Power Generation from LPG

The Global Status of LPG-based Power Generation in Commercial, Industrial, and Power Sectors

GLOTEC

The World LPG Association

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

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

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Delta-ee are experts in heat and distributed energy. Our commercial insight and market expertise helps utilities, product manufacturers and policy makers navigate the transformation to a more distributed, customer centric and service-orientated energy future. We provide research services and bespoke consulting on a wide range of decentralised energy topics such as Micro-CHP, Heat Pumps, Energy Storage, Connected Homes, Demand Response and Customer Data Analytics.

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Chapter One

Introduction

1.1 Brief introduction

The aim of this document is to **promote understanding amongst the LPG (Liquefied Petroleum Gas) industry and other stakeholders of the technical possibilities, applications and market potential for power generation technologies using LPG**. Ultimately this is to inform the LPG community of the opportunities in this application and how to maximise them.

The report scope includes:

- Global scan of the market landscape for power generation in commercial, industrial, and power sectors, focusing primarily on 50 kWe – 20 MWe (unit size) reciprocating engines and gas turbines (because the market for these technologies are currently most developed and suitable to LPG), as well as other emerging technologies. The three applications considered are mono-generation (power-only), co-generation (power and heating), and tri-generation (power, heating, and cooling).

This report contains:

- **A 'fact sheet'** for each 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 the association members on how to overcome the barriers and maximise the market opportunity

Chapter Two

Executive Summary

2.1 Key Messages - Fact Sheet

The global decentralised market for 50kWe – 100 MWe power plants and cogeneration systems is established. The trigeneration market remains a relatively niche application.

- There are three main power generation applications:
    - **Monogeneration or Power-only**
    - **Cogeneration or Combined Heat and Power (CHP)**
    - **Trigeneration or Combined Cooling, Heat and Power (CCHP)**
- The most common combination of end-use sector, application, and prime mover technology are as follows:

	Small stand-by / back-up power generators	Commercial sector	Industrial sector	Independent power producer (IPP) sector / peaking and balancing plants
Prime mover technology	Reciprocating engines	Reciprocating engines Micro-turbines	Gas turbines Reciprocating engines	Gas turbines Reciprocating engines
Application	Monogeneration	Cogeneration (CHP) Trigeneration (CCHP)	Cogeneration (CHP)	Monogeneration

Note: Delta-ee limits the analysis of power generation technologies in the table above to reciprocating engines, gas turbines, and fuel cells; Delta-ee does not consider other technologies such as boilers, steam turbines, solar photovoltaics, wind turbines, etc.

There are no major technical barriers in the adaptation of monogeneration, CHP, and CCHP technologies to run on LPG and the appeal is becoming more prominent across key LPG markets. However, on a global scale, the use of LPG in power generation applications is still relatively small compared to other fuel types (natural gas, diesel, fuel oil).

- There are no significant technical or economic barriers in the adaptation of power generation technologies (reciprocating engines, gas turbines, and fuel cells) to run on LPG.
- Product efficiencies and costs are comparable to natural gas-fired versions.
- **Most major manufacturers with international presence have already adapted the technology, most comprehensively engine-based,** and are selling LPG versions into numerous end-use applications.
- Those that have not yet introduced LPG generally recognise that it is possible, **but are mostly still trying to establish the technology for natural gas - the biggest potential growth market and therefore the most attractive at first.**
- LPG power generation activity today is most highly concentrated in US, East Asia, and South America (although there is much potential elsewhere). **The total installed base of LPG power generation systems in the world is 10 - 15 GWe. Conversely, power generation capacity being fuelled by high sulphur fuel oil (HSFO), low sulphur fuel oil (LSFO), and diesel is in the 100s of GWe.**

2.2 Key Messages - Roadmap

The market for >50kWe gas-based decentralised power generation could see significant growth to 2021, predominantly in engines. In terms of the share of LPG within the global stationary power generation market, we estimate that this is small. In terms of annual installed capacity, this is less than 1 GWe per year (average annualised installations) accounting for LPG-only based systems and dual fuel* systems using LPG.

Table 1: Global >50kW (Stationary) Power Generation Market – Annual installed capacity of competing technologies

	Annual installed capacity (average of 2013-2016)	Growth in annual installed capacity up to 2021?	Where and why by 2021?
Diesel reciprocating engines	45 - 50 GWe / yr	↑ / →	Asia and Africa due to increasing power demand, but weak grid. Elsewhere emissions regulations, subsidy removals, and growth in gas systems are limiting further deployment.
Dual fuel* reciprocating engines	0.1 – 0.5 GWe / yr	↑	Asia, Africa, Middle East, and South America where there is increasing power demand - but insufficient access to gas supplies or end-users are exposed to volatile pricing (and hence prefer hedges against this via dual fuel systems).
Fuel oil reciprocating engines	0.5 – 1 GWe / yr	↓	South America and East Asia which have had higher oil-based power generation in the past may witness more oil-to-gas switching. The Middle East might maintain its reliance on oil up to 2021.
Natural gas reciprocating engines	4 - 6 GWe / yr	↑	Europe, North America, and Japan in CHP mode due to abundant gas supplies, modestly improving regulatory support, and increasing electricity prices (which improves the economics of CHP). Large power-only plants in North America and Asia to ramp up security of supply and balance intermittent renewables.
Micro turbines (<1 MWe unit size)	0.1 – 0.5 GWe / yr	↑	North America and Russia in off/onshore platforms and the oil and gas industry.
Natural gas turbines	30 - 40 GWe / yr	↑ / →	Europe, North America, and Japan in CHP mode due to similar reasons as gas reciprocating engines. Large power-only plants in Asia / Middle East to ramp up security of supply. Large gas engines may steal some market share from smaller gas turbine projects (<100MWe plant size).
Dual fuel* turbines	5 – 10 GWe / yr	↑	Similar to dual fuel reciprocating engines
Fuel oil turbines	1 – 5 GWe / yr	↓	Similar to fuel oil reciprocating engines
Fuel cells	0.1 GWe / yr	↑	North America and East Asia where there is government support in pilot projects, market push, and higher GDP per capita.

Note: *Dual fuel systems can typically switch from gaseous to liquid fuels and vice versa [i.e can run on natural gas, LPG, diesel, biofuel or fuel oil]. The table above does not include technology units <50kWe, nor portable power generation units.

There are several inherent market characteristics which support the LPG power generation opportunity:

- Limited gas grid / large areas with no gas connection
- Climate which creates a year-round heating demand
- Climate which creates a year-round cooling demand
- High/increasing electricity prices relative to gas
- Incumbent technology is expensive to run relative to LPG
- Unreliable electricity grid
- Expected growth in power demand
- Focus on emissions reduction
- Government incentives for oil-to-gas or coal-to-gas switching

LPG power generation faces several strong barriers which need to be overcome.

The following barriers are identified which need to be overcome in order for the full potential of LPG power generation to be realised:

- Economics of competing fuels
- Logistics – transportation, storage and infrastructure required for liquid fuels
- Volatility in LPG pricing
- Lack of understanding / education amongst relevant stakeholders
- Policy / Regulatory Framework: The benefits of CHP and CCHP should be fully recognised in the policy framework

All relevant market players need to work together in a coordinated way to overcome the barriers and maximise the market opportunities for LPG power generation.

Key actions identified in the recommendations are as follows:

1. **Raise awareness of LPG and highlight key strengths against competing fuels amongst policy-makers, customers, installers, utilities and the industry:** This means positioning LPG as a cleaner (i.e. emits less greenhouse gas emissions) fuel and generally having lower fuel costs and operations and maintenance (O&M) costs than diesel, HSFO, and LSFO-based power generators. This should be backed up by robust analysis and collection of real-life market data.

2. **Invest in extending the LPG infrastructure:** The investments needed to utilise liquefied natural gas (LNG) is high, with infrastructure requirements including distribution, storage, and regasification facilities. Construction lead times can take up to 2-5 years depending on the scale of the project. LNG utilisation is more cost-effective the larger the project, and does not scale down cost-efficiently to smaller sizes. This is where LPG can be used instead or be positioned as a "bridge" fuel while construction or extension of LNG infrastructures takes place. However, multiple stakeholders (local gas distribution companies, retailers, leasing companies, etc.) need to be involved as LPG infrastructure projects also require investments (albeit less than LNG infrastructure projects).

3. **Overcome the economic challenge for LPG CHP / CCHP and volatility in pricing for LPG:** Examples of ways to overcome this barrier could include economic support to end-users through financing packages (e.g. ESCO models), fixed price contracts, technology development which results in upfront cost-reduction and running cost savings.

4. **Ensure that policy/regulatory frameworks create a level playing field for CHP with competing technologies:** Lobbying is one of the most important activities to ensure this.

Chapter Three

Fact Sheet

This Fact Sheet provides an overview of the major power generation technologies, their major applications, and the global regions and market applications in which they have come to be used. It also provides a snapshot of the main players globally.

3.1 Breakdown of different types of power generation applications

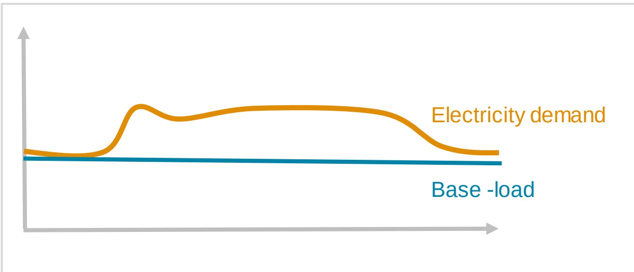
Within this Fact Sheet, we describe three main power generation applications:

- Monogeneration or Power-only
- Cogeneration or Combined Heat and Power (CHP)
- Trigeneration or Combined Cooling, Heat and Power (CCHP)

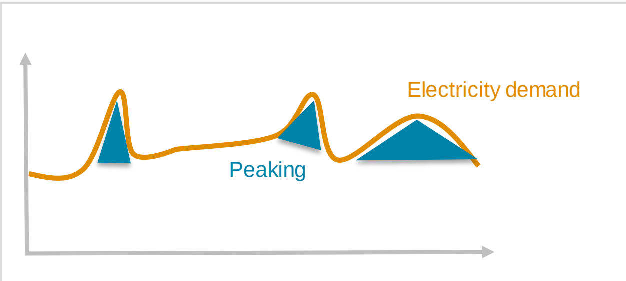
3.1.1 Definition of Monogeneration (Power-only)

Power-only: The generation of electricity alone typically takes place where there is no local need for heating and cooling. The power that is produced can either be exported to the local electricity grid, or alternatively be used in island mode operation to power local facilities. There are three main applications for power-only generation:

- **Base-load:** Base-load generation involves a power generator or power plant which can continuously generate electrical power needed to satisfy minimum demand. It is useful where there is a stable source of fuel, such as natural, liquid propane, landfill, or coal gas to power the generators or plants.



- **Peaking:** Peaking plants are designed to help balance fluctuating electrical power requirements. Peaking stations typically operate in standby mode; then when there is a peak in demand for power, the peaking plant receives a signal to commence operation. Due to their flexibility and robustness they are able to provide a rapid response to fluctuating demand. They are then turned off as demand reduces.



- **Standby / backup:** A standby generator is an automatic back-up electrical system. Within seconds of a utility outage an automatic transfer switch senses the power loss, and the generator will start supplying power. After utility power returns, the electrical load is transferred back to the utility and the standby generator returns to standby mode. Most standby / backup generators tend to run on diesel, but also natural gas or LPG.

3.1.2 Definition of Cogeneration (CHP) and Trigeneration (CCHP)

Combined heat and power (CHP) means the simultaneous generation of two useful forms of energy, electrical and thermal, from a single fuel source. This is also commonly referred to as ‘cogeneration’. CHP scale is identified based on the rated *electrical* output of the cogeneration appliance, e.g. all 500kWe systems provide 500 kilowatts of electricity (at peak), but not necessarily the same amount of heat.

"Trigeneration” is the simultaneous production of electricity, hot water and/or steam, and chilled water from one fuel. Essentially, it can be thought of as a cogeneration power plant that has added absorption chillers for producing chilled water from the heat that would have been wasted in a cogeneration power plant. Trigeneration has its greatest benefits when scaled to fit buildings or complexes of buildings where electricity, heating and cooling are perpetually needed. Such installations include but are not limited to: data centers, manufacturing facilities, universities, hospitals, military complexes, colleges, hotels and resorts.

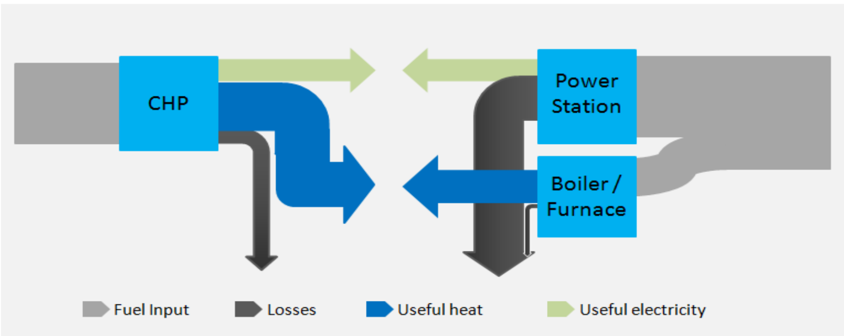
3.1.3 The CHP / CCHP Principle

Energy efficiency is the basis of the CHP principle. By generating both heat and power together, CHP maximises the conversion of the potential energy in the fuel into useful energy for the user, usually at or near to 90% overall efficiency.

Typically, CHP is located at the same site as the energy consumer and this ensures that energy loses from transmission are also minimised. In addition, through the use of a single fuel source CHP gives environmental benefits in terms of reduced carbon dioxide and other pollution/particulate emissions.

CHP is either ‘heat-led’ whereby cogeneration follows the demand for space / process / water heating (the conventional way), or ‘electricity-led’ where heat is produced only when there is a requirement for electrical power. The CHP principle is explained below. The graphic illustrates how it is a more efficient process than obtaining heat and power from separate sources:

Figure 1 CHP principle, in comparison to the separate generation of heat and power



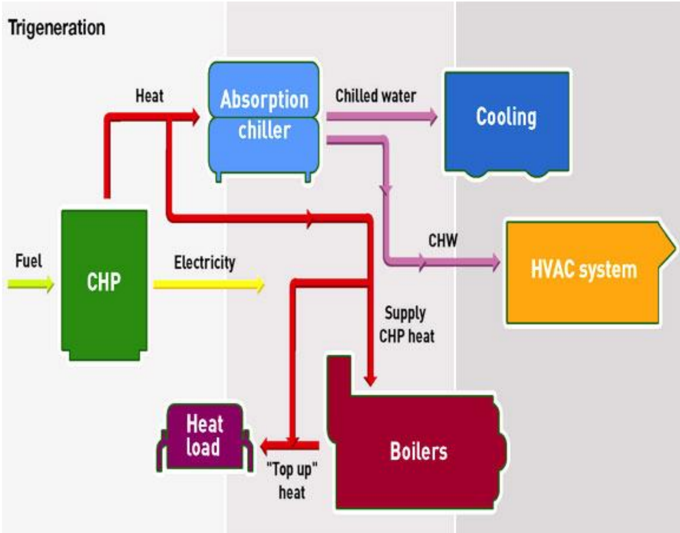
Explanation of the CHP process:

① Fuel is delivered to the **prime mover**, a generic term for any machine that converts fuel to useful work where it is combusted and generating thermal and kinetic energy inside the system[1].

[1] For simplicity, the traditional CHP process is described, where an engine or a turbine is the prime mover, which combusts the fuel. In a fuel cell CHP system there is no combustion as both heat and electricity result from a chemical reaction instead (although the overall input/process/output concept is largely similar).

❷ A **heat exchanger** captures this heat and transfers it to useful heat for the building's heating / hot water circuit (or for process heat, such as steam). If an absorption chiller is added to the set-up then this heat may be used to drive a cooling process, providing chilled water e.g. for distribution through an air conditioning system.

❸ An **electrical generator** connected to the prime mover utilises the kinetic energy to induce an electric current. An **inverter** is most often used to ensure the same voltage and frequency of the grid is provided



3.1.4 Benefits of the different power generation applications

The use of distributed power generators, CHP, and CCHP gives benefits over the common means of deriving electricity from the national grid and the use of conventional heating / cooling systems. Key advantages include:

Benefits	Power-only	CHP / CCHP
Cheaper Electricity: Electricity produced on-site can cost less than half of what it would if it were bought from a power retailer instead (although this does depend on the region in question).	X	XX
Security of supply: Another benefit to the above is that it gives a degree of independence from external providers. Increasingly the use of storage via batteries is also being explored. Automatic standby generator systems may be required by building codes for critical safety systems such as elevators in high-rise buildings, fire protection systems, standby lighting, or medical and life support equipment.	XX	XX
Greater Efficiency: Producing electricity on-site also avoids the typical losses that come via the national / regional transmission and distribution network. Typically, only 40% of the energy used to generate grid electricity is supplied to the end user as useful energy, as heat is wasted in the generation process and energy is lost in transmission between the power station and the end user.	X	XX
Deferred Network 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.	XX	XX
Financial Remuneration: Excess electricity can be fed back to the grid, sometimes at a premium for CHP / CCHP and at the wholesale price of electricity for power-only generators.	X	XX
Standby / Peaking Assistance: Standby generators and CHP can be quickly fired-up to assist with electricity production at times of peak demand or to balance intermittent renewable generation. Many parties are now looking into the idea of capacity markets or 'virtual power plants' of many connected generators and CHPs.	XX	XX
Reduction in Carbon Emissions: Due to fuel efficiency, installing a CHP / CCHP system can reduce carbon emissions. However, in some situations, installing a CHP / CCHP system may cause overall emissions of air pollutants to fall but local emissions may actually rise. The exact impacts will depend on the type of technology and fuel used, the presence of any emission abatement equipment, and the nature of emission dispersion from exhaust stacks.	X	XX

3.2 Current Technologies

3.2.1 Reciprocating Engine

A well-established technology for the back-up / standby generator, commercial and light industrial sector which is highly-suited to LPG applications.

Reciprocating engines operate on the same principles as petrol and diesel automotive engines. They enjoy high volume mass production and are often the lowest capital cost per kW of capacity. Reciprocating engines currently account for the majority of decentralised power generation units for continuous use under 5 MWe and for back-up power. Like automotive engines, reciprocating engines can be split into two categories; compression ignition (diesel cycle) engines and spark ignition (otto cycle) engines.

Electrical efficiencies are in the 30 - 40% range. Spark ignition engines have lower efficiencies due to the possibility of knocking - caused by over rapid combustion of fuel in the cylinder. They are also smaller in unit size, ranging from 50 kWe to 20 MWe.

Main Applications

- CHP mode - Residential (multi-family homes)
- CHP mode - Commercial sites with high / higher than average heating demands, and a greater demand for heat relative to electricity
- CHP mode - Small industrial sites (e.g food & drinks industry, textiles industry)
- Back-up / standby generators (typically diesel due to cheaper upfront cost)
- Peaking power plants to balance intermittent renewable energy generation
- Reciprocating engines in CCHP mode can also provide cooling, but to date such installations have been in the minority.

Suitability for LPG

Internal combustion engines are highly-suited to run on LPG. System developers typically launch products based on a natural gas engine first, but then adapt it to an LPG version too. The differences between the two are minimal, exemplified by how they come off the same production line.

3.2.2 Gas Turbines

Gas turbines are currently the favoured prime mover in larger-scale power generation, where total power plant size exceeds 50 or 100 MWe

Gas turbines are typically used in larger-scale power generation and CHP projects; especially wherever natural gas is available at costs less than three to four times the equivalent energy cost of solid fuels. For operation, intake air passes through a compressor before being heated by the combustion of the fuel. The expanding air is then used to drive a turbine before exiting through the exhaust and heat processes. Compressors require a large amount of energy, making the choice of compressor crucial to the overall efficiency of the turbine.

The electrical efficiencies of modern gas turbines range from 25 - 35% simple cycle efficiency, with typical efficiencies of 32%. For systems larger than 5MW, the gas turbine exhaust, typically around 540ºC, can be used to produce high-pressure steam, which then powers a second generator. Such combined-cycle gas turbines (CCGT) have electric efficiencies of 35%-55%. The pass-out steam from the steam turbine can be used to meet on-site heat requirements increasing overall efficiencies to 75% to 90%. This lowers electricity production, but improves overall economics.

Main Applications

- Simple cycle gas turbines are generally used to provide peaking power or back up power without any provision of heat.
- Cogeneration cycle gas turbines are suitable for industrial and commercial applications (typically large industrial sites such as petrochemical industry, cement industry). In industrial applications the exhaust gases can be used to produce process steam or chilling, or directly for drying processes if direct contact with exhaust gases is permissible

Suitability for LPG

Gas turbines are typically suited to LPG. Fuel regulation is different when using LPG due to its slightly different flow characteristics compared to natural gas, but this adds minimal manufacturing cost and is equally un-impactful on overall system efficiency.

3.2.3 Microturbines

An example where an LPG system can perform better than a natural gas one.

Microturbines are small high-speed generator plants. Microturbines evolved from automotive and truck turbochargers, auxiliary power units for airplanes and small jet engines. They consist of a single shaft connecting a turbine, compressor and generator. Air is drawn in through a compressor into a recuperation unit that has been heated by the exhaust gases. The air flows into a combustion chamber where it is mixed with the fuel and burned. The hot gas is expanded through the turbine creating mechanical energy. The exhaust gases pass out through the recuperation unit to capture some of the remaining heat.

Main Applications

- Small commercial / light industrial
- In remote oil extraction applications

Suitability for LPG

Modifications must be made to a conventional gas microturbine to protect it from any condensation occurring inside the system but, this further pressure control can also be dealt with at the LPG tank. Microturbines do have a high tolerance of differing qualities of the fuel though, including variations of LPG. The heating value and flame temperatures are very close to natural gas-based systems, and the combustor can be 're-tuned' with simple engineering. As the flammability limit of LPG is better than natural gas, these systems could even expand the possible range of power modulation.

3.2.4 Fuel Cells

Currently a very small but emerging option, with numerous types of fuel cell technologies – each suited for specific power generation applications.

Fuel cells are electrochemical devices that produce electricity and heat from a fuel (often hydrogen) and oxygen. Unlike conventional engines, they do this without burning the fuel and are therefore generally cleaner and more efficient. There are many different types of fuel cell technologies, as listed below, but we focus on the three most common types in Table 2.

- PEMFC (Polymer Electrolyte Membrane)
- SOFC (Solid Oxide)
- MCFC (Molten Carbonate)
- DMFC (Direct Methanol)

- AFC (Alkaline)
- PAFC (Phosphoric Acid)

Table 2: Technical characteristics of PEMFC, SOFC, and MCFC

Fuel Cell Type	Operating Temperature	Typical Stack Size	Electrical Efficiency	Advantages	Challenges
Polymer Electrolyte Membrane (PEMFC)	<120°C	<1 kWe – 100 kWe	25 – 35%	• Solid electrolyte reduces corrosion and electrolyte management problems • Low temperature • Quick start-up and load following	• Expensive catalysts • Sensitive to fuel impurities
Solid Oxide (SOFC)	500°– 1,000°C	1 kWe – 2 MWe	50-60%	• High efficiency • Fuel flexibility • Solid electrolyte • Suitable for CHP • Hybrid/gas turbine cycle	• High temperature corrosion and breakdown of cell components • Long start-up time • Limited number of shutdowns
Molten Carbonate (MCFC)	600°–700°C	300 kWe – 3 MWe	43%-50% (higher w/ turbine or organic rankine cycle)	• High efficiency • Fuel flexibility • Suitable for CHP • Hybrid/gas turbine cycle	• High temperature corrosion and breakdown of cell components • Long start-up time • Low power density

Suitability for LPG

It is well-suited to LPG, and products require only little modification from natural gas-based designs. But, fuel quality can provide a technical challenge. The degree of sulphur contained in LPG may affect the lifetime of the platinum catalyst used in the stack. Many of the manufacturers have developed 'multi-fuel' reformers, which overcomes the variations in the level of odorants in LPG during the desulphurisation process.

Requirements for Maintaining Utmost Performance of Fuel Cell

For fuel cells in general, the quality of LPG is an important factor in system performance. Therefore, it is necessary to maintain consistency in the quality of LPG. In addition, it is important to reduce sulphur level in LPG and avoid contamination with other impurities.

3.2.5 Summary of key differences between different CHP technologies

Historically, steam turbines have been the main CHP prime mover, but today, gas engines and industrial gas turbines are the technologies of choice. Gas engine CHP is applied mainly in buildings and applications requiring heating and hot water. Gas turbine CHP tends to be applied in larger industrial applications where they provide steam. The table below highlights some key differences between the different prime movers when used in CHP mode.

Table 3: Key differences between various CHP technologies

	Size range	Electrical efficiency (50kWe – 5MWe) **	Flexibility of operation***	Maintenance costs	Average installed costs / kWe (0.5 – 5 MWe CHP plants)
Gas engine	1 kWe – 20 MWe	30 – 40%+	High	Moderate	~£800
Gas turbine*	1 MWe – 20 MWe+	25 – 35%	Low / moderate	Moderate	>£800
Fuel cell	1 kWe – low MWe	30 - 60%	Low	Very high	>£2,000
Microturbine	Low 10s to high 00s kWe	20 – 30%	Moderate	High	>£1,000

* For the sake of comparison, we have considered smaller gas turbine units here.

** Note 'overall efficiency' is the electrical efficiency (electricity output / energy input) + the thermal efficiency (heat output / energy input). The overall efficiency for CHP systems can reach 80-90%.

*** A high flexibility of operation enables a prime mover to easily modulate (vary output) without a significant fall in energy efficiency.

The main comparison points between gas-based reciprocating engine CHP and gas-based turbine CHP (the two main gas-based CHP technologies) are as follows:

- Reciprocating gas engines have higher electrical efficiencies than gas turbines of comparable size, and thus lower fuel-related operating costs. Also, as load falls, engine efficiency is maintained better than in gas turbines.
- The installed costs of reciprocating engines are generally lower than gas turbines up to 3-5 MW in size.
- Reciprocating engine maintenance costs are generally higher than comparable gas turbines, but the maintenance can often be handled by in-house staff or provided by local service organisations.

3.3 Market Status

3.3.1 Stationary Power Generation Market

In this section we discuss the annual installed capacity of reciprocating engines, gas turbines, and fuel cells for stationary power generation applications. Based on Table 4, we can see that reciprocating engines and gas turbines have similar annual installed capacity trends, 40 – 60 GWe per year, but reciprocating engines enjoy far greater numbers in terms of unit sales. The fuel cell market is still small in comparison, roughly around 100 MWe per year.

Table 4: Global (stationary) Power Generation Market

Reciprocating Engines		Average 2013 - 2016	
Size band	*Unit sales*	*Capacity output (MWe)*	*Main fuel type*
0.05 – 0.5 MW	Low 10,000s	10,000 – 30,000 MWe per year	Diesel
0.5 – 5 MW	Mid 10,000s	30,000 – 50,000 MWe per year	Diesel
5 – 10 MW	Mid 100s	1,000 – 5,000 MWe per year	Natural gas
10 – 50 MW	Low 100s	1,000 – 5,000 MWe per year	Heavy fuel, Dual fuel
Total		**~ 50 – 60 GWe per year**	

Gas Turbines		Average 2013 - 2016	
Size band	*Unit sales*	*Capacity output (MWe)*	*Main fuel type*
0.05 – 1 MW	Mid 10s	1,000 – 5,000 MWe per year	Natural gas
1 – 10 MW	Mid 100s	1,000 – 5,000 MWe per year	Heavy fuel
10 – 60 MW	Low 100s	5,000 – 10,000 MWe per year	Dual fuel
60 – 200 MW	Low 100s	30,000 – 50,000 MWe per year	Natural gas
Total		**~ 40 – 50 GWe per year**	

Fuel Cells		Average 2013 - 2016	
Size band	*Unit sales*	*Capacity output (MWe)*	*Main fuel type*
0.05 – 0.5 MW	Mid 10s	<1,000 MWe per year	Natural gas
0.5 – 5 MW	Mid 10s	<1,000 MWe per year	Natural gas
Total		**~ 0.1 GWe per year**	

- *<1,000 MWe per year*
- *1,000 – 5,000 MWe per year*
- *5,000 – 10,000 MWe per year*
- *10,000 – 30,000 MWe per year*
- *30,000 – 50,000 MWe per year*

In terms of the share of LPG within the global stationary power generation market, we estimate that this is small. In terms of annual installed capacity, this is less than 1 GWe per year (average annualised installations). **The total installed base of LPG power generation systems in the world is 10 - 15 GWe.** Hitachi Ltd., for instance, has installed a total of 121 LPG-based turbines across the globe since 1964 (Figure 2), mainly using gas turbines with capacity outputs less than 100 MWe (as illustrated in Figure 3). All units are dual or triple fuel systems*.

Note: *Dual fuel and triple fuel systems can typically switch from gaseous to liquid fuels and vice versa [i.e can run on natural gas, LPG, diesel, biofuel or fuel oil].

Figure 2: Number of LPG turbine units installed by Hitachi Ltd. since 1964

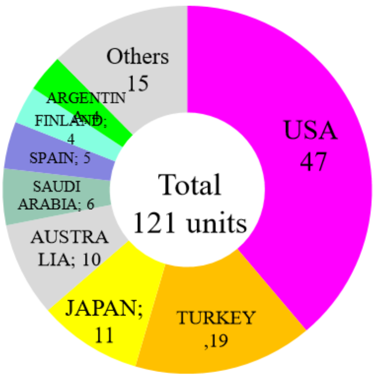
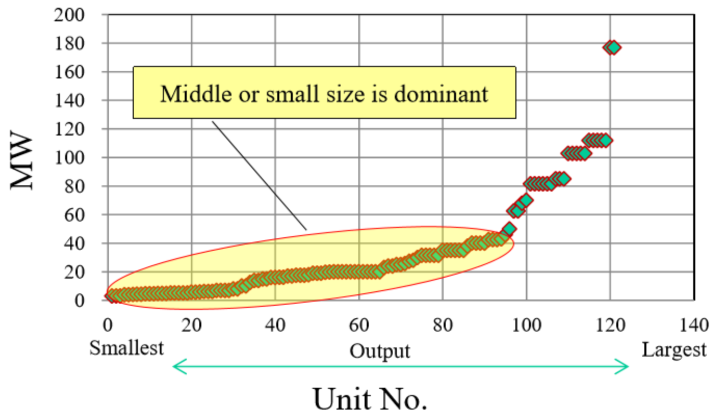


Figure 3: Capacity outputs of typical gas turbine units installed by Hitachi Ltd.



Source: Hitachi Ltd., 2014 – presented at the WLPGA Regional Summit, Jan 2014

3.3.2 Rental and Portable Power Generation Market

While the focus of this report is on stationary power generation applications, it is important to highlight portable and rental offerings as well. At times, temporary power is needed and this is where emergency or rental generators come in. Portable units can be delivered immediately to minimise downtime and keep for example, facilities or industrial production running. Rented systems can be used for emergency outages, a planned project, or a temporary surge in demand. Some generating sets incorporate high-performance sound-reduction technology and are ideal for sensitive environments, such as events and urban areas.

Companies like Caterpillar, Cummins, Aggreko, and Kohler offer solutions for rental power needs of all sizes and shapes, from temporary, single-site power, to baseload-scale, multi-megawatt power for regional grids.

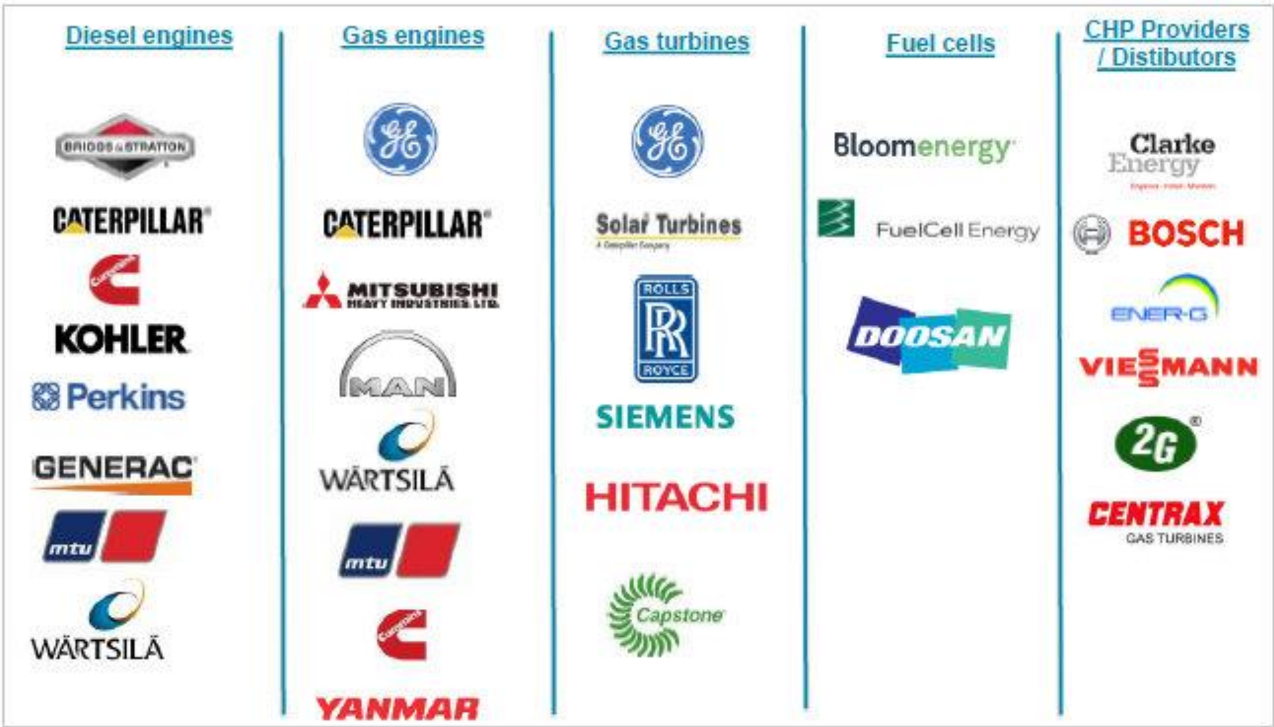
The global power rental market is estimated to be a multi-billion-dollar market (in the high 1s of billion US Dollars). Market growth will be driven by factors such as the growing demand for power, aging grid infrastructure, lack of access to electricity, and increasing construction and infrastructural activities across the globe. Data is limited but we anticipate that less than 10% of this market value accounts for the LPG rental and portable power generation market globally.

3.4 Main Players

3.4.1 Main Players: >50kWe Power Generation Market

In Figure 4 below we highlight some of the key players in the power generation market (not exhaustive list). It is clear to see that most major OEMs (Original Equipment Manufacturer) have a wide product portfolio (e.g. General Electric, GE, has a range of reciprocating engines, gas and steam turbines which can operate on gaseous, solid, and liquid fuels). Some OEMs also take on CHP packaging (offering containerised units) and operations & maintenance (O&M) contracts (e.g. Cummins). Others leave distribution and CHP package provision to specialist CHP packagers. Capstone enjoys a monopoly on the microturbine market. As discussed in Section 3.4.3, many of the market players below also have LPG offerings.

Figure 4: Key market players offering power generation solutions



***Note: Order of company logos are not indicative of market share**

3.4.2 Main Players: <50kWe Power Generation Market

While the focus of this report is on the >50kWe power generation market, it is important to note that there are smaller units as well on the market. For example, we highlight below some CHP packagers operating within the 5-50kWe size range.

Greengear (in partnership with Calor) offer 2kWe – 7.5kWe LPG power generators. In UK, this partnership is effective in gaining market share as for example, if customers fuel their generator with Calor gas, they get a £500 3kW Greengear generator for only £250, plus £100 of gas vouchers.

3.4.3 LPG Offerings from Key Players

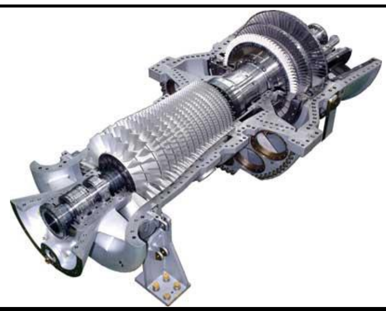
In the following pages, we provide eight profiles of companies offering LPG power generation products.

Kohler		
Company Background		Kohler Power Systems specialise in power systems and components (generators, transfer switches, paralleling switchgear and controllers). Kohler supports a fully integrated approach, from engineering EPA-compliant diesel and gas generator sets from 10 to 2800 kW, a full line of automatic transfer switches, customisable paralleling switchgear, and controls that can manage a multitude of power systems applications, along with wireless monitoring and Web-enabled remote PC.
LPG Product Portfolio	**Prime mover type**	Internal combustion engines
	Size range	25 kWe – 50 kWe
	Other fuel types	Natural gas
Services offered		Design, Installation, Operations & Maintenance, Rental
Geographic coverage		USA-based, worldwide network of distributors

Yanmar			
Company Background		Yanmar specialise in sales of a range of products including compact industrial engines, micro-CHP systems, gas heat pumps, and components. It has a history of 100 years in diesel engine manufacturing in a wide range of applications, including seagoing vessels, construction equipment, agricultural equipment and generator sets – but in the past 20 years has established itself in gas-based engine solutions as well.	
LPG Product Portfolio	Prime mover type	Internal combustion engines [YEG-G series]	
	Size range	10 -25 kWe	
	Other fuel types	Natural gas, Biogas	
Services offered		Installation	
Geographic coverage		Mainly Japan, but with worldwide network of distributors	

Wärtsilä			
Company Background		Wärtsilä Energy Solutions is a leading global supplier of flexible baseload power plants of up to 600 MW operating on various gaseous and liquid fuels. Their portfolio includes unique solutions for peaking, reserve and load-following power generation, as well as for balancing intermittent power production. Wärtsilä Energy Solutions also provides LNG terminals and distribution systems. As of 2015, Wärtsilä has 58 GW of installed power plant capacity in 175 countries around the world.	
LPG Product Portfolio	Prime mover type	Internal combustion engines	
	Size range	4,000 – 18,000 kWe	
	Other fuel types	Natural gas	
Services offered		Design, Installation, Operations & Maintenance	
Geographic coverage		Worldwide	

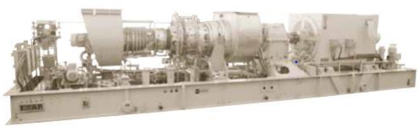
<table>
<tr><th colspan="4">Capstone</th></tr>
<tr><td colspan="2">Company Background</td><td colspan="2">Capstone is a leading manufacturer of micro turbine technology for electrical power generation, cogeneration, biogas-fueled renewable energy, and hybrid vehicle power. 60% of Capstone's power generation-related sales go to off/onshore platforms and oil and gas industry due to their technology's ability to handle to "dirty" fuel types.</td></tr>
<tr><td rowspan="3">LPG Product Portfolio</td><td>Prime mover type</td><td colspan="2">Micro turbines</td></tr>
<tr><td>Size range</td><td colspan="2">30 – 1,000 kWe</td></tr>
<tr><td>Other fuel types</td><td colspan="2">Natural gas, Biogas</td></tr>
<tr><td colspan="2">Services offered</td><td>Design, Installation, Operations & Maintenance, Finance</td><td rowspan="2"></td></tr>
<tr><td colspan="2">Geographic coverage</td><td>Mainly North America and Russia , but has worldwide coverage</td></tr>
</table>

<table>
<tr><th colspan="4">Hitachi</th></tr>
<tr><td colspan="2">Company Background</td><td colspan="2">Hitachi, Ltd. is a Japanese multinational conglomerate company that operates eleven business segments: Information & Telecommunication Systems, Social Infrastructure, High Functional Materials & Components, Financial Services, Power Systems, Electronic Systems & Equipment, Automotive Systems, Railway & Urban Systems, Digital Media & Consumer Products, Construction Machinery and Other Components & Systems. In 1964, Hitachi signed a joint manufacturing agreement with GE, the world's leading gas turbine manufacturer.</td></tr>
<tr><td rowspan="3">LPG Product Portfolio</td><td>Prime mover type</td><td colspan="2">Gas turbines</td></tr>
<tr><td>Size range</td><td colspan="2">17,000 – 110,000 kWe</td></tr>
<tr><td>Other fuel types</td><td colspan="2">Natural gas, Biogas</td></tr>
<tr><td colspan="2">Services offered</td><td>Design, Installation, Operations & Maintenance</td><td rowspan="2"></td></tr>
<tr><td colspan="2">Geographic coverage</td><td>Mainly in Japan and Asia, but has worldwide coverage</td></tr>
</table>

Siemens		
Company Background		Siemens is a German company headquartered in Berlin and Munich and the largest engineering company in Europe with branch offices abroad. The Siemens gas turbine range with capacities ranging from 4 to 400 MW fulfil the high requirements of a wide spectrum of applications. A recent addition to their portfolio are the Dresser-Rand gas turbines as well.
LPG Product Portfolio	**Prime mover type**	Gas turbines
	Size range	4,000 – 400,000 kWe
	Other fuel types	Natural gas, Biogas
Services offered		Design, Installation, Operations & Maintenance
Geographic coverage		Worldwide

GE (General Electric)		
Company Background		GE is the world's largest supplier of gas turbines. Half of the world's installed power base is from GE, with more than 10,000 gas and steam turbine generating units, representing more than 1,000 GWs of installed capacity in 120 countries. It is also a leading manufacturer of gas engines through its Jenbach and Waukesha brands.
LPG Product Portfolio	**Prime mover type**	Gas turbines, internal combustion engines
	Size range	18,000 – 470,000 kWe (Gas turbines); 165 – 9,500 kWe (Internal combustion engines)
	Other fuel types	Natural gas, Biogas
Services offered		Design, Installation, Operations & Maintenance
Geographic coverage		Worldwide

<table>
<tr><th colspan="4">CATERPILLAR</th></tr>
<tr><td colspan="2">Company Background</td><td colspan="2">Caterpillar Inc., is an American corporation which designs, manufactures, markets and sells machinery, engines, financial products and insurance to customers via a worldwide dealer network. Caterpillar is a leading manufacturer of construction and mining equipment, diesel and natural gas engines, industrial gas turbines and diesel-electric locomotives.</td></tr>
<tr><td rowspan="3">LPG Product Portfolio</td><td>Prime mover type</td><td colspan="2">Internal combustion engines</td></tr>
<tr><td>Size range</td><td colspan="2">100 – 9,000 kWe</td></tr>
<tr><td>Other fuel types</td><td colspan="2">Natural gas, Biogas</td></tr>
<tr><td colspan="2">Services offered</td><td>Design, Installation, Operations & Maintenance, Rental</td><td rowspan="2">
</td></tr>
<tr><td colspan="2">Geographic coverage</td><td>Worldwide</td></tr>
</table>

<table>
<tr><th colspan="4">SOLAR</th></tr>
<tr><td colspan="2">Company Background</td><td colspan="2">Solar Turbines (a CATERPILLAR company) manufactures mid-size industrial gas turbines for use in electric power generation, gas compression, and pumping systems. More than 70% of Solar's products are exported from the United States. Solar sells, manufactures, and services its products in 98 countries from 43 locations. Solar participates in two major market segments: Oil and Gas Production and Transmission (O&G), and Power Generation (PG).</td></tr>
<tr><td rowspan="3">LPG Product Portfolio</td><td>Prime mover type</td><td colspan="2">Gas turbines</td></tr>
<tr><td>Size range</td><td colspan="2">1,000 – 22,000 kWe</td></tr>
<tr><td>Other fuel types</td><td colspan="2">Natural gas, Biogas</td></tr>
<tr><td colspan="2">Services offered</td><td>Design, Installation, Operations & Maintenance, Financing</td><td rowspan="2"></td></tr>
<tr><td colspan="2">Geographic coverage</td><td>Worldwide</td></tr>
</table>

3.4.4 Engagement of Utilities and Other Stakeholders

The engagement of utilities, industry associations and other players can be instrumental in driving growth in the market; helping products commercialise and also raising consumer and policy-maker awareness. Some key examples of such activity are highlighted below. Many of these initiatives do not specifically support power generation using LPG, but the projects will have a positive impact on LPG power generation, helping product concepts to reach commercialisation, raising the profile with policy-makers and end-users, and ensuring the inclusion of technologies in regulations and incentive schemes.

WLPGA **WLPGA: Supporting LPG products and its applications globally**

The World LPG Association (WLPGA) is the authoritative voice of the global LPG industry representing the full LPG value chain. The primary goal of the association is to add value to the sector by driving premium demand for LPG, while also promoting compliance to good business and safety practices. The WLPGA has over 250 members, operating in approximately 125 countries involved in one, several or all activities of the industry; develops long-term partnerships with international organisations; and implements projects on local and global scales.

WLPGA has created a website called "Exceptional Energy in Action" which aims to be the most comprehensive database for LPG applications available on the web.

AEGPL EUROPE European LPG Association

AEGPL: The European Association for the promotion of LPG

AEGPL comprises national LPG associations, representing the main European LPG suppliers, distributors and equipment manufacturers. It aims to identify and monitor European LPG markets and policies that affect it; engage with the European Commission, Council and Parliament to ensure the sector's initiatives are consistent with the needs of EU; develop best practises and standards, and promote the LPG industry.

COGEN Europe. The European Association for the promotion of cogeneration

COGEN Europe is Europe's main industry association for the cogeneration industry. COGEN works at the EU and Member State level to help promote CHP. Members include those companies involved with CHP of all different sizes and using any variety of fuels.

PERC: Supporting LPG products and its applications in North America

Among other activities, PERC (Propane Education and Research Council) is involved with supporting research, development, and demonstration of innovation LPG products and applications. Sponsored by PERC, the Propane Heat and Power program provides a financial incentive to qualifying and select participants who purchase and use eligible propane-fuelled products such as installed and towable generators, CHP systems, and other solutions.

Virgin Islands Water and Power Authority: Supporting conversion to LPG and setting a new model for other island power authorities and small utilities serving confined areas to consider adapting

The U.S. Virgin Islands has set a new model for other island power authorities and small utilities serving confined areas to consider adapting. Their conversion to LPG for electrical power generation is the first project of its kind and hopes to pave a new path for clean, affordable power. The U.S. Virgin Islands Water and Power Authority (WAPA) is in the middle of a US$150 million transition from fuel oil to propane. The project is expected to cut WAPA's fuel costs by 30%, amounting to annual savings of around US$90 million. Seven GE turbines at the 198-MW plant on St. Thomas and the 118-MW plant on St. Croix that previously ran on No. 2 fuel oil are being converted to dual-fuel operation by Dutch firm Vitol.

3.5 Case Studies

In the following pages, we provide five case studies on LPG power generation projects.

WÄRTSILÄ Case Study 1 - Wärtsilä

Manufacturer	Wärtsilä Corporation
Customer	Roatan Electric Company (RECO) - provide electricity to the Roatan Island.
Other project partners	N/A
Date	March 2016
Brief description	RECO to use Wärtsilä's LPG gas engines to meet growing electricity demand.
Case study description	The growing tourism industry in Roatan means that electricity demand is increasing. RECO need to therefore create additional capacity and opted for a multi-fuel gas engine. This is currently under construction, but due to be operational by December 2016.
Rational	Propane use for electricity generation is an attractive solution for islands with no access to natural gas pipelines, such as Roatan, as the infrastructure for importing, storing and handling propane is reasonably simple and inexpensive.
Location	Honduras
Asset type	Gas engines
Asset power	28 MW (4 gas engines)
Asset brand	Wärtsilä 34SG-LPG engines
LPG composition	Engines can run on propane, ethane or methane due to multi-fuel capability.
Sector	Electricity generation plant
Application	Power plant
Result	Expected to provide clean, reliable, more efficient energy and cheaper electricity for customers (mainly due to multi-fuel capabilities).
Picture	

Case Study 2 – General Electric

Manufacturer	GE
Customer	Pegsa LTDA (authorised distributor of GE's gas engines)
Other project partners	Colgas (owner of LPG storage facility in Colombia)
Date	September 2015
Brief description	Pegsa LTDA completes LPG demonstration using Waukesha VHP 3600GSI Enginator gas engine
Case study description	GE demonstrated the ability to efficiently generate industrial-scale electricity using Liquefied Petroleum Gas (LPG) in a gas engine supplied by GE Power & Water. The demonstration was performed at the largest LPG storage facility in Colombia.
Rational	This demonstration fits with the 2014–2018 National Development Plan of Colombia. LPG is one of Colombia's most important and available energy resources. The gas engine helps Colombia to increase local energy security and use more of their own local energy resources. Moreover, using LPG to displace oil at the industrial scale can help decarbonise the energy industry and reduce energy costs.
Location	Colombia
Asset type	Gas Engine
Asset power	375 kWe at 1,200 rpm
Asset brand	Waukesha VHP 3600GSI Enginator engine
LPG composition	More than 50% propane and 45% butane, with lower heating value of 2700 Btu/ft^3 (106 MJ/m^3).
Sector	Electricity generation
Application	Industrial-scale electricity from LPG.
Result	Economic (cost savings) and environmental benefits (reduce greenhouse emissions NO_x and CO_2) by 75%+, due to using LPG instead of diesel. Also technical benefits as this trial proved that LPG is a suitable fuel for Waukesha gas engines.

Case Study 3 – Caterpilar

Manufacturer	Caterpillar
Customer	Kauai Marriott Hotel
Other project partners	Partnerships with Propane Education & Research Council (PERC), the Gas Technology Institute (GTI), The Gas Company of Hawaii (TGC), and the U.S. Department of Energy (DOE), to initiate design, testing, and verification of an advanced integrated energy system at Marriott Hotel.
Date	2007 - 2010
Brief description	To reduce energy-related costs at the Kauai Marriott Resort and Beach Club.
Case study description	Installation of an LPG fuelled engine CHP in a Hotel in Hawaii to reduce energy costs, electrical grid dependency, and greenhouse gas emissions. This demonstration project spanned 18 months, concluding in April 2010.
Rational	Hawaii has no natural gas, so LPG displaces diesel, which helps to lower emissions. There are tax incentives in Hawaii for lower carbon installations. LPG fuel supply is similar to diesel, however LPG storage is improved due to eliminating the site-contamination problems associated with diesel storage.
Location	Hawaii
Asset type	Engine CHP
Asset power	810 kW system: 2x 405 kW propane-fired reciprocating engines, a 244-ton absorption chiller, a 480-ton cooling tower, an 800-gallon water pre-heating tank, and additional balance of plant to supply recovered heat.
Asset brand	Caterpillar 3412 units
LPG composition	Unknown
Sector	Hotel
Application	Electricity, heating and cooling for the hotel: The CHP system will provide 50 percent of the hotel's base power load on a 24-hour basis while maintaining system efficiency in the range of 70 to 80 percent. The heat recovery system is designed to meet 100 percent of the hotel's domestic water heating load and 15 percent of its cooling load, effectively eliminating two existing low-performing heat pumps.
Result	This project is expected to save the resort about $706,000 per year. The payback of the CHP system capital cost was 6.3 years (analysis pre-installation suggested 4 years based on anticipated energy savings). The LPG CHP system reduces dependency on the electrical grid, energy costs and greenhouse gas emissions.
Picture	

Case Study 4 - Capstone

Manufacturer	Capstone
Customer	The Royal Playa del Carmen & Gran Porto Real Hotels (Real Resorts Group)
Other project partners	N/A
Date	December 2011
Brief description	Hotel installed CCHP system to save on growing energy costs.
Case study description	Hotel management wanted to use additional energy to increase hotel guest comfort (i.e. heating swimming pools) whilst at the same time save energy and hence costs throughout the hotel estate. They choose a CCHP system as it could provide energy more efficiently (reducing overall energy consumption) whilst providing extra capacity via 'waste heat' for their additional needs.
Rational	Energy saving initiative to save on energy costs.
Location	Playa del Carmen, Quintana Roo, Mexico
Asset type	Micro turbine CCHP (combined cooling, heating and power)
Asset power	273,750 kWh of energy per year. 4,076 MBTU/hr heat exchanger. 150-ton absorption chiller.
Asset brand	Capstone C1000 Dual Mode Power Package.
LPG composition	Propane-butane mix
Sector	Hotel
Application	Exhaust heat is captured to provide steam and hot water for the hotels' facilities, including a 24-hour laundry facility and to heat two large pools to a comfortable 28–31°C. The system provides the hotel with 40% of their electrical needs and 100 refrigeration tons (RT) of cooling. Energy consumption at the hotels has been lowered by almost 25%. A SCADA system allows for operators to monitor the CCHP plant 24/7 both locally and remotely, facilitating preventive maintenance actions.
Result	The Royal Playa del Carmen hotel save an estimated $450,000 to $500,000 Mexican pesos a month with the C1000 system. The CCHP system also lowered emissions and lowered energy consumption by ~25%.
Picture	 

SIEMENS Case Study 5 - Siemens

Manufacturer	Siemens
Customer	Tianjin Bohai Chemical Industry Group Co.
Other project partners	CB&I Lummus – Their Catofin technology produces propylene.
Date	August 2011 (completed 2013)
Brief description	Propane dehydrogenation (PDH) plant.
Case study description	Construction of a propane dehydrogenation plant to make propylene as the raw material for the plastic polypropylene. The first of its kind in China. The plant has 600,000t capacity of propylene every year.
Rational	The demand for propylene in Asia is growing very fast. The implementation of PDH projects will facilitate China's own propylene production and the development of its downstream industries.
Location	China
Asset type	Gas turbine
Asset power	32MW
Asset brand	Siemens 2x SGT-700 gas turbines
LPG composition	Propane (the incoming propane will be hydrogen-reduced to produce propylene).
Sector	Chemical industry - Propane dehydrogenation (PDH) plant.
Application	Dehydrogenation of propane will help manufacture propylene. As per Catofin technology process, the catalyst will be heated repeatedly and regenerated with heated, compressed air alternately with the dehydrogenation reaction. In the plant, this air is provided by two axial- flow compressors are driven by SGT-700 gas turbines. The gas turbine is provided with a duel fuel system to operate the gas turbine with natural gas from a pipeline or with the feed gas of the plant, which is mainly propane.
Result	Axial-flow compressors and gas turbines have superior efficiency rates.
Picture	 

Chapter Four

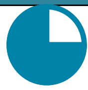
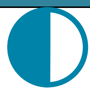
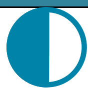
Roadmap

4.1 Market Outlook - Technology and Fuel Developments

The market outlook will look forward up to a maximum of five years. Indication of the major technology and fuel trends expected over the next few years, and how this will affect the potential applications and market suitability are considered for both power-only generation and CHP / CCHP.

4.1.1 Technology Developments

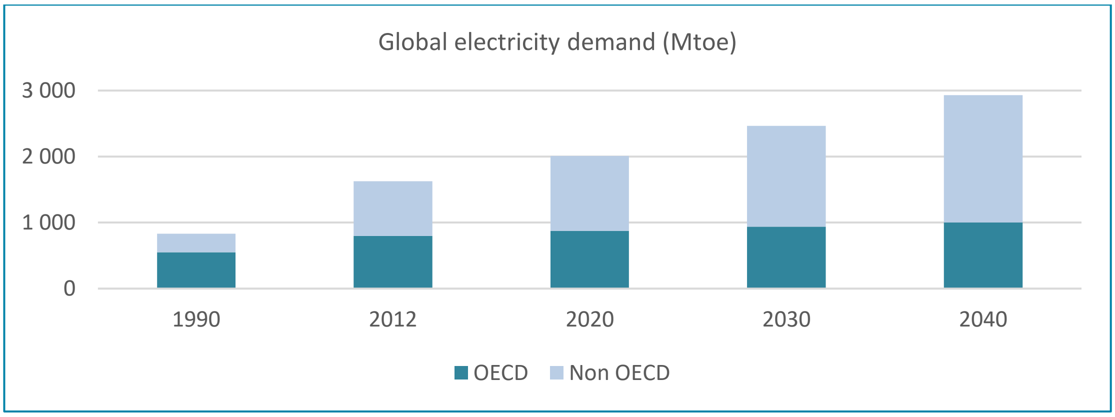
In general, reciprocating engines and gas turbines are already widely applicable to a range of applications at a range of capacity scales, running on both LPG, natural gas, biogas, and other gaseous products. It is unlikely there will be a step change in the applicability of power generation over the next five years. Conversely, fuel cell technology is still in a nascent stage of mass-market commercialisation, and hence we anticipate larger improvements in performance and cost reduction.

Design concepts	Incremental improvements	Expected performance improvements	Expected cost reduction improvements
Reciprocating engines and gas turbines			
Both technologies are mature technologies, with general consensus regarding design concepts amongst manufacturers. However, there seems to be a renewed interest in this technology, with a burst of new products being launched at the lower size ranges for CHP / CCHP applications (<1MWe). Many do not offer ground-breaking conceptual developments, with some cost reduction and remote monitoring and communication with internet protocol standards the main improvements. Regarding the use of LPG, many products on the market already offer this option, and there are no major developments expected.	• Some improvements to system control. • Some improvements to emission reductions. • Only limited efficiency improvements. • Cost reductions should come, as competition in key markets heats up.		
Fuel cells			
Fuel cell technology has now been available for a decade and some products have now gone through several generations. As the technology is still fairly new, new developments will be focussed on refinement, making it more efficient, more compact, and cheaper. There will also be efforts focussed on making the product more durable. Regarding the use of LPG, while technically possible, there is uncertainty on whether manufacturers will actively create market push for their products to run on LPG.	• Some efficiency improvements. • Overall system cost and component reductions as more R&D investment is poured in and more products come to market.		

4.1.2 Fuel developments

Global demand for both energy and electricity is forecast to continue to rise for decades to come, especially in emerging markets. The International Energy Agency (IEA) projects global energy demand growth rates of 1.5% per annum (electricity demand equivalent of 2.4%) to 2040, and non-OECD growth rates of 2.1% per annum (electricity demand 3.4%) over the same period.

Figure 5: Global power demand is projected to rise leading out to 2040



Source: International Energy Agency 2014. World Energy Outlook

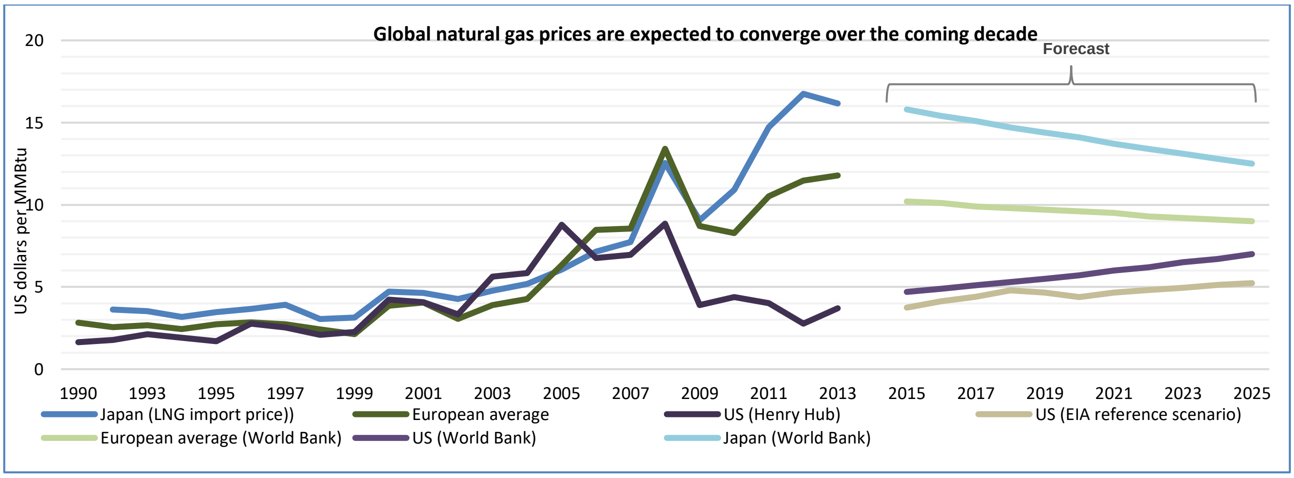
Natural Gas

Global power generation trends are beginning to move sharply away from coal and towards natural gas and renewable energy. In addition, proven global gas reserves are expanding strongly. This growing levels of global reserves and production suggest that prices will remain competitive in most markets, despite demand growth.

Global gas prices are forecast to converge as the market moves from regional to global in nature (as shown in Figure 6):

- US prices are likely to increase slightly, but remain relatively low until the late 2020s – driven by domestic supply / demand balance and growth in gas exports from US.
- Prices in Europe are more likely to decrease slightly due to weaker indexation with oil, more spot market pricing and diversification of supplies.
- Asian prices gradually reduce as some nuclear plant capacity comes back online and eliminates the need for replacement fuels such as natural gas.

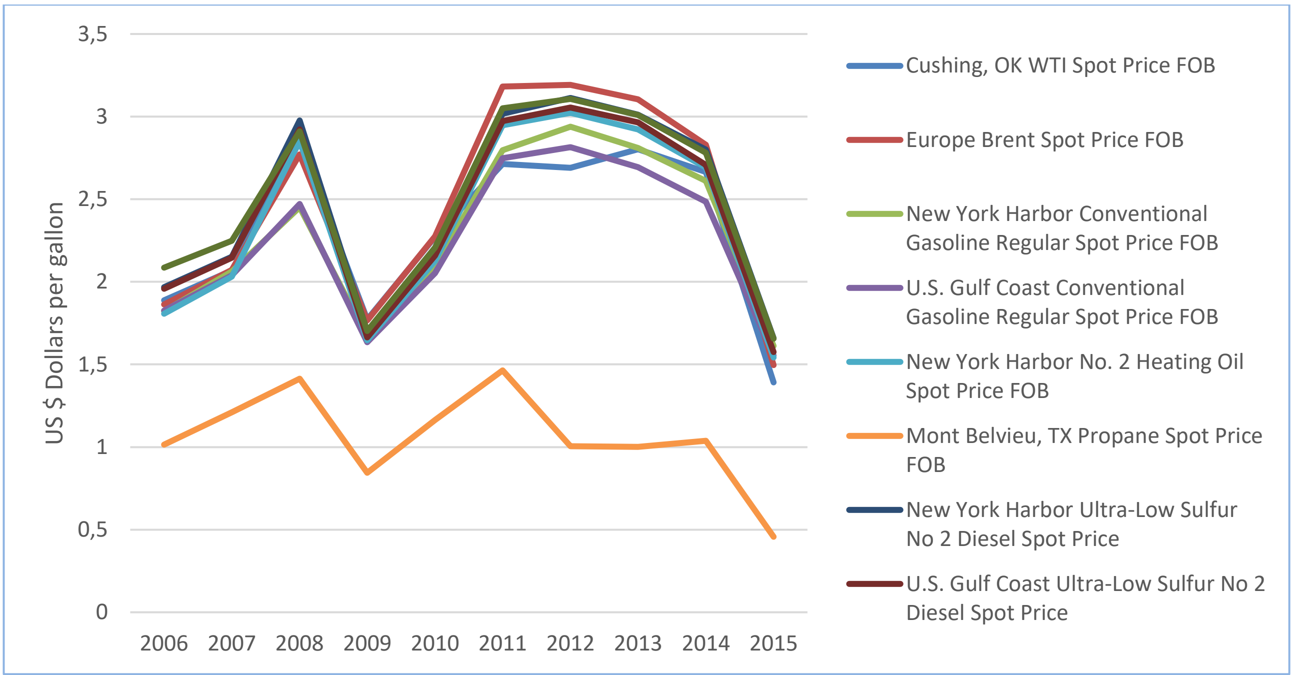
Figure 6: Global natural gas supply / demand trends suggest price convergence, with decline in Europe and increase in the US



Petroleum Products

In 2014, international oil prices were still at ~US$100 / barrel. However, since then, oil prices plummeted to ~US$35 / barrel and currently oscillates between US$40 - 50 / barrel. This has affected the price gap between petroleum products and natural gas [though oil-linked natural gas prices also enjoyed a slight reduction as well). If we focus on the US market as an example – we see that Mont Belvieu propane spot prices are lower than that of fuel oil and diesel spot prices historically and currently (Figure 7). We anticipate this to remain the case up to 2020 – 2025.

Figure 7: Historic prices of petroleum products in USA



LPG

As a by-product of the production of crude oil, natural gas, and refined products, the global supply of LPG is expected to continue to increase steadily through 2030 - especially a continuing rise in output from the USA, which consolidates the country's new position as the world's largest LPG exporter. Increased LPG production does not just feature in the USA, but it's dominance is unmistakeable in 2016, producing more than the entire output from the Middle East region. Other growing LPG producers include Russia and Nigeria and international markets typically adjust to new, relatively cheap and abundant fuel sources in the form of increased infrastructure project developments and new or strengthened uses of LPG to absorb the extra output. Power generation projects using LPG is a growing area of LPG applications. **Global annual LPG production is expected to increase by more than 120 million tonnes per year through 2030.**

4.2 Market Trends: Inherent Characteristics of Strong Market for Power Generation with LPG

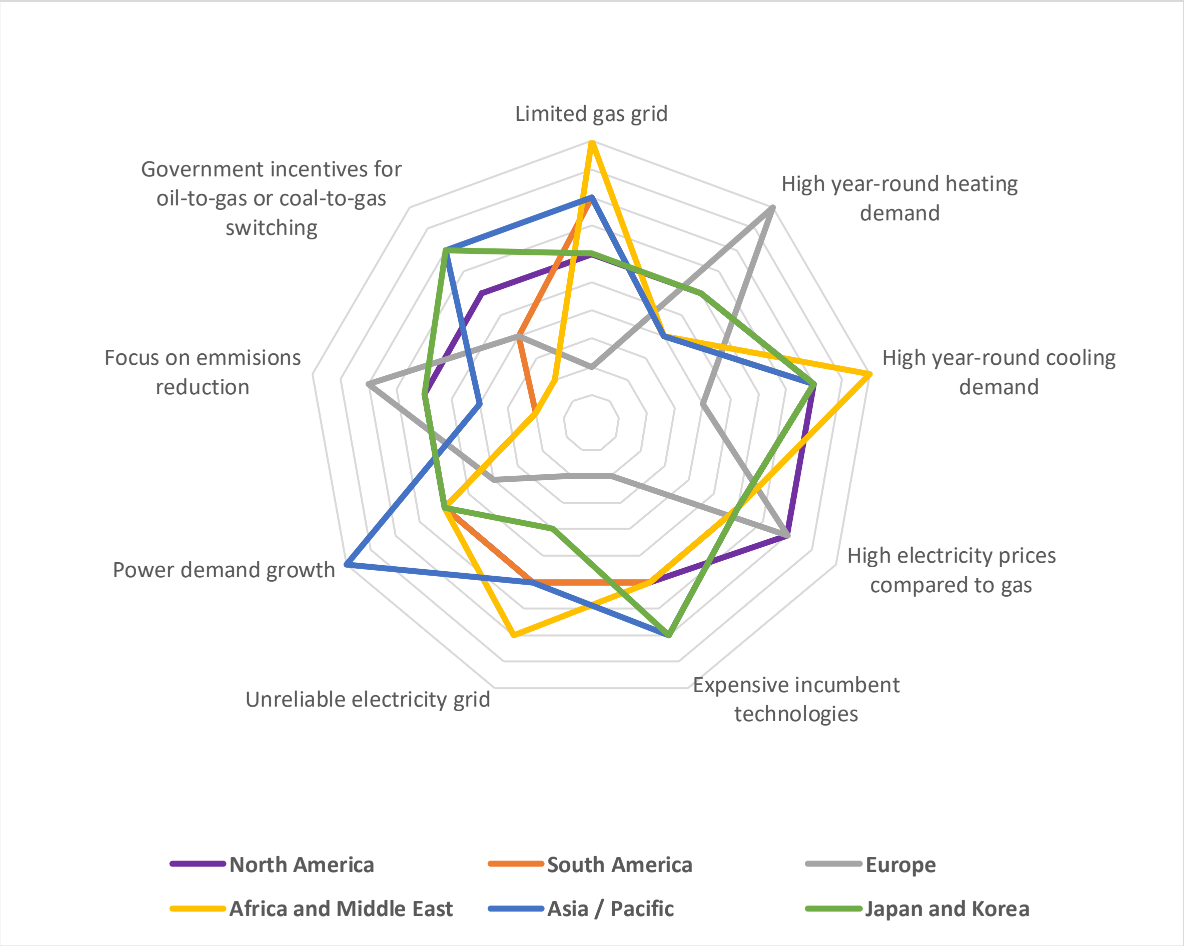
There are several high-level market characteristics which create a strong potential for LPG-fired power generation. Below, these characteristics are used to rate the overall market potential in each global region. If a region has all these characteristics, the potential is *strong* for LPG power generation. If it has several of these factors, the potential is *moderate*, and if it has none of these characteristics the potential is *weak*.

Table 5: Market characteristics that influence the potential for LPG-fuelled power generation

Market Characteristic	Reason why LPG power generation can benefit from this
Limited gas grid / large areas with no gas connection	The core regions for LPG are of course regions with no access to natural gas so the most attractive countries for LPG power generation are those with limited gas grids (or with large regions with a limited gas grid).
Climate which creates a year-round heating demand	Systems are more efficient (and so more economically viable) when they can clock-up as much running hours as possible. To ensure the benefit of year-round CHP autoproduction of electricity, there must also be a constant use for the associated heat that is produced. This is especially true for some countries (like the UK) where the 'dumping' of excess heat is legislated against. Markets with a high demand for heating have traditionally been the strongest targets for CHP.
Climate which creates a year-round cooling demand	CHP systems are more efficient and so more economically viable where they are able to clock-up as long running hours as possible. Via the addition of an absorption chiller to CHP plant cooling can be provided at less cost than the conventional means, the electricity provided can also be to power electrically-driven cooling (chillers, air-con etc.) elsewhere on site. Markets with a constant demand for cooling will increasingly emerge as strong targets for *C*CHP (Combined Cooling Heat and Power).
High / increasing electricity prices relative to gas	This improves the economic proposition for LPG relative to the alternative of grid electricity. Strong spark spreads / spark gaps become inherently more attractive as the difference widens. If electricity prices are high, or rise more steeply than gas (which is expected in most parts of the world), the case for LPG power generation will improve (providing LPG stays linked to gas prices). Markets with ageing grid infrastructure or high targets for renewable energy penetration often have inflated electricity prices.
Incumbent technology is expensive to run relative to LPG	In off-gas grid areas, oil is a significant fuel for heating globally, the customer economics of an LPG CHP system versus traditional oil boiler are strong especially in payback calculations that take account of the added value from electricity generation. Similarly, with diesel generators for power-only applications.
Unreliable electricity grid	This issue is typically more prevalent in developing countries, but even in North America intermittent brown outs are an expected occurrence.
Expected growth in power demand	Economic growth, along with accompanying structural changes, strongly influences world electricity consumption. As countries develop and living standards improve, electricity demand grows rapidly.

Focus on emissions reduction	There is ever growing political and public pressure to reduce global carbon emissions from the energy sector. Apart from greenhouse gas (GHG) emissions, targets are gradually being considered for criteria pollutants such as carbon monoxide, lead, ground-level ozone, particulate matter, nitrogen dioxide, and sulphur dioxide, as well as some non-criteria pollutants such as arsenic.
Government incentives for oil-to-gas or coal-to-gas switching	Involves a variety of measures from mandated initiates to voluntary schemes. For example, some countries have introduced an emissions trading scheme, which is designed to encourage coal-to-gas switching over the long term as the price of carbon increases. Some governments may reduce subsidies for diesel to encourage switching to gas. For instance, the U.S. Virgin Islands Water and Power Authority (WAPA) is in the middle of a US$150 million transition from fuel oil to propane [see section 3.4.4 for more].

Figure 8: Regional Attractiveness Index: Technical potential for power generation using LPG - based on inherent market characteristics



4.3 Identification of Barriers to Market Growth

The inherent market characteristics which will make some regions more attractive to power generation using LPG have been discussed above. Beyond these inherent market characteristics, there are several specific barriers / drivers which vary significantly by region, and which will determine the size of the market opportunity. The key issues are highlighted below, and the following "Recommendations" chapter comprises a discussion about how these barriers can be overcome.

❶ Economics of competing fuels

In general, retail prices for natural gas tend to be less expensive than LPG. Furthermore, in countries where electricity prices are highly regulated and subsidised, the economics of using LPG compared to natural gas or grid electricity may not stack up. **Favourable economics is the main driver for anyone investing in (LPG) power generators, CHP, or CCHP systems. The final cost of the fuel (i.e. the retail price which includes the wholesale cost as well as distribution charges, storage, taxes, and other final price components) affects the operating cost (OPEX) of power generation projects.**

❷ Logistics – transportation, storage and infrastructure required for liquid fuels

Propane is produced from both natural gas processing and crude oil refining. Given its by-product nature, the shale revolution has introduced the USA as a new and powerful player able to help serve growing world LPG demand, especially from South America and Asia. The Middle East has historically been the largest LPG exporter in the world (ranging between 25 – 45 million tonnes per year). **To ensure supply meets demand, comes the need for greater export terminals, storage facilities, as well as expansion of rail and trucking capabilities – all of which require substantial investment and time. Construction delays may occur (for example, the Panama Canal upgrade which significantly widened and deepened the 80-km waterway, to enable the transit of vessels, including very large gas carriers (VLGCs) from US Gulf coast LPG export terminals was completed two to three years later than scheduled); or hazardous weather conditions may place logistical challenges on on-land transportation systems. End-customers need to be confident of security of supply, in order to choose LPG over another competing fuel for power generation.**

❸ Volatility in LPG pricing

The wholesale price of LPG takes into account a number of factors which amongst other things include weather, crude prices, natural gas prices, refinery and gas plant production, net imports, petrochemical demand, and overall propane inventory levels. Wholesale contracts are generally negotiated on an annual or monthly basis between upstream producers of propane and their midstream and downstream customers using posted prices as references. In these negotiations, buyers and upstream sellers generally do not lock in fixed prices, but negotiate discounts from, or premiums to, posted wholesale prices. **While some end-customers may choose a fixed price contract and pay a premium for price certainty, others may be reluctant to choose LPG over competing fuels or grid electricity if LPG in their region are prone to price swings.**

❹ Lack of understanding / education amongst relevant stakeholders

In general, LPG - while not a renewable energy source such as solar, wind, or biomass - should be recognised for its lower greenhouse gas emissions compared to diesel or oil in power generation applications (or even relative to grid electricity with high carbon intensity factors). Also, one that in CHP or CCHP mode in particular provides added value based on energy costs saving opportunities. The value distributed generation, CHP and CCHP offers to the wider electricity system through peak load shaving should also be recognised. This is relevant for all types and classes of LPG power generation. **The way LPG is perceived by the market is critical to its success. The specific use of LPG for CHP is comparatively well-known in Japan but in more attractive LPG markets (e.g. where LPG cost is lower) there is a need for stakeholders to step in and raise the profile of LPG-fired CHP and CCHP.**

❺ Policy / Regulatory Framework: The benefits of CHP and CCHP should be fully recognised in the policy framework

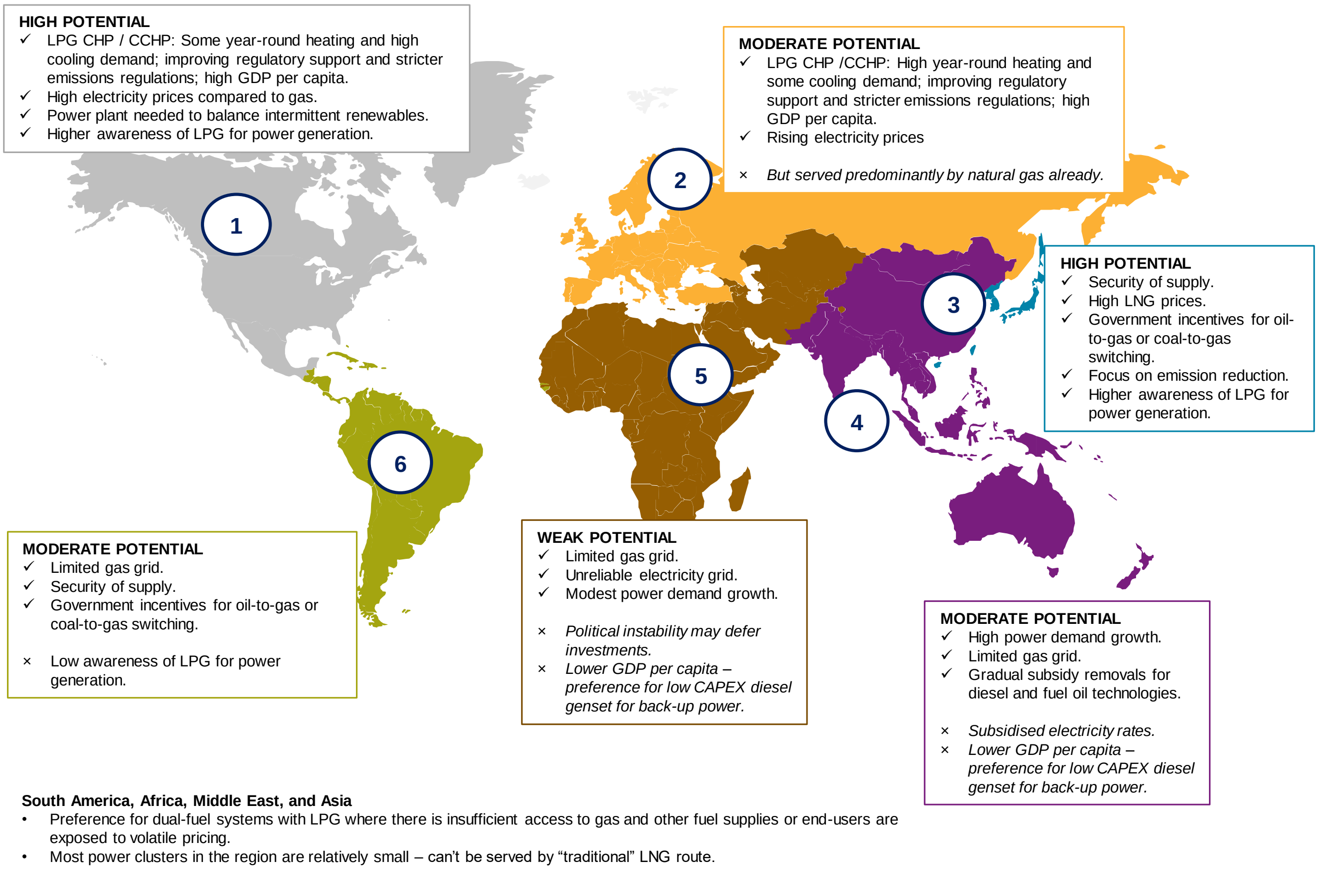
Support for CHP and CCHP in policy is generally intermittent. While it is explicitly considered in some low-carbon policy and regulations (e.g. Germany's CHP Law) more often CHP is only indirectly supported (through regulations on primary energy savings in new build, for example). The support for LPG as a fuel is comparable to that for fossil-fuelled CHP, installations receive lower subsidy and tariff support than other low-carbon (renewable) options. Regulations do not yet reward CHP for its ability to produce electricity when the stress on the electricity grid is at its highest. It is unlikely market potential will be realised until this changes. **The inclusion of CHP in the policy / regulatory framework is critical for all types of system, especially those at the early market stages, smaller-scale systems, where the economic case is not as strong as it is for larger products, would benefit from financial support.**

4.4 Market Potential: Target Regions for LPG Power Generation

4.4.1 Target Regions

Based on an analysis of the inherent market characteristics and strength of barriers across major global regions, Figure 9 identifies core regions where potential could be strongest for LPG power generation. The six regions are [1] North America; [2] Europe; [3] Japan and Korea; [4] Asia / Pacific; [5] Africa & Middle East; and [6] South America

Figure 9: Target regions for LPG-based power generation



Chapter Five

Recommendations

In the Roadmap section, five critical barriers to market uptake for power generation with LPG were identified. Recommendations on how these barriers can be overcome, and which type of market actors have a role to play, are given below.

5.1 Key Actors with a Role to Play in Implementing Recommended Actions

The varying roles of each type of actor in overcoming the barriers to market growth are allocated below. Roles are differentiated between the "Lead Role" (the actor(s) is critical in implementing the recommended actions), and the "Support Role" (the actor(s) can support but is not the critical element in overcoming the barrier).

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

Recommendations	Market Actor					
	Industry Associations	Utilities	Manufacturers	Government	LPG Distribution companies	Energy Service companies (ESCOs)
Raise awareness of LPG and highlight key strengths against competing fuels	XX	X	X			
Invest in extending the LPG infrastructure		XX		X	XX	
Overcome the economic challenge for LPG CHP / CCHP and volatility in pricing for LPG		XX	XX	XX		XX
Ensure that policy / regulatory frameworks create a level playing field for CHP with competing technologies	XX					

5.2 Recommendations

5.2.1 Raise awareness of LPG and highlight key strengths against competing fuels amongst policy-makers, customers, installers, utilities and the industry

- This means positioning LPG as a cleaner (i.e. emits less greenhouse gas emissions) fuel and generally having lower fuel costs and operations and maintenance (O&M) costs than diesel, HSFO, and LSFO-based power generators.
- This should be backed up by robust analysis and collection of real-life market data to prove the contribution which LPG are making to carbon saving targets etc, to be targeted at governments. **ROLE FOR ASSOCIATIONS.**
- Marketing / awareness-raising activities involving for example information dissemination (showing the real technology performance, applicability and potential), targeted marketing events for end-users, information / training events for installers etc. **ROLE FOR ALL MARKET ACTORS-ASSOCIATIONS** could be the primary driver of this activity but LPG companies / utilities could also play a role.

5.2.2 Invest in extending the LPG infrastructure

- The investments needed to utilise liquefied natural gas (LNG) is high, with infrastructure requirements including distribution, storage, and regasification facilities. Construction lead times can take up to 2-5 years depending on the scale of the project. LNG utilisation is more cost-effective the larger the project, and does not scale down cost-efficiently to smaller sizes. This is where LPG can be used instead or be positioned as a "bride" fuel while construction or extension of LNG infrastructures tale place. However, multiple stakeholders need to be involved as LPG infrastructure projects also require investments (albeit less than LNG infrastructure projects). **ROLE FOR LOCAL GAS DISTRIBUTION COMPANIES & UTILITIES, but may need support from government.**

5.2.3 Overcome the economic challenge for LPG CHP / CCHP and volatility in pricing for LPG

- Examples of ways to overcome this barrier could include economic support to end-users through financing packages (e.g. ESCO models), fixed price contracts, technology development which results in upfront cost-reduction and running cost savings. **ROLE FOR ESCOS & UTILITIES (financial support), MANUFACTURERS (to lead development).**
- 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 FOR GOVERNMENT.**

5.2.4 Ensure that policy / regulatory frameworks create a level playing field for CHP with competing technologies

- Lobbying to ensure that CHP (including CHP using LPG) is included in regulatory framework and incentive schemes. Primary **ROLE FOR ASSOCIATIONS** and potentially a role for other actors to make policy-makers aware of the potential for LPG CHP, and ensure the treatment of the technology is fair.

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