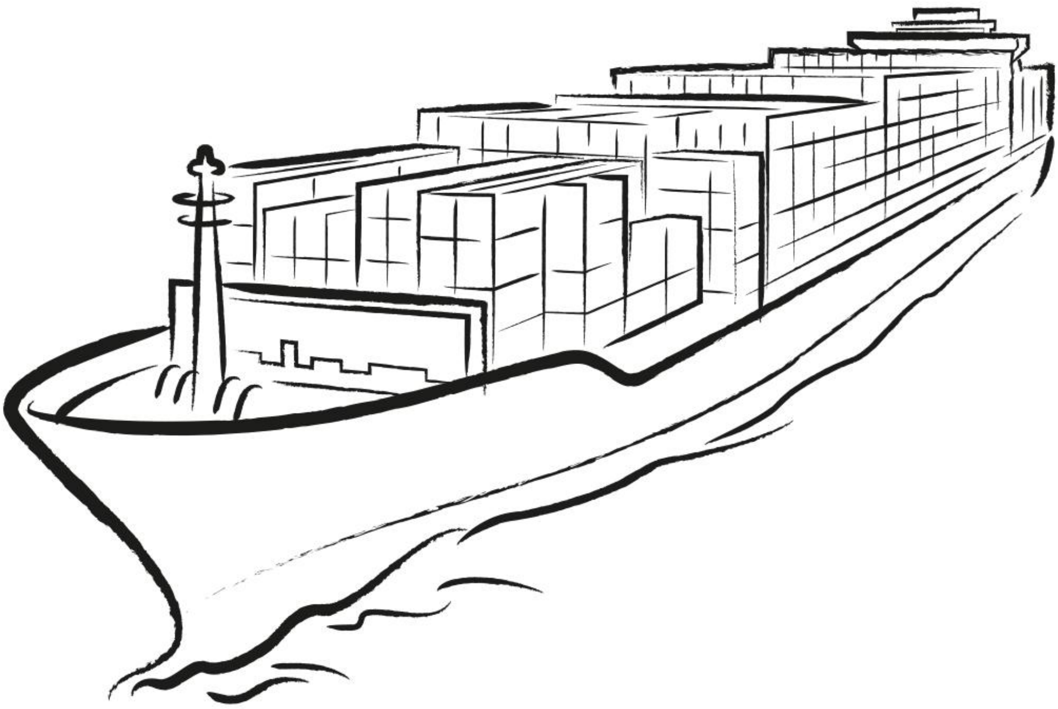
Engine selection for very large container vessels



Winterthur Gas & Diesel Ltd.

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1 Introduction – 8’000 to 22’000 TEU container vessels

The trend towards increased vessel capacity for the transportation of containers is continuing to meet the steadily increasing demand in goods transportation between the five continents.

The first vessels able to transport containers with a volume of more than 8’000 TEU (Twenty-foot equivalent unit) were built in 1997. In 2013, the first vessel with a capacity above 18’000 TEU was delivered and went into operation. The first vessel with more than 21’000 TEU is expected to come into service in 2017.

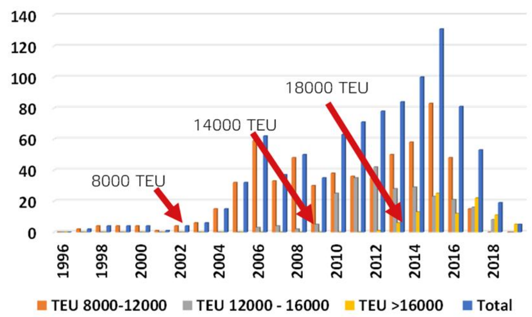

Figure 1: Very large container vessel deliveries over 20 years (Source: Clarksons Research June 2015) with starting dates for high number deliveries of vessels in the range of 80’00TEU, 14’000TEU and 18’000TEU.

Initially, the installed main engine power followed the trend with increased output. But around 2010 this declined as a result of the consistent application of slow steaming. The first 8’500 TEU vessels driven by 12RT-flex96C engines went into operation with 61’900 kW power. Main engines with a power rating above 80’000 kW were installed in 14’000 TEU vessels delivered from 2006 onwards (engine type 14RT-flex96C).

But the newest vessels, with a capacity of more than 18’000 TEU, are being ordered with a comparatively low main engine power output of close to 60’000 kW (engine type Wärtsilä 11X92). Similarly, some new 14’000 TEU vessels have been ordered with power ratings of less than 40’000 kW (8X92 or 9X82).

The lower power demand of these container vessel orders can be explained by the increased focus on reduced fuel consumption: Shipyards have improved hull designs and hydrodynamic propulsion efficiency, thereby reducing power demand at the same vessel speed by ~10%, and combining this with de-rated engines having better fuel efficiency.

On the operational side, vessel owners and operators have reduced vessel target design speeds considerably, thus allowing larger steps in reducing main engine power requirements.

WinGD’s low-speed engines are following the market trends. Today, the built-in flexibility of their engine specifications allows shipyards and ship owners to adapt performance to specifically meet the intended operational requirements.

This paper is intended to assist in the selection of the best WinGD low-speed engine for new, competitive, and future proof very large container vessels.

2 Boundary conditions for the engine selection

2.1 Energy Efficiency Design Index – EEDI

In 2012 the IMO (International Maritime Organisation), the regulatory body for international seagoing vessels, introduced the Energy Efficiency Design Index (EEDI) to help drive efforts aimed at reducing greenhouse gas emissions, specifically CO_2, from seagoing vessels. The vessel specific EEDI is calculated as being the CO_2 emitted by a vessel for every transported cargo in dwt per nautical mile.

The reference EEDI depends on the date of the contract, and is defined in regulation 21 of the Marpol Annex VI (also described in the IMO resolutions MEPC 203(62), see www.imo.org). A guideline for evaluating a vessel's EEDI value is given in resolution MEPC 245(66). To ensure continuous improvement and innovation within the shipping and shipbuilding industries, the target levels are reduced in stages.

The target EEDI for container vessels built between 1. January 2013 and 31. December 2014 is calculated by the formula:

174.22 * DWT^(-0.201) in g/dwt/nm

The curve reflects the possibility for reducing CO_2 emissions per TEU by applying larger vessels.

From 1. January 2015 the target EEDI is reduced by 10%, from 1. January 2020 by a total 20%, and from 1. January 2025 by a total of 30%.

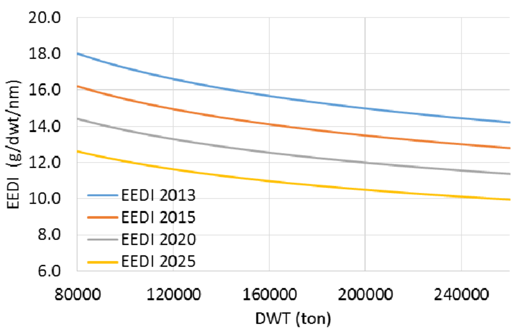

Figure 2: The EEDI target levels introduced by the IMO for very large container vessels

A 14'000 TEU vessel with a DWT of around 160'000 built after 2015 needs to meet the limit of 14.1 g/dwt/nautical mile.

To achieve a low EEDI, the following main measures can be considered:

1. Reduce the installed engine power (either by increasing the hull and propulsion efficiency, or by reducing the maximum vessel design speed)
2. Select engines with lower fuel consumption
3. Install additional energy saving technologies, such as waste heat recovery
4. Burn gas instead of HFO because it has less CO_2 emissions for the energy equivalent volume burnt.

2.2 The global economy, worldwide container transport capacity and fuel prices

The target vessel speed is a key factor in defining the required main engine power. The optimum vessel speed is strongly influenced by the actual economic environment and the state of the container shipping market.

For example, in the case of a low ratio of market transportation demand against the available container vessel transportation capacity, reducing the vessel speed can be considered as a way to reduce operating costs and ensure well loaded vessels. Conversely, high market demand may justify a higher vessel speed.

At very low fuel prices (per ton), the importance of fuel to operating costs is reduced and an increase in vessel speed may be considered for maximizing the vessel's operating result. When targeting for a specific number of containers to be transported per voyage, one consequence would be to also reduce the number of vessels required to cover the specific roundtrip.

By defining a scenario for the coming years in view of expected market developments, the overall available shipping capacity, as well as fuel market trends, the right choice of propulsion system becomes easier to make.

2.3 Fuels and related regulations

Regulations, issued either by the IMO or by local authorities, that limit the maximum allowed sulphur content in the fuel used can have a significant impact on today's vessel operational costs. The worldwide sulphur cap limit of 3.5% introduced in 2012 is planned to be lowered to 0.5%. This limit will be applied in EU waters from 2020. The IMO will decide in 2018 on the worldwide sulphur cap implementation in 2020 or 2025.

The different sulphur levels as such have only a small impact on the choice of engine, as today's WinGD designed marine two-stroke diesel engines can burn any kind of diesel fuel without restrictions (considering the adapted fuel treatment and cylinder lubrication).

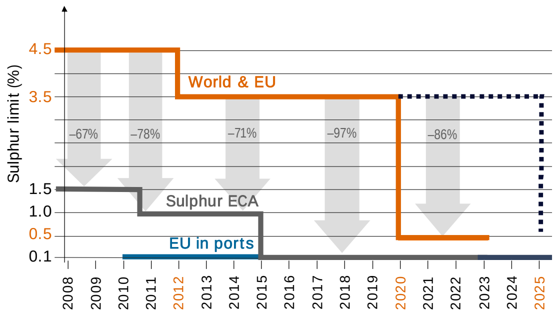

Figure 3: Present and future IMO sulphur emission regulations.

However, the sulphur limitations may influence the choice of either running on low sulphur fuels, or continue with high sulphur HFO fuels and apply exhaust gas scrubbers to remove the sulphur oxide (SO_X) emissions from the exhaust gas flow.

Another option is the application of LNG as the main fuel, thus cutting sulphur emissions to the lowest level and also reducing CO_2 emissions by 25% to 30%. For WinGD X-DF engines, a low-pressure dual-fuel engine technology breakthrough has been realized. By applying the low pressure gas concept, the investment in an expensive high pressure gas system is avoided, and no NO_X reduction system is needed for operating in NO_X emission control areas – see chapters 4.1.3 and 5.2 for more details.

2.4 NO_X Emission limits

The first globally applied NO_X emission limits were implemented by the IMO in 2000 (Tier I), and were followed by a further reduction in 2011 (Tier II). The Tier III regulations represent an even bigger step, even though the lower emission limits are only valid in designated ECA areas (Figure 4).

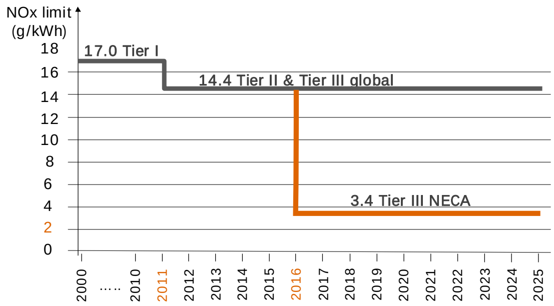

Figure 4: Valid IMO NOx emission limits depending on vessel keel laying date

To meet the low Tier III NOx emission limits, diesel engines necessitate an investment in NO_X reducing technologies. For WinGD's low-speed engines, SCR technology is offered with two solutions:

a) The high pressure SCR (HP SCR) installed between the exhaust receiver and the turbocharger takes the least amount of space but requires being placed in the engine room
b) The low pressure SCR (LP SCR) solution allows installation of the SCR reactor after the turbocharger outside of the engine room or in the stack.

Choosing the right solution needs to be based on the ship's design and the operator's requirements. See chapter 4.4 for more details.

2.5 Flexible propulsion setup

Compared to the situation before 2008, the boundary conditions for ships and their operators are now changing more frequently throughout the life of the vessel. The changing demand and supply situation, varying fuel prices, the possibility to utilise different fuels, and new emission regulations give an advantage to flexible vessel and propulsion designs able to be reconfigured for optimum performance according to any and all conditions.

Year	2017	2020	2025
Item \ Description	Vessel travels only between Europe and Asia with slow steaming	0.5% fuel sulphur cap introduced worldwide. Continue operating with high sulphur HFO and install sulphur scrubber. Good market condition allows higher vessel speed	LNG becomes much cheaper than HFO. Convert propulsion system fully for continuous LNG operation. Extension of operations to US coast.
Engine	X92 derated	X92 with higher rating	Conversion to X92DF
Fuel	HFO & engine and vessel installation ready for LNG	no change	LNG
NOx emission level	Tier II	no change	Tier III – engine already compliant with X-DF technology
Sulphur strategy	HFO LSFO in ECA area	Installation of scrubber	LNG operation. Removal of scrubber
Propeller	Propeller optimized for low speed	Change propeller for high speed operation	-

Table 1: Example of possible operational scenarios for owners to decide on the appropriate propulsion and engine technology

This flexibility can be addressed in three different ways, which correspond to the different compromise concepts between ease of flexibility and the related costs to achieve it:

- Apply a design, which can be easily changed to operate efficiently at any new boundary condition. For example, by preparing the engine for optimum slow or fast operation with dual tuning or dual rating of the main engine
- Make small investments in the initial design to prepare the vessel for later conversion and upgrades, with less cost and less time out of operation. For example, prepare the vessel for installation of a NOx reducing technology, LNG supply, or the installation of an exhaust scrubber.
- Make no preparations during the newbuilding stage, and decide on installation modifications when a major change in boundary conditions occurs.

3 Engine power and speed selection

3.1 Vessel speed and operational economy – slow steaming

Slow changes in vessel speed (v) are correlated with high changes in engine power (P_E). The correlation is shown as:

$$P_E = const * v^{\beta}$$

The factor β depends on the actual propeller and hull design. For very large container vessels designed for a speed of 21 knots, β is about 3.4 leading to the following correlation:

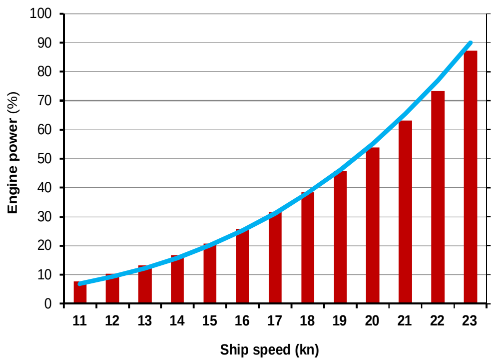

Figure 5: Power and vessel speed correlation for a very large container vessel

The above curve is similar to the theoretical ideal propeller law correlating engine speed (now vessel speed) and power, applying a factor 3.

Deciding on a newbuilding series of container vessels to cover a transportation route with several vessels, fuel costs represent only one aspect to be considered. The total cost of ownership might look as follows, including the investment (capital) costs, operating costs (manning, maintenance, insurance, etc.) and voyage costs including fuel and travelling fees:

The achievable total cost of ownership savings through increasing the size of the fleet will depend on the actual fuel prices and interest rates, as well as the realized vessel purchasing price.

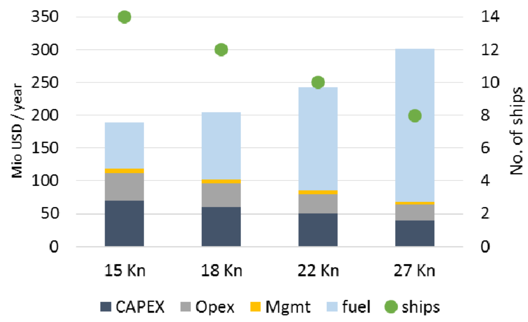

Figure 6: Qualitative figures for total cost of ownership per year with different numbers of container vessels (8 to 14) and adjusted vessel design speeds for the same total transportation volume per year

3.2 Define engine rating

The starting point for any engine selection is the power and propeller speed required to achieve the target vessel speed. The reference value set for ideal ambient conditions, and with the vessel's hull in new condition, require the addition of margins for safe operation of the engine in real life. The additional margins are:

LRM – Light running margin to reflect the changed propeller curve (power versus vessel and propeller speed) due to fouling of the hull and propeller and heavy weather conditions

SM – Sea margin to reflect the increased power demand with fouling and heavy weather conditions

EM – Engine margin as mechanical and thermodynamic power reserve for operating with the best fuel consumption

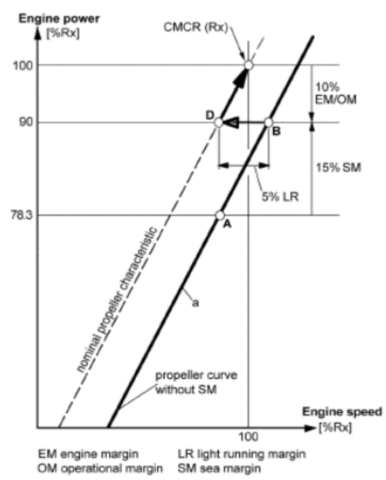

Figure 7: Light running margin (LR), Sea margin (SM) and Engine margin (EM) (%-values are examples)

For the light running margin, a value of between 4% and 7% is recommended. Typical values for the sea and engine margins are 15% and 10% respectively.

3.3 Propeller selection

The choice of propeller design influences the propulsion efficiency considerably.

As a basic law, the lower the propeller rotation speed, the larger can be the diameter of the selected propeller (the maximum propeller rotation speed being limited by the maximum allowable tip speed). And the bigger the propeller, the greater is the achievable maximum propeller efficiency.

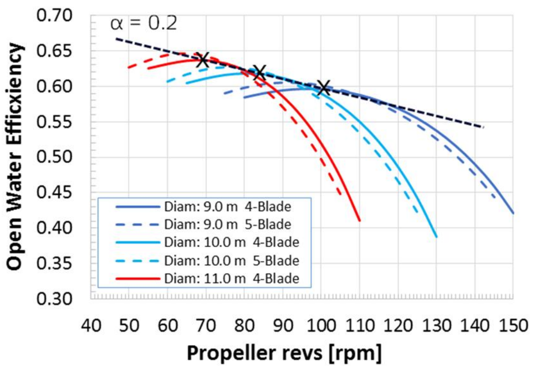

Figure 8: Example of achievable propeller efficiencies at given vessel design and propeller speeds, with varying propeller diameters and number of blades

The propeller diameters used on very large container vessels are between 9 and 11 metres. The maximum attainable open water propeller efficiency η_O achievable with a specified propeller diameter at propeller speed n is described by the factor α, usually being about 0.2 for large container vessels:

$$\eta_O = const * n^{\alpha}$$

The value of const depends on the selected hull and propeller technology. The improved open water efficiency of the propeller with an increased diameter has to be balanced against the higher investment costs for the propeller and shaft, and the limitation in space under the hull given by the draft limitations of the vessel. At the upper limit of the allowable diameter, losses in hull efficiency also need to be considered.

In addition to the diameter, the number of blades can also be increased or reduced so as to move the efficiency peak to lower or higher propeller speed ranges while keeping the same diameter. This avoids changing the hull design and ensures keeping the propeller fully in water – a propeller with the highest number of blades achieves the best efficiency at lower rotation speeds. As a rule of thumb, one blade difference moves the efficiency peak by about 10% of the rotation speed.

4 Engine selection

4.1 Engine types and their characteristics

4.1.1 Available engines for operating on diesel and LNG

The WinGD X-engine series succeeds the RT-flex engine series introduced from 1999 onwards. It has been designed to meet the latest emission regulations with the lowest fuel consumption and increased maintenance friendliness.

To meet the target power range of between about 35000kW and 70'000kW, two engine types can be considered:

The X82 engine with 6 to 9 cylinders or the X92 available with 6 to 12 cylinders (see Table 2).

Both the X82 and X92 engines are available for operating on HFO and MDO/MGO, and also come in X82DF and X92DF versions for operation with LNG or diesel fuel.

The power and speed range covered by the two engines is shown in Figure 9.

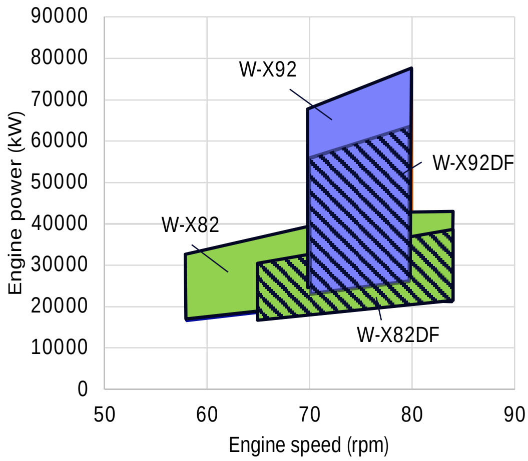

Figure 9: Power and speed range covered by the X82 (6- to 9-cylinder), X92 (6- to 12-cylinder) and their related gas engine versions, the X82DF and X92DF.

Basic engine parameters	Unit	WX82-B	WX92
Bore	mm	820	920
Stroke	mm	3375	3468
Stroke / bore	-	4.11	3.77
Number of cylinders	-	6 - 9	6 – 12
Speed range	rpm	58 - 84	70 - 80
Max mean piston speed	m/s	9.45	9.25
Max mean effective pressure	bar	21	21
Fuel consumption (R1, standard tuning)	g/kWh	165	166
Power / cyl	kW	2765 - 4750	4070 - 6450

Table 2: The main characteristics of the X82 & X92 engines

4.1.2 Common characteristics of the X82 and X92 diesel and gas engines

Basic layout:

The design of the new X-engines is a result of the continuous research and development efforts by WinGD on marine low-speed engines aimed at enhancing reliability, engine performance, and easy maintainability.

Common proven technology platforms form the basis for the full X-engine portfolio with individual adaptations of the engine to meet different engine size and power requirements.

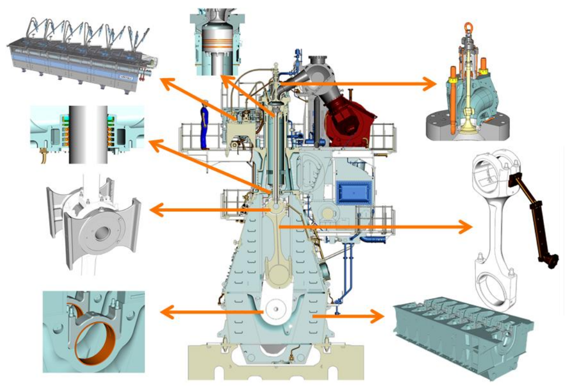

Figure 10: Common technology platforms for the X-series

Flex common-rail system

Since its introduction in 1999, the unique Flex common-rail system has been continuously improved to increase component reliability and lifetime and to reduce the maintenance costs.

The X82 and X92 engine series incorporate this well proven technology with further improvements.

The Flex common-rail technology allows individual control of the fuel injectors in each cylinder, thereby optimising the operating injectors' atomization characteristics according to the available air and fuel demanded.

Flex common-rail technology provides great flexibility in the engine setting for lower fuel consumption, lower minimum running speeds, smokeless operation at all running speeds, and better control of the exhaust emissions. The integrated redundancy maintains the high reliability of the engines.

In combination with the optimised thermo-dynamic process and the adaptive engine parameter setting concept, the common-rail system provides superior engine performance. The ability to regulate the engine's operational performance results in good manoeuvring capabilities and allows the lowest possible operating speeds, for example, during canal transit and port entrance.

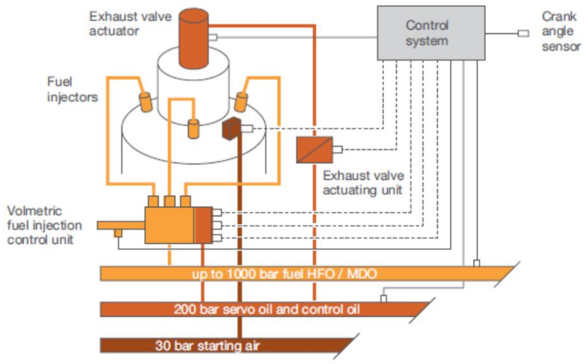

Figure 11: The unique Flex common-rail system allowing individual fuel injection characteristics and exhaust valve timing

The X-engines' Flex common-rail technology plays a key role in enabling ship owners to meet the challenge of higher fuel costs.

Advanced cylinder lubrication concept

The trends related to slow steaming vessel operations and towards high stroke to bore ratios, require improved cylinder lubrication systems to cope with the more challenging conditions in the combustion chamber.

The X82 and X92 engines apply the electronic controlled Pulse Lubricating Systems (PLS) introduced in 2006 to replace the mechanically controlled CLU3 lubrication system. Since then, the PLS has been continuously improved and adapted to meet the latest operating boundary conditions. It now includes Pulse Jet technology to provide the best possible cylinder oil distribution on the cylinder liner and piston rings.

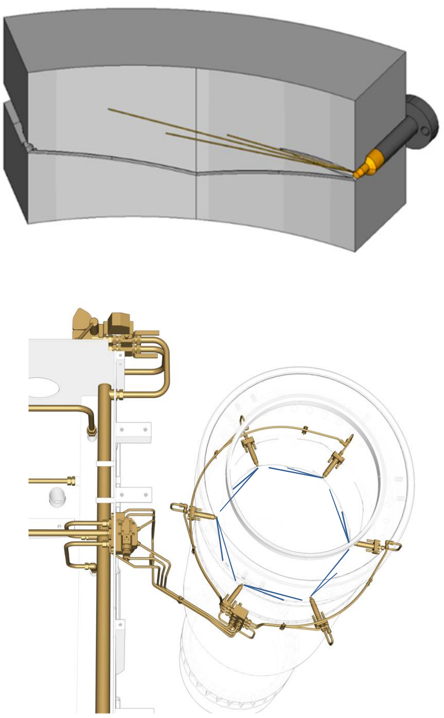

Figure 12: The Pulse lubricating system with pulse jet technology to distribute the oil evenly on the cylinder liner surfaces

Through the use of additional isolation, reduce cooling area and/or bypass cooling, great care has been taken to increase the liner wall temperatures against cold corrosion under slow steaming conditions, thus allowing continuous operation at between 10% and 100% load.

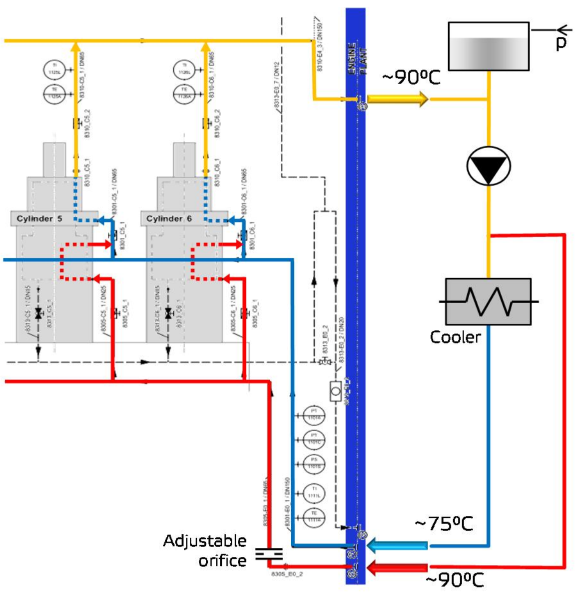

Figure 13: Cylinder bypass cooling for the lowest liner and ring wear rates at any load

Automation concept

The X82 and X92 engines are controlled by a highly redundant engine control system with distributed intelligence.

The well proven and validated WECS embedded control system allows the engine to be operated even if the bridge management system is out of order. It features a high level of redundancy to ensure the highest engine availability.

Communication with external systems (Propulsion Control, Alarm Monitoring, and Tier III solutions) is facelifted by CAN or Mod-Bus and is ready for interfacing with new technologies, such as BIG DATA.

Low maintenance costs

WinGD X82 and X92 engines are designed to achieve as much as five-year's time between overhauls (TBO).

The TBO of low-speed marine diesel engines are largely determined by wear to the piston rings and cylinder liners. The X-engines' piston-running package with a chrome ceramic coating ensures extended life time of these components, whilst maintaining low lubricating oil consumption.

The well-proven combustion component bore-cooling principle is employed in the cylinder cover, exhaust valve seat, cylinder liner, and piston crown to control both high temperature corrosion and stress factors.

All other engine components exposed to wear and tear have also been further optimised to achieve a high TBO.

The crank train bearings are of white metal design, and the cross head bearings with their well proven lubricating oil pockets function with excellent reliability. For X82 engines selected in the low speed area of the rating field (low engine speed), high pressure system oil (10 - 14 bar) is used to ensure trouble free operational behaviour of the cross head bearings.

4.1.3 Low pressure X-DF engines

For the operation with LNG an additional injection system is required to introduce LNG into the combustion chamber for optimum combustion, performance and emission results.

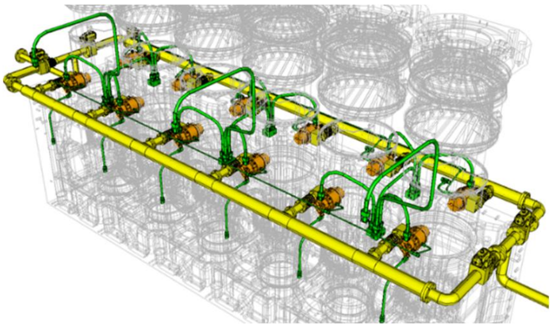

Figure 14: The low-pressure gas injection system for the X-DF engine

The X-DF engines are the only low-speed marine engines able to operate according to the Otto combustion principle, which is the only technology able to combine the use of reliable and cost efficient low-pressure gas injection with high performance and the lowest exhaust gas emission levels.

With the inclusion of the fuel gas supply system (FGSS), the propulsion system looks as follows.

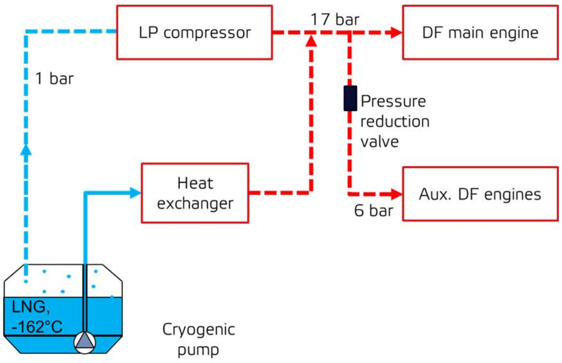

Figure 15: The low pressure fuel gas supply system (FGSS) for the low pressure X-DF engine with tank, low pressure compressor and pumps, and piping. Only low gas pressure components are required.

This low-pressure technology reduces NOx emissions in compliance with IMO Tier III limits without any additional cost intensive reduction technology.

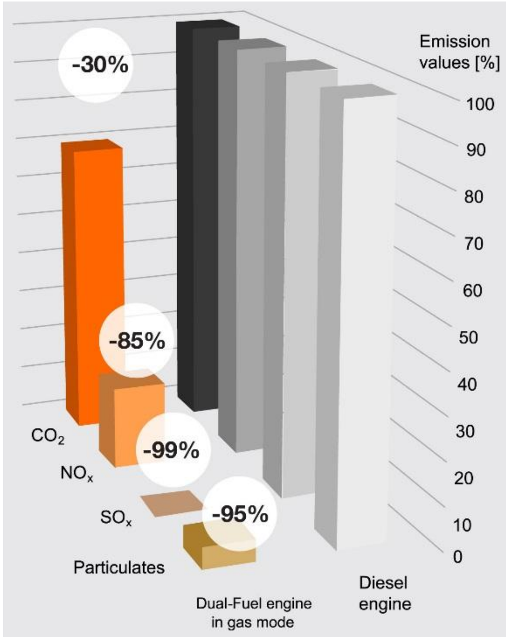

Figure 16: Reduced emissions of X-DF engines with low-pressure gas technology. The NOx level meeting IMO Tier III limits is achieved without additional equipment

The advantage of the low-pressure system from a financial investment and operational perspective is described in chapter 5.2.

4.2 Engine tuning

The X-engines can be optimised for low, partial, or high load operation. The following tuning options can be selected:

1. Standard Tuning: high load tuning, optimised for engine loads above 90 % (in the same way that mechanical engines have been tuned)
2. Delta Tuning: part load tuning, optimised for engine loads between 75%-90%
3. Delta Bypass Tuning: part load tuning, optimised for increasing steam production above 50% engine load, and reduced fuel consumption below 50% engine load.
4. Low-Load Tuning: optimised for engine loads below 75 %.
5. TC cut off: Where applicable, X82 and X92 diesel engines with a multi-turbocharger configuration can be equipped with TC cut off tuning that significantly reduces the engine's fuel consumption at low loads. One of three turbochargers can be cut off to improve low load performance.

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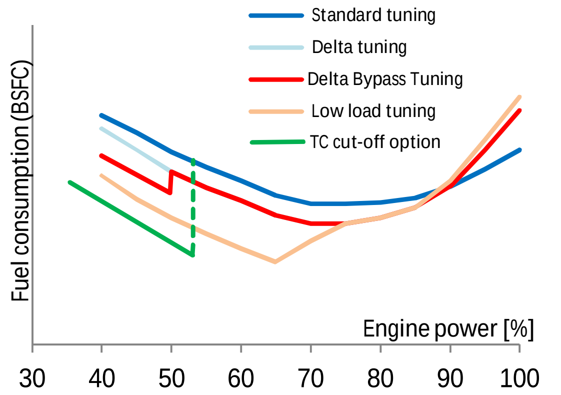

Figure 17: Engine tuning options to optimize fuel consumption for individual operational profiles

An additional option is the "steam production control" (SPC). Instead of a bypass valve, which can only be fully open or closed, it can vary the bypass rate continuously. This allows the opening to be set according to the needs of the economizer for steam production, while at the same time ensuring the best possible engine fuel consumption.

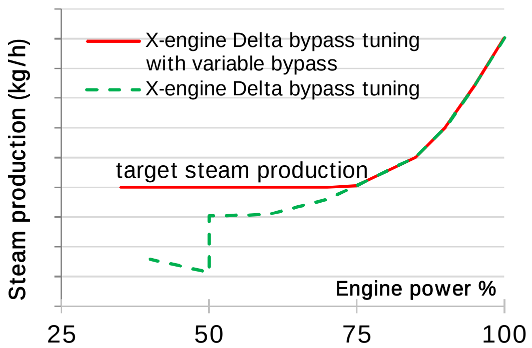

Figure 18: Variable steam production with a variable bypass for steam production control (SPC)

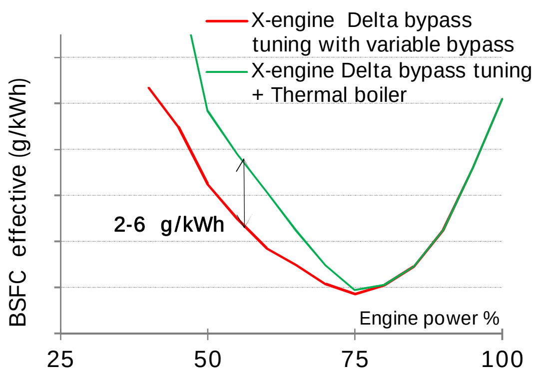

Figure 59: Effective overall fuel consumption by applying SPC (red curve) compared to steam increase by a thermal boiler (green curve)

4.3 Waste heat recovery

Waste heat recovery is an effective technology for simultaneously cutting exhaust gas emissions and reducing fuel consumption. High- Efficiency Waste Heat Recovery plants with WinGD engines enable up to 10% of the main engine shaft power to be recovered as electrical power for use as additional ship propulsion power and for shipboard services. These WHR plants thus cut exhaust gas emissions, deliver fuel savings of up to 10%, and improve the ship's EEDI.

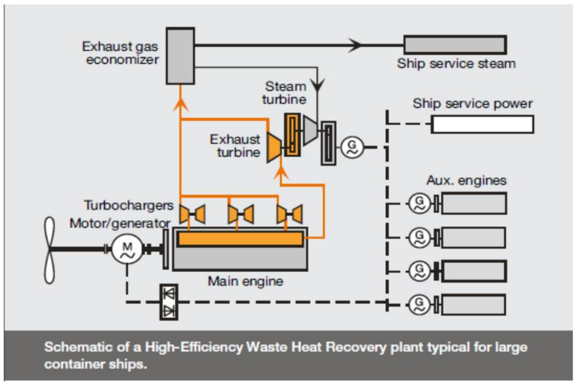

Figure 20: Layout diagram with waste heat recovery system

Steam based WHR plants have already been successfully fitted in several installations using WinGD low-speed marine engines. In the WHR plant, a turbo-generator combines the input from a steam turbine with an exhaust gas power turbine to generate electrical power, while steam from the economiser is available for the ship's service heating.

4.4 NOx and SOx emission reduction technologies

In order to achieve compliance with the IMO Tier III NOx regulations and the requirements for SOx control, various solutions are possible. These may include alternative fuels, advanced tuning concepts, the addition of selected substances, and after treatment systems.

4.4.1 DF ready

Switching from liquid to gas fuel is a viable solution for dealing simultaneously with both the NOx and SOx requirements. X-engines have been designed to be DF ready, meaning that the standard diesel engine can be converted to a low-pressure X-DF engine by adding only the gas components. Operating on gas as X-DF, compliance with IMO Tier III NOx and SOx limits is guaranteed.

The installation of an LNG fuelled propulsion system, including the fuel gas supply system (FGSS), requires significantly higher investments for new vessels.

Therefore, from a total cost of ownership point of view, an investment in X-DF operations makes sense only if LNG can be bunkered at much lower prices than HFO or MDO.

If the operational savings with LNG are not big enough, operating on diesel and installing an SCR system for IMO Tier III compliance would be the preferred solution.

4.4.2 SCR solutions

X-engines comply with the IMO Tier III limits for NOx thanks to the designed interface with SCR systems.

SCR technology reduces emissions of nitrogen oxides (NOx) by means of a reductant (typically ammonia, generated from urea) at the surface of a catalyst in a reactor.

Compared to EGR, SCR is a proven technology that has been used for decades in land based power plants as well as on marine engines. Due to the higher investment and maintenance costs, as well as the imminent risk to engine reliability by re-circulating polluted exhaust gas into the cylinder, EGR is not viewed as being the primary solution for compliance with the IMO Tier III NOx limits.

In the SCR reactor, the temperature of the exhaust gas is controlled to maintain constraints on both the upper and lower sides. The latter is particularly relevant with fuels containing higher fractions of sulphur, such as those present in the typical quality of heavy fuel oil (HFO).

High pressure SCR (HP SCR)

The SCR reactor is installed on the high-pressure side, before the turbine. This configuration allows the reactor to be designed in the most compact way because of the higher density of the exhaust gas.

All X-engines have been designed for easy interfacing with HP SCR systems. A specific engine tuning for IMO Tier III allows fuel consumption to be minimized whilst the required exhaust gas temperature, the mechanical interface for the HP SCR off engine components, and the SCR valve control system are controlled.

HP SCR can be operated with MDO/MGO or HFO.

Low pressure SCR (LP SCR)

The SCR reactor is installed on the low-pressure side, after the turbine. The two-stroke engine interface specifications for low pressure SCR applications comply with all known low pressure SCR system providers. Low pressure SCR systems are typically larger in volume, but have the possibility to be integrated into the exhaust stack stream.

Again, the engine tuning is defined to minimize fuel consumption whilst controlling the required after turbocharger exhaust gas temperature.

Depending on the ambient condition and selected engine tuning, slightly higher fuel consumption than that of HP SCR may have to be accepted.

Only MDO/MGO can be used with LP SCR.

When considering liquid fuels only, a combination of individual solutions can be applied to control the two key pollutants NOx and SOx: For fuels with a sulphur content below 0.1%, LP and HP-SCR solutions can be applied. With high sulphur contents, a SOx scrubber has to be combined with the HP SCR solution.

	Concept 1	Concept 2
Fuel	MDO 0.1% S	HFO
SOx	-	SOx-scrubber
NOx	HP or LP SCR	HP-SCR

Table 3: Concepts for addressing SOx and NOx emission compliance limitations for diesel engines

4.5 Flexible operation adaptation

4.5.1 Dual tuning

Dual Tuning can be selected when a special operating profile is required. All X-engines can be built and certified with two different tuning combinations.

For example, typical applications include:
- Delta Bypass Tuning (DBT) and Low Load Tuning (LLT)

or
- Delta Tuning (DT) and Low Load Tuning (LLT)

These engine tuning options provide customers with benefits in terms of specific fuel consumption, and improved exhaust gas flow and temperatures.

The engine's NOx certification is carried out with individual Technical Files and EIAPP certificates for each tuning. Thus, NOx emissions on the test bed need to be measured for both tunings.

4.5.2 Dual rating

X-engines can be designed and shop tested for two different engine ratings. This means that the engine can have two optimised CMCRs points following the same propeller curve.

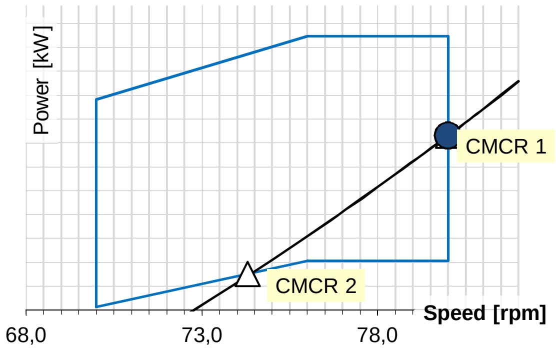

Figure 21: Selection of two engine rating points on the same propeller curve

As a consequence, the ship operator can select two possible optimal service speeds, depending on the market conditions.

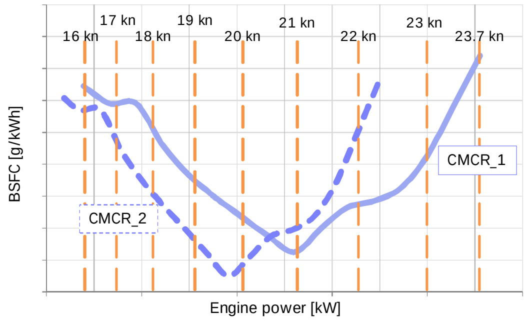

Figure 22: Fuel consumption optimisation possibilities for two different operating profiles through the selection of two CMCRs on the same propeller curve – savings in low load operation with CMCR_2 compared to higher rating CMCR_1.

4.5.3 Changing from diesel to LNG

Both engines, the X82-B as well as the X92, can be converted for dual fuel operation with the emphasis on the use of LNG. The major retrofitting work on the vessel concerns the installation of the LNG fuel tanks and the fuel gas supply system (FGSS):
- LNG tank
- Cryogenic pumps and evaporators for cold LNG to produce LNG at max 16 bar
- Optional compressor pumps for boil off gas (BOG)
- Gas valve unit to control gas pressure and supply before the engine

The original diesel engines are modified to X82DF or X92DF respectively by:
- Installation of the low pressure gas fuel injection system
- Adding the pilot fuel injection system for ignition of the LNG engine
- Install the control system for LNG operation
- Adapt the turbocharging system for LNG operation

5 Newbuilding cases

5.1 X82 and X92 for 14'000 TEU vessels

The target vessel should be able to transport 14'000 TEU while meeting the following performance specifications:

Vessel design speed	22 Kn
CMCR 1 required engine power with 76 rpm	42500 kW

As an option, a dual rating can be considered as a means to improve the fuel consumption for low load operation, while applying the same propeller:

Vessel 2nd design speed	19.3 Kn
CMCR 2 required engine power with 66.5 rpm (according to propeller law)	28500 kW

To improve the propulsion efficiency, the impact of a larger propeller achieving 22 Kn can be considered for an engine layout at 72 rpm:

Vessel design speed	22 Kn
CMCR 3 required engine power with 72 rpm (constant speed coefficient α=0.2)	42000 kW

and a 3rd design speed:

Vessel 3rd design speed	20.3 Kn
CMCR 4 required engine power with 70 rpm	33200 kW

To cover the above demand, the following engines can be considered:

- 9X82
- 7X92
- 8X92

In the layout field for power and engine speeds, the selected points look as follows:

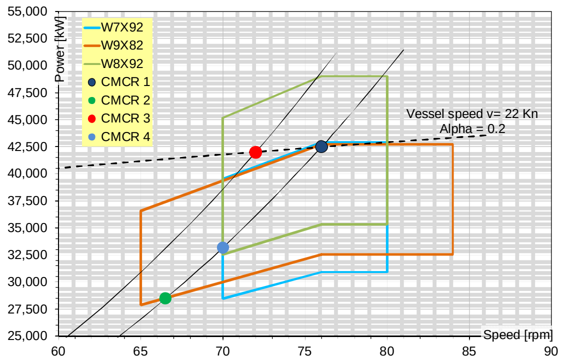

Figure 23: CMCR selection, propeller curves and X82 and X92 engine layout field

	9X82	7X92	8X92
CMCR 1, 22 Kn 42500 kW@76 rpm	x	x	x
CMCR 2, 19.3 Kn 28500kW@66.5 rpm	x		
CMCR 3, 22 Kn 42000kW@72 rpm			x
CMCR 4, 20.3 Kn 33200kW@70 rpm	x	x	x

Table 4: 3 engine options for four layout points

All three engines can be applied for CMCR 1. The lower propeller speed option is available only with the 8X92, whereas the 9X82 engine allows the widest dual rating as requested.

For best performance, Low Load Tuning is selected. The engine's fuel consumption in g/kWh over load for the different engines looks as follows:

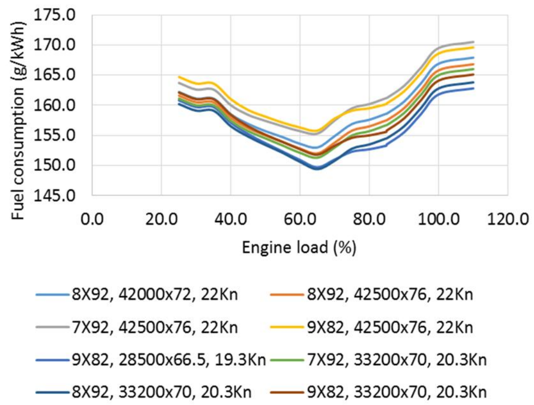

Figure 24: Power specific fuel consumption over load for the different engine and rating selections for different maximum vessel speed

Drawings of fuel consumption over vessel speed indicate the potential of the derated engine for low load operation below 18.5 Kn:

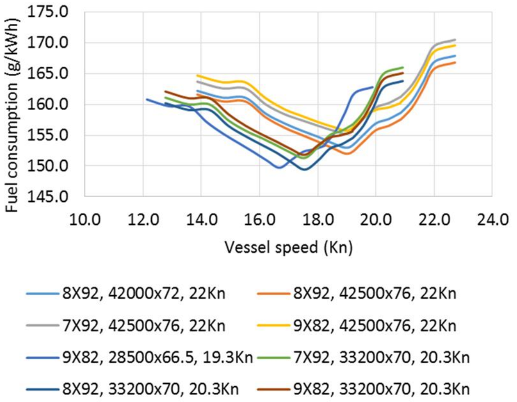

Figure 25: Power specific fuel consumption drawn over ship speed.

The 9X82 engine has the best fuel consumption when derated by 33% power for CMCR 2, or the 8X92 when derated by 22%. The 7X92 has the highest power specific fuel consumption in CMCR 1.

When calculating tons per day at 20.0 Kn or 18 Kn, and then calculating the fuel tons consumed per TEU for a single trip (considering the longer trip with 18Kn), the following results can be seen:

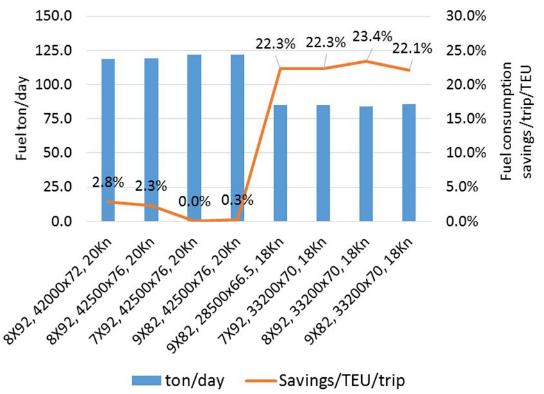

Figure 26: Comparison of fuel ton / hour and resulting savings in % per TEU transported from A to B at 20Kn and 18Kn speeds

At 20 Kn, the best fuel consumption is obtained with the 8X92, saving at least 2.3% in fuel costs compared to the 7X92 and 9X82. By taking the larger propeller for CMCR 3, the fuel costs can be reduced by an additional 0.5%, thus reaching 2.8%.

The derated engines give the best results at a vessel speed of 18Kn. 22% to 23% savings can be achieved for the transport of one TEU from A to B by reducing the vessel speed. The lowest fuel cost per TEU in this case can be achieved with the derated 8X92, which has a 1% advantage compared to the derated 7X92 and 9X82 engines.

In this specific study, the strongest derated 9X82 engine (CMCR 2) would give benefits at continuous vessel speeds below 17 Kn.

For investment purposes, the above savings need to be counterbalanced against the installation costs and the obtainable revenue:

- With a 8X92, the savings of 2.3 to 2.8% have to be counterbalanced against a higher investment cost for one more cylinder compared to the 7 cylinder X92
- By derating and slow steaming, the reduced cost per TEU needs to be considered in view of the fewer number of voyages the vessel can make per year, thereby reducing the income for the vessel. The additions to the operational costs to cover the higher financing costs for the vessel need to be increased to ensure the same payback time (see explanation in chapter 3.1).

5.2 12X92 and 12X92DF for DF ready 20'000 TEU vessels

The target vessel with a 20'000 TEU transportation capacity should meet the following performance specifications:

Vessel design speed	22 Kn
CMCR required engine power with 78 rpm	60'000 kW

The ship owner anticipates switching to LNG when the HFO sulphur cap is reduced worldwide to a maximum of 0.5%. The vessel should be run at the same speed with both diesel and LNG. The engine therefore should be easily convertible to X-DF for dual fuel operability.

At the time of conversion, IMO Tier III NOx compliance is also required.

The best selection for this requirement is the 12X92/12X92DF engine:

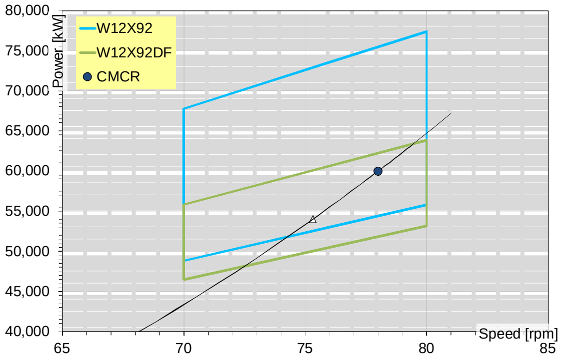

Figure 27: Operating line in the engine layout fields for the 12X92 and 12X92DF engines

It is important to note the Tier III compliance of the 12X92DF compared to the 12X92 engine, since the installation of NOx reducing systems, on or after the engine, are not required. Furthermore, CO_2 and particulate matter can also be reduced considerably. All these low values are achieved not only in ECA areas, but whenever the engine is operated with LNG fuel.

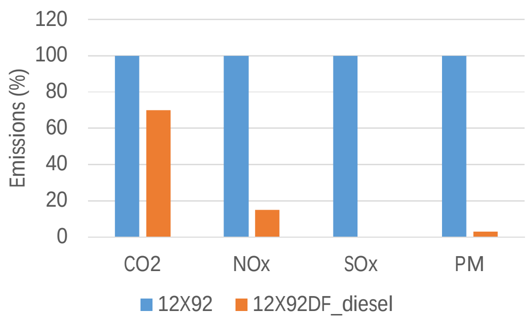

Figure 28: Emissions reduction comparison between the 12X92 in diesel operation and the 12X92DF in LNG mode.

A switch to LNG operation starts to makes sense with the much lower price of LNG compared to low sulphur HFO (LSHFO). In the following case study, it shall be assumed that LSHFO costs 500 USD / ton and LNG 400 USD / ton.

With savings of some 24'000 USD per day when running continuously at 80% load, annual savings of about 6 Mio USD can be considered. Taking into consideration the investments needed for operating the vessel on LNG, including the LNG fuel handling infrastructure and the engine, which one can assume to be in the range of 30 to 50 Mio USD, the payback time would be 5 to 9 years.

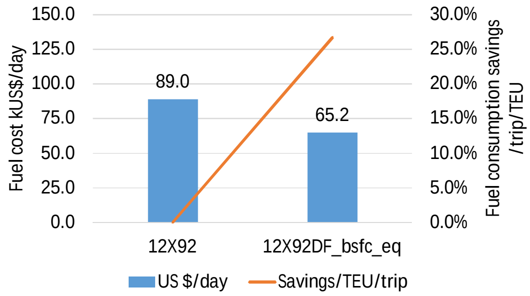

Figure 29: Fuel costs per day and savings with LNG compared to diesel at a continuous 80% load assuming a fuel price of 400USD/ton for LNG and 500 USD/ton for low sulphur HFO.

6 Conclusions

The WinGD X82 and X92 low-speed diesel engines and their related versions, the X82DF and X92DF for LNG operation, represent optimal propulsion engine solutions for very large container vessels with freight capacities between 8'000TEU and 22'000TEU.

One great advantage is the high level of flexibility by which the engines can be configured. The various engine tunings and ratings to optimize the operation for different operating profiles and varying fuel cost scenarios, as well as the possibility to use any diesel fuel or LNG, provide the means of finding the optimum installation for any need. As such, these engines can meet customer requirements, both at the initial project stage as well as after some years of operation. The engines can be adapted with low modification costs for any future new boundary conditions regarding the vessel's operational profile, fuel application, or environmental regulations.