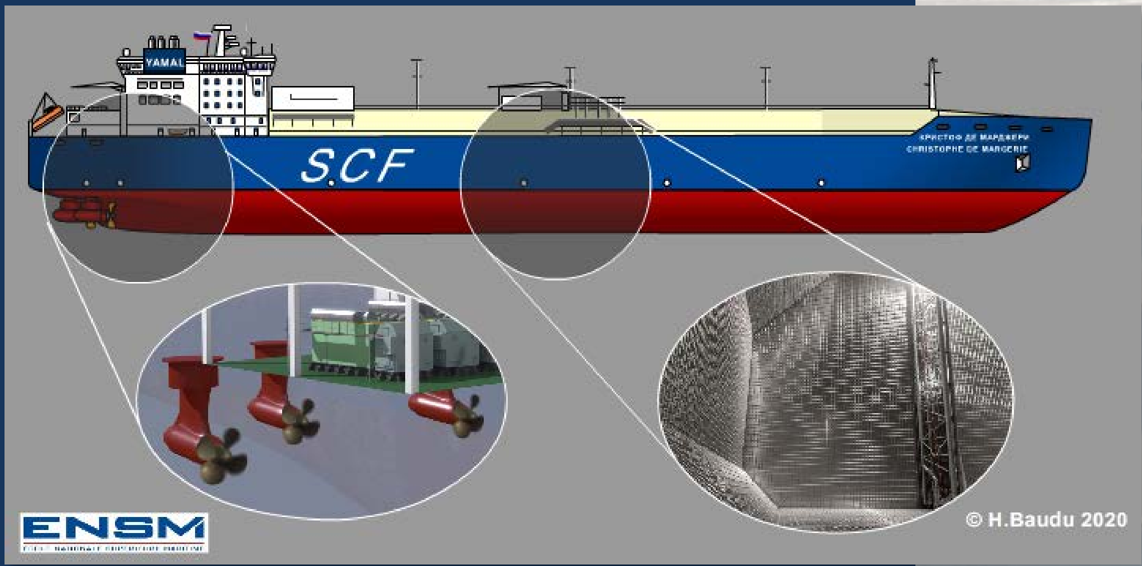
ARC7 YamalMax LNG Tanker engine concept by Hervé Baudu 2020

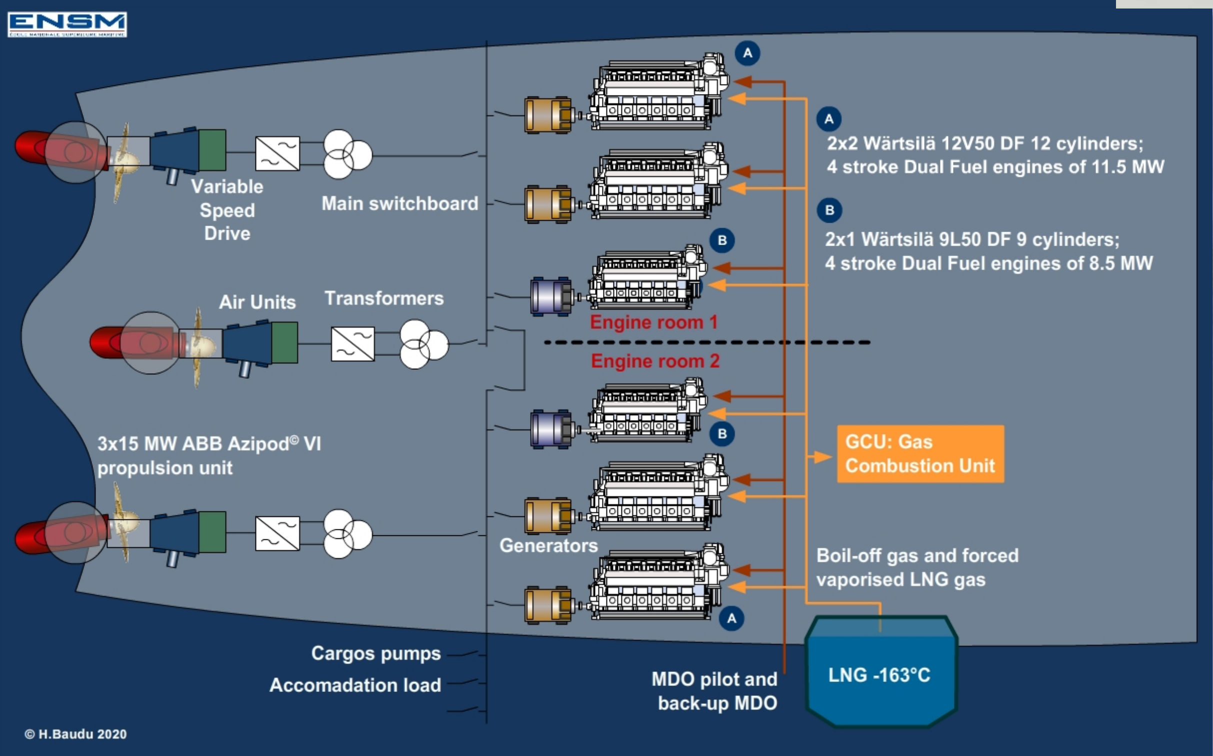
1. Why use gas as a fuel in the Arctic?



The International Maritime Organization (IMO) has introduced various measures since 1 January 2020, emissions from shipping such as sulphur oxides (SO_X), nitrogen oxides (NO_X) and other particulate matter (PM). MARPOL Annex VI, Regulation for the Prevention of Air Pollution from Ships, limits now the sulphur content of marine fuel. Hence, ships will have to use marine fuels with a sulphur content lower than 0.5 % m/m. For NO_x emissions, ships must be Tier III compliant from 1 January 2020. When these emission limits cannot be met by the engine itself, either approved Selective Catalytic Reduction (SCR – reducing No_x), Exhaust Gas Recirculation (EGR – reducing NO_x) and EGC (Exhaust Gas Cleaner – reducing So_x) technologies, such as a scrubber, must used (or any other means to achieve these limitations). Liquified Natural Gas (LNG seems to be the most promising alternative low carbon fuel on a short to medium term. However, LNG (CH_4) as fuel has a greater warming potential than CO_2. These direct emissions to atmosphere have different origins: incomplete combustion (methane slip) in the engine, venting pipes in operation, wells and gas liquefaction plant. On a counterpart, combustion of LNG as marine fuel shows greenhouse gas (GHG) reduction of up to 21% compared with current oil-based marine fuels. Due to the negligible amount of sulphur in the LNG fuel, SO_X emissions are drastically reduced and considered close to zero.

Post-2020 fuels will have to comply with the following requirements:

- Liquefied Natural Gas (LNG);
- Marine Gas Oil (MGO) as distillate marine fuel with a sulphur content of 0.1 m/m %;
- Heavy Fuel Oil (HFO) as residual marine fuel with an average sulphur content of >2.5 m/m % with scrubbers as approved exhaust gas cleaning system (EGCS);
- Low Sulphur Fuel Oil (LSFO) as residual marine fuel with a sulphur content of 0.5 m/m %.



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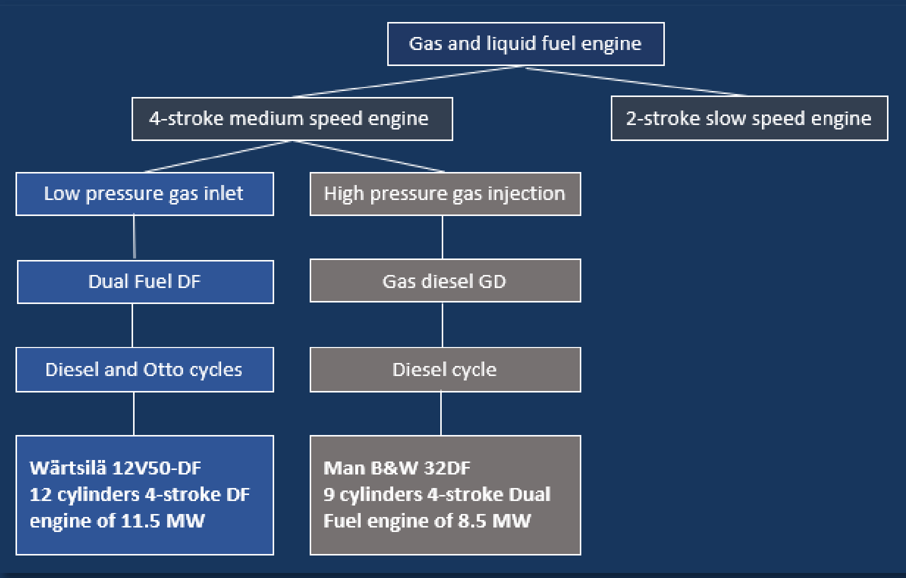
2. LNG engine Concept



LNG carriers are designed to carry liquefied natural gas. To be kept in liquid state at ambient pressure, methane must be cooled at a temperature below its boiling temperature point (- 161°C). Despite tank insulation designed to limit the heat transfer, evaporation of the cargo occurs. This phenomenon is known as natural boil-off gas (nBOG). As this gas cannot be send to the atmosphere, pressure will rise in the tank and must be removed. High pressure in the tank can leads to severe damages if too high. To relieve the pressure in LNG tanks, excess gas can also be used to burn as a fuel in the engines. The Arc7 LNG Yamal tanker use GTT NO 96 type prismatic membrane tanks to optimize its size in the hull shape. There are various propulsion systems for LNG carriers. The most common engines are four-stroke medium speed Dual Fuel Diesel Electric (DFDE) engines and two-stroke slow speed dual fuel engines. Both engines have largely replaced previously prevalent steam turbines.

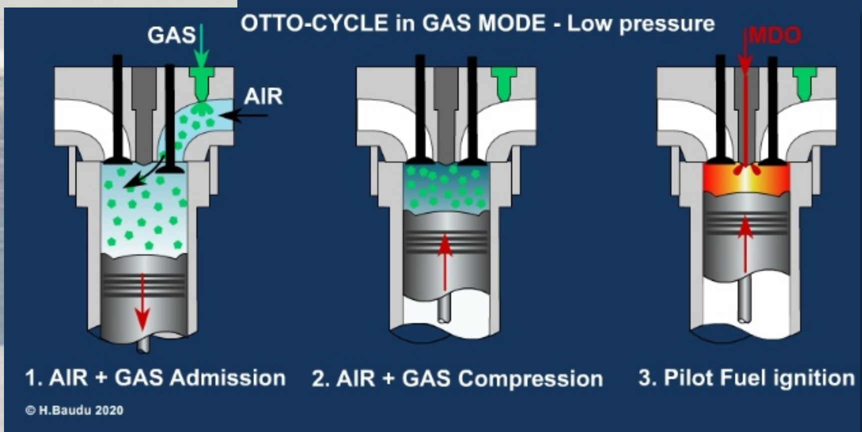
3. Diesel and Otto cycles

These engine technologies are further distinguished by the combustion cycle, either the Otto combustion cycle with low-pressure gas intake or the Diesel combustion cycle with high-pressure gas injection.

1. Otto cycle; LNG: Otto-cycle medium-speed engines (pure gas and Dual Fuel engines) can meet NO_X Tier III requirements without additional exhaust gas treatment. Unburned exhaust gas, (methane slip) has a significant impact on the overall GHG reduction potential.
2. Diesel cycle; LNG: LNG is sulphur-free, so there are no SO_X emissions. The effort required to achieve Tier III compliance is lower than for oil fuel, but EGR/SCR equipment is sometimes needed. High-pressure, Diesel-cycle LNG engines achieve near-zero methane slip.
3. Diesel Mode; MGO (Back up mode): SO_X compliance is ensured by the low sulphur content of the fuel. EGR/SCR equipment is required for NO_X Tier III compliance.

4. 4-stroke medium speed engines of ARC7 YamalMax LNG carriers

4.1. Wärtsilä 12V50 DF 12 cylinders; 4 stroke Dual Fuel engine of 11.5 MW – Low pressure gas inlet



The Dual Fuel Diesel Electric (DFDE) propulsion system uses multiple engines of the same type, coupled to electrical generators to supply energy to the entire ship including propulsion, which is driven by means of electric motors. Dual fuel engines can operate on BOG / MDO (or HFO). Dual fuel engines have different operation modes depending on the used fuel. When gas is burned as fuel (gas mode), the engine runs according to the Otto cycle. If MDO or HFO are used (classic diesel mode), the engine operates on the Diesel cycle. BOG is injected in the admission pipe at a low pressure (4 to 5 bars), this cycle reduces the complexity of the gas fuel supply system and thus the risks using methane at high pressure in the engine room. A small amount (approx. 1% of the combustion heat) of MDO is also required as a pilot fuel when operating on gas, giving a high-energy ignition source for the poor gas mixture in the combustion chamber. In diesel mode, the DF-engine is like any diesel engine, with a traditional pump fuel injection system. Switching between the two operating modes can be conducted automatically without interruption in power supply. The diesel mode performances better in terms of thermal efficiency and dynamic response, while the gas mode has advantages in terms of fuel cost and exhaust emissions. The Wärtsilä 50DF engine is fully compliant with the IMO Tier III (Gas mode) and Tier II (Diesel mode) exhaust emissions regulations set out in Annex VI of the MARPOL 73/78 convention.

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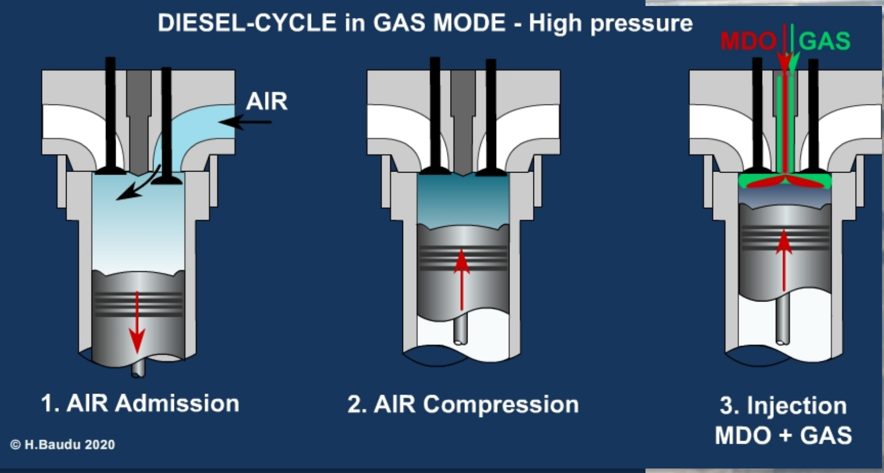
4.2. Man B&W 32DF 9 cylinders; 4-stroke Dual Fuel engine of 8.5 MW – High pressure gas injection

The BOG is pressurized through the fuel gas supply system (FGSS), and then directly injected at high pressure (250–300 bar) into the cylinder after the diesel pilot fuel has ignited near the top dead center. It is claimed that this concept would have significant advantages compared with the premixed Otto cycle gas process, i.e. eliminates the risk of knocking and capable of burning gas from any source irrespective of the methane number, due to the fact that the gas fuel is not injected in the compression stroke. This concept should offer higher energy efficiency in terms of emissions, the high pressure 4-stroke engines reduce the NOx emissions by 40% compared to HFO without exhaust gas treatment, which fulfills the IMO Tier II NOx limits. To achieve Tier III limits, the high pressure 4-stroke engine requires equipping with an EGR (exhaust gas recirculation) or SCR (selective catalytic reduction) system.



4.3. Strengths and weaknesses

The methane slip would be less of an issue in two stroke engines than in four-stroke engines. 4-stroke Otto cycle reciprocating engines are sensitive to methane slip with emissions resulting from unburned methane in the combustion process. 4-stroke Diesel cycle engines are less so. The 4-stroke medium speed engines have a higher fuel consumption due to the lower engine efficiency compared with 2-stroke slow speed engines. The low-pressure engines have certain advantages in terms of NO_X emissions, gas fuel supply systems and investment costs, while high pressure engines perform better in terms of power, thermal efficiency, gas compatibility and methane slip. There is also a greater risk of knocking on the low-pressure engine. Due to the high gas injection pressure and the combustion in a Diesel cycle, methane emission in the combustion of the Man 4-stroke Diesel-Dual Fuel medium speed engines are representing less than 1 % of the total GHG emissions better than engine technologies using an Otto combustion cycle. In terms of NOX emissions, the four-stroke and two stroke low-pressure engines reduce these emissions by 85% compared to HFO. Because LNG does not contain sulphur, these emissions are eliminated completely.

4.4. Summery

		Dual Fuel Diesel Electric (DFDE) 4-stroke medium speed engines	
		Wärtsilä 12V50 DF	Man B&W 32DF
Cycle		Otto	Diesel
Pressure injection		Low pressure (5-6 bar)	High pressure (250–300 bar)
Diesel consumption		170 g/kWh	192.2 g/kWh
Gas consumption		149 g/kWh	149 g/kWh
SOx emission reduction		Almost full	Almost full
NOx emission reduction		85%	40%
CO_2 reduction		Yes (CH_4 slip)	Yes
IMO Tiers 2020	LNG	IMO Tiers III	IMO Tier III (with EGR/SCR)
	MDO	IMO Tier II	IMO Tier II
Strengths		Investment costs Gas fuel supply systems	Power - Gas compatibility < 1% GHG emission
Weaknesses		Methane slip Risk of knocking	Very high pressure
Building costs		$1,072/m3	
Charter costs		$81,700/day	

References:
www.thinkstep.com
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