM	Parts per million
SI	Spark ignition
THC	Total hydrocarbons
VOC	Volatile organic compounds
VPI	Vapour port injection
ULEZ	Ultra Low Emission Zone
UNECE	United Nations Economic Commission for Europe
VAT	Value-added tax
WLPGA	World LPG Association

LPG
EXCEPTIONAL
ENERGY

182 avenue Charles de Gaulle, 92200 Neuilly-sur-Seine, France
Tel: +33 1 78 99 13 30
association@wlpga.org
www.wlpga.org
@ExceptionalNRG