# LIQUEFIED PETROLEUM GAS (LPG)

# Overview

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- LPG fuel production value chain
- Feedstocks and energy sources
- Production technologies
- Onshore requirements
- Onboard requirements
- Regulations, standards and guidance
- Environmental impact
- Cost overview
- Barriers and risks
- Summary

# Background and key characteristics

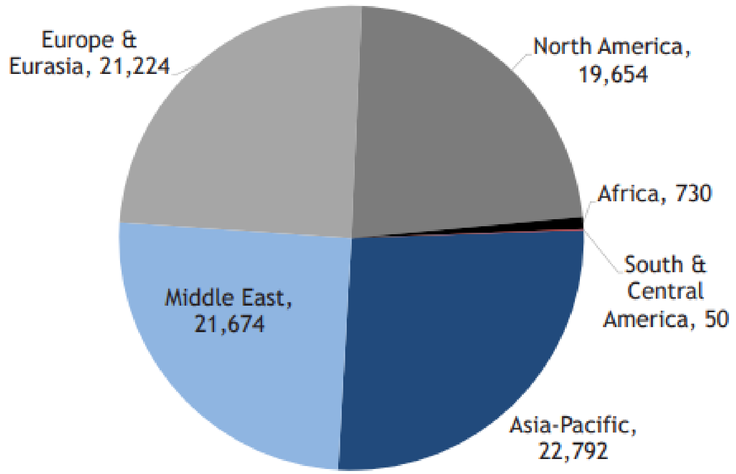
## HFO

- Energy density: 42 MJ/kg = 35 MJ/dm$^3$.
- Flashpoint: 60°C.
- Water solubility: None.
- Most widely-used fuel.

## Propane & Butane (LPG)

- Energy density: 49.6 MJ/kg = 25.3 MJ/dm$^3$.
- Boiling point between -42°C (pure propane) and -0.5°C (pure n-butane).
- Flashpoint: - 104°C.
- Water solubility at 20°C is less than 200ppm.
- Commonly used as a domestic & industrial fuel.

Petrochemical demand for LPG, by region ’ooot,




Source: Statistical Review of Global LPG, Argus Media, 2019

2017 global supply[1] = 308 Million Tonnes.

[1] WLPGA LPG Bunkering Guide for LPG Marine Fuel Supply.

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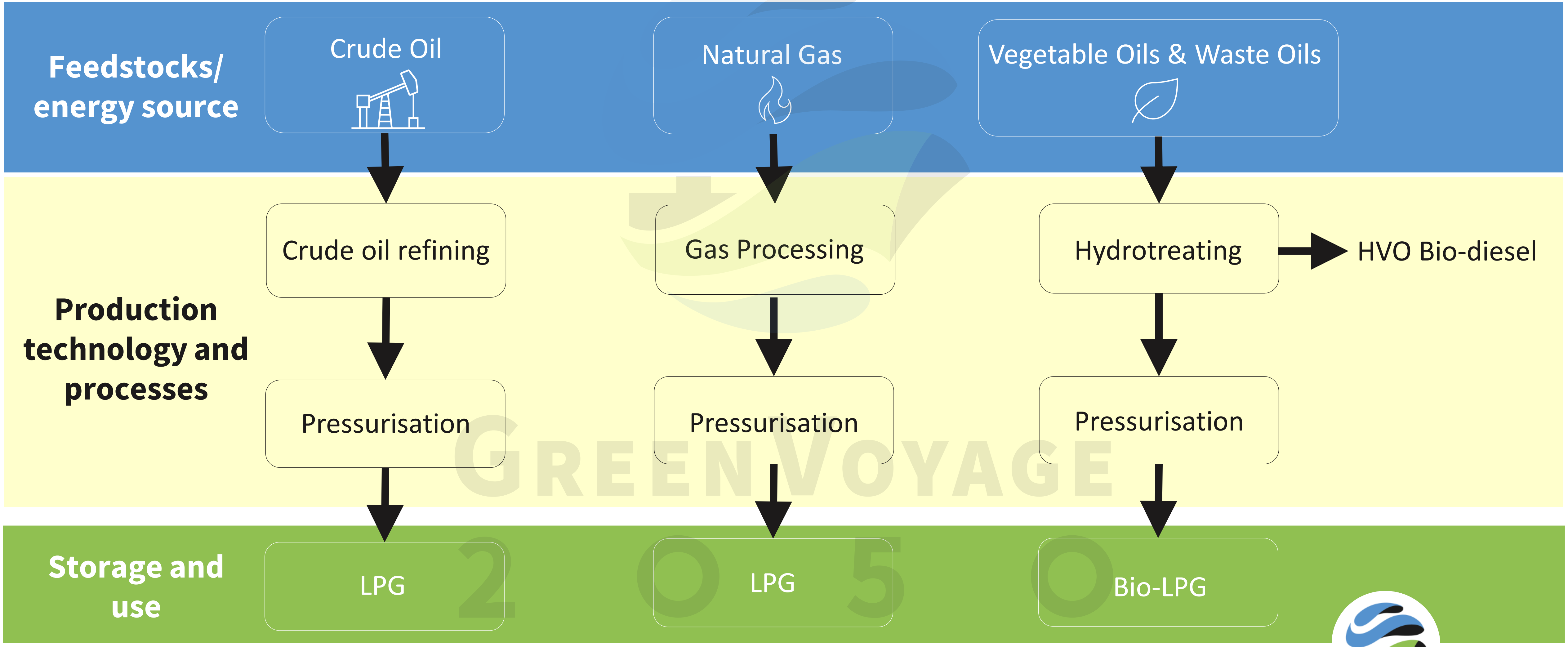
# LPG fuel production value chains



# Feedstocks and energy sources

**Current availability**

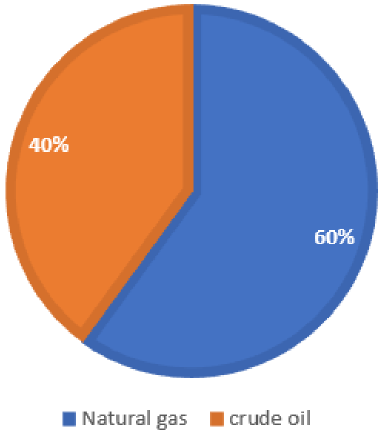
| Crude Oil | Natural Gas | Vegetable Oils & Waste Oils |
| --- | --- | --- |

Widely Available | Availability Constrained | Availability Very Restricted

## Key Points

- Nearly all LPG is currently produced from fossil feedstocks (crude oil and natural gas).
- Availability of waste oils is constrained and is not likely to increase, whilst use of vegetable oils competes with food and land demands.
- Alternative feedstocks for bio-LPG may become more dominant as demand for biofuels increase.

### Global LPG Production by Feedstock[1]




[1] World LPG Association

# Production technologies

| | | | |
|---|---|---|---|
| **Production technology and processes** | Crude Oil Refining → LPG | Natural Gas Processing → LPG | Hydrotreating → Bio-LPG |
| **Readiness** | TRL 9 | TRL 9 | TRL 9 |

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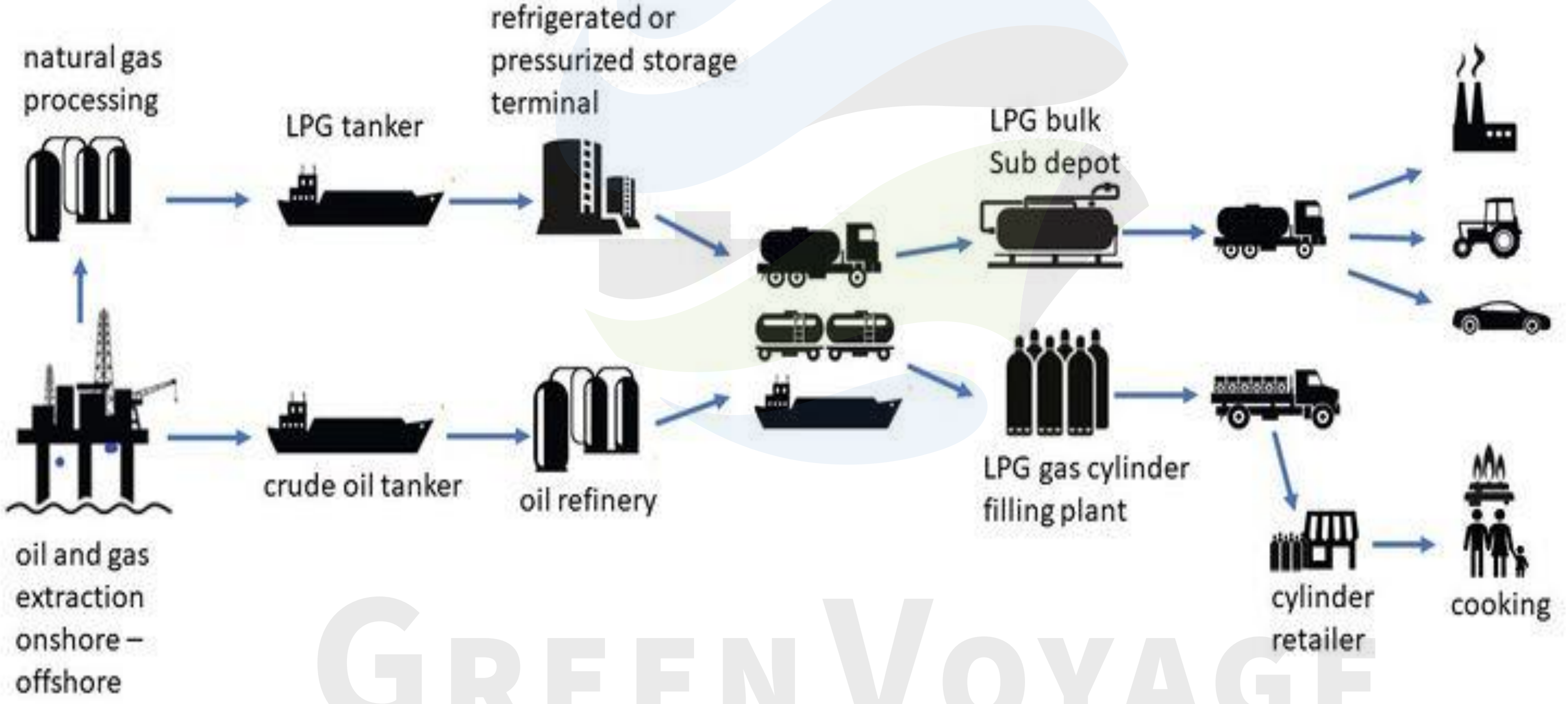
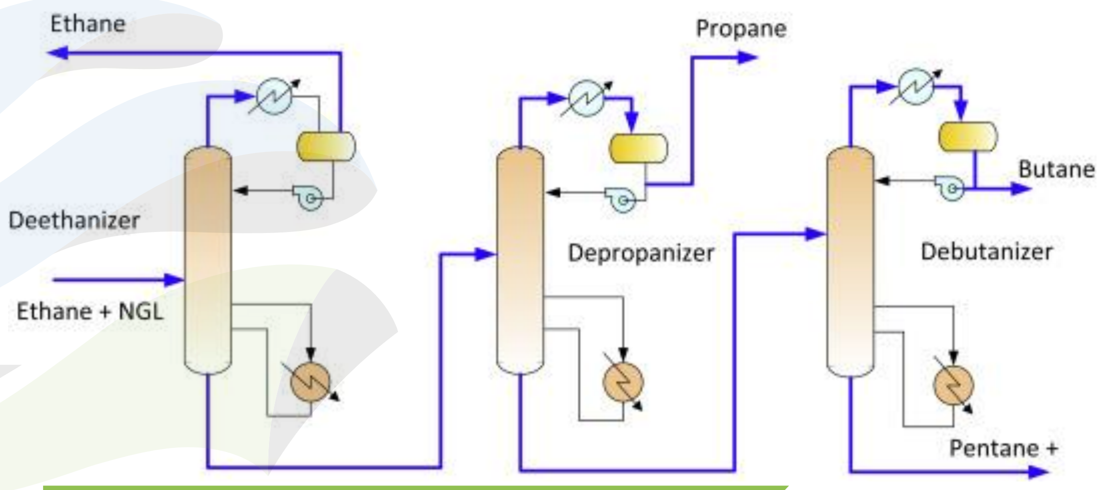
# LPG Value Chain



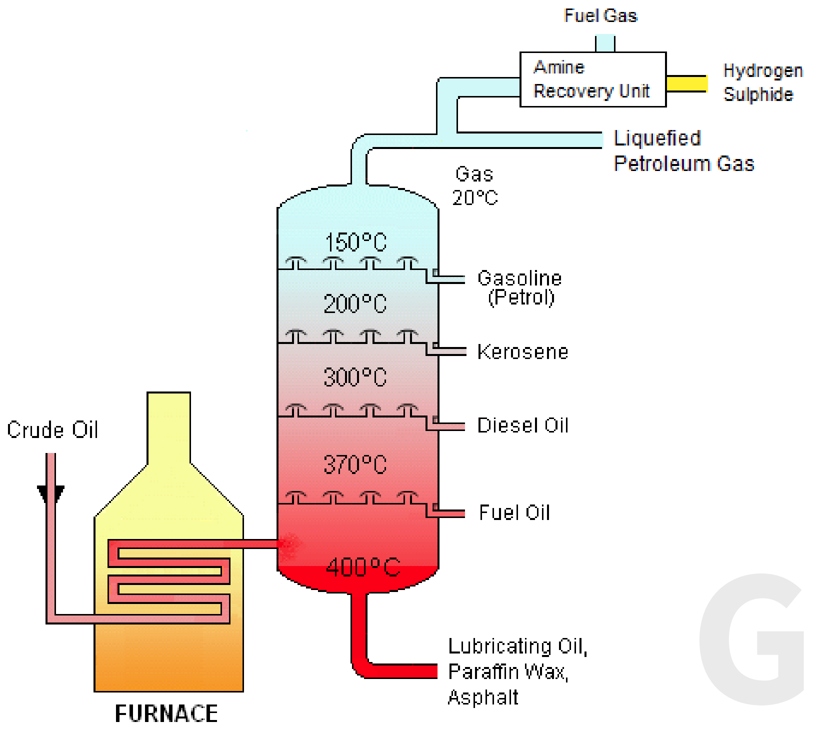

*LPG Processing, storage & distribution*

# Production technologies



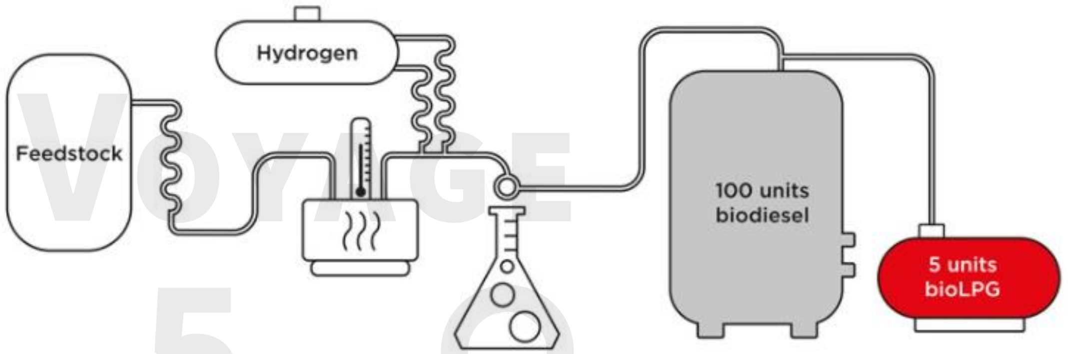

*LPG recovery from natural gas production*

Source: Handbook of Liquefied Natural Gas, 2014




*LPG production from crude oil refining*

Source: www.enggcyclopedia.com




*Bio-LPG production*

Source: SHV Energy

# Onshore requirements

**Storage and use** | LPG

## Storage

- Existing storage infrastructure widespread – many ports already have existing LPG storage facilities.
- Only minor modifications are needed to current fuel storage equipment (due to low flashpoint).
- No impact of LPG on stainless steel, ferrous metals or cast iron.

## Transportation

- LPG currently widely transported globally (via ship, trucks and rail).
- Widespread familiarity with loading and unloading LPG as a bulk product.
- LPG can be transported by three ship types: refrigerated, semi-refrigerated or pressurised.

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# Onshore requirements

**Storage and use**

LPG

## Bunkering

- Bunkering can be completed directly at the load terminal, either by truck or via ship-to-ship bunkering.
- Very few current examples of LPG bunkering as relatively new use as fuel in shipping.
- IGF code, effective January 2017 allows the use of LPG as fuel.

# Onboard requirements

## Storage

- Double walled pipes required as a low flash point fuel.
- Larger tanks (2-3 times larger [1]) required for equivalent energy content of fossil fuels (due to lower volumetric energy density).
- For pressurized tanks, if stored at atmospheric pressure, a reliquefaction system will be required to handle boil-off gas.
- Low viscosity of LPG makes it prone to leaks.

## Handling

- LPG is already handled as a cargo product in compliance with IGC Code.
- Regulations covering LPG as a fuel are covered by IGF Code.

**Storage and use** LPG

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*[1] Comparison of Alternative Marine Fuels, SEA\LNG Ltd, 2019.*

# Onboard requirements

## Propulsion

- LPG combustion engines already commercially available (including as dual-fuel model).
- LPG fuelled engines have been in operation for many years ashore.
- Retrofit ICE conversions are possible, adaptations include modifying the fuel injection system.
- Purging system required ($N_2$ or other inert gas) to enable safe maintenance.

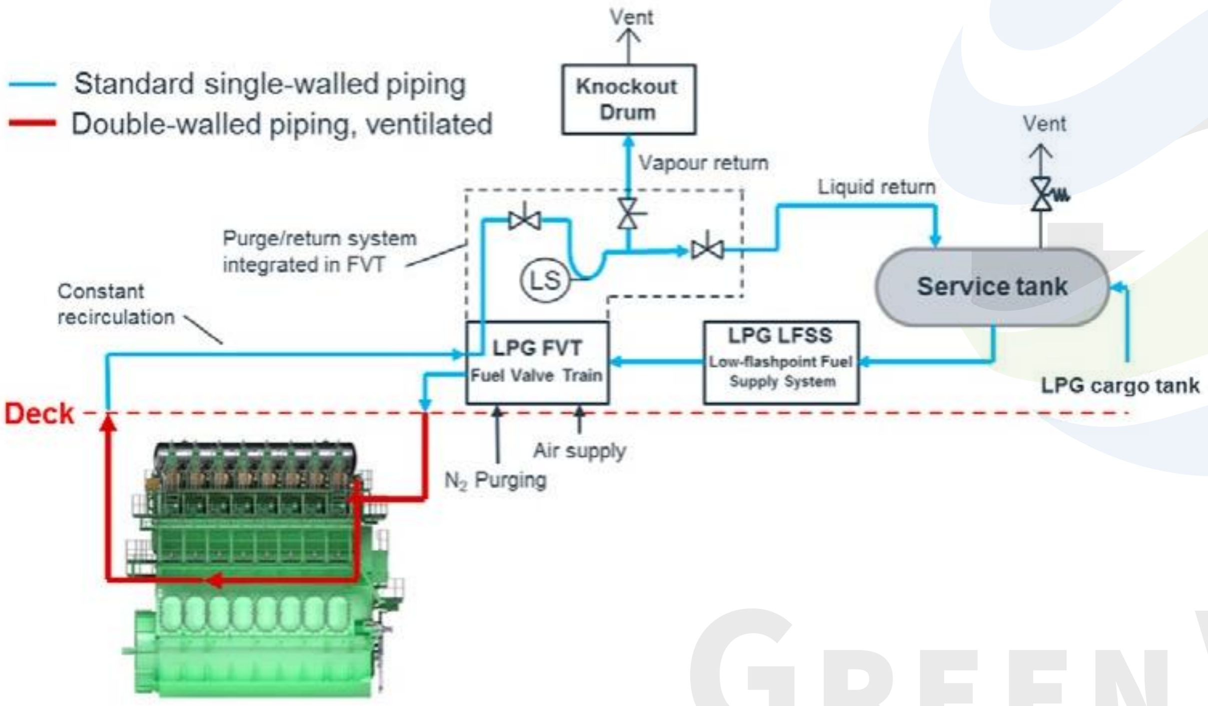
**Storage and use** | LPG

# LPG propulsion options

| Option | Existing fossil engine retrofit conversion | Dual Fuel Engine |
|---|---|---|
| **Readiness** | TRL 9 (current examples in service) | TRL 9 (now commercially available) |
| **Capital cost** (including required changes to ancillary onboard systems e.g. fuel supply) | Highly project specific. Estimated ~600 USD/kW [2] | Estimated ~300 - 400 USD/kW |
| **Efficiency** (at shaft) | <55% (project specific) | ~55% |

[1] Costs and Benefits - Alternative fuels for an LR1 Product Tanker, DNV GL and MAN Energy Solutions joint study, 2018
[2] Pioneering programme hails shift to LPG as fuel, Riviera, 2020

# LPG fuelled engines




*LPG Fuel System Configuration, MAN*

Source: LPG as a Marine Fuel, DNV GL, 2017.

## LPG fuelled two-stroke dual-fuel engine

- Can run on LPG, HFO, MDO, MGO.
- BW Gemini (LPG Tanker) with carrying capacity 84,000m$^3$ has been retrofitted with liquified petroleum gas dual-fuel propulsion technology.


*LPG Fuelled 2 – Stroke Engine on Test Bed*

# Regulations, standards and guidance

| Body/Organisation | Documentation | Status/Comment |
|---|---|---|
| IMO | The International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code) | In force from January 2017 |
| IMO | IGC Code for LPG bunkering vessel, but does not cover requirements for LPG transfer system. | Mandatory under SOLAS chapter VII since 1$^{st}$ July 1986 |
| ISO | ISO 8216-1:2010 – Liquefied Petroleum Gases | In place |
| SIGTTO | Ship to Ship bunkering of LPG is a form of LPG transfer and therefore SIGTTO, Society of International Gas Tanker & Terminal Operators, guidelines must be considered. | In place |
| Fuel Suppliers | Proprietary guidance | Currently available |

# Examples of LPG vessels

## Vessels

The first conversion of a vessel to run on LPG was completed by BW LPG for their vessel BW Gemini. The LPG tanker was retrofitted at You Lian Dockyard in 2020 with two fuel tanks, fuel supply system and modifications to the main engine to run on both diesel and LPG. BW LPG plan to complete similar retrofits for a total of 12 vessels.

*BW GEMINI, LPG tanker*

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# Environmental impacts

| | Fossil LPG | Bio LPG |
|---|---|---|
| **Emission reduction drivers** | • Source of energy for production & transportation | • Nature of feedstock |
| **Reduction in well-to-wake GHG emissions*** | **17%[1]** | **53 to 89%[2]** |

*vs. HFO

**Emission reductions**

| SOx | PM | NOx |
|---|---|---|
| -90% | -90% | -20% |

# Fuel cost overview

| Production route | LPG | Bio-LPG |
|---|---|---|
| **Key drivers** (Expected trend: positive/negative/either) | • Crude oil and natural gas production | • Biomass feedstock cost and supply |
| **Current cost (per GJ fuel)** | **~10 USD[1]** | **~11 USD[3]** |
| **Current production cost vs HFO market price (per GJ fuel)[2]** | Approx. equivalent | Additional ~1 USD |
| **Potential for cost reduction vs current cost** | Low | Possible in short term, less in medium term |

[1] Guide for LPG Marine Fuel Supply, WLPGA, 2019
[2] Based on HFO market price of *250-500 USD/tonne*
[3] The role of LPG and bioLPG in Europe, WLPGA, 2020 – relative price of LPG vs. bio-LPG fuel.

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# Barriers and risks

| Category | Barrier / Risk | Rating |
|---|---|---|
| **Policy** | Low uptake of LPG technology due to uncertainty in future policy. | High – vessel owners may seek other low(er)-carbon solutions. |
| **Commercial** | Cost of engine replacement/conversion. | Medium – Cost of LPG propulsion is less than that of LNG |
| | Low volumetric energy density leads to loss of space for cargo or passengers. | High/medium – (application specific). |
| | Low carbon production routes dependent on demand of other fuels and sectors; other low carbon routes not economically favourable | Medium – other low carbon fuels may be favoured either for lower cost production and/or ease of use |
| **Sustainability** | Potential for sustainability concerns from some biomass sources. | High – assuming associated with crop and waste oils |
| | Lock-in by fossil LPG which does not meet targets | High - locked in to lower carbon methods to produce LNG which may not be most economic/scalable, to reach targets |

# LPG summary

## Key points

- LPG is currently widely handled as cargo substance with recognised regulations and guidelines.
- Limited deployment as marine fuel, but promising results from early adopters.
- Production uses generally well-established processes.
- Engine retrofit conversion possible and availability of off-the-shelf LPG engines is increasing.
- Onshore infrastructure and equipment for storage and transportation of LPG is well understood.
- Cost comparisons show that while currently more expensive than MGO and HFO, there is potential for future cost reductions.

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