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GRENDEL

LNG as a fuel is a technologically proven and available solution. LNG offers huge advantages, especially for ships with a high energy demand and load factor which benefit from the lower energy costs. Conventional oil-based fuels will remain the main fuel option for most vessels in the near future, and, at the same time, the commercial opportunities of LNG are interesting for many projects. While different technologies can be used to comply with air emission limits, LNG technology is a smart way to meet existing and upcoming requirements for the main types of emissions (SO_x, NO_x, PM, CO_2). This fact sheet offers insight into gas and gas-electric propulsion, ranging from relevant regulations, technical concepts, information on economics and environmental sustainability as well as references to deployed examples.

FACT SHEET N° 1

GAS AND GAS-ELECTRIC PROPULSION

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REGULATIONS

Requirements governing the use of liquefied natural gas as a fuel for inland waterway vessels are set in the **European Standard laying down Technical Requirements for Inland Navigation vessels (ES-TRIN)** which is constantly updated.

Regulation (EU) 2016/1628 (NRMM) sets, so called, **Stage V emission limits** for new (main and auxiliary) engines placed on the market and installed in inland waterway vessels *(entering into force as of 1 Jan 2019 for engines with a reference power of less than 300 kW and as of 1 Jan 2020 for engines with a reference power including and above 300 kW)*. The Stage V calls for limit values for emissions of carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NO_x) for internal combustion engines installed in inland waterway vessels. The certification of engines to comply with Stage V limits is on-going and first certified engines are expected later in 2019[1].

The **classification societies** developed a set of safety criteria for gas as vessel fuel which are included in their rules and focus at minimising risks associated with building gas-fuelled vessels (dealing with propulsion, power generation and auxiliary systems, equipment and design features or development and operation of LNG bunkering facilities, etc.).

LIQUEFIED NATURAL (LNG) FACTS

Liquefied Natural Gas (LNG) is natural gas (predominantly methane, CH_4) produced by cooling down the natural gas to minus 162°C, thus converting it to liquid form for ease of storage and transport.

PHYSICAL PROPERTIES

Structure	More than 90 % methane (CH4) with the rest mostly ethane, propane, butane, nitrogen. LNG shall not to be mistaken for LPG – Liquefied Petroleum Gas (mainly propane and butane).
Temperature	-162°C (-260°F)
Volume	1/600 of the volume of natural gas in gaseous form and 3.5 times more compact than compressed natural gas (CNG)
Density	Between 430 kg/m³ and 470 kg/m³ (compared to water it is less than half as dense, which means that LNG will float on water if spilled)
Conversion	1 ton LNG = 2.2 m³ LNG; 1 ton LNG = 15.2 MWh (GHV); 1 MWh = 3.4121 MMBTu
Attributes	Odourless, colourless, non-toxic, non-corrosive
Flammability range	5-15 % of fuel-air mixture
Behaviour if spilled	Evaporates, forming visible “clouds”. Portions of cloud could be flammable or explosive under certain conditions. A fuel-air mixture of about 10 % methane in air (about the middle of the 5–15 % flammability limit) and atmospheric pressure might be ignited if it does encounter an ignition source (a flame or spark or a source of heat of 1000°F (540°C) or greater). Otherwise the vapour will generally dissipate into the atmosphere, and no fire will take place.
Energy density	21 MJ/l (diesel 36)

ENVIRONMENTAL DRIVERS

LNG contributes to significant reduction of sulphur oxides emissions (SO_x), nitrogen oxides emissions (NO_x), Particulate Matters (PM) and carbon dioxide emissions (CO_2) from engine exhaust emissions in comparison to traditional fuels.

In comparison to diesel:
- CO_2 reduced up to 25 % (for near zero methane slip)
- PM reduced nearly to 100 %
- NO_x reduced up to 90 %
- SO_x emissions up to 95 %

In comparison to LPG:
- Greenhouse gas emissions reduced by 15 %
- PM reduced by up to 10 %
- NOx reduced by up to 50 %

The use of liquefied bio-methane further increases CO_2 performance of LNG at short term perspective. Currently ongoing exploration of next generation renewable gas production technologies such as the Austrian “Underground Sun Conversion” project will further diversify gas (fuel) market by offering synthetic gas produced from renewable sources.

[1] Status from January 2019.

TECHNICAL CONCEPT

The applied technical concept for the propulsion of inland ships depends on the vessel type, targeted speed and sailing profile. In order to be a case for gas and gas-electric propulsion, a vessel should meet one or more of the following criteria:

- Ships with a high energy demand and load factor benefit from the lower energy costs
- Operational area with a LNG bunkering infrastructure
- Pushers may benefit from LNG retrofitting in combination with lengthening of the hull.

ENGINE TYPES

LNG power offers a number of engine configurations for inland waterway vessels. The following engine suppliers offer LNG (gas)-powered engines: Wärtsilä, Caterpillar, MAK, Rolls Royce, MAN, ABC, MTU, Mitsubishi, Hyundai, DAIHATSU, Deutz, Scania, Agco Power and Dresser-Rand Guascor. These engine manufacturers each have their own engine configurations. More engines may become available in the future.

For LNG either a full gas-engine (Otto-cycle) or a dual-fuel engine (Diesel-cycle) can be used. In case of the dual-fuel engine, the ratio of diesel and gas is variable.

DUAL FUEL ENGINE (Diesel-cycle)

In dual-fuel mode, natural gas is fed into the engine's intake system. The air-natural gas mixture is then drawn into the cylinder, just as it would be in a spark-ignited engine, but with a leaner air-to-fuel ratio. Near the end of the compression stroke, diesel fuel is injected and ignites the natural gas. A dual-fuel engine can operate on pure diesel fuel or a mixture of diesel and natural gas, delivering the same power density, torque curve and transient response as the base diesel engine.

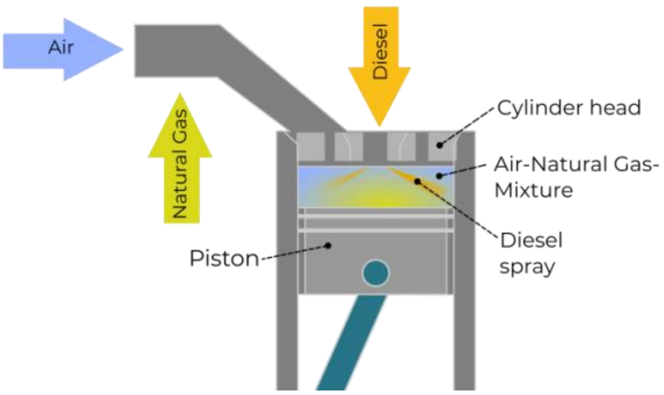


Figure 1: DUAL FUEL ENGINE (Diesel-cycle)

GAS ENGINE (Otto-Cycle)

Mono-fuel gas-engines work with the Otto principle and have a spark-ignition. They also have a different characteristic which is a bit more suited for gas-electric applications in gensets than for direct drives.

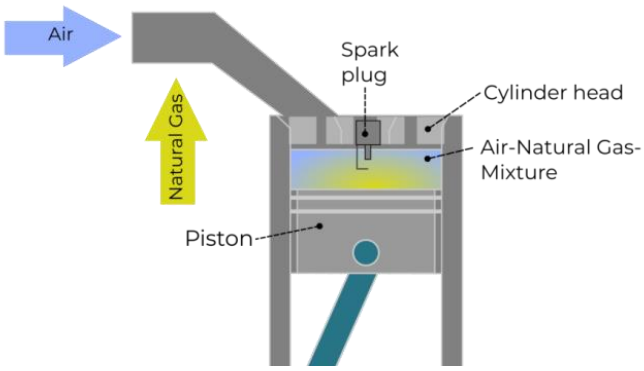


Figure 2: GAS ENGINE (Otto-Cycle)

PROPULSION CONCEPTS

Basically, one can divide between direct drive and gas-electric drive propulsion concepts.

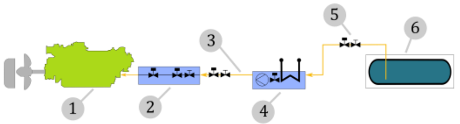
DIRECT DRIVE

The direct drive system with a gas engine is comparable to a diesel direct drive system. In the context of the required redundancy, it may be necessary to install two independent gas supply systems including a tank for multi screw vessels. A single screw vessel has the option to use the bow thruster (360° thruster) as redundant propulsion device in case the gas system fails. The bow thruster then also needs an independent energy source.

GAS-ELECTRIC SYSTEM

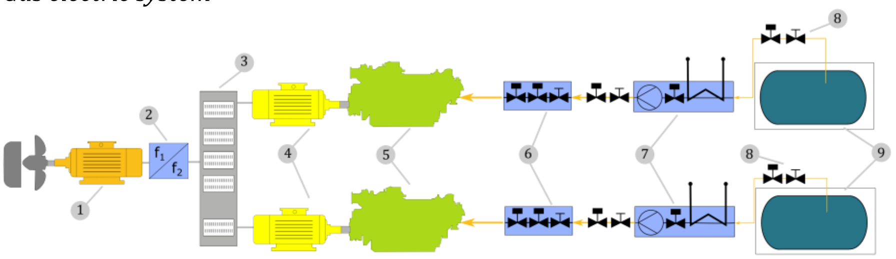
The design of the gas-electric system is comparable to that of the diesel-electric system: it uses gas gensets and electric drive motors. ES-TRIN 2019 requires a redundant electric energy source. One solution, the installation of two gensets is shown below. The gensets can be of different size.

Direct drive



1. *Engine:* In the engine the gas is burned. The two main engine types are dual-fuel engines that run on diesel and gas and pure gas engines. In case of a dual-fuel engine, an additional diesel tank is necessary.
2. *Gas Valve Unit (GVU):* It controls the gas flow to the engine and can also perform an emergency stop.
3. *Pipes:* The pipes are double walled. The space between the inner and the outer pipes is flooded with Nitrogen. Each pipe has an automatic and a hand operated valve; sections of pipes also have a release valve. The automatic valves are closed at an emergency shutdown.
4. *Cold Box:* In the Cold Box the LNG is evaporated. Then the gas is pressurized. The energy (heat) for the evaporation often comes from the cooling water of other engines on board. This part of the installation is also known as gas treatment system.
5. *Safety Systems:* Pipes and tanks have safety valves to protect them from overpressure. All systems are redundant. This means that there are at least two individuals of each safety system in case one fails.
6. *LNG Fuel Tank*

Gas electric system



1. *Electric Motor:* The electric motor drives the propeller at any load case. Its advantage is a nearly constant efficiency at all load cases. Depending on the selected electric motor a gear box can be omitted.
2. *Frequency Converter:* The frequency converter supplies the electric motor with a frequency and voltage amplitude variable AC voltage. The converter can be supplied by any AC or DC on board energy grid. The rotational speed of the electric motor is controlled, by varying the output frequency.
3. *Main Switch Board:* The main switch board distributes the energy from all sources to all loads. The loads are frequency converters at the propulsion systems, hotel load, pump systems and so on. It could be designed as a single AC or DC rail, which can be separated in a starboard and portside system.
4. *Generator Set:* The generator set can consist of any combustion engine (e.g. diesel or LNG) and an electric generator. The combustion engine drives the generator to convert the chemical energy from fuels to electric energy. The generator can provide AC or DC power, depending on the selected main switch board and frequency converters.
5. *Gas or Dual-Fuel Engine:* In the engine the gas is burned. The two main engine types are dual-fuel engines that run on diesel and gas and pure gas engines. In case of a dual-fuel engine, an additional diesel tank is necessary.
6. *Gas Valve Unit:* The Gas Valve Unit (GVU) controls the gas flow to the engine and can also perform an emergency stop
7. *Cold Box:* In the Cold Box the LNG is evaporated. Then the gas is pressurized. The energy (heat) for the evaporation often comes from the cooling water of other engines on board. This part of the installation is also known as gas treatment system.
8. *Safety Systems:* Pipes and tanks have safety valves to protect them from overpressure. All systems are redundant. This means that there are at least two individuals of each safety system in case one fails.
9. *LNG Fuel Tank*

EQUIPMENT FOR GAS POWERED INLAND VESSELS

Besides engines, special safety provisions (crew training, bunkering requirements) and additional equipment are required to propel an inland waterway vessel on LNG, like LNG tanks, systems for LNG withdrawal from a tank or a cold box.

LNG TANKS

Two different types of LNG tanks are available: Membrane Tanks and Pressure Tanks. For LNG as fuel only the Pressure Tanks (IMO Type C Tanks) are interesting. They are mostly cylindrical and have either foam or a vacuum insulation. For the vacuum insulation the space between the inner and outer hull is filled with perlite, an insulation material, then the vacuum is drawn. Another option is foam insulation; here the heat transfer is higher.

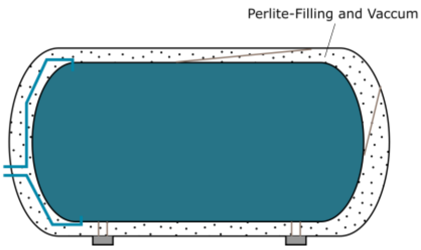


Figure 3: Pressure tank - vacuum insulated

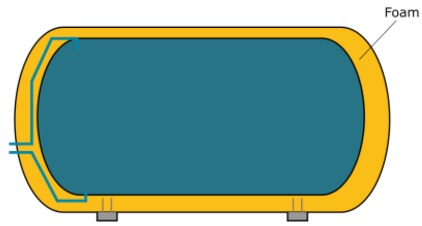


Figure 4: Pressure tank - foam insulated

SYSTEMS FOR LNG WITHDRAWAL FROM THE TANK

There are two different methods available to extract the LNG from the tank.

Cryogenic pump: the pump is suited for the low temperature of the LNG. Since cryogenic pumps are quite costly, this is not a widespread solution.

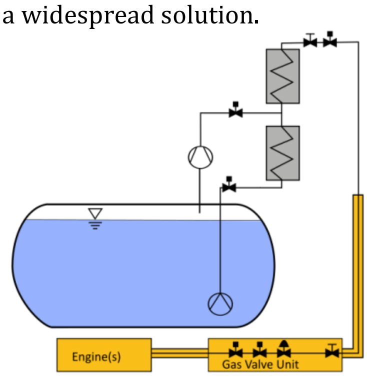


Figure 5: Cryogenic pump

Pressure-build-up system (PBU): The PBU consists of heat exchanger that evaporates a small amount of LNG. The resulting gas is fed back into the tank and the rising pressure then causes LNG to be forced out of the tank. The PBU system is a common solution for LNG on inland vessels.

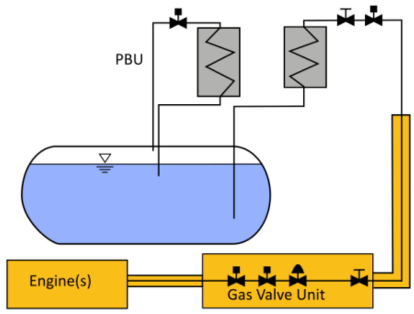


Figure 6: Pressure-build-up system (PBU)

COLD BOX

In the cold box the LNG is prepared for the combustion in the engine. This means it is evaporated and adapted to the pressure that the engine demands. The complete components in the cold box are suitable for cryogenic temperatures. For insulations the cold box is often filled with perlite.

SPECIAL SAFETY & OTHER REQUIREMENTS

CREW SKILLS

The qualification "LNG expert" (Directive of the European parliament and of the council on the recognition of professional qualifications in inland navigation) is necessary for at least one crew member of an LNG powered vessel.

BUNKERING & BUNKERING INFRASTRUCTURE

Currently, a common temporary solution is LNG bunkering by LNG fuelling trucks. The fixed LNG bunkering infrastructure is under construction along the European waterways.

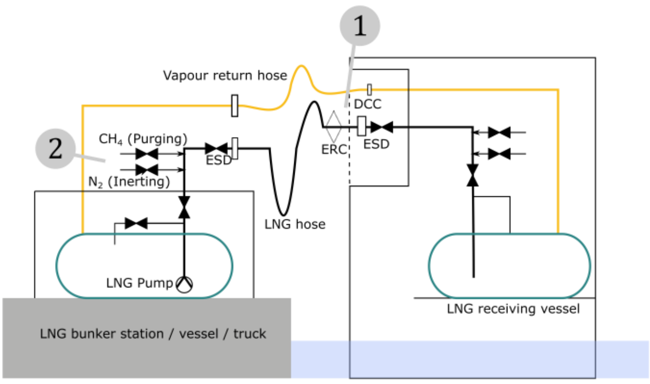
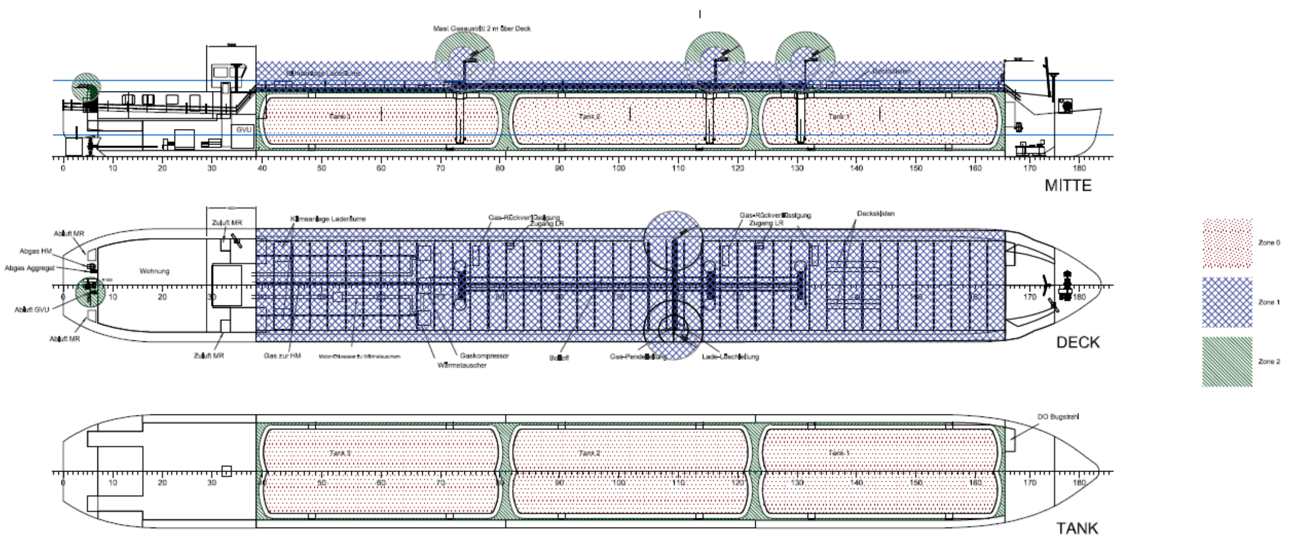


Figure 7: Bunkering scheme

1. The LNG is transferred via a flexible reinforced hose that is held and guided by a crane. The connection between the hose and the tank is made with a dry cryogenic coupling (DCC). The use of automatic and manually operated shut-off valves (ESD) is necessary to interrupt the charging process at any time. ESD valves have the effect of an emergency stop switch, i.e. they stop the entire charging process. The emergency release coupling (ERC) is the design breakpoint within the system. According to the regulations, the manual activation devices must be operated both on board and also be available on land.
2. Before the transfer starts the transfer line is inerted with Nitrogen. Through the vapour return hose the bunker station takes back the gas in the fuel tank during filling. After the bunkering the LNG lines have to purged, to ensure no LNG remains there.

EX-ZONES

Once the vessel shall be equipped with an LNG-system, the establishment of ex-zones is mandatory and an important aspect of the safety concept. Especially for retrofitting it is important to plan the zones in an early stage. There are three different types of EX-Zones (1999/92/EC) illustrated for a LNG tanker with gas engines below:



Zone 0: Location where an explosive atmosphere is present continuously or for long periods or frequently.
Zone 1: Location in which an explosive atmosphere occurs occasionally during normal operation
Zone 2: Location where an explosive atmosphere is not liable to occur during normal operation or, if it does, is only short-lived (foreseeable abnormal operation).

ECONOMICS AND ENVIRONMENTAL SUSTAINABILITY

INVESTMENT COSTS

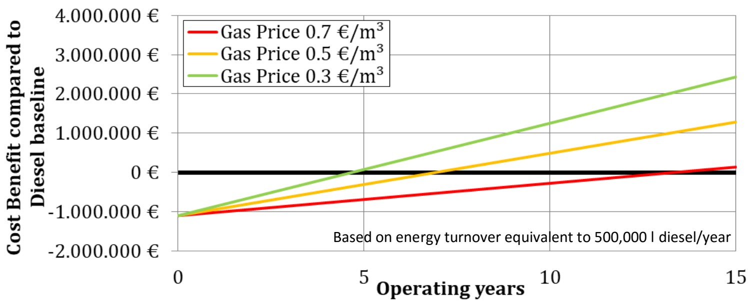
It is possible to convert diesel engines to use LNG as an alternative fuel. Alternatively, the old diesel engine is replaced by a new gas or dual-fuel engine. The investment is dependent on the engine power and size and type of ship. As a first estimate for an inland ship an investment for the whole LNG system of about 1.2 Mio € (2018) can be assumed. This includes the costs of an engine, a tank system and LNG preparation equipment like the cold box and installation. Operational costs are dependent on the LNG price development, the bunker contract and the general energy consumption of the vessel on its route. Due to the high investment, it is best to install the LNG on board of larger ships with high energy / fuel consumption.

The sailing range of an LNG-propelled vessel depends on the capacity of the fuel storage tank. For example, the ship EIGER-NORDWAND has a fuel storage tank with a capacity of 60 m^3 which enables the vessel to sail from Rotterdam to Basel and back (approx. 1700 km) without any refuelling. Currently, it is only possible to perform truck-to-ship bunkering at locations such as the ports of Amsterdam, Rotterdam, Antwerp and Mannheim. The fixed LNG bunker stations are under construction (shore-to-ship bunkering) in Cologne, Germany and in Antwerp, Belgium. In the Danube region, LNG is available in Ruse, Bulgaria (as of 2016) and will be available in Bratislava, Slovakia (as of 2020), in the near future in Hungary and Austria. With deployment of more LNG bunkering stations for inland vessels (in line with the Directive on alternative fuels infrastructure 2014/94/EU by 2030 in inland ports), a requirement for a big capacity tank will diminish.

Contrary to diesel, the quantity of LNG is being expressed in kilograms and not in litres. An indicative price estimate for a ton of LNG is 400 €[2]. LNG becomes an interesting economic alternative to diesel, when the yearly diesel consumption of the ship is in the range of 500,000 l (425 t).

Various European countries offer a subsidy programmes or public support schemes to retrofit inland vessels to LNG propulsion. Examples are France, Germany or the Czech Republic. A model State Aid scheme to be deployed in Danube countries is part of the outcomes of the project GRENDEL.

OPERATIONAL COSTS



The higher investment cost is earned back depending on the energy consumption and the price gap between diesel and LNG. The assumed diesel price in the example is 0.70 €/l. The green line indicates the optimistic scenario with an ROI after 4 years; the red line a pessimistic scenario with and ROI after 14 years.

ECONOMIC DRIVERS

- Price gap LNG – diesel reduces fuelling costs for barge operators. Price gap is expected to widen due to massive increase of LNG liquefaction in next few years and due to spot market developments.
- Cost reduction in fuelling results in higher profitability, lower transport costs and higher demand of inland water transport services.
- Switch to LNG triggers modernisation of fleet and facilitates additional measures increasing energy efficiency.
- LNG can become a commodity (cargo) which needs transportation on European rivers.

[2] Estimated based on: www.dnvgl.com/maritime/lng/current-price-development-oil-and-gas.html

FACT SHEET
GAS AND GAS–ELECTRIC PROPULSION

CONSIDERATIONS FOR DEPLOYMENT

- Strongly dependant on the infrastructure that is yet under construction
- Certification of personnel
- Restrictive safety rules
- Risk assessment is necessary (e.g. HAZID study)
- Bunker process requires a checklist

DEPLOYMENT EXAMPLES

MS EIGER-NORDWAND RETROFIT

Operator: DCL Barge B.V.
Location: Netherlands, Rhine
Organisers: DCL Barge, Koedood, Wärtsilä
In operation: 2014

ⓘ www.danser.nl


Copyright: © DCL Barge

Vessel type: inland container vessel
ENI: 02324957
Vessel size: 105 × 11.45 m (L × W), Draught (max): 3.55 m
Propulsion: 2 dual-fuel Wärtsilä 6L20DF, 900 kW each at 1,200 rpm
Tank capacity (LNG): 60 m³ (gross) sufficient for the roundtrip Rotterdam - Basel
LNG tank: Vacuum-insulated double-wall pressurised tank IMO type C
Benefits: fuel consumption reduction by approximately 20 %

MS SIROCCO

Operator: Chemgas Barging s.a.r.l
Location: Luxemburg, Rhine
Organisers: Chemgas Barging
In operation: 2015

ⓘ www.chemgas.nl


Copyright: Chemgas Barging s.a.r.l.

Vessel type: LNG-fuelled type G tanker
ENI: 02324789
Vessel size: 110 × 11.40 m (L × W), Draught (max): 3.15 m
Propulsion: Single 8L20DF Wärtsilä main engine capable of running on LNG & marine gasoil
Tank capacity (LNG): 88 m³ (gross)
LNG tank: Single wall independent vacuum-insulated pressure tank with design pressure of 10 bar

RPG BRISTOL
RPG STUTTGART
RPG STOCKHOLM

Operator: Shell Trading BV
Location: Netherlands, Rhine
Organisers: Plouvier Transport NV/ Intertrans Tankschiffahrt AG
In operation: 2017

ⓘ www.plouvier.be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Vessel type: LNG-fuelled type C tanker
ENI: 02337327
Vessel size: 110 × 11.4 m (L × W), Draught (max): 3.21 m
Propulsion: Wärtsilä 6L20 DF dual fuel engine , 1100 kW
Bunker capacity (LNG): 60 m³
LNG tank: Wärtsilä LNGPac

Contact

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